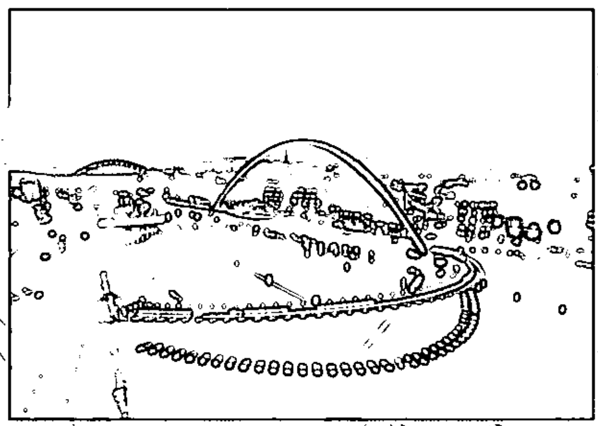
39TH WEGEMT SCHOOL

Marine Science and Technology for Environmental Sustainability

16 - 19 December 2002



Organised by the

School of Marine Science and Technology

at the

University of Newcastle upon Tyne UK

Sponsored by

EU Research Directorate Programme on Improving Human Research Potential

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Socio-Economic Knowledge Base through WEGEMT

UNIVERSITY OF NEWCASTLE UPON TYNE

WEGEMT

High-level Scientific Conferences

39^{th} WEGEMT School

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Publisher

School of Marine Science and Technology
University of Newcastle upon Tyne, UK

Published by

School of Marine Science and Technology. University of Newcastle upon Tyne

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

First Published 2002

ISBN - 0 7017 0155 2

Printed in Great Britain by:
AlphaGraphics
19-21 Collingwood Street
Newcastle upon Tyne
NE1 1JE, UK

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KEYNOTE ADRESS
By
Nils Telle Co-ordinator TRESHIP

Introduction

This paper is split into two separate parts

- The first part deals with emissions and releases to air and sea
- The second part deals with our experiences after working with Thematic Networks through 4 years

The facts and figures in this presentation are all gathered from the latest State of the Art report developed by TRESHIP.

Maritime pollution

TRESHIP has dealt with all forms of maritime pollution, i.e. CO_2, NOx, SOx, CFC, oil, TBT etc. This presentation will concentrate on CO_2, NOx, SOx and oil pollution.

In a lifetime perspective, pollution from ships can be separated in three different parts.

- Pollution related to building of ships
- Pollution from ships in operation
- Pollution related to scrapping of ships

Building of ships

Design and building of ships is a low polluting industry. The releases of greenhouse gases are negligible, and the industry's contribution to regional and global pollution is very low. Noise, releases of metal waste, oily water and grinding and blasting substances might represent a problem locally.

Scrapping of ships

Scrapping of ships is a labour intensive industry, and the majority of this industry is located in third world countries.

Normally the ships arrive at the scrap yard selfpropelled and the ships then will contain materials necessary to sail the ship, such as fuel oil, CFC- gases etc. The effect on global warming from scrapping of ships is minimal, but the industry will have local pollution effects.

The working conditions in the scrapping yards should be improved, but that is another topic.

Ships in operation

Operation of ships is what most people think of when talking about maritime pollution. This relates especially to releases to the sea, especially disasters like grounding of Exxon Valdez, Tory Canyon and Amoco Cadiz.

Ships in operation will therefore be the principal theme for the rest of this presentation.

Marine pollution

Total releases to the sea of oil amounts to 2.4 million tonnes annually. Only 24% originates from shipping. 0.12 tonnes or 5% is releases from accidents with ships.

Of the total emissions to the atmosphere

- 2% of CO_2 comes from shipping
- 5-7% of total SOx emissions comes from ships
- 10-13% of NOx emissions comes from ships

Emissions of Volatile Organic Compounds (VOC) from shipping in transit amounts to 1,5 million tonnes a year. This is about 3 times the amount of oil spill from shipping and corresponds to less than 0.1% of all oil transported.

It is estimated that shipping contributes to 5-10% of the acid rain (NOx and Sox) in coastal areas, perhaps even more in certain coastal zones.

Marine bunker oil is in many ways to be considered as a waste product from the oil refineries, and as such it solves a global waste problem. This should be kept in mind when comparing emissions of harmful substances from ships to air with other transport forms and land based industries.

Shipping versus other transport forms

Emissions to air per tonne transported with ships are much lower than emissions per tonne from any other transport form.

This comparison does not render full justice to other transport forms. In many cases transport by truck can't be replaced by ships and vice versa.

TRESHIP has made a comparison of emissions of CO_2, NOx and SOx where a certain cargo of fish was transported from a coastal town in Norway to its destination on the European continent. In one case the fish was transported by trucks, in the other case it was brought to a harbour in the Belgium by ship and from there further with truck. This study showed that the emissions was lower for CO_2 and SOx when maritime transport was one of the links in the transport chain than when the cargo was transported by truck all the way. But the NOx emissions were higher.

Taking into account that the truck travels through built up areas and the ship travels far from populated areas, maritime transport is by far the most environmental friendly.

Potential for improvement

Shipping is often considered as a mature industry, but TRESHIP points on a number of areas where there are a very interesting potential for improvement.

Reduction of oil spills

Nearly all tankers delivered today, have double hulls. This represents an improvement compared to tankers delivered before these new rules came into force. But talking of high-energy collisions and grounding, ships with double hull represent only marginal improvements. The construction of double hulls can certainly be improved through energy-absorbing structures, but for high-energy collision or grounding the gain is marginal.

Atmospheric pollution

It is both economic and environmental friendly to reduce ship resistance and thereby reduce the need for propulsion power. This can be achieved through improved hull-forms, better propulsion devices and improved engines.

But even if both ships and propellers are mature technologies, there are still potential for improvement. Alternative propulsion systems have been tested, and some seem to be interesting. But we can't expect major improvements in the near future.

Diesel engines have been and for many years to come will be the dominating prime mover. It represents a mature technology but with interesting potential for reduced emissions. NOx emissions can be reduced up to 60 to 70% but that will lead to increased CO_2 emissions and increased costs.

There are technologies available for reducing SOx emissions. The most efficient way to reduce the SOx emissions is to lower the Sulphur content in the heavy fuel oil. IMO has accepted a sulphur cap of 4.5% or 1.5% higher than the average sulphur content in fuel oil to day.

Alternative engine systems

Gas turbines and fuel cells are promising as both auxiliary engines and prime movers. We have already signed a contract for studying maritime application for fuel cells. In the project we will study safety and reliability questions plus indicate the economic and environmental potential for fuel cells in ships. Finally we will draw a road map for future research in this interesting field.

R&D Needs Report.

Our R&D Needs Report indicates a number of ideas for reduced environmental impact from ships. The most interesting proposals do not propose to implement new technology. A few of them are listed below:

- Establish the basis for legislation and incentive schemes that can stimulate a reduction of environmental impact and simultaneously contribute to making "green shipping" profitable.

- Develop and demonstrate vessel traffic and management and information systems in European waters

- Develop and demonstrate contingency and intervention systems for European waters.

- Improved education and training for maritime personnel.

Our Experiences with Thematic Network

TRESHIP is a combination of two proposals submitted in 1996. We have had some 30 Partners, but most of the work has been carried out by less than a third of the partners.

In our TN we had not any Partners from the shipyards and we had only one active shipowner directly involved in our consortium. But this type of instrument where the objective is to develop a State of the Art report, will not have much appeal to practical people. The R&D Needs report seems to be more interesting. When developing the reports mentioned above I had close contact with some Norwegian Shipowners, and their interest was concentrated around the future R&D needs.

The SoA- and R&D Needs reports are valuable, and our SoA report is used among others in the education in some universities. But these reports could have been developed simpler and cheaper. We could for instance have signed a contract with a classification society or a R&D institute and perhaps achieved the same result.

We are convinced that the most important result is the network of experts that has been developed through TRESHIP. We have learned to know each other and we know where to find the expertise we do not control in-house. Further contacts and cooperation between experts is essential in developing new ideas. In our case it has resulted in developing two new projects financed by EU.

- MARTOB – a combination of two proposals developed by the TRESHIP partners. The projects deals with treatment of ballast water and the market situation for low sulphur heavy fuel oil.

- FCSHIP is about maritime application of fuel cells.

Both of the topics are very important for the maritime industry both in a short-, medium- and longterm perspective.

- MARTOB has been running for 2 years and the project partners have done a very good job, and have developed results of great value for the industry. The timing is perfect and the results should form the basis for IMO when developing new regulations for ballast water onboard ships.

- FCSHIP started primo September this year, and it is two early to predict the outcome. But the project has already created an overwhelming interest also among parties not being involved in FCSHIP.

TRESHIP was heavily underfunded. It has not been possible to carry out any R&D work except the SoA report and the R&D Needs report. The TN should have had more money available to develop the inventory over emissions to air and releases to sea form shipping.

Such information is important, but the information is not easily available and the data varies, depending on the sources. But even with lack of funds, we think the inventory developed in our SoA report represents the most reliable data available to day.

Our TN had its "kick-off" meeting in January 1999 and the project will be closed 31. December 2002. The two first years the partners were actively participating. But it has been difficult to keep the motivation among the partners during the last two years, and some of the partners have hardly participated at all. We should perhaps have closed the project one year earlier.

An advice to the Commission: For TNs like this where the purpose primarily is to develop a SoA- and R&D reports, the duration should be limited to three years at the most.

On the other hand we recommend that the Commission nominate an advisory group to follow the development in this important field. It is important to have a group of people working together over some years to follow the development and to develop new ideas and proposals for future R&D.

CONCLUDING REMARKS

Shipping is the most environmental friendly transport form there is. But that does not that we can allow ourselves to rest on our laurels. There are interesting potential for improvements, both for reduction of releases to sea and emissions to air. The oceans have had and will in the future have major importance for our environment. Everybody should feel responsible for protecting the oceans, especially we who have our work so closely tied to the oceans. And the shipping industry is prepared to take responsibility and play an active part also in the future.

Environmental protection in shipping has so far been driven by governmental regulations, and new rules have normally been introduced after major accidents. The shipping companies have had to comply with these rules.

Shipping companies, as all companies involved in international business, are working in tough competition. It is a challenge to balance between cost-effective operation and environmental friendly operation. Too little action and the company may not be complying with rules and regulations. Too much action and the company may loose competitiveness.

A healthy maritime industry requires equal terms and fair competition. This means that all rules and regulations implemented to reduce environmental impact from shipping must be internationally accepted and governed, if not – the competition will suffer and those not complying might gain a competitive advantage.

The primary driving force in all industries are economy. An interesting new trend is stricter requirements from our customers who more and more often have environmental friendly operation as one of their requirements to their suppliers to be short-listed. So far we have not experienced that the customers are willing pay any extra for quality, but we have seen that sub standard operators have been excluded. The quality operators welcome this development!

To develop and implement new rules continuously is not necessarily the right way ahead. The "stick" might be replaced with the "carrot" and financial benefits should be introduced. Investing in environment friendly equipment should be profitable and environmental friendly operation should be a competitive advantage. We therefore recommend a totally new international regime for reducing the environmental impact from shipping.

But we must also bring about a change from the current position of compliance with prescriptive and reactive regulations to a state of proactive and self-motivated improvements in all aspects relevant to the environment and safe ship operation.

It is not only a question of technology. We are also talking about the organisational culture in the companies. For better protection of the environment, the current dominating "Compliance culture" should be replaced with a "Safety culture" and the responsible in this case is only the shipping company.

The effect of a foul release coating on propeller performance

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SYNOPSIS

With the imminent ban on the application of coatings of TBT self-polishing co-polymers in January 2003 and their eventual prohibition in 2008 a great deal of research is being conducted into the performance of the possible alternatives. As part of the ongoing work investigating the hydrodynamic performance of foul release systems, being carried out at the University of Newcastle upon Tyne, a study into the possible benefits of their use on propellers has been conducted. The benefits that this method of propeller protection offers are potential fuel savings from increased propulsive efficiency as well as lower maintenance costs and a cleaner environment. Initially a literature review exploring the effect of propeller surface conditions on ship performance and previous work on propeller coatings for merchant ships was conducted. Theoretical calculations on the possible gains were then explored for a merchant ship propeller type using a propeller lifting surface analysis program. These showed that the significant losses in efficiency caused by blade roughening can be avoided by the application of a foul release coating with a surface finish equivalent to a new or well polished propeller.

INTRODUCTION

When the reduction in ship performance is associated with the condition of the ship hull, the effect of the propeller surface condition is often overlooked. Nevertheless, the effect can be significant. Mosaad[1] states that in absolute terms, the effect of the propeller surface condition is less important than the hull condition, but significantly more important in terms of energy loss per unit area. In economic terms, high return of a relatively cheap investment can be obtained by propeller maintenance. When considering the propeller surface condition a distinction has to be made between fouling and surface deterioration coupled with an increase in propeller roughness. Surface deterioration may be caused by corrosion, impingement attack, cavitation erosion or improper maintenance as described in the following.

The most common cause of propeller deterioration is corrosion. This will occur on both sides of the propeller blade and in particular in the outer half regions, where the speeds are very high relative to the water. When a new propeller is immersed in sea water it becomes the cathode in the hull-propeller electrolytic cell. Alloys such as Nikalium or Superston have about one half to one third the rate of deterioration of manganese bronze, cast steels or cast iron. The deterioration can be further minimised by the adoption of properly designed and maintained cathodic protection systems.

Impingement attack, as described by Patience[2], usually happens at the leading edge and the outer part of the propeller blades. The surface damage has a widespread distribution of fairly shallow depressions. Again the use of alloys such as Superston and Nikalium will withstand attack. Stainless steels are highly resistant to this type of attack, but mild steel and cast iron have very poor resistance to it.

Cavitation erosion is usually a concentrated and localised damage near the tip and back of the blade. It is very highly dependant on the pressure distribution of the propeller and the wake flow. With modern design techniques this can be minimised and is generally negligible even after years of service. However it is still recommended to check for indications of cavitation damage during the propeller's early service life so that, if necessary, modifications to the blade sections may be adopted. It must be noted that these modifications cannot be regarded as a routine part of the propeller surface maintenance.

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Dr Candries is a research graduate from the School of Marine Science and Technology.
Mr Mutton is a research student in the School of Marine Science and Technology.
Dr Anderson is Business Manager-Antifouling at International Coatings Ltd, Felling, Gateshead and Visiting Professor in the School of Marine Science and Technology.

Improper maintenance such as poor grinding during cleaning may worsen the blade roughness due to scratching of the surface. Damage to the leading edge can seriously impair performance. Another aspect which needs attention during maintenance is that during hull painting splashes of conventional anti-corrosive or anti-fouling paints can drop onto the propeller, which increases the surface roughness of the blade. During maintenance periods the propeller should be protected from any grit blasting on the hull.

Fouling (the majority of marine growth on the propeller surface is of the animal type, acorn barnacles and tubeworms being the most frequent) may cause a much greater effect than roughness. However, the effects of fouling upon the propeller are difficult to quantify since little theoretical and experimental work has been done on the subject. The experimental work conducted by Kan et al.[3] investigated the characteristics of a fouled propeller using self-propulsion tests with the propeller covered in various rubber sheets to mimic the fouling. They found that small increases in roughness will cause large increases in delivered horsepower (DHP), producing a worse effect on propulsive efficiency than hull fouling but the reduction in thrust due to roughness was very small. These experiments, however, did not give very good agreement with their full-scale results. The full-scale measurements showed that the rate of increase of DHP will decrease as the roughness increases; the initial roughness has the greatest effect on performance. Because of propeller fouling, the DHP decreases by 20% and from these results, it can be seen that the effects of propeller fouling in terms of a power penalty are much greater than those of surface roughness.

Assessing the effect of the propeller surface condition on ship performance

Before the effects of roughness upon the performance of a propeller can be quantified the roughness of the surface has to be measured. There are various methods for doing this, such as using a propeller roughness comparator, by using a portable stylus instrument or by taking a replica of the surface and measuring it with laboratory equipment such as optical measurement systems. Thomas[4] describes both stylus and optical measurement systems in good detail. The propeller roughness comparator is a simple gauge by which the roughness of a propeller can be compared to a surface of known roughness. A typical example is the Rubert propeller roughness comparator that is shown in figure 1.

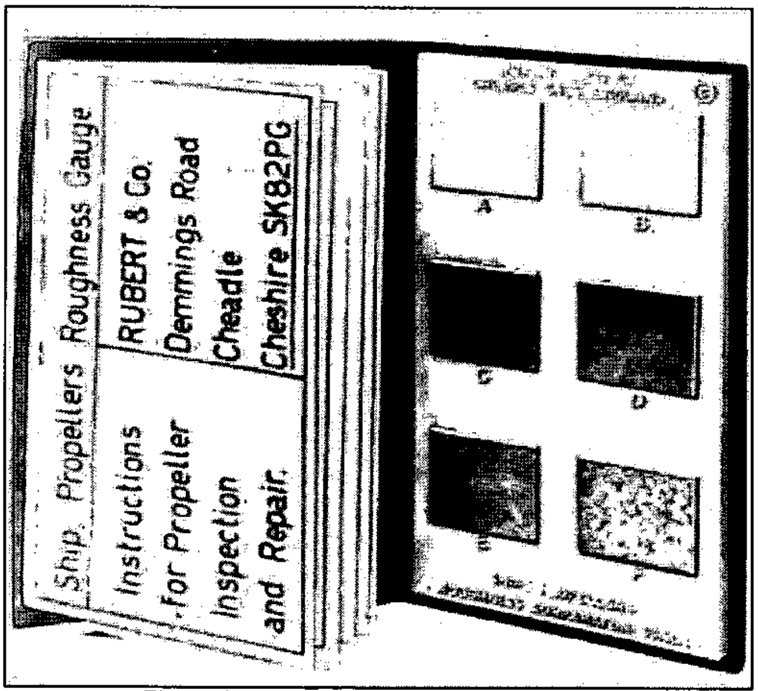

Fig. 1. The Rubert Propeller Roughness Comparator.

The gauge consists of six examples (A, B, C, D, E and F) of surface finish that range from an average roughness amplitude Ra = 0.65μm to an amplitude of Ra = 29.9μm[5]. The examples represent the surfaces of actual propeller blades. Examples A and B represent the surface roughness of new or reconditioned propeller blades while the remaining examples are replicas of surface roughness taken from propellers eroded by periods of service. C, D, E and F can be used to assess and report upon the propeller blade surface condition after periods of service.

In order to carry out detailed calculations on the effect of propeller roughness upon ship power and hence the effect of a foul release coating, a drag-roughness correlation is needed. Mosaad[1] carried out extensive measurements upon the Rubert comparator specimens. From these measurements he calculated the characteristic roughness measure h'. This parameter was proposed by Musker[6] to characterise a surface by a single parameter, taking both the amplitude and texture of the roughness into account. It must be noted that a single parameter (such as roughness *height*) as those measured by Broersma and Tasseron[7], will not be suitable for this purpose. This is because although a surface may have a relatively large average roughness amplitude, its texture may have a long-wavelength sinusoidal texture. This type of surface may cause lower drag when compared to a surface consisting of smaller amplitudes but with a jagged texture consisting of closely packed sharp peaks[8]. When looking at coatings, a foul release system belongs to the former type, but a tin-free self-polishing co-polymer belongs to the second type, as the roughness profiles in figure 2 show[9].

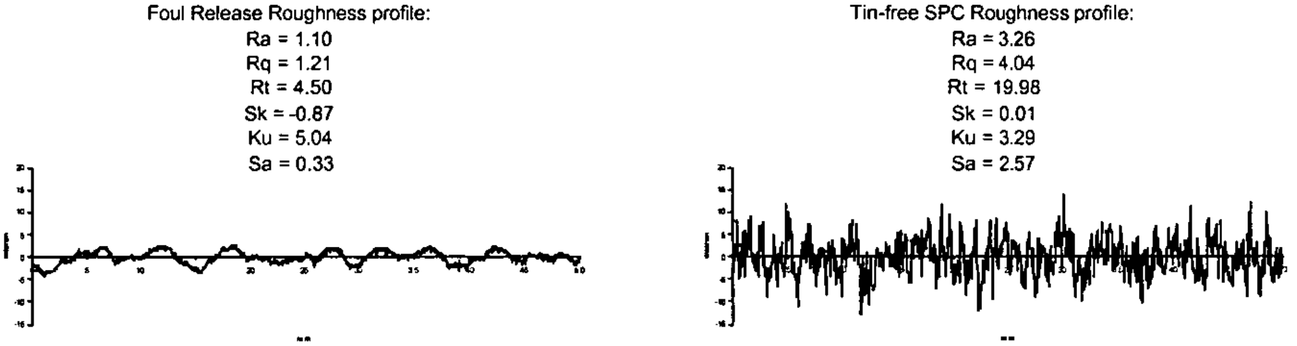

Fig 2. Characteristics of a typical foul release (Intersleek) and tin-free SPC (Ecoloflex) roughness profile.

From Figure 2 it can be seen that when long-wavelength waviness (which is unlikely to have any effect upon the drag) has been filtered out, two striking features appear: not only are the amplitudes (Ra, Rq, Rt) of the foul Release profiles typically lower, the texture of the surface (Sa) is very different. In metrological terms this type of texture is known as 'open' whereas the spikier texture of a tin-free SPC surface is known as 'closed'. Using the characteristic roughness measure h' Mosaad[1] carried out measurements in a rotating drum and established the relationship between h' and increased torque, and hence drag. This relationship will be used later on in this work.

The coating of propellers

Coating propellers is not a new concept – several experiments have taken place from as early as World War II – but no follow-up was made on the experiments. Consequently, not much has been published in the open literature on the coating of propellers. Dashnaw et al.[10] have reported on the coating of propellers which provided protection against cavitation erosion and corrosion while providing a smooth propeller surface having lower hydrodynamic drag. They evaluated the hydrodynamic resistance of various coatings and surface finishes by means of a rotating-disk apparatus. Of the surface finishes designated for steel, a surface finish with a Root Mean Square roughness amplitude of Rq = 3.175μm was according to the authors similar to a new commercial propeller finish. This surface exhibited a higher drag than a propeller coated with a urethane system of higher roughness (Rq = 3.81μm).

Matsushita[11] tested a foul release system on both boat hulls and a propeller from the training ship 'Yuge-Maru'. These tests showed that a foul release system can protect propellers from fouling and electrochemical corrosion, with only a small amount of fouling near the hub of the propeller and a 30% reduction in the consumption rate of the ships sacrificial anodes. Matsushita also found problems with the robustness of the coatings used past a surface time of one year. Since 1993 more development of these coatings generally has taken place, and in particular research into improving the adhesive qualities of these coatings to marine propellers[12].

THE LIFTING SURFACE ANALYSIS PROGRAM

To investigate the effect of a foul release coating on propeller performance use was made of a state-of-the-art numerical tool which predicts the performance of a propeller in a given wake flow. The computer program Unsteady Propeller Cavitation Analysis, UPCA91, was a product of collaboration between the Department of Marine Technology (now the School of Marine Science and Technology) at the University of Newcastle upon Tyne and the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences. A description of an early version of the program is given by Szantyr[13].

The input to the program comprises the complete propeller geometry, details of the three-dimensional wake pattern and the ship condition, speed and propeller rpm for which the analysis is to be made. The analysis of the flow on the blades and hence the determination of the blade and shaft forces, the extent of cavitation on the blades and the resulting fluctuating hull surface pressures is carried out for a number of positions in one revolution, 36 in this case. The results produced by the program consist of:

- Pressure distribution on the propeller blade for all specified blade positions.
- Distribution of boundary layer momentum thickness, together with locations of laminar separation, laminar/turbulent transition and turbulent separation for all blade positions.
- The extent and thickness distribution of sheet cavitation for all blade positions.

- The extent of bubble cavitation for all blade positions.
- The diameter of the cavitating tip vortex for all blade positions.
- The six components of hydrodynamic forces acting on a single propeller blade
- The six components of the total hydrodynamics forces and moments acting on the propeller shaft.
- The fluctuating pressures induced at specified points on the hull surface by a single propeller blade (including the effects of cavitation).
- The fluctuating pressures induced at specified points on the hull surface by the whole propeller.

The last four results undergo harmonic analysis and, in addition to their total values, they are presented in the form of harmonic amplitudes and associated phase angles. For the work reported here, cavitation and hull surface pressure fluctuations are of little interest and the only significant output from the program is the values of propeller thrust and torque corresponding to each specified operating condition.

INPUT DATA

The computer calculations were carried out for a typical, fixed pitch, merchant ship propeller that has the following main particulars:

Diameter = 6850mm
Mean Pitch = 4789mm
Number of blades = 4
Expanded Area Ratio = 0.524

The propeller geometry was taken from the appropriate manufacturer's drawings.

The calculations were made for the propeller in open water, with the wake corresponding to a uniform axial stream. The assumption that the propeller works in a uniform stream rather than a 3-dimensional ship wake is considered to have little effect on the conclusions drawn from this present study. To suppress the effects of cavitation a high, fictional value of the shaft centre-line immersion was inputted.

BLADE SECTION DRAG COEFFICIENTS

In a similar way to most propeller design and analysis procedures, the effects of blade drag are accounted for by the inputting of the appropriate blade section drag coefficients usually denoted by the term, C_D. The drag coefficients that correspond to a new or freshly polished propeller were taken from Burrill[14]. These values would normally be used in the propeller design calculations, and are thus referred to here as Design C_D's. They will be used to form the basis for the calculation of the drag coefficients corresponding to various degrees of blade roughness. The increase in section frictional resistance due to roughness can be represented by the expression[1]

$$1000\,\Delta C_F = 8.1\,\mathrm{Re}^{0.093}\left[\frac{1}{3}(h'/c) - 4.5\,\mathrm{Re}^{-1/3}\right] \qquad (1)$$

Where Re is the blade section Reynolds' Number
c is the section chord length
h' is the roughness parameter as defined by Musker[6]

Values for h' for the various Rubert surfaces were calculated by Mosaad[1] and are given in table I.

Table I. Musker's characteristic roughness measure of Rubert gauge surfaces.

Rubert Surface	*h' (μm)*
A	1.32
B	3.4
C	14.8
D	49.2
E	160
F	252

The sum of the frictional drag and the form drag will give the increase in total drag. This is given by:

$$\Delta C_D = 2(1 + t/c)\Delta C_F \qquad (2)$$

where t is the maximum thickness of the blade section.

It is the opinion of a major UK propeller manufacturer[15] that a roughness equivalent to Rubert A represents a degree of smoothness unlikely to be achieved in practice. Rubert B is considered characteristic of a new or well polished propeller and Rubert D to E would be equivalent to the blade roughness after 1 to 2 years in service. For this investigation it has been assumed that the new or polished propeller has Rubert B blade surfaces, the drag of which is represented by the design C_D values. The increase in C_D caused by blade roughening is then given by the difference between the ΔC_D values corresponding to the Rubert surface in question and that for Rubert B. If we take for example Rubert D

$$C_D D = Design C_D + (\Delta C_D D - \Delta C_D B) \qquad (3)$$

The effect of the increased roughness on the drag coefficient for the section at r/R = 0.7 is shown in table II.

Table II. Drag coefficients of Rubert surfaces (Design = Rubert B).

Surface	*Design*	*Rubert D*	*Rubert E*	*Rubert F*
C_D	0.00838	0.01003	0.01138	0.01206
% Increase		19.7	35.8	43.9

Candries carried out experimental work with various surfaces coated with a foul release system[16]. The surface characteristics of 5 different applications were studied using a UBM Optical Measurement System from which it was found that the roughness measure h' varied between 0.5 and 5µm. The quality of application ranged from excellent to good, so that it was considered appropriate to assume a value of h' = 5µm. The calculated values were negligibly different form those calculated when using the Design C_D values. From this it can be inferred that a foul release coated blade surface is equivalent to the new or well polished blade surface.

CALCULATIONS WITH UPCA91

The propeller performance with the design C_D values was calculated for five operating conditions corresponding to J = 0.3, 0.4, 0.5, 0.6 and 0.7. This will provide a basis for comparison. J is the non-dimensional advance coefficient given by

$$J = \frac{V_A}{nD} \qquad (4)$$

where V_A is the propeller advance in m/s
n is the propeller rate of rotation in rps
D is the propeller diameter in metres.

This procedure was then repeated with the drag coefficients corresponding to Rubert D, E and F surfaces and for all the above advance coefficients.

Thrust and Torque values that are derived from these calculations were made in non-dimensional terms as shown below

$$\text{Thrust Coefficient, } K_T = T/(n^2 D^4 \rho) \qquad (5)$$

$$\text{Torque coefficient, } K_Q = Q/(n^2 D^5 \rho) \qquad (6)$$

where T is the propeller thrust in kN
Q is the propeller torque in kN.m
ρ is the mass density of sea water in kg/m³

The efficiency of the propeller for each case is calculated from

$$\eta_0 = J/2\pi \times K_T/K_Q \qquad (7)$$

The values of K_T, $10K_Q$ and η_0 are plotted against J and the results are shown in figure 3.

From this figure it can be seen that the predominant effect of an increase in the roughness of the propeller blades is an increase in the propeller torque. The decrease in propeller thrust that accompanies the increased torque is too small to be obvious on the figure's scale.

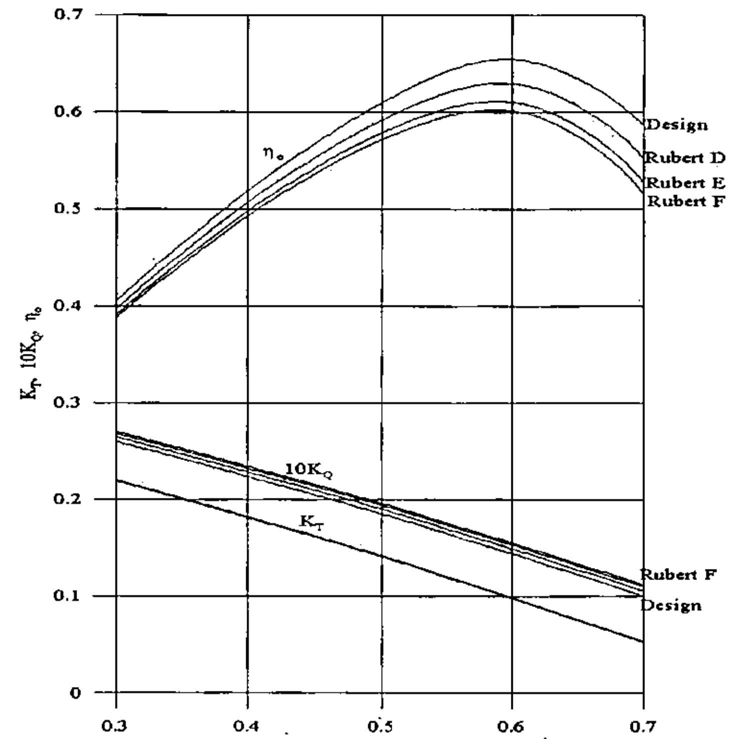

Fig 3. Propeller open water characteristics for various values of blade surface roughness.

The loss in propeller efficiency as the propeller blades roughen, to a base J, is shown by figure 4. It is defined by

$$\%\text{Efficiency Loss} = (\eta_0 \text{Design} - \eta_0 \text{Rubert}) / \eta_0 \text{Design} \times 100 \tag{8}$$

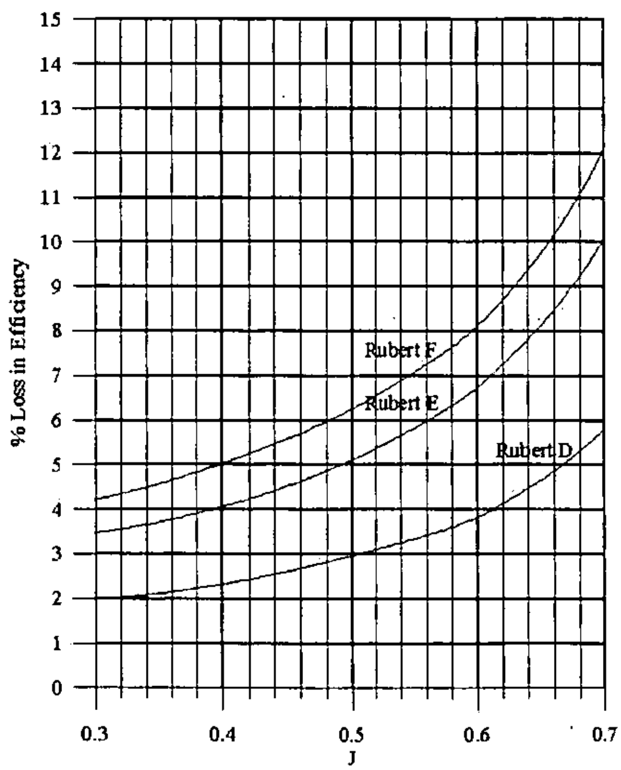

Fig 4. Loss in efficiency in going from Design Drag Coefficient to specified Rubert Surfaces.

In a similar way the gains in efficiency possible due to the blade being polished are shown in figure 5. It is defined by

$$\%\text{Efficiency Gain} = (\eta_0 \text{Design} - \eta_0 \text{Rubert}) / \eta_0 \text{Rubert} \times 100 \qquad (9)$$

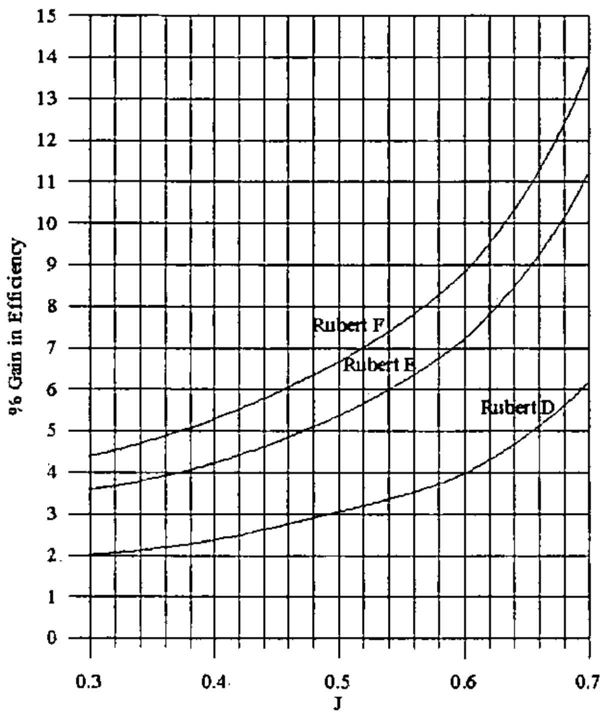

Fig 5. Gain in efficiency in going from specified Rubert Surfaces to Design Drag Coefficient

The gains in efficiency by polishing are, of course, slightly greater than the losses in efficiency with blade roughening. There is an increase in efficiency with the increase in J because as the propeller forces decrease in magnitude, the section drag will comprise a larger proportion of the total energy that is lost. Performance data for the ship from which the propeller that was modelled is taken shows that on average the propeller works at a value of J = 0.48. From figures 4 and 5 it is shown that the propeller efficiency losses and gains are about 3%, 5% and 6% for surfaces of roughness represented by Rubert D, E and F respectively.

CONCLUSIONS

The results of the calculations described above show that significant losses in propulsive efficiency resulting from blade roughening can be regained by cleaning and polishing of the blades. Alternatively, the efficiency losses could be avoided, perhaps indefinitely, by the application of a paint system that gives a surface finish equivalent to that of a new or well-polished propeller. A foul release coating is such a paint system.

This research is ongoing and the calculations presented above are to be validated in the near future with model tests using the Emerson Cavitation Tunnel at the University of Newcastle upon Tyne. The model will also be used to consider the effects of coating thickness and investigate the durability over time of the coating as there is some concern of detachment at the blade tips. For full-scale evaluation sea trials are to take place using the University research vessel 'Bernicia' and a number of larger commercial vessels. These results will be published in due course.

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Engine Exhaust heat utilisation — A Diesel Generator-set based Trigeneration

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SYNOPSIS

A theoretical and experimental investigation of a small scale diesel generator-set based trigeneration is performed. The results show that the utilisation of a diesel engine exhaust heat to drive a trigeneration is feasible. A test rig for the trigeneration has been set up. A series of tests were carried out, and the results show that the thermal efficiency of trigeneration is 81%, comparing to that of the conventional power generation only 36%, and the thermal efficiency of cogeneration is 80%. This trigeneration saves 127% CO_2 emission than that from the coventional power generation system.

NOMENCLATURE

COP	coefficient of performance
E	energy input (kW)
F	coefficient of CO_2 emission per kWh of power / fuel (kg CO_2 / kWh)
m_{CO_2}	quantity of CO_2 emission (kg/h)
m_{fuel}	fuel consumption of the engine generator (kg/kWh)
P	power (kW)
Q	heat flow rate, extracted or supplied (kW)
η	thermal efficiency
ΔE	savings of energy (kW)
Δm	quantity of saved emission
ε	relative ratio of saved energy or saved emission

Subscript

abs	absorption refrigerating system
com	power driven compression refrigerating System
e	electrical generation, electrical power
E	evaporator
f	fuel
G	generator in the absorption system
h	heating
h1, h2,	heat exchanger HE1, HE2
p	primary
re	refrigerating
co	cogeneration
tri	trigeneration

INTRODUCTION

Global warming trends have been seen since the last two centuries. Continued increase of emissions to the environment have become a real and serious threat with damaging consequences to life on earth, which are shown in Fig 1 and Table 1 [1, 2] (Intergovernmental Panel on Climate Change (IPCC) [1]). Fig 1 illustrates the effects of the large growth over the industrial

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era in the emissions of greenhouse gases from human activities. The concentration of CO_2 increased from 288 ppm at pre-industrial period to 350 ppm at 2000. The average rate of increase since 1980 is 0.4%/year. Most of the emissions during the past 20 years are due to fossil fuel burning. The concentrations of Methane (CH_4) and Nitrous Oxide (N_2O) are also increasing greatly. The concentration increase of green house gas has resulted in an increase of the atmospheric temperature – better known as Global Warming (see Fig 2, IPCC).

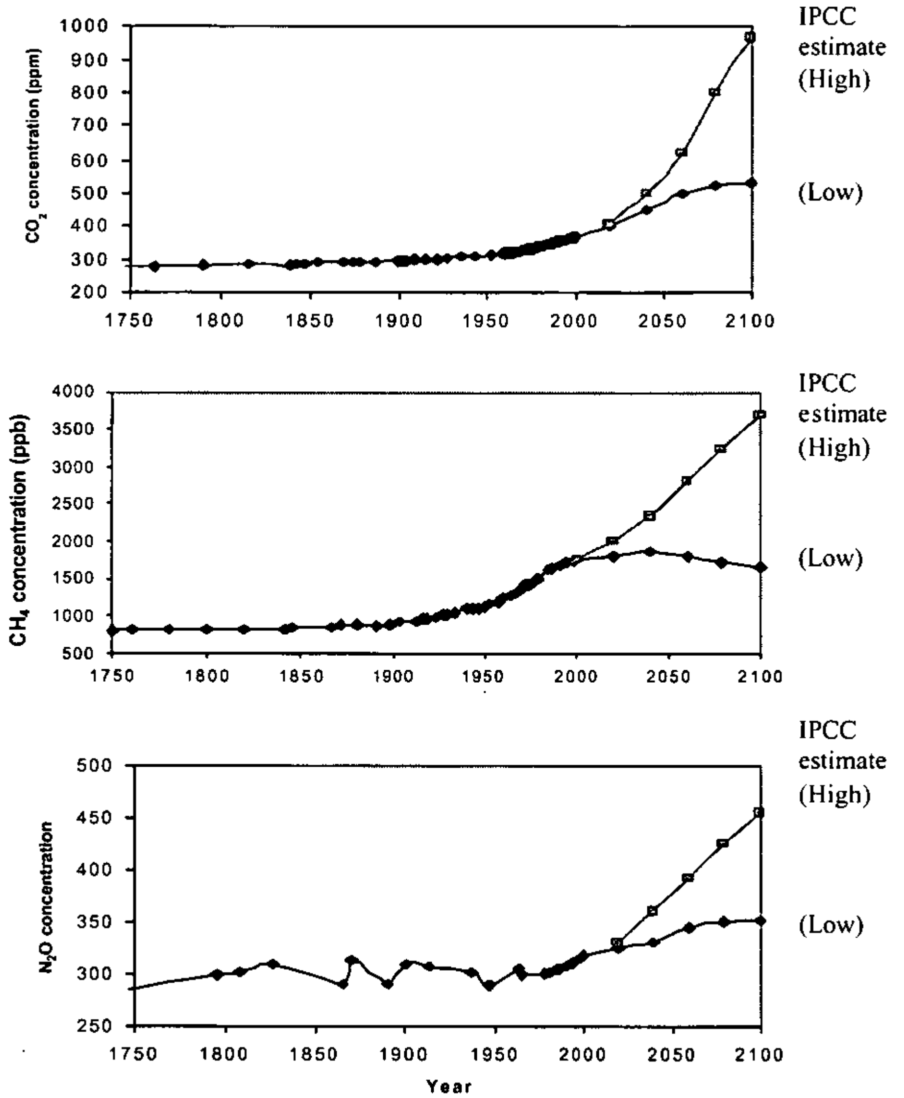


Fig 1 Atmospheric concentrations of CO_2, CH_4 and N_2O: the past and the predicted by models

Table 1 Current Main Greenhouse Gas Concentrations (Updated September 2001)

Green house gas	Contribution to warming	CO_2 equiv /molecule	Pre-industrial concentration (1860)	Current concentration	Growth rate (%/year)	Atmospheric lifetime
Carbon dioxide	50%	1	288 ppm*	350 ppm	0.5	7 years
Methane	19%	30	0.848 ppm	1.7 ppm	1.0	10 years
CFCs	17%	3,900 ~ 10,000	zero	0.20 ~ 0.32 ppb	5	77~139 years
Tropospheric ozone	8%	2,000	-	~20 ppb	0.5	Several weeks
Nitrous oxide	4%	150	285 ppb	310 ppb	0.25	120 years
Water Vapour	2%	-	-	-	-	-

* Present tropospheric concentration estimates are calculated as annual arithmetic averages; ppm =parts per million (10^6).

According to estimation by IPCC, the global average surface temperature has increased by 0.6± 0.2 °C since the late 19th century.

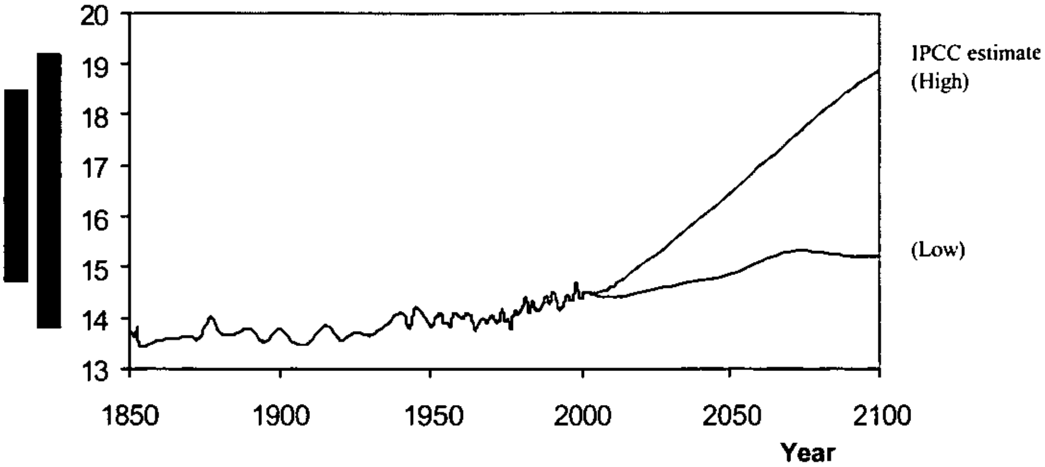


Fig 2 The global average surface temperature yearly rise: the past and the predicted by models

There will be a more serious growth of these green house gases according to their prediction. There will be a trend of global temperature increasing accompanying the green house gas increasing (shown in Fig 2). The globally averaged surface air temperature is predicted by models to warm 1.4 to 5.8 °C by 2100 relative to 1990.
Measurements during the past 100 years reveal that sea level has already risen worldwide by 10 to 25 cm. In this century, rapid global warming could triple that rate. By 2050, the oceans may rise another 20 cm, causing low-lying shorelines to recede significantly. Vast coastal areas would be lost [3].

Global warming has caused serious environmental problems around the world, flooding, droughts, in particular partial melting of polar ice-caps and an attendant rise in sea level. Low-lying coastal areas worldwide are being flooded as the sea level rise.

One way to control this undesirable trend is to reduce the emissions of Green house gas from the human activities. To increase the energy utilisation efficiency of energy consuming facilities is an option to reduce the Green house gas emission. To realise this goal, it is the task for scientists and engineers, to develop new energy systems, which have less green house emissions to the environment.

Many researches in this area have been done during the last decades [4,5,6]. Trigeneration [7,8,9,10], utilising the waste heat from power generation to provide heat, and refrigeration (or cooling), is an excellent measure to reduce emission from power generation system.

A trigeneration system proposed in this paper utilises the waste heat from the exhaust of an diesel engine generator, to drive heating and refrigeration, generating electricity (power), heat and refrigeration at the same time. As diesel engine generators are widely used in many cases, it will save a great deal of energy, and will produce less emission, if the proposed trigeneration system apply to the similar cases.

THE PROPOSED TRIGENERATION SYSTEM

Fig 3 shows a skeleton diagram of the trigeration system used in this study. It comprises a diesel engine, an electrical generator, an exhaust heat exchanger (HE1), an engine block cooling heat exchanger (HE2), and an absorption refrigerator. The engine drives the generator through a common shaft to generate power; The engine exhaust gas distributes heat to HE1 which supplies heating; and the HE2 for engine cooling also supplies heat for heating; a part of the exhaust drives absorption refrigerator to get refrigeration.

The primary energy input (E_p) from diesel fuel is supplied to the diesel engine. The electrical power output (P) is generated by the electrical generator. The heat outputs (Q_{h1}, Q_{h2}) are from heat exchangers HE1 and HE2. The refrigerating effect (Q_E) is achieved from the heat input (Q_G) to the generator in the absorption system.

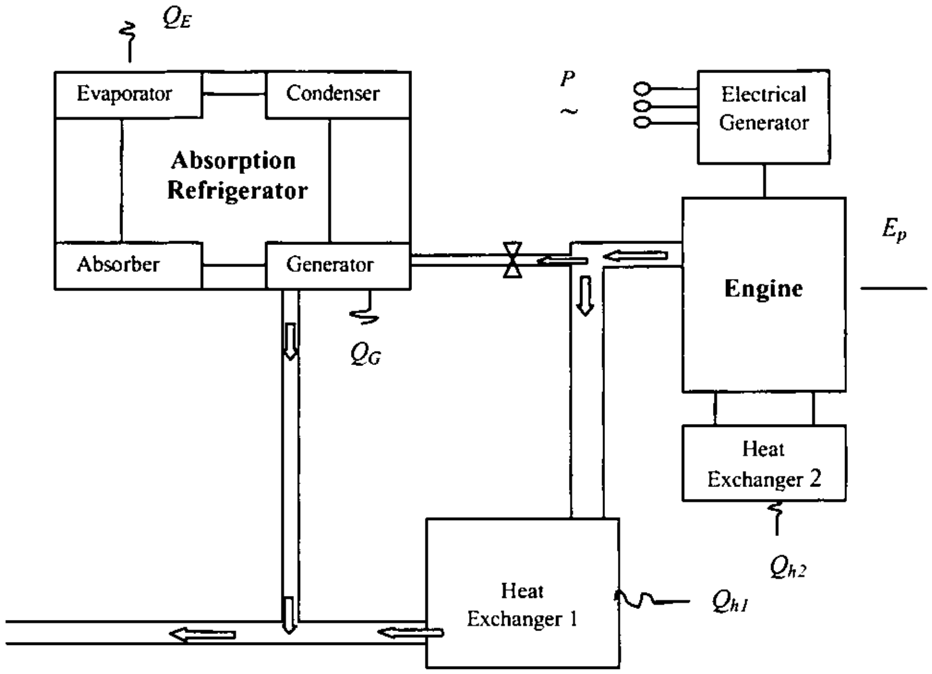


Fig 3 The trigeneration skeleton diagram

MATHEMATICAL MODEL OF TRIGENERATION

Fig 4 shows an overall representation of a trigeneration system. In the system, diesel fuel is converted into electricity (power), heating, and refrigeration effect. In order to find out how much energy savings and green house gas emission savings can be achieved by trigeneration, a conventional power generation (Fig 4 (b)), a cogeneration (Fig 4 (c)) are also discussed in this part. The discussion below, is based on the power output of a diesel generator set.

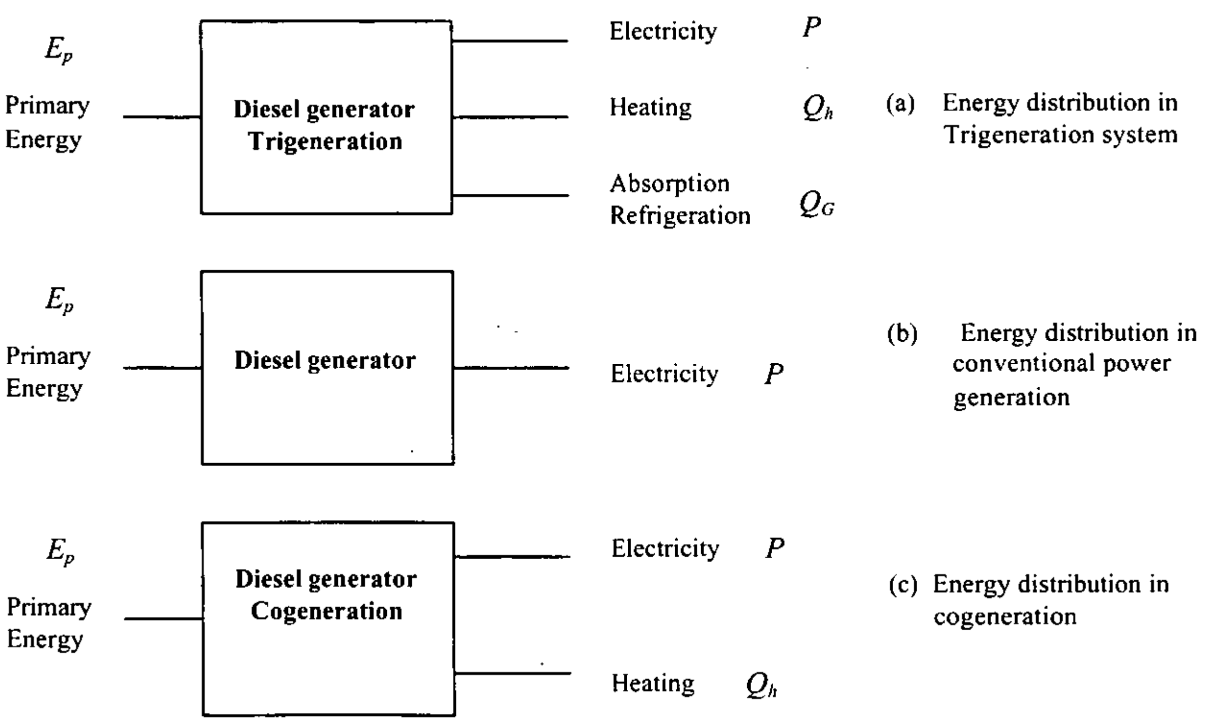


Fig 4 Schematic overview of energy distribution for different generation systems

The energy efficiency of trigeneration system and separate generation system

In order to evaluate the energy efficiency of the trigeneration system, the following parameters are defined:

- The efficiency of electrical power generation:

$$\eta_e = P / E_p \qquad (1)$$

Equation (1) can be written as:

$$E_p = P / \eta_e \qquad (1a)$$

- The coefficient of performance (COP) of absorption refrigerating system:

$$COP_{abs} = Q_E / Q_G \qquad (2)$$

And, Equation (2) can also be written as

$$Q_G = Q_E / COP_{abs} \qquad (2a)$$

The heat output Q_h (kW)can be calculated as follows (see Fig 3):

$$Q_h = Q_{h1} + Q_{h2} \qquad (3)$$

The primary energy input E_p (kW), is from diesel supplied to the diesel engine

$$E_p = m'''_{diesel} \; Q_{LHV} \qquad (4)$$

m'''_{diesel} is the fuel consumption of engine per second (kg/s), Q_{LHV} is the Low heating value of diesel (J).

The heat efficiency of trigeneration is:

$$\eta_{tri} = (P + Q_G + Q_h) / E_p \qquad (5)$$

The heat efficiency of power generation is:

$$\eta_e = P / E_p \qquad (1)$$

The heat efficiency of cogeneration is:

$$\eta_{co} = (P + Q_h) / E_p \qquad (6)$$

The real savings of the primary energy consumption by using trigeneration system comparing to the conventional power generation is:

$$\varepsilon_{\Delta E} = (\eta_{tri} - \eta_e) / \eta_e \qquad (7)$$

And the real savings of the primary energy consumption by using trigeneration system comparing to the cogeneration is:

$$\varepsilon'_{\Delta E} = (\eta_{tri} - \eta_{co}) / \eta_{co} \qquad (8)$$

CO_2 emission

The quantity of CO_2 emission from trigeneration system, coventional power generation system and cogeneration depend on the quantity of fuel they consumed.

The CO_2 emission from trigeneration $m_{CO2(tri)}$ (kg/h) can be given by the product of energy consumed E_p and the CO_2 emission per kWh of fuel consumed by trigeneration F_{tri} (kg/ kWh):

$$m_{CO2(tri)} = E_p F_{tri} \qquad (9)$$

F_{tri} (kg/ kWh) is the CO_2 emission per kWh trigeneration output, and

$$F_{tri} = F_f / \eta_{tri} \quad (10)$$

And the CO_2 emission from conventional power generation $m_{CO2(e)}$ (kg/h) can be given by the product of energy consumed E_p and the CO_2 emission per kWh of electrical power F_e (kg/ kWh):

$$m_{CO2(e)} = E_p F_e \quad (11)$$

F_e (kg/ kWh) is the CO_2 emission per kWh of electrical power, and

$$F_e = F_f / \eta_e \quad (12)$$

And the CO_2 emission from cogeneration $m_{CO2(co)}$ (kg/h) can be given by the product
of energy consumed E_p and the CO_2 emission per kWh of electrical power and heat F_{co} (kg/ kWh):

$$m_{CO2(co)} = E_p F_{co} \quad (13)$$

F_{co} (kg/ kWh) is the CO_2 emission per kWh of electrical power and heat, and

$$F_{co} = F_f / \eta_{co} \quad (14)$$

The relative ratio of saved emission of CO_2 from trigeneration compare to the emission of CO_2 from conventional power generation ε_{CO2} is:

$$\varepsilon_{CO2} = |(m_{CO2(tir)} - m_{CO2(e)}) / m_{CO2(tri)}| \quad (15)$$

The relative ratio of saved emission of CO_2 from trigeneration compare to the emission of CO_2 from cogeneration ε'_{CO2} is:

$$\varepsilon'_{CO2} = |(m_{CO2(tir)} - m_{CO2(co)}) / m_{CO2(tri)}| \quad (16)$$

EXPERIMENTAL EQUIPMENT

According to the purpose of the experiment, more attention will be placed on the realization of a real trigeneration system. The whole plan is realized in two aspects: (1) constructing the trigeneration system; (2) instrumentation for measuring and collecting data. Fig 3 shows the schematic diagram of completed test rig of trigeneration. The experimental equipment used in the tests are:

Diesel engine

A Lister-Petter T series diesel engine, 9.5 kW capacity, fixed speed (1500 rpm), type TS2, made by the Lister-Petter Ltd , is mounted on a test bed. The TS2 engine is a generator engine equipped for Lister-Petter series of diesel generating sets. It is an Air-cooled, direct injection diesel Engine (Manual of Lister-Petter Ltd).

Generator

A Leroy Somer LSA410 type generator, 415V, Synchronous, 10A full load current, Single bearing, is connected to the engine by a prop shaft.

Heat exchanger

The heat exchanger is an air-air cross-flow heat exchanger, which is made in the laboratory, as shown in Fig 5.

Absorption refrigerator

An Electrolux absorption refrigerator, model RM 4213S, energy input is 125 Watts

by electric power, 186 Watts by LPG gas, is used in the test for trigeneration.

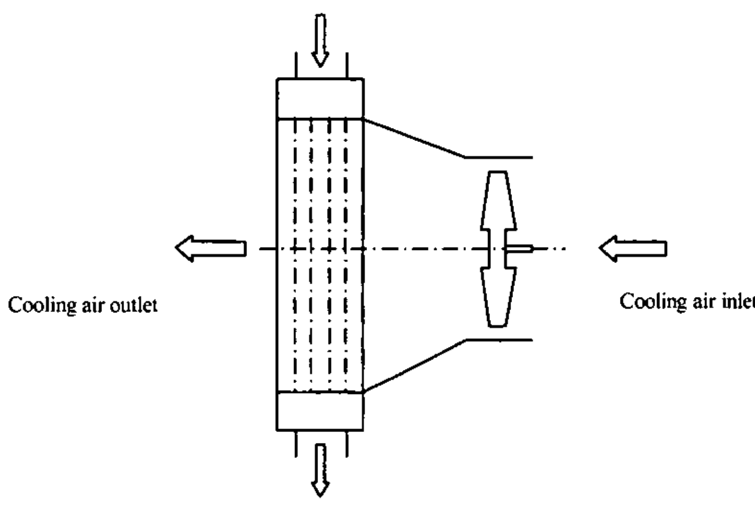


Fig 5 Air-air heat exchanger

THE RESULTS AND DISCUSSION

A series tests has been done and the simulation of a small-scale diesel generator-set based trigeneration and the relative separate generation system as shown in Fig 4 is carried out. The given data are as follows:

Electrical power generated by generation	P = 8.000 kW
Diesel fuel low heat value	Q_{LHV} = 42500000 J/kg
Fuel consumption of engine	m_{fuel} = 0.238 kg/kWh
Heat input to the generator in the absorption system	Q_G = 0.186 kW
Power consumed by power driven refrigerating system	P_{ele} = 0.125 kW
Heat output from heat exchanger HE1	Q_{h1} = 5.674 kW
Heat output from heat exchanger HE2	Q_{h2} = 4.303 kW
CO_2 emission per kWh of fuel	F_f = 0.270 kg/kWh

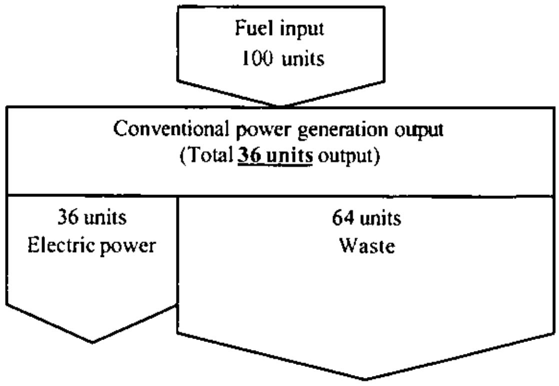
The test and calculation results are shown in Table 2 to Table 3. Table 2 presents the calculations of Ep (kW) and the thermal efficiency of conventional power generation, cogeneration, and trigeneration systems (formulae (1) to (6)). Given P, Q_{LHV}, m'''_{diesel}, Q_G, Q_{h1}, Q_{h2}, the values of Q_h, Ep, η_e, η_{co}, η_{tri} can be calculated separately.

Table 2 calculations of η_e, η_{co}, η_{tri}

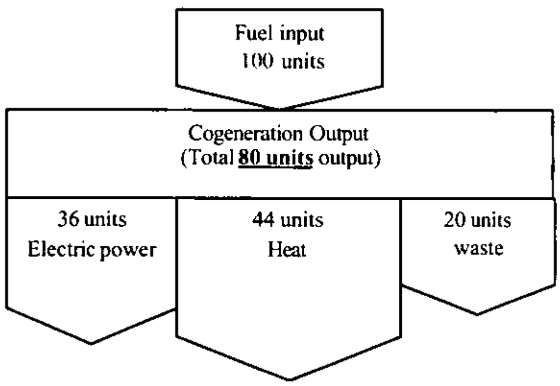
Given	Q_{h1}(kW)	Q_{h2}(kW)	P(kW)	Q_G (kW)	Calculated	Q_h(kW)	Ep(kW)
	5.674	4.303	8.000	0.186		9.978	22.478

Calculated	η_e	η_{co}	η_{tri}	$\varepsilon_{\Delta E}$	$\varepsilon'_{\Delta E}$
	0.36	0.80	0.81	1.27	0.01

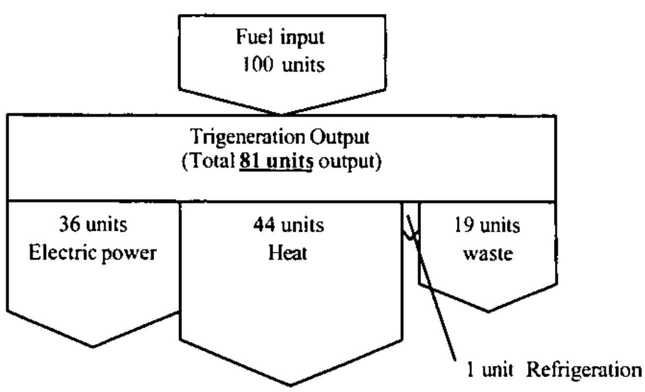
Fig 6 shows the energy distribution of the three generation systems. Comparing Fig 6 (a), (b), and (c), from the same fuel energy input (100 units of fuel input), conventional electrical power generation output electrical power 36%, its total thermal efficiency is only 36%; cogeneration, output 36% of electrical power, 44% of heat, the total thermal efficiency reaches 80%, higher than that of conventional electrical power generation; trigeneration output 36% of electrical power, 44% of heat, 1% of refrigeration, the total thermal efficiency reaches 81%, not only much higher than that of conventional electrical power generation, but also higher than that of cogeneration.



(a) Energy distribution of conventional power generation



(b) Energy distribution of cogeneration



(c) Energy distribution of trigeneration

Fig 6 Energy distribution of different generations

Table 2 also shows the comparison of thermal efficiency of trigeneration to the other two generation systems.The thermal efficiency of trigeneration is 1% higher than that of cogeneration; and the thermal efficiency of trigeneration is 127% higher than that of conventional electrical power generation.

Table 3 shows the calculation results of CO_2 emission from trigeneration, conventional power generation system, and cogeneration. Table 3 also shows the comparison between the three systems (formulae (9) to (16)). It can be seen that the CO_2 emission from trigeneration is lower than the cogeneration system; and CO_2 emission from trigeneration is much lower than the coventional power generation system. The CO_2 emission from trigeneration is 7.512 kg/h, from cogeneration system is 7.590 kg/h, from conventional power generation is 17.055 kg/h. Trigeneration is 127% less than the conventional power generation.

Table 3 The comparison of CO_2 emission of trigeneration with conventional power generation system and cogeneration

Given :	F_f (kgCO_2/kWh)	Calculated:	F_e (kgCO_2/kWh)	F_{co} (kgCO_2/kWh)	F_{tri} (kgCO_2/kWh)
	0.270		0.76	0.34	0.33
Calculated: CO_2emission	$m_{CO2(e)}$ (kg/h)	$m_{CO2(co)}$ (kg/h)	$m_{CO2(tri)}$ (kg/h)	ε_{CO2}	ε'_{CO2}
	17.055	7.590	7.512	127%	1%

Besides of less green house gas (CO_2) emission, trigeneration utilizes ammonia-water refrigeration to produce cold (cooling), there is no CFCs emission. Considering that CFCs contribute 17% of global warming and the CFCs lifetime is very long (Table 1), trigeneration (ammonia-water refrigeration) can save 17% of green house emission as well.

CONCLUSION

Trigeneration for generating electrical power, heat and refrigeration is highly efficient in terms of fuel energy utilisation, and contrastively lower green house gas (CO_2) emission. It can be used to where that electrical power, heating and refrigeration are needed, such as ships, supermarkets, food industry, some small islands as well.

Energy efficiency of trigeneration can be expressed by comparing values of thermal efficiency for designed trigeneration to that of conventional power generation system and cogeneration. According to the tests and calculation, the thermal efficiency of trigeneration is 81%; but for the conventional power generation, the thermal efficiency is only 36%, and the thermal efficiency of cogeneration is 80%. The thermal efficiency of trigeneration is 127% higher than that of conventional electrical power generation.

From the environmental point of view, trigenreration may save the green house gas (CO_2, CFCs) emission accompanying by its high energy efficiency. According to the results achieved above, The CO_2 emission from trigeneration saves 127% than that from the coventional power generation system. This CO_2 emission and the CFCs emission savings are of more important significance to the environment.

A conclusion can be drawn that trigeneration is an environment friendly system, from which energy can be saved and less emission is exhausted to the atmosphere.

ACKNOWLEDGEMENTS

The authors want to thank Professor Tom Ruxton who supported the project, and Mr Ian Pinks who helped to set up the test rig of trigeneration. The support of the School of Engineering and Advanced Technology of Staffordshire University is greatly appreciated.

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A Study of Numerical Analysis for the Fluid Motion in the Ballast Water Exchange
- Numerical Simulation for the 2-Dimensional Tank Fluid Motion -

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ABSTRACT

This study was performed for the elucidation of actual ship ballast tank's fluid motion on Ballast Water Exchange. Two-dimension moving tank's fluid motion in time step domain was simulated by numerical analysis on the fluid volume decrease situation. For the numerical analysis of fluid motion, Boundary Element Method was used. Experiment of moving two-dimensional rectangular tank model was proceeded as the verification of simulation results. From the compared simulation results of free surface motion with experiment one, both results were agreed. Tank's interior fluid velocity was calculated and shown at each other position in the fluid from the velocity potential obtained from the result of this simulation.

1. INTRODUCTION

Ballast water is indispensable for the preset displacement type ship's navigation as it is used for the adjustment of ship draft and the enhancing the ship maneuverability. Ballast water is pumped in ballast tanks either at shipment port, gulf or the coastal area at the empty condition of ship hold. When ship arrived to the destination port, this water is discharged into the sea. In recent year, it has been identified as a threat to the ocean environments.

Discharged ballast water includes many species of animals and microorganisms. If these creatures that came from other sea area stay in the sea area and that have the strong power of breeding than native species, it is possible that they expelled the native one. This matter becomes a harmful effect to the human society. These problems on ballast water are being discussed seriously and continually at IMO higher committee. IMO is under examination of new international convention of the control and management of ship's ballast water and sediment. Moreover, strict domestic laws are also in enforcement in few countries (AUSTRALIA, U.S.A etc.) [1), 2)]

Today, as the recognized only way under the ballast water management in the world, ballast water is discharged and recharged at the deep ocean by the ship officer and staff (Ballast Water Exchange). However, in this method, verification and validation has not been performed on scientific level, so far. This verification needs great studies and investigations on exchange of ballast water. Especially, in the ballast water management, management of sediment is important because it has some of the micro organism's cysts. For the analysis of sediment motion in the ballast tank, the analysis of tank fluid motion with much circumstance is necessary.

In this paper, as the first step of analysis of fluid motion in the ballast water exchange, analyzing for the movement of the inside fluid in the moving tank on the situation of fluid volume changing was performed. There are many studies and investigations for the calculation of the free surface movement as the sloshing problem until now. However, the studies that computed the sloshing model on transitional condition as the change of fluid volume in continual time step domain is very rare. Therefore, the numerical simulation that is assumption of a 2-dimensional tank sloshing problem on volume transitional condition was preformed. Boundary Element Method (BEM) was utilized for this study and calculations results with computed values of experiments that were performed for the verification was compared.

2. CALCULATION METHOD

2-1. Mathematical Model

Let us consider two-dimensional motion of a fluid in tank show in **Fig.1**. Fluid region V is bounded by the boundary G which is composed of a free surface part G_f and a wall part G_w of the tank. The tank has angular velocity $\vec{\Omega}$ and linear motion velocity $\vec{U}$ with respect to the space co-ordinate system. The coordinate systems o-xy and 0-XY are fixed with respect to the tank and the space respectively. It is assumed that the fluid is in viscid and incompressible, and the flow is irrotational. Under these assumptions it is possible to get the following governing equation (1) in V and boundary conditions (2)-(4) on G .

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$$\nabla^2\Phi = 0 \qquad \text{in } V \quad (1)$$

$$\frac{\partial\Phi}{\partial t} = -\frac{|\nabla\Phi|^2}{2} + \dot{\vec{\Omega}}\cdot(\vec{r}\times\nabla\Phi) - \dot{\vec{U}}\cdot\vec{r} - gY_h \qquad \text{on } G_f \quad (2)$$

$$\frac{d\vec{r}}{dt} = \nabla\Phi - \vec{\Omega}\times\vec{r} \qquad \text{on } G_f \quad (3)$$

$$\frac{\partial\Phi}{\partial n} = \vec{n}\cdot(\vec{\Omega}\times\vec{r}) \qquad \text{on } G_w \quad (4)$$

Here Φ denotes the velocity potential, $\vec{r}$ denotes the position vector in the coordinate system that is fixed with respect to the tank, n denotes the outward unit normal vector on the boundary, g is the acceleration of gravity and Y_h is distance from the initial free surface.

Therefore, the motion of the fluid is obtained by solving the Laplace equation (1) using the boundary condition (2)-(4). [3)]

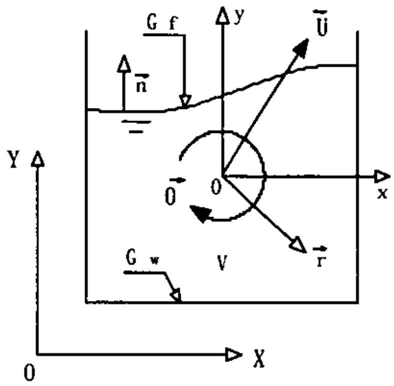

Fig.1 Coordinate System

2-2.Boundary Element Method

By taking into account the linearity of Laplace equation (1), it is possible to transform the field equation (1) into the following boundary integral equation:

$$\frac{\alpha(\xi)}{2\pi}\Phi(\xi) = \int_\Gamma q(x)\Phi^*(x,\xi)d\Gamma(x) - \int_\Gamma \Phi(x)q^*(x,\xi)d\Gamma(x) \quad (5)$$

where α denotes shape-function. The fundamental solution Φ^* is given by, respectively.

$$\Phi^*(x,\xi) = \frac{1}{2\pi}\log(1/r_\xi),\ r_\xi = \sqrt{(x-x_\xi)^2+(y-y_\xi)^2} \quad (6)$$

$$q(x,\xi) = \frac{\partial\Phi}{\partial n},\ q^*(x,\xi) = \frac{\partial\Phi^*}{\partial n} \quad (7)$$

In order to solve approximately boundary integral equation (5), by boundary element method, the boundary G was divided into N linear elements. Let the Coordinate of each mesh point on the boundary be $x_i(i=1,2,???,N)$, and applying selection point method by using these mesh points to (5) the following discrete expression (8) can be obtained.

$$\frac{\alpha(x_i)}{2\pi}\Phi(x_i) + \sum_{j=1}^{N}\hat{H}_{ij}\Phi_j - \sum_{j=1}^{N}G_{ij}Q_j = 0 \quad (i=1,2,???,N) \quad (8)$$

Here, $\hat{H}_{ij}$ and G_{ij} are influence coefficient vectors, Φ_j and Q_j are velocity potential value and its derivative at the mesh point j . When the form of the element is straight line the influence coefficient vector can be obtained analytically.

Here, the unknown quantities are Φ and $\partial\Phi/\partial n$ of each mesh point on the free surface G_f and tank side wall G_w respectively. When Φ and $\partial\Phi/\partial n$ are given to (8), on the basis of initial conditions or boundary conditions, linear equations that have N unknown variables can be obtained and it is possible to solve for these unknown quantities. When (8) is solved and the value of Φ and $\partial\Phi/\partial n$ at all mesh points are obtained, It is possible to find the velocity potential value and the velocity of fluid at any position. The following equation is used for calculating the velocity potential value.

$$\Phi(\xi) = \int_\Gamma q(x)\Phi^*(x,\xi)d\Gamma(x) - \int_\Gamma \Phi(x)q^*(x,\xi)d\Gamma(x) \quad (\xi\in V) \quad (9)$$

On the other hand, the velocity fluid is obtained by differentiating (9) with respect x and also y.

2-3.Form Change of the Free Surface

As described in the above paragraph, If the initial conditions are given, $\partial\Phi/\partial n$ of each mesh point at any position on the free surface G_f can be obtained. And using these values, $\nabla\Phi$ can be calculated. Tangent direction differentiation value $\partial\Phi/\partial s$ can be obtained by using initial condition Φ of mesh point. We can determine $\partial\Phi/\partial s$ of mesh point i which is between element j and element j-1 using the following equation:

$$(\frac{\partial\Phi}{\partial s})_i = \frac{l_j}{l_{j-1}+l_j}(\frac{\partial\Phi}{\partial s})_{j-1} + \frac{l_{j-1}}{l_{j-1}+l_j}(\frac{\partial\Phi}{\partial s})_j \qquad (10)$$

$$(\frac{\partial\Phi}{\partial s})_j = \frac{\Phi_{i+1}-\Phi_i}{l_j}$$

where l_j denotes the element length of element j.

The rate of increase of the velocity potential of each mesh point at any position of on the free surface G_f can be obtained by substituting $\nabla\Phi$ in (2), and Φ at the next increment of time can be estimated. Similarly, the rate of increase of the position of each mesh point at any position of free surface G_f can be obtained by substituting $\nabla\Phi$ in (3), And new position of each mesh point can also be estimated. Taking the new position and velocity potential, calculated for next time increment as initial values, calculation can be repeated until a time period by repeating the same procedure and can simulate the change of the free surface configuration. Furthermore, we used the Euler method that is the first-order advanced difference method in the calculation of the time integration.[4),5),6)]

3. EXPERIMENT AND CALCULATION

For the vilification of the calculation, the experiment using a rectangular tank model was performed and compared with experiment result and numerical calculation one. In the experiment, the simulation of tank fluid motion is carried out in a model tank which discharges fluid at constant quantity while rolling.

3-1. Experiment

Experiment was carried using model tank as shown in **Fig.2** which can be considered as a two dimension tanks because it does not move in the direction of depth. This model tank has a depth of 0.04(m). There is a drain hole at the bottom of right wall of tank through which fluid flows out at constant quantity by pump.

Fluid of tank is kept at complete rest at $t = 0$. The tank rolls about the center line and the fluid is drains out. Speed of the receding free surface was kept at 0.00185(m/sec). We adopt the amplitude θ= 1.0(deg) as parameter of rolling. Other experiment conditions are shown in **Table.1**. Changing the free surface level was recorded as pictures by using a digital video camera. The data of free surface motion was obtained visually from these pictures.

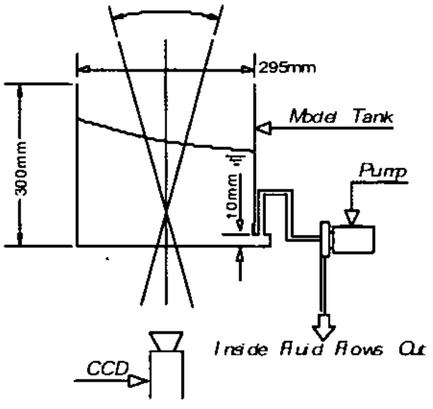

Fig.2 2-Dimension of Model Tank

Table.1 Experiment Conditions

Condition	1	2	3	4
Water Depth	200(mm)			
Outflow	Off	On	Off	On
Rolling Frequency	1.5(Hz)		1.6(Hz)	

3-2.Numerical Calculations

The simulation of fluid was carried out by using the same model tank as used in the experiment and also using same conditions. By using same symbols as used in Sec2.1, the boundary condition at the flow exit is given by:

$$\frac{\partial\Phi}{\partial n} = -fv + \vec{n}\cdot(\vec{\Omega}\times\vec{r}) \qquad (11)$$

where fv is the velocity of fluid at the flow exit. In order to simulate the outflow, we took the element at the flow exit within the mouth of the flow exit. The boundary condition for this flow exit is shown in (11). We adopted the time increment Δt=0.01(sec). And the outflow quantities of fluid and rolling angle are taken same as in the experiment. The boundary of fluid domain is divided into 70 boundary segments which consist of 40 free surface segments and 10 segments each on walls and bottom of tank.

3-3.Results and Consideration

Fig.3 (a)-(d) show images of the entire free surface forms in time ranging from 5.00(sec) to 5.20 (sec) on the experiment condition 2. And beside graphs indicate the calculation result of the free surface forms and the velocity vector of fluid at the same time. From these results, it is clear that the free surface form agreed between the experimental results and calculations one. Also repetition of free surface from by an amount of half wave length can be observed and the simulation of the motion of the fluid during the first characteristic frequency neighbourhood of the tank is simulated satisfactory.

Fig.4 shows the comparative graphs of experiment values and numerical calculations of wave heights at the right side wall of tank. In these graph, the ordinate show the elevation of free surface and the abscissa is time. Upper graph indicates comparison with results of experiment condition 1 and 2. And under graph shows comparison with results of experiment condition 3 and 4.

From the graphs, it is clear that the periods and amplitudes, in the calculation by both methods, are coinciding with each other. The different of values that changing fluid volume and fixed it are indicated in graphs.

Phenomenon of the beet that occurs due to the difference of the characteristic frequency of the tank and its rolling frequency is simulated satisfactorily. Depression of the average free surface during the outflow of the fluid was also simulated satisfactorily. Furthermore, Maximum value of the error of the amplitude is about 20%, which can be attributed to the measuring error by the image analysis of the video camera.

From the aforementioned results it is able to say that the simulation in the numerical calculation method is effective when the water is flowing out due to the rolling of the tank.

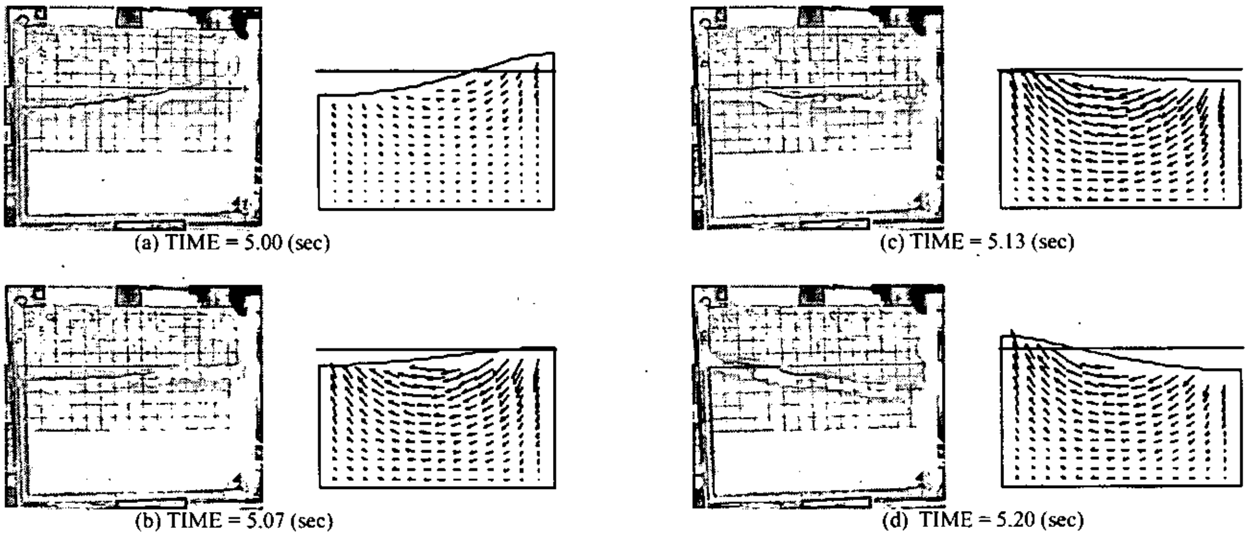

Fig.3 Comparison between the experiment and calculation values (Condition 2)

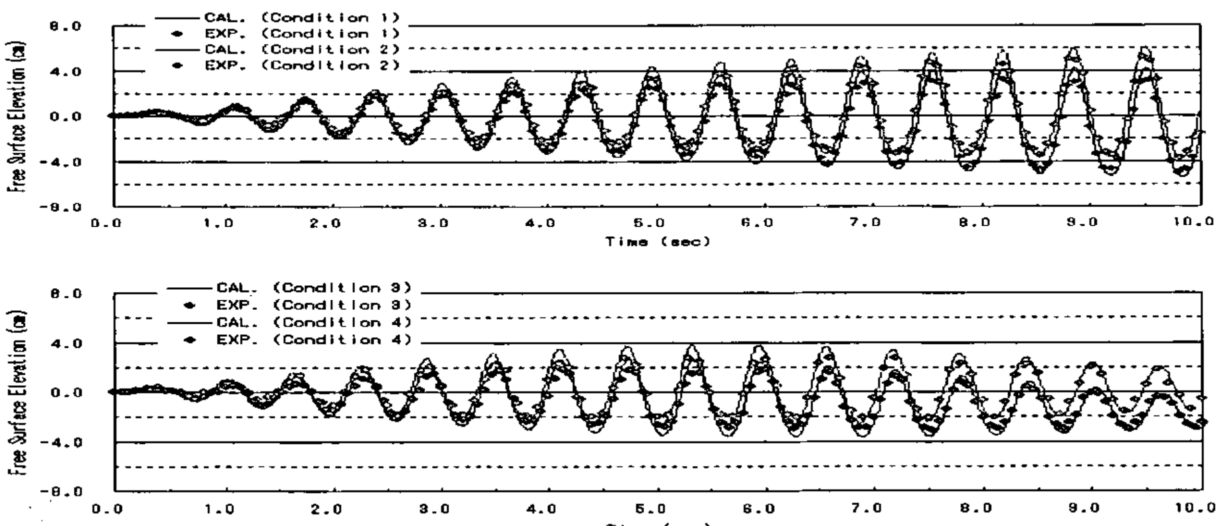

Fig.4 Time histories of the free surface elevation at right wall
(Upper: Compared values experiment condition 1 and 2 Lower: Compared values experiment condition 3 and 4)

4. CONCLUSIONS

In this study, as the basic research of the effective inspection of the ballast water exchange, we carried out sloshing simulation in the 2-dimension rectangle tank which is provided with the outflow of the inside fluid by using the numerical value calculation method on the basis of BEM and compared these results by carrying out experiment. We adopted BEM by using linear elements and the Euler method for time integration method, for finding results and simulated the outflow by giving the boundary condition to the element at the flow exit. As a result, it was confirmed that the effectiveness of the calculation method by the experiment using two-dimensional tank with outflow facility and analyzed the motion of the fluid when there is outflow. By using this method, it is possible to know the action of the inside fluid at any position of the tank and this can be applied for studying the flow of ballast water. For example, we think that the analysis for the motion of sediments, which deposits at the bottom of the ballast tank, is possible by if the velocity of fluid at its neighbourhood is known to advancing these studies. As a further study, we would like to apply this method to the circumstance analysis of fluid motion in the actual ship's ballast water exchange situation as the purpose for the understanding of the motion of sediments that are included to the ballast water. This is one of the important problems associated with the ballast water.

ACKNOWLEDGEMENT

The authors like to thank for Dr. Toshio ISEKI, Associate Professor of Tokyo University of Mercantile Marine and Shigeo MITA, Assistant of Tokyo University of Mercantile Marine. Also, The authors are very grateful to Professor Pandeli TEMAREL, Depart of Ship Science, the University of Southampton, UK, with whom one of authors, Dr. K. MINAMI, had fruitful discussion during tine spend at the University of Southampton as a over sea researcher of Ministry of Education, Culture, Sports, Science and Technology .

This research was funded by the Grant-in-aid for scientific research of Japan Society for the Promotion Science of Science (2001-2003).

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Tool for Environmental Efficient Ship Design

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SYNOPSIS

Energy consumption and related emissions are the most important environmental effects of transport. This applies to all transport modes even though the contribution from waterborne transport in general is less severe than for instance from road transport. Also the environmental effects from waterborne traffic can be substantially reduced, but this will depend on, among other, better design methodologies and tools. Use of Life Cycle Assessment (LCA) in the ship design process may help the designer to optimise a project concerning energy use over its entire life span. As part of "The Energy Efficient Ship"-project funded by the European Commission and a number of small and medium sized enterprises, a prototype ship design tool is developed. The purpose of the tool is to assist the designer in reducing not only the energy consumption during the entire life span of a ship, but also important environmental aspects. The tool is developed for design of fast ferries, containerships and fishing vessels. The paper presents the computer model including a case study demonstrating its use in design of a long lining fishing vessel. Environmental effects of alternative conceptual choices in the design phase will be demonstrated.

INTRODUCTION

Severe, human-induced climatic change is possibly the largest environmentally related challenge the world has ever faced. People have during the last decade grown more and more sensitive to this issue and a stronger focus has been set on producing goods in an environmentally friendly way. There is also a tendency to go from reactive reparation to preventive measures when ensuring a future healthy environment. Several studies have identified general trends in the society in the direction of increased focus on environmental issues and expected increased requirements for environmental performance information from industrial activities [1]. This is also expected to be of increasing importance for the shipping industry.

Commercial fishing today is totally dependent on energy-intensive technology. Energy usage constitutes an important threat to the sustainability of fishing as a food producing industry [2]. At the

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same time, it has been noticed that the market is paying more attention to the way in which fish are being caught. In the western world in particular, a tendency has been observed for consumers to make stricter demands of their food sources, including fish products. Consumers are more demanding not only with respect to fish as food but also to the ways in which it is brought to them. Consumers are becoming more and more conscious of such concepts as sustainability. These are global trends, which are reinforced by the growing power of both the retail sector and the media, both of which interpret and reinforce consumer perceptions. As far as the major retail chains in Europe are concerned, it is, or at least is perceived as, a competitive advantage to promote the cause of the consumers [3].

As an outcome of such pressure, methods for environmental friendly product development have been introduced. These contribute to minimise the total environmental impact during the life cycle of the product. The fishing vessel of the future must be based upon a new concept of functionality. Such a concept ought to embrace areas such as the total utilisation of raw materials, the processing of byproducts, reduced, or ideally zero emissions, market based production onboard or ashore, the use of new information technology and the appropriation of new logistic solutions in a value chain perspective.

THE LIFE CYCLE CONCEPT

Life Cycle Assessment (LCA) is increasingly used for assessing the environmental impacts of technologies and products. LCA is generally accepted as a suitable tool for analysing the impact that different solutions have on their external environment throughout the duration of their lifetime. LCA is a structured and standardised method for calculating a product, a process or an activity's environmental load throughout all its phases. That is to say, from the extraction of raw material through production, distribution, use and to recycling and the treatment of waste. This method was first developed for the environmental assessment of industrial products in the 1960's [4]. Since then it has been improved considerably and is today standardised in the ISO 14040- standards [5].

Such tools are developed in light of a "from cradle to grave" perspective, and they can be used in a comprehensive early planning or design phase that, for example, includes an evaluation of the environmental impact of different conceptual choices.

Within the commodity industry, and with the car manufacturing industry in the forefront, LCA is today used as a tool for product development. Within the maritime industry some projects have been performed during the latest years [6]. Det Norske Veritas [7] has introduced a new environmental class in which ships are certified in accordance to specified environmental requirements. The arrangement is voluntary and is typically applied within the areas of cruise, car and paper transportation. That is to say, in cases where the environmental effect of the transportation can be identified and linked to the end product and where it can be actively used in the shipping owners' marketing activities.

Due to the increased focus on environmental issues, LCA is viewed as a tool in the development of new types of vessels in an early planning or design phase with the evaluation of the environmental consequences of different conceptual choices in mind. For both shipping companies and producers of seafood it will become increasingly important to document that the activity takes place in accordance with the sustainability principles. By means of LCA it is possible to assess the environmental impact of new solutions in an objective manner and to compare these with reference values.

In order to be able to establish objective criteria for the measurement of the environmental impact from fish products, the whole value chain must be analysed, starting from the point the fish is removed from the sea and ending when it arrives at the consumer, see Fig. 1.

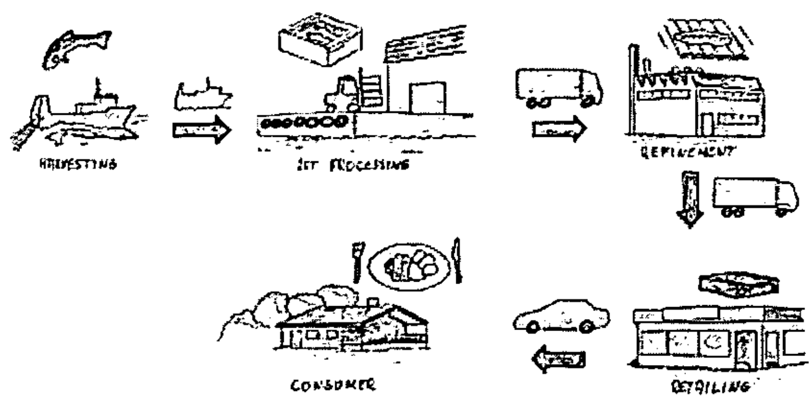

Fig. 1: The value chain in the fisheries

Though harvesting operations amounts to only one part of this chain, it constitutes a dominating portion even if we take into consideration variables such as the catch method, the distance to the markets and so on. Christensen and Ritter (Ref. 8) have employed a Life Cycle Screening (LCS) method[1] which estimated that 46% of the total load on the environment could be ascribed to the fish-capture phase in connection with the production of trawl-caught herring in glass containers.

THE PROJECT "THE ENERGY EFFICIENT SHIP" – THE TEES PROJECT

To be able to incorporate environmental aspects in an early planning phase, the project "The Energy Efficient Ship" was performed as a joint project between Hauschildt Marine in Denmark, Armstrong Technology Ltd. in UK, Fiskerstrand Yard in Norway and PE product Engineering GmbH in Germany as enterprise (SME) partners. NEA Transport and Trading, the Netherlands, Institute für Kunststoffprüfung und Kunststoffkunde at the University of Stuttgart in Germany and SINTEF Fishery and aquaculture in Norway participated as research partners. The project was led by Eric Støttrup Thompsen ApS in Denmark..

The Vessel Design Tool Package

The Energy Efficient Ship (TEES) project has resulted in an overall computer software package, the Vessel Design Tool Package. In principle the Package consists of the following modules: the Design for Environment tool (DFE tool), the Environmental and Energy Database, the Design Features and Functions tool and the Cost-Income Features tool.

The Vessel Design Tool Package is developed initially for three vessel types:
- long lining fishing vessel
- fast ferry
- container vessel

The reason for this is that the design parameters are developed as vessel specific databases, based on the parameters from a large number of designs. The design types are chosen by the SME partners for their specific sector of interests. Further, by choosing different vessel types experience is gained on how to generalise the model, in order to make the model applicable on widely different ship types in future developments.

The structure of this package is illustrated in Fig. 2. The various parts of the Vessel Design Tool Package are shortly described in the following.

[1] A LCS consists of a simplified life-cycle analysis that aim to reveal where the most important contributions to pollution come from in connection with producing a product or carrying out a process.

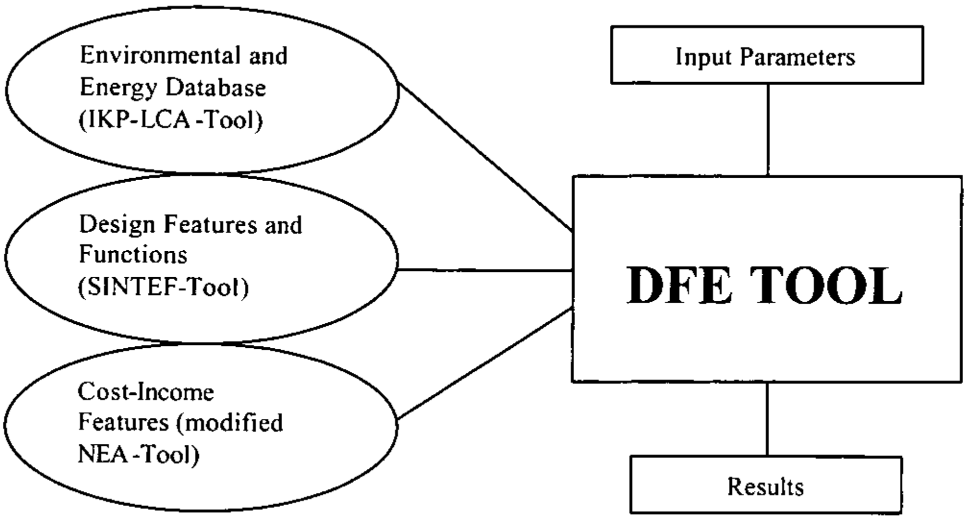

Fig. 2 The Vessel Design Tool Package

The Design for Environment (DFE) Tool

The DFE Tool is developed by PE product Engineering GmbH as the tool for user interface and co-ordination with the other programme packages. The DFE Tool provides possibilities for quick assessment, with an accepted higher uncertainty, of a new ship or ship idea if needed. Further the tool provides the possibility to refine the modelling by communication with the other tools. Guidelines are developed to secure important materials and design features are taken into account by the DFE-user when refining the ship concept.

Typical input parameters are:

- Type of vessel (passenger vessel, container vessel or fishing vessel)
- Hull material
- Superstructure material
- Main dimensions (length, breadth, depth)

The DFE Tool can also calculate optional input parameters:

- Block coefficient
- Weight data
- Capacities (cargo space, passenger capacity, fishing quota etc.)
- Speed
- Power
- Electrical load
- Endurance

The results are described as diagrams that can easily be interpreted. The diagrams are of the kind shown in Fig. 3. Results can be presented in a similar way related to the various lifetime phases also when it comes to emissions and costs.

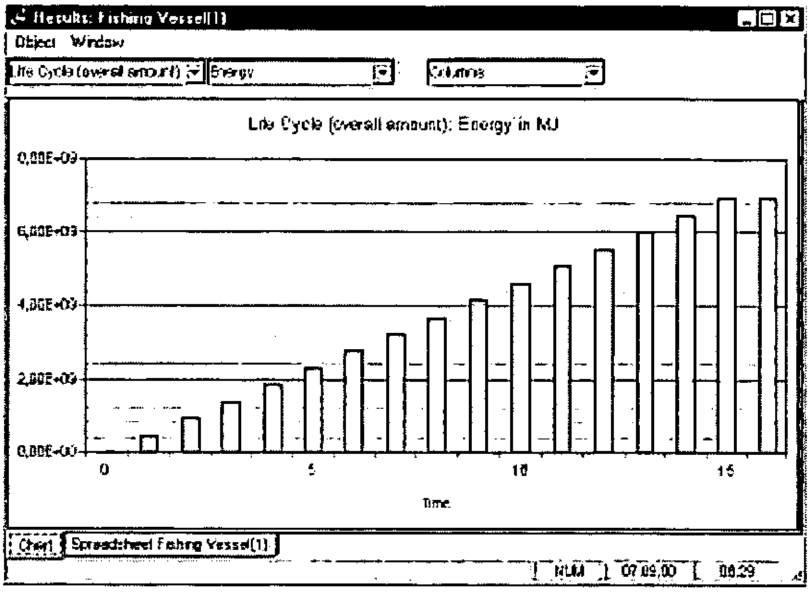

Fig. 3 Typical output presentation

Further it has been the aim to be able to calculate and display results on more detailed levels as which materials will cause the most severe environmental effects, what is the most cost effective maintenance process and so on. The energy unit is aggregated MJ, the environmental categories are GWP (Global Warming Potential), ODP (Ozone Depletion Potential), AP (Acidification Potential), NP (Nutrification Potential) and POCP (Photochemical Ozone Creation Potential). To be able to compare different vessels by means of an overall environmental profile, a weighting method is available which also can be adapted to the users needs.

The Design Model

The design model consist of the following three tools:

The Fishing Vessel Design Tool is a further development of a long liner design model previously developed by the Norwegian University of Science and Technology and SINTEF Fisheries and aquaculture in cooperation with Fiskerstrand Yard as a nationally finded project. This tool, in a modified version, was made available for the TEES project. This tool will be described in detail as a "stand alone" unit in a later chapter.

The Fast Ferry Design Tool, a software partly based on the Fishing Vessel Design Tool and adapted by a student project work at NTNU in Trondheim for Hauschildt Marine for integration in the Vessel Design Tool Package. This tool is based on statistical analysis (regression) of earlier built vessels.

The Containership Vessel Design Tool, a software part based on the Fishing Vessel Design Tool and adapted by a student work at Newcastle University for Armstrong Technology and integrated in the Vessel Design Tool Package. This tool is based on statistical analysis (regression) of earlier built vessels.

These tools provide possibilities to go closer in detail into the technical questions, relations, assessments and empirical information, which are to be integrated into the Vessel Design Tool Package. Possibilities for quick assessments based on default values are further provided, as well as the possibility to overwrite these with more exact information, formulas etc.

The environmental and cost impact can be assessed for the various lifetime-phases as the building phase including shipyard processes, the operational phase and the scrapping and recycling phase.

The environmental/energy database

An environmental/energy database is developed by Institut für Kunststoffprüfung und Kunststoffkunde, the University of Stuttgart. This database is partly based on original data collected in the project period from the shipyard activities and from shipping. However, most of the data are from existing in-house software, the Ga Bi3 Tool [9]. This has partly been integrated into the Vessel Design Tool Package.

The Cost-Income Model

NEA Transport and trading have developed a universal cost and income model for the TEES project. This is a further development of an existing in house software at NEA, the NEAC and the Inbiship tools [10]. The Cost-Income Model is of a general nature and can be adapted for the three basis vessels as well as for "generic vessel design".

The functionality of the tool

An optimal compromise between all relevant aspects in the decision support of a new ship design is more sensible than the isolated optimum of single tasks, as the decision support in industry is always dealing with several aspects. The intention of the tool is to help the user to optimise a ship design with regard to energy and environmental aspects, being aware of the influences of the decision.

One purpose with the tool is to provide the ship designer or ship owner with decision related information (technical, environmental and economic) in an efficient way. The additional decision support provided by the tool, is done so with information that is generated anyway, but is not normally presented and available in such a format without such a tool. The aim has been to afford extra multi-dimensional decision support with little extra time consumed.

Further, if the ship designer and ship owner wish to refine the information produced by the tool, this possibility is kept open, as it is possible to enter own extra information.

It shall be both possible and easy to go back and use the DFE-Tool over and over again during the concept, design and construction taking the operation of the vessel into account. New data shall be accumulated to provide better understanding of the present design and better data for design of the next vessel.

THE FISHING VESSEL DESIGN TOOL

General description

The prototype model is developed as a stand-alone unit, but the necessary interfaces with the Vessel Design Tool Package are developed in collaboration with the University of Stuttgart.

The objective for this model has been to develop a data model that offer the user support in the decision making process. To support decision making in design, the tool may be used to compare different concepts under the assumption of identical external conditions. Points of uncertainty in these cases will be for instance the fish- and fuel prices and the fishing quotas relative to different time intervals. Furthermore, a sensitivity analysis on one or more of the parameters can be conducted to get a picture of the current concept's resilience in a dynamic and unpredictable market.

Results may be presented as:

- Tables which show and compare results from different concepts in the same figure or
- curves showing which phase in the lifecycle or which subsystem that is the most important with regards to economic, energy and environmental consideration. It should also be possible to look

more specifically into each phase of the life cycle to get more details about the economic and environmental calculations.

It is important to emphasise that this is not an optimisation tool. The user will, however, be able to define different scenarios and see how concepts will perform both economic and environmentally. The user will be able to document that a particular design will be better for some categories than an alternative design or existing vessel.

The model is developed to support Life Cycle Analyses and results can be generated for different:

- Operational profiles
- Vessel designs
- Choice of equipment / subsystems

As criteria for evaluation, the user can apply:

- Life cycle costs
- Life cycle energy consumption
- Potential life cycle environmental impacts

To achieve flexibility, two levels of input can further be applied:

1. Minimum amount of input can be used to obtain fast results based on regressions, empirical formulas and default values.
2. Detailed input can be used to achieve control of all input parameters.

It is also possible for the user to overrule the calculations and default values.

Tool development process

The development process has, as far as possible, followed the standard steps in a Life Cycle Assessment process [5]. Thus, when developing the tool, work has been performed within the following work packages and tasks:

1. Energy data for a new case vessel are collected from Fiskerstrand Yard. Also data for an older long liner vessel are collected in order to compare results.
2. Data from both the construction and the operation phase are collected, based on various data books from the construction phase, and measurement and logging during operation.
3. The collected data with respect to material and energy consumption over the vessel's life cycle are systemised. Special concern has been given to systemisation of the operational data for the various modes of fishing as steaming, setting of the fishing line, hauling and in port. Preliminary energy life cycle analyses have shown the operational phase to be the most significant area with respect to energy consumption.

In close cooperation with Fiskerstrand Yard (and the ship owner of the long liner vessel) the preliminary collected energy and mass data have been further refined, supplemented and systemised.

Programme description

Fig. 4 illustrates the structure of the programme module. The model is programmed in Excel supported by Visual Basic subroutines.

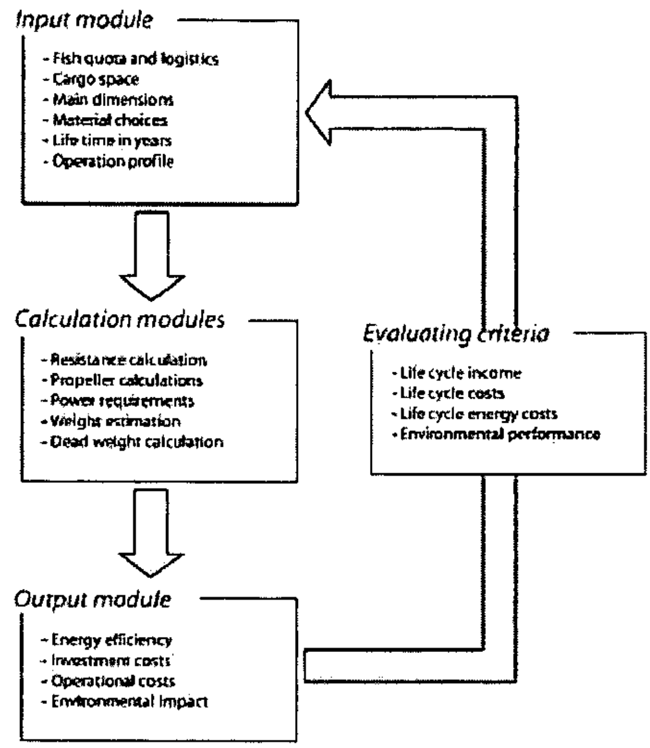

Fig. 4 Fishing Vessel Tool Structure

The various steps and modules in the Fishing Vessel Tool are explained in the following.

<u>The Input Module</u>

The following can be used as initial input data:

- Fish quota and logistics
- Cargo space
- Main dimensions

<u>Calculation module and output module.</u>

After the user has chosen his input values, the tool calculates a hull resistance value, based on empirical formulas. With basis in the necessary propeller power and other power requirements, the tool calculates the fuel consumption for each operational phase. The lightship weight and dead weight are also being calculated. We are thus able to calculate some important steel- and aluminium values for the LCA.

In the prototype two levels of input exist:

- *Minimal amount of input:*
  This implies fast results using rough estimates. (Regression, empirical formulas and default values).
- *Detailed input.*
  The user is able to control all input parameters and calculating formulas.

A key feature with the tool is that it should be flexible and adjustable to the users own requirements. As regards the calculation tool, the user can replace the existing empirical formulas with his own ones, if they are more suitable for his project. It is thereby possible for the user to overrule the calculations and default values. When the user is starting a new project, it is also possible to choose between the initial input data, cargo space or main dimensions..

Evaluation criteria
Different evaluation criteria can further be used as:

- Life cycle profit
- Life cycle income
- Life cycle costs
- Life cycle energy consumption
- Environmental performance

The model then shows which life cycle phase is the most important with regards to economic, energy and environmental consideration. Further when using the model to analyse various conceptual alternatives, it is possible to look more specific into the most important phase as building, repair, maintenance, steaming, setting, hauling, in port and end of life.

DEMONSTRATION OF THE TOOL

The use of the tool is demonstrated for a long lining fishing vessel with two different engine alternatives. A conventional machinery arrangement is defined to be the base case as a diesel electric arrangement is analysed as an alternative. The base case is in combination with a pitch propeller. The lifetime of both cases is stipulated to 25 years, the hull consists of 95% of steel and 5 % of aluminium and the material for the rest of the vessel is 90 % of steel and 10 % aluminium. Fish price is 1,3 USD/kg and number of missions are 10 per year. Mean velocity is 7 knots while setting and 2 knots while hauling. Data are gathered for the operational phase, which is separated in time in port, for steaming, setting and hauling. Further data are given in Table I and Table II. As seen from Table II time spent on active fishing (the setting and hauling) dominates the time consumption. 5.635 hours pr. year is spent in active fishing. This is approximately 74% of the total of 7.644 hours (defined to be a full year).

Table I: Data for fishing vessel

Loa [m]	Bsp [m]	Catch [tons/year]	Cargo space [m3]	T [m]	Cb	Service speed [knots]
37,9	8,7	1600	320	4,1	0,58	12,6

Table II: Time spent pr. year during operation

Phase	In port	Steaming	Setting	Hauling	In total
Hours	420	1.589	980	4.655	7.644
In percent	5%	21%	13%	61%	100%

The *functional unit*[2] is one kg round fish delivered on quay. The geographical area of operation is the North Sea and the Barents Sea.

A screening of the case is performed initially demonstrating that the environmental impact from the use phase is totally dominating. Further refinement of the concept should consequently focus on this phase, see Fig. 5.

[2] According to the ISO 14040-standard, a functional unit is a measure of the performance of the functional outputs of the product system. The primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results.

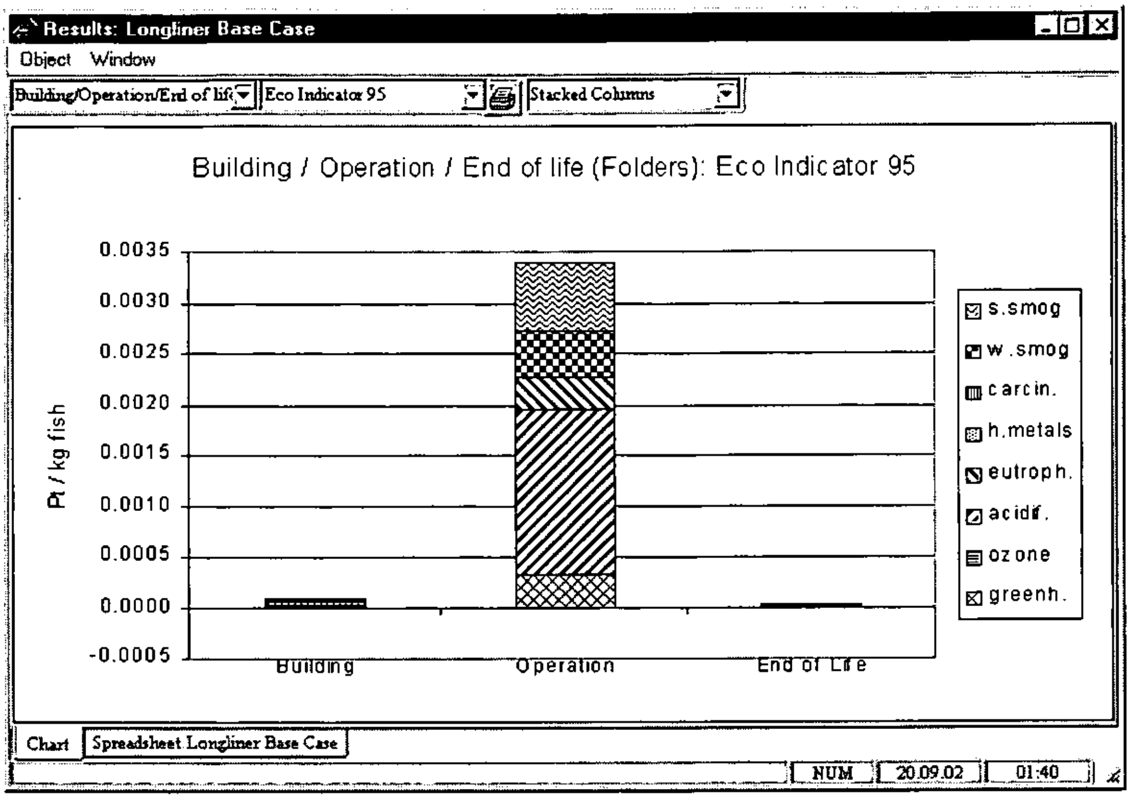

Fig. 5: Lifetime screening of base case

Fig. 6 shows the environmental profile of the operation of the vessel during an average year. It shows that the most significant impact category is acidification with the hauling phase as the dominating contributor. The main contribution here is NOx-emission from the combustion.

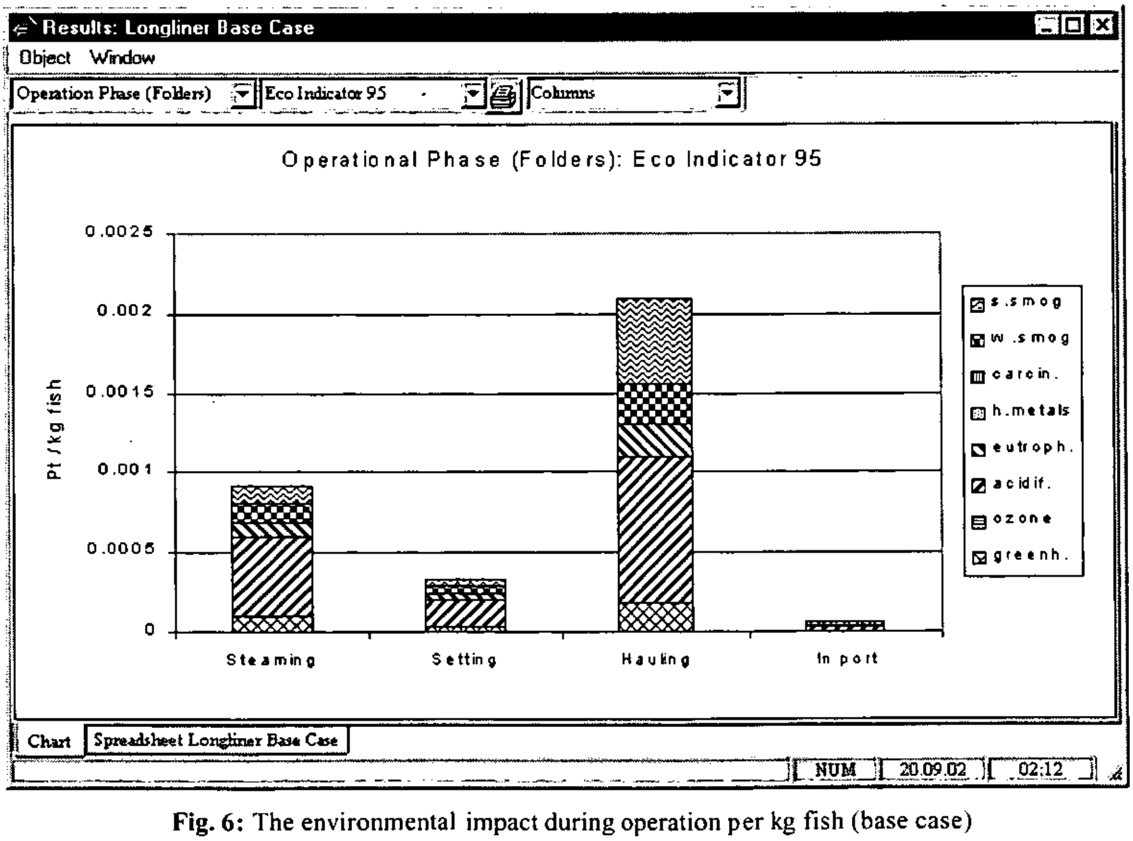

Fig. 6: The environmental impact during operation per kg fish (base case)

In order to evaluate the environmental impact, a screening was performed comparing the base case with an alternative case with diesel-electric machinery. First the energy efficiency during operation of the two alternatives was analysed, see Fig. 7.

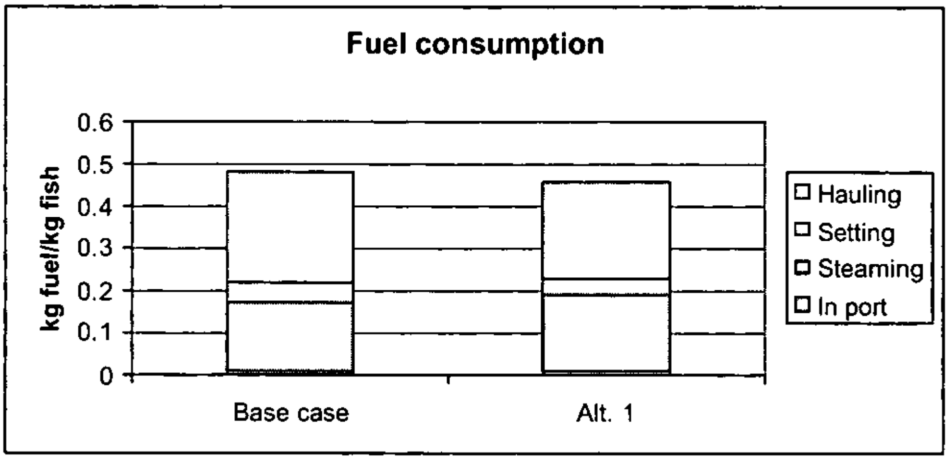

Fig. 7: Energy efficiency during operation for both alternatives

The energy efficiency for the alternative case is better than for the base case. The explanation can be found in the utilisation profile for the engines. The base case has a conventional diesel engine with pitch propeller. During most of the use phase the engine load is not full and the engine is run at half power a load condition, which it is not optimised for. The alternative machinery configuration entails a generally better utilisation profile of the machinery as can be seen from Fig. 8.

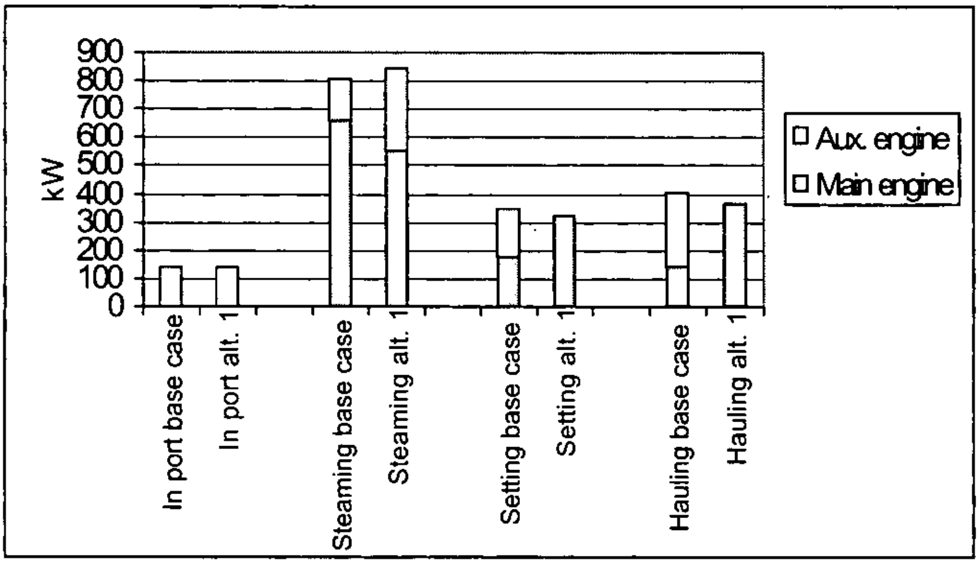

Fig. 8: Utilisation profile of the to machinery alternatives

By further analysis of the two machinery alternatives, the environmental profiles are found and shown in Fig. 9. This shows that the diesel electric arrangement has a better performance than the base case. .

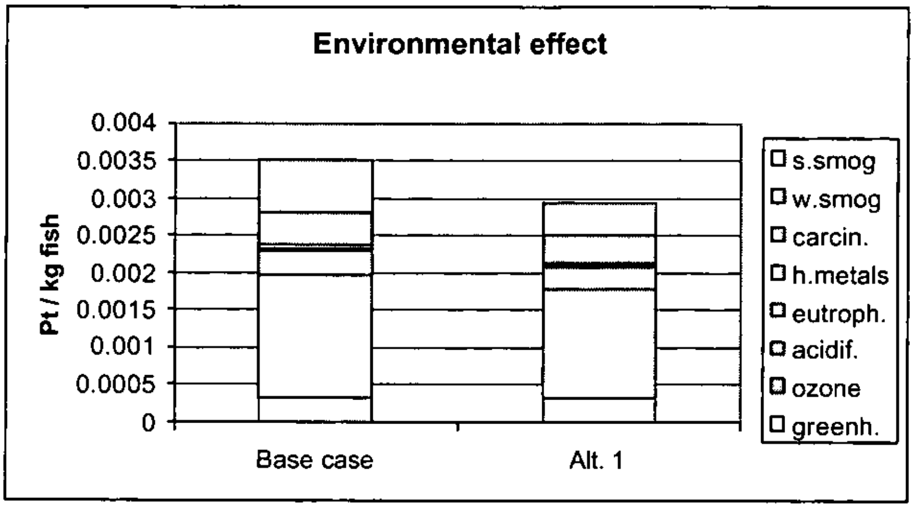

Fig. 9: Environmental profile of the base case and Alternative 1.

DISCUSSION AND CONCLUSIONS

The above example demonstrates that a DFE-tool can be used to reveal life time environmental effects of various conceptual choices in the early design phase. This can be useful for ship designers, yards and ship owners.

The tool demonstrated here is a prototype version and further development and refining is in process. An important area for further research is to develop better databases covering more detailed environmental data for reference ships. Today there are no developed standards or references that new designs can be compared to with respect to environmental impact. Further work should therefore focus on the development of environmental profiles of the entire life cycle. Based on environmental improvement goals, the profile of the "design for tomorrow" could be demonstrated. This is one of the research areas in a new strategic research programme at SINTEF Fisheries and aquaculture in Trondheim.

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More than TBT – the environmental challenges facing marine painting processes

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SYNOPSIS

While there has been an incredible amount of attention paid to the environmental effects of Organotin anti-foulants, the marine painting industry has faced, and continues to face, challenges on a much broader front. Much has been written on the trade-off between the environmental effects of TBT-based anti-foulants and reduced consumption of fossil fuels and reduced emissions of environmentally undesirable exhaust gases. However, in future the consumption of energy and of resources in a ship's life-cycle will need to be addressed.

In recent years, much effort has been devoted to the development of low volatile organic content (VOC) – or even VOC free – paints. The technical challenges for certain applications are more demanding than for others: some examples will be discussed. The life of these coatings is critical: quite apart from the purely economic considerations, the greater the consumption of resources and of energy if performance and longevity are compromised.

The entire preservation and painting process has to be taken into account. For high performance coatings, there are associated requirements for surface preparation, environmental conditions for application, application techniques and the curing of the coatings. All such areas of work involve environmental 'pollution' considerations and, of course, consideration of the Health and Safety of the operatives and of fellow workers. The environmental concerns of appropriate surface preparation techniques will be discussed.

The requirement to limit, or to eliminate, the input of pollutants into the aquatic environment together with the wider implications of pollution prevention and control imposes intellectual, practical, and economic challenges. Several options will be presented, but no attempt to suggest a 'magic' solution will be made.

INTRODUCTION

It is probably reasonable to say that the advent of TBT anti-fouling paints concentrated attention on the environmental impact of marine paints. Certainly, TBT generated problems spawned a virtual industry, and significant sums of money and vast amounts of work were devoted to various aspects of TBT anti-fouling paints, their use and their effects. The author must admit to having been part of this 'industry', having delivered his first paper on the subject in 1987 (ref 1). The biocidal aspects of anti-fouling paints have attracted, and continue to attract, considerable attention, the agenda of ENSUS 2000 being but one example. Much attention has been devoted to the paints.

However, the environmental impact of marine paints, and of the painting process, is more widespread and complex. The marine painting process can be considered to encompass all the following:

The production of raw materials
The production of the paint
The transportation and storage of the paint
Surface preparation
The application of the paint
Maintenance of the painted surface
Paint and corrosion removal
The disposal of arisings and of waste

It is difficult, if not impossible, to consider any one aspect in isolation when evaluating environmental impact. The environmental impacts are diverse and do not necessarily have a demonstrable long term effect on the marine environment – environmental noise is one concern which has yet to be shown to have a long term effect on the marine environment.

Author's Biography
Mr. D.M. Allison is Chairman of the Marine Painting Forum and was formerly (1986 – 1996) Head of Non-Metallic Materials in the Directorate of Naval Architecture, MOD (UK)PE.

While the past practices of many shipyards took (at least some) notice of environmental protection, there were glaring examples of inadequate, even irresponsible, practices. The industry is now subject to increasing regulation: some examples applicable to the UK will be found in Refs 2, 3, 4, 5, 6 and 7! E C Directives are an increasing commitment. Health and Safety requirements are further driving forces and there will, no doubt, be instances where such considerations preclude or constrain, the use of particular equipments which deliver environmental benefits. Of course, the requirements are often the same.

MARINE PAINTS

The details of paint formulation, development and manufacture, are left to others more directly concerned to describe. It is, however, necessary to appreciate that this can be a complex and expensive process as performance, application properties, shelf life, health and safety aspects and environmental impact must all be addressed. Meeting the registration requirements for products such as anti-fouling paints is already expensive: proposed E C Regulations for all chemical products will add to this burden and may result in a reduction in the range of products available.

Paint is rarely a simple product, consisting of binder, pigments, extenders, solvents (organic or water) and various 'aids' such as driers, anti-skin agents, rheological agents, etc. Some paints (e.g. acrylics) are physically drying, others 'dry' by chemical reaction (curing). Particular types of binder have requirements for particular solvents to aid application properties. There is thus a cornucopia of potential environmental impacts resulting from paint formulation.

Although difficult to consider environmental factors in isolation, one factor which is the subject of legislative restrictions (in the UK, P G 23, Ref 4) is volatile organic content (VOC) of the paint. Table 1 shows the latest Figures promulgated by the Defence Procurement Agency (Ref 8) for coatings defined as 'compliant'.

Table I VOC Levels for Compliant Coatings

Category No.	*Category*	*VOC limit gms/litre Paint (less water)*
(I)	Blast/Weldable primer	600
(II)	Tiecoats/sealers	550
(III)	General primer/undercoat	200
(IV)	External finishes	420
(V)	Internal finishes	200
(VI)	Anti-fouling systems	400
(VII)	All tank coating systems	300

Some new generation anti-fouling systems may have higher VOC values than those pertaining. Thus it may be necessary to 'trade' VOC for biocide acceptability.

Many products are now 'water based', although some water based products contain VOCs. Unfortunately, some of the volatiles necessarily used in some water-based products are more 'hazardous' than those used in typical solvent based materials.

High solids products are an alternative approach. There are numerous advantages and disadvantages associated with both these and with water based coatings.

Despite the attention devoted to anti-fouling paints, it must be appreciated that anti-fouling characteristics can be considered to be a lesser, albeit vital, part of the overall picture. While ships continue to be constructed from steel (and even from aluminium) the author considers the primary role of paint to be the protection of the structure from corrosion. Inadequate corrosion protection has resulted in serious structural degradation and to the loss of vessels. This is both a safety and an environmental issue.

Paints are also used to endow metallic (or composite) surfaces and paint-protected surfaces with characteristics necessary to the operation and to the survival of the vessel. Apart from anti-fouling coatings, other examples are flight and weather deck coatings, fire retardant coatings, coatings which can be readily decontaminated, coatings which give a particular aesthetic result, and signature reduction coatings: there will be other examples. Tank and cargo hold coatings must be compatible with the contents of the tank or of the hold.

These diverse and challenging requirements have been met with a variety of paint technologies. Particular paint products require appropriate surface preparation if the full potential of the paint is to be realised: Ships are large artefacts, and the mass of materials involved is significant. Thus, if coatings fail to provide the required performance for the maximum time possible, repetition of the job results in additional inputs into the environment, quite apart from the material and power consumed. Ironically, one of the great benefits derived from the use of TBT anti-fouling coatings was the reduction in the number of dockings necessary to provide the required anti-fouling performance. Every such docking consumes energy, utilises materials, releases organic volatiles and generates waste. Of course, dockings consume money from both loss of earnings and from the direct costs.

Shipowners, shipyards and others have been, and will continue to be, involved in the generation of requirements for paints and in the evaluation of new products. The latter is particularly important, as paint must be matched with process. Trial applications can raise problems and it is essential that such problems do not delay a vessel's sailing or cause further significant problems during the vessel's voyage. A partial solution to this problem is to make trial applications of coatings on ships which 'aren't going anywhere' such as those in reserve, laid-up, used for harbour training, or used as museum ships. While such applications can prove application characteristics, they can provide but a guide to in-service performance. Of course, for some applications, such as weatherwork paint systems, the guidance can be relatively comprehensive and reliable.

The early programme in the development of low VOC weatherwork paint with which the author, on behalf of MOD (PE), was involved is described in ref 9. The former HMS PLYMOUTH was used as a trials 'vehicle' and the paint industry responded with a variety of products. There were problems and disappointments with some early products. Paints were applied both to washed, existing, weatherwork paint and to surfaces prepared to an ST3 standard (using power tools). Neither brush nor roller applications could achieve, at that time, the required wet (and hence, dry) film thickness for the water-based primers under evaluation. Not every finishings coat had reasonable brushing properties. While levels of gloss achieved at that time were lower than those achieved on initial application of the then current silicone alkyd-weatherwork finish, initial assessments indicated good gloss retention (important for weatherwork finishes). Further products offered for evaluation demonstrated higher initial values of gloss. It was possible to specify the use of low VOC weatherwork finishes for RN use by 1996 – those currently 'specified' are listed in ref 8.

High-solids, low VOC, epoxy tank coatings proved to be readily available, although not so easy to use in situations requiring brush application, being intended for application by airless spray. Although able to be applied (and cured) at temperatures down to 10°C, Northern European conditions often proved to be 'unsuitable'. Heating of the structure to be coated does, of course, require the consumption of energy.

A particularly challenging requirement was that to find a VOC compliant replacement for the chlorinated rubber finish used in the reactor compartments of nuclear submarines for the past 30 years or more. VOC compliance was merely one of a lengthy list of requirements, but this requirement, together with severe limitations on trace elements and certain pigments, limited the number of candidate coatings offered for evaluation. The most severe test requirement was the evaluation of the paints in a "Design Basis Fault (DBF) Simulation" test – also referred to as the Loss of Coolant Accident (LOCA) test. The tests were undertaken to a commercial standard for the Nuclear Power Generating Industry as this was (relatively) conveniently available. The test profile is shown in Figure 1. Only one candidate paint passed this test – it was, in fact, a ballast tank coating already in use, overcoated with a water-based epoxy to improve the decontamination characteristics.

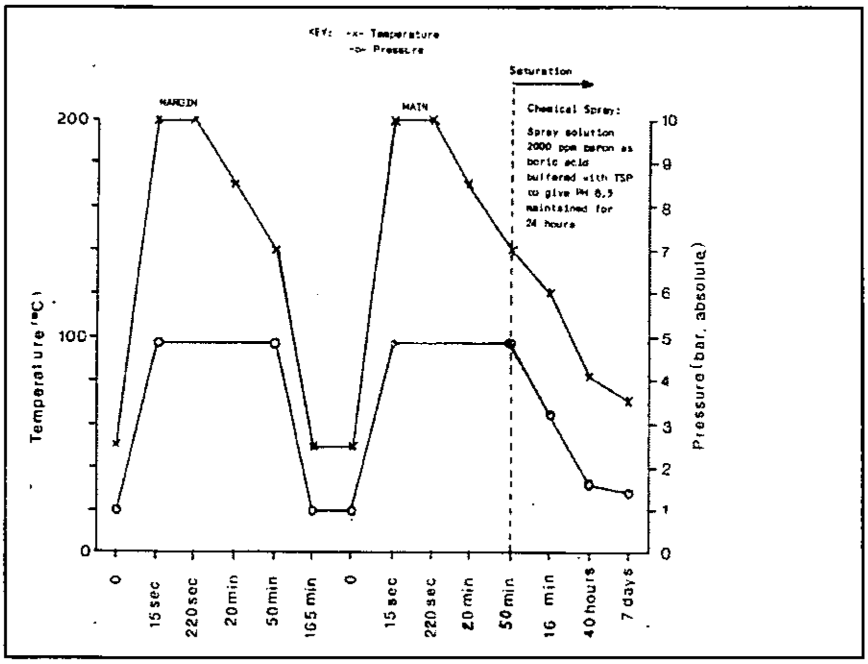

Figure 1 - Temperature/Pressure Profile for Design Fault Basis (DBF) Environment Simulation

Possibly the most critical requirements for this coating is that under the 'Loss of Coolant' conditions, it has a thermal conductivity which is sufficient to allow thermal energy to be dissipated through the hull plating to the surrounding sea. This provided the most challenging scientific requirement, especially as the thermal conductivity of the coating was required to be determined at 200°C, in a steam atmosphere at 5 bar pressure. There is no standard method for determining the thermal conductivity of thin films, and the technique found to be available does not use a steam atmosphere. The technique used was the determination of thermal diffusivity using the heat pulse or laser flash technique. The thermal conductivity is calculated from the relationship

$$K = \alpha\rho Cp$$

where k is the thermal conductivity, α is the thermal diffusivity, ρ is the density and Cp is the specific heat at constant pressure. The specific heat is determined using Differential Scanning Calorimetry (DCS).

Thermal diffusivity in air was determined and the thermal conductivity calculated. A test rig was being modified to measure thermal diffusivity in a steam atmosphere at 200°C and 1 bar pressure. Measurements were also made in argon, a more usual-and cheaper-method, to establish whether or not the steam atmosphere affects the results obtained.

While the volume of paint required for this application is small, the laboratory work necessary to assess the coating provides an example ofthe extensive work required to evaluate paint products for certain applications.

ENVIRONMENTAL 'TRADE'OFF

Anti-fouling paints present an obvious example of the often experienced conflict of environmental requirements. The perceived environmental hazard of TBT has resulted in the increasing use of TBT-free products even before the application of TBT products is discontinued from 1 January 2003 (or 31 December 2002 in EC proposals!). Although certain products specified in ref 8 refer to a 5 year 'life' for the replacement products, early examples had a life of 2 to 3 years. At the time, a typical system of TBT free anti-fouling paint for a Type 42 Destroyer (area of outer-bottom, 2016 square metres including boot-top) required the application of approximately 1215 litres of anti-fouling paint (ref 10). Taking the target VOC level for anti-fouling paints from ref 8, such an application will result in the release of approximately 4.86 kilogrammes of VOC. Thus, over a ten year cycle, a 'five year' system results in the release of approximately 10kg of VOCs, whereas a 'three year' system results in the release of some 20kg of VOCs. However, TBT has been perceived to be 'the greater evil. Obviously, precise figures depend upon both the product and the particular specification, but the figures may be taken as indicative.

TRANSPORTATION AND STORAGE OF THE PAINT

Most paint products are supplied to the shipping industry in drums or cans. These containers have to be disposed of as hazardous waste, an increasingly expensive (£90 per 6 cubic metres of such waste was quoted in ref 10 – that was in 1993) and increasingly unpopular and difficult procedure. The supply of paint in Intermediate Bulk Containers (IBCs) which are returned to the paint supplier for cleansing and re-use overcomes this difficulty. However, paint in an IBC is rarely what is practically required for use with ships and the containers need to be solvent washed on return to the supplier – a further environmental problem. Primer is supplied in IBCs to some building yards.

Paint stores present many hazards. It is recommended that TBT anti-foulings are stored within a bund. Such storage may be required for other products.

Water based products need to be stored at temperatures above 0°C. Thus, energy may be consumed to maintain the required conditions.

SURFACE PREPARATION

All paint systems require appropriate surface preparation. Apart from the specified standard of surface cleanliness, steelwork requires to have the surface profile defined for the paint system. The initial preparation of the steel surface for application of a holding primer may be undertaken by the steel supplier or by the shipyard. The use of the appropriate grade of abrasive is, currently, necessary to achieve the desired profile. Even if the steel is supplied to the yard in a 'blasted' and primed condition further surface preparation will normally be required following working of the steel and to provide the surfaces appropriate to particular paint systems.

Dry abrasives become contaminated waste requiring disposal. There are also environmental problems arising from the dust generated – in some locations containment is required. For the outer-bottom of the Type 42 Destroyer used as an example in ref 10, open blasting with expendable abrasive requires some 100 to 150 tonnes of abrasive. Production rates are approximately 10 square metres per man-hour.

Vacuum blasting uses abrasive, but recovers most of it. Re-use of the abrasive, following cleaning (a further consumption of energy) is limited by the need to produce a surface profile (the abrasive becomes 'blunted'). Some abrasives, such as garnet, can be re-cycled a number of times, but can be more expensive initially.

'Portable' vacuum blasting equipment has a production rate of about 2 square metres per man-hour. There are remotely controlled systems for one of which a production rate of 100 square metres per hour has been claimed. However, there are limitations imposed by the double curvature of many hull surfaces, by particular structural configurations, and by the restricted access in many dock situations.

Increasing attention is being given to 'damp' blasting systems to reduce immediate environmental hazards and to improve production rates.

The use of Ultra-High Pressure (UHP) water jetting has been advanced as a solution to environmental problems as the water used can be recovered and filtered for re-circulation. This process certainly has a part to play, but apart from any difficulty in obtaining a surface cleanliness required for many paint systems, it does not generate a surface profile. Apart from hazards to the workers, there is a consumption of both power and of water.

In all cases, good 'housekeeping' is essential. If surface preparation is undertaken on a vessel while it is afloat, the containment requirements can be onerous, but essential for environmental protection – and to avoid breaches of the law!

The author regards surface preparation as one of the greatest challenges facing the marine painting industry. It is also a challenge in terms of Health and Safety requirements. Surface preparation continues to receive much attention and to generate new 'technologies', some of which generate certain problems while providing solutions to others!

APPLICATION OF PAINT

Most marine paints are designed to be applied by a spray process. Overspray must be minimised – this is also a Health and Safety issue. Over application of paint can, of course, result in the unnecessary release of excessive quantities of VOCs, quite apart from causing difficulties with curing and drying the paint system.

Paints require to be applied under specified environmental conditions: this can require the consumption of energy. Of course, many ships are too large to be accommodated in an enclosed facility. Local heating and ventilation (airflow is important for the release of solvents, apart from being necessary for Health and Safety considerations) may suffice in certain circumstances.

It should be obvious that adequate training, qualification and supervision of painters is essential for environmental protection and for the achievement of the required result.

MAINTENANCE OF PAINT SYSTEMS

Maintenance of paint systems, usually involves activities such as the washing down of the system, the 'touching up' of defects and local breakdown, or both. Complete renewal of a paint system requires the same consideration as the initial application of the system. Washing down and 'touching up' can both require environmental concerns to be addressed.

Washing down needs to be done with fresh water. In addition to considerations of the consumption of water, and of power, wash water will often need to be contained and disposed of appropriately. Disposal may require treatment of the effluent to remove environmentally undesirable substances – TBT is a particular example. While anti-fouling coatings may not need to be overcoated when a ship is docked, the anti-fouling coating usually requires to be washed down to remove fouling, contamination and expended material, all of which can, when exposed to oxygen and to drying out, impede the operation of the coating after the vessel is refloated. Washing down of a Type 42 Destroyer can entail the consumption of some 60-75,000 litres of water (ref 10). The containment and disposal of the water in the case of 'naval' yards has been reported on at length – refs 1, 9 and 10 are but a sample.

The treatment and disposal of such effluents present very real problems, yards being subject to the controls laid out in ref 3. Naturally, scientists and engineers have devoted considerable energy and resources to developing and implementing practical effluent treatment systems. Ref 11 provides a good exposition of activities centred on the NE coast of the UK, while ref 12 gives some details of a pilot plant with which the author was concerned.

Maintenance of paint systems encompasses the range of activities already described, but work on a 'running' ship can present particular difficulties and limit the choice of processes. Such work can conflict with, or be incompatible with, other activities and time constraints are not uncommon. When such work is carried out afloat – as will usually be the case – special containment measures must be implemented to prevent debris or arisings entering controlled waters (ref 5). Good practice should not, of course, be confined to work carried out in controlled waters!

A common maintenance procedure is the application of weatherwork finishes to maintain appearances or to prepare the ship for a special event. Every such activity may result in the release of volatiles into the atmosphere, and will present a range of environmental challenges. Hence, the formulation of a paint for the maximum retention of colour and gloss has environmental importance in addition to rather important economic importance

PAINT AND CORROSION PRODUCTS REMOVAL

It is difficult, but not impossible, to consider the removal of paint and corrosion products separately from surface preparation. In most cases, surface preparation requires the removal of paint and of corrosion products, although the requirements should be less severe in the case of new construction than with ships which have seen service. However, the processes and equipment will be identical, as will the environmental considerations. Contamination of the abrasive or other medium will be, generally, more severe.

Paint can be removed using 'environmentally friendly' paint strippers, and in appropriate cases, electrolytic processes may remove corrosion. However, the 'usual' surface preparation techniques may (and probably will) be necessary to prepare the surface for recoating.

The arisings from the removal of 'old' paint systems will be contaminated with paint residues and with corrosion products. Hence it is necessary to know what is being removed. This is not always easy. The author believes that the overcoating of TBT anti-fouling coatings will exacerbate this problem and that particular vigilance will be necessary.

THE DISPOSAL OF ARISINGS AND OF WASTE

This process has already received mention – painting processes are inextricably linked. The disposal of abrasives and other media contaminated with TBT and lead compounds present particular problems. Disposal sites are limited and in some cases distant from the shipyard.

While the proper (and regulated) disposal of arisings from surface preparation processes and of empty (or partially empty) paint and solvent containers are obviously of environmental importance, the handling and disposal of other items must not be overlooked. Examples are used rags, protective clothing, old brushes, protective covers and equipment which has been contaminated with paint.

Restrictions and regulations are likely to increase, and the challenges become ever more 'interesting'.

CONCLUSION

The world economy will continue to need shipping and this shipping will need to be painted. Marine painting has many environmental impacts. The industry faces, and has met, many challenges. Further related challenges are presented by Health and Safety requirements, by the need for efficiency, and by economics. The total painting process needs to be planned and to be managed. The training and qualification of all concerned is of paramount importance. The marine painting industry alone cannot ensure that the painting process has the minimum possible impact upon the environment. Shipowners and shipyards need to allow sufficient time for jobs to be completed in safety and in an environmentally responsible manner. While there are some 'easy' answers to some problems, there is no overall 'magic' solution. Some will, no doubt, continue to seek and to promote (allegedly) 'magic' technologies.

There will continue to be difficult choices to be made: a sensible balance may need to be struck.

Answers lie in sound science; sound engineering practices and responsible execution of the work.

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The Challenges Facing Coating of Ships

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This paper reviews the production and environmental factors that influence the coating process in shipyards. It identifies those areas where shipyards commonly have problems in managing the coating process and describes some of the opportunities for improvement.
Historically the painting process has been seen at best as an inconvenience to the real task of building ships from steel and outfit. It is often afforded little weight in the planning process of building a ship, while it is responsible for the majority of the re-work, waste and environmental concerns of a shipyard.

INTRODUCTION

This paper sets out to review some of the production and environmental challenges faced by many shipyards in managing the coating process at new building and the impact of this process on the time and cost to build a ship.

How any one yard meets these challenges will depend on its cost structure and the local/national regulations to which it is subjected. The process of properly integrating the coating process into the new building process is becoming more and more important as ship owners and classification societies take a greater interest in the through life performance of coatings and their influence on the integrity of the vessel structure. This, combined with increasing environmental and legislative pressures on the coating process (including surface preparation), is creating a bottleneck in production, where the costs of error are often unacceptably high.

HISTORICAL PERSPECTIVE

" The method of surface preparation will be shifted from the mechanical process of shot blasting to a chemical treatment of spraying acid or rust removing chemicals from now on. It is being studied whether to perform this operation after subassembly or after completion of hull blocks. The hand spraying method of painting, which is current practice, may be replaced in the future by Electro static spray or flow on painting conducted after subassembly or completion of hull blocks, or by submersion of hull units or blocks in a tank of paint. Another treatment system under study is to pour paint into the ship's tank to be coated. In any case, development of new paints themselves and the large quantity of paints to be stored still remain a problem to be solved." ...I Takezawa, 1972 [1].

This is the first significant evidence of thinking about the coating process at new building. Just 3 years before a milestone paper was presented by Kawasaki Heavy Industries[(2], which considered future shipbuilding methods, in which no specific mention was made of coating.

It is clear that the solutions being sought by Takeazwa, recognised the need for reducing manpower and the selection of the best time to coat the steel structure was being viewed from both a low cost and a low labour requirement approach. He does not however dwell on the need to match coating attributes with process requirements and thus integrating the coating process into the rest of production.

With the rise of environmental concerns and Health and Safety issues facing the modern shipyard, the proposed solutions may not be entirely suitable under current conditions, the reasons for wanting to make a change however remain as valid today as they did nearly 30 years ago.

The process of coating and surface preparation has by and large not changed since 1972, although the pump and delivery systems have had to adapt to plural component products with lower viscosity. Some attempts have been made to adopt electrostatic application and Hitachi [3] has recently launched a coating robot.

The problem of managing the stock, issue and handling of paint containers was clearly identified at that time and remains a problem for many yards, with a uniform cost effective and environmentally friendly solution evading the coatings industry as a whole. Today this is compounded by the problem of managing the waste and other sources of pollution from the process, which dominates shipyard waste management costs.

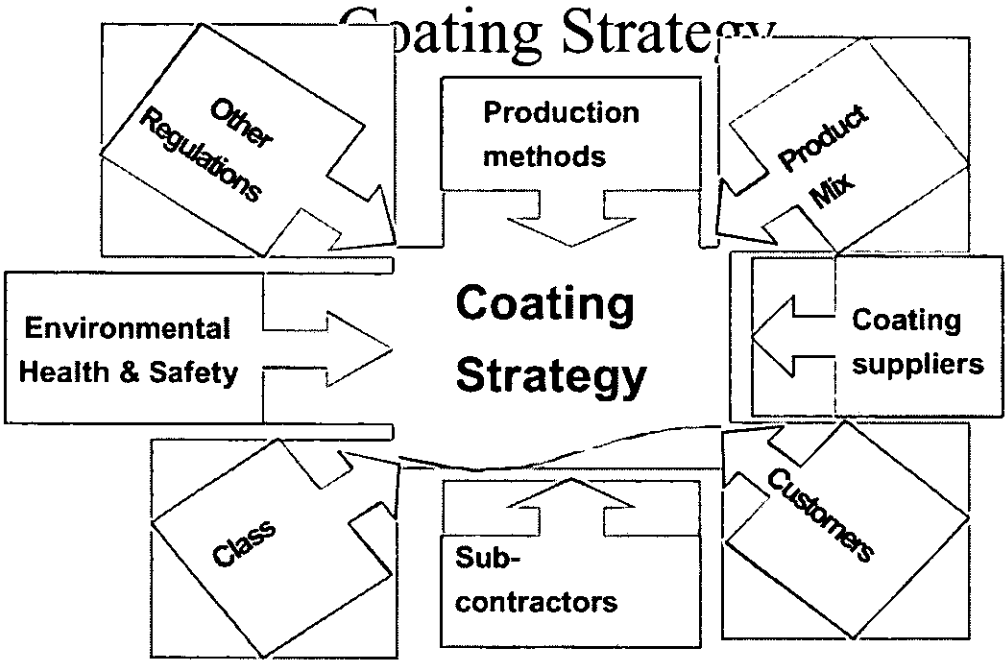
From 1972 there was long gap until the late 1980's and early 1990's when several papers, were published regarding the problems faced by shipyards in managing the coating process [4,5 and 6]. The recent interest has been steadily increasing with a number of projects both in Europe and then USA increasingly focusing on environmental and productivity issues.

Coating strategy

Many yards have a broad coating strategy that is they have decided when and where they should carry out their coating activities for the majority of key areas. The decision is often based on facilities, climate, cost, and previous experience as well as whatever pressure a customer can bring to bear upon them for a particular contract. In reality, many yards find that they are unable to adhere to their own defined coating strategy and procedures because of schedule pressures resulting from poor planning of the coating process or poor control of other production activities.

What is clear is that the earlier you can coat in the production process, the lower the labour costs, as productivity is generally higher and the easier it is to control the environmental impact of the process by carrying it out in enclosed cells or work-shops. However, this broad statement does not reflect the specific needs of different shipyards, and assumes adequate control to mitigate re-work at subsequent stages of production. The factors that influence the development of a good coating strategy are shown in figure 1.

Figure 1 Development of a coating strategy.



The Coating Strategy should include the following:

- The functional based specification for coating the vessel taking into account:
    - Performance requirements
    - Environmental issues
    - Health and safety issues
    - Waste issues
    - Etc.
- The breakdown of the vessel into coating tasks by unit/block, area or zone
- The specific production attributes required for each task
- The location where the work will be carried out for each task
- The time when the work will be carried out for each task
- The time required for the work to be carried out for each task
- The preferred method of carrying out the work
- Inspection timings
- Re-work/touch up plan and timings
- Alternative approved strategy (in the event of schedule pressures)
- Environmental Impact

Health and Safety

Health and safety is becoming more and more important. The regulations and legislation on the use of hazardous air pollutants is increasingly controlling the exposure of workers to toxic products. This is not only leading to improved paint formulations but also to careful consideration as to how the physical coating process is carried out.

The physical handling of paint containers has come under scrutiny in a number of yards. In particular for storage, yards should consider the adoptions of systems that either reduce the overall manual handling required or adopt products that can be delivered through suitable delivery systems to over come these problems (bulk supply).

Environmental protection and management

The biggest burden that environmental protection and management will impose on the yard is the need to keep proper records for:

- VOC and other emission management
- Waste management

There is an increasing need to compare tenders not only on the usual factors of price, quality etc. but also on the emission package and the total waste likely to be generated. It is the liquid waste that is the more critical and is directly related to the pack size that is used and the vessel type being built.
As more and more pressure is put on yards to properly manage these activities, then the workload on the paint department will increase. Thus, the obvious solution will be to develop appropriate computer software that can automatically compare bids on this basis and manage both the waste and emission processes properly.

It is clear that the development of software to assist in the following can have a considerable impact:

- Product selection
- Emission monitoring
- Waste management

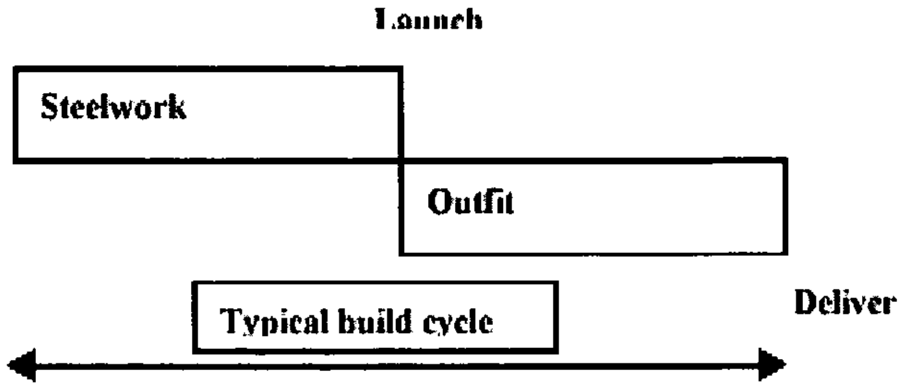
Solutions to the first two of these now exist with the third being currently addressed [7,8,9]. It is notable that no existing shipyard production control software has an integrated coating package.

PRODUCTION

Review of the production process

To examine the influence of the coating process on the production cycle, it may be helpful to briefly review the development of production technology over the preceding 5 decades to understand the integration required today between coating activities [10]. In 1940's ships were built sequentially using the "layer" method of construction. This led to long build times with steel work carried out pre-launch and the outfitting carried out afloat and finally painting as shown in figure 2.

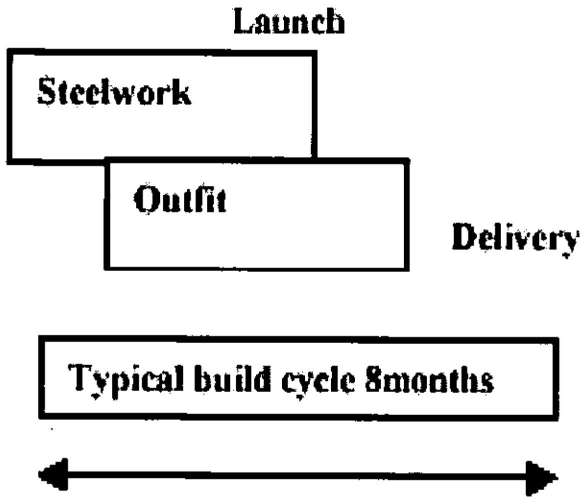
Figure 2



With the introduction of welding in the 1940's and automated cutting shops in the early 1950's, steelwork time was reduced considerably and the use construction of sub-assemblies and unit assemblies (with the appropriate crane capacities), more work could be carried out in fabrication sheds under cover.

By the late 1960's and early 1970's, improvements in welding, material handling and the increasing size of ships, saw the first panel lines and twin skin lines introduced and the advent of advanced outfitting. The integration of the activities was at last given some thought in Japan with the adoption of the "Integrated Hull Outfit and Painting" method (IHOP) [11]. The improvements are shown in figure 3.

Figure 3.



The principal coating problems have resulted from this combination of reduction in build cycle times and the need to run processes in parallel. The coating process is not very compatible with other activities, often leading them to be stopped and it is a notoriously unpredictable process at present, as it is dictated to by climatic conditions.

The reduction in the build cycle time and the overlapping of steel and outfit activities coincided with considerable investment in steelwork automation and hence a reduction in steelwork manning levels and man-hours (manpower in steelwork has been reduced by about 2/3rds since the 1960's). This has resulted in an imbalance in most facilities, relatively high productivity steelwork being followed by labour intensive and relatively low productivity coating and surface preparation activities. This has caused a bottleneck in the production process at the coating activities and especially at the unit/block stage where 80-90% of coating is carried out in larger yards.

Steelwork, Outfit and Coating

In the past the coating process has been viewed as more of an unwanted necessity by shipyards and of less importance than steel and outfit work. The foundations of this may lie with the fact that the steel and outfit work is usually in conflict with the coating activities. When coating takes place all other work must stop for both practical and health and safety reasons. The steelwork and outfit activities also tend to cause damage to the previously applied coating unless great care is taken (not very often).

The following activities typically comprise coating activities during production in a shipyard.

- Shop primer line
- Shop coat application
- On unit/block coating
- Post erection coating
- Post launch coating
- Touch up and re-work

COST PENALTIES

Labour costs - The increase in coating process man-hours due to re-work will lead to an increase in direct labour costs and, therefore, the indirect labour costs associated with the co-ordination of these activities. The coating process will account for about 5-10% of the price of the vessel depending on the vessel type [12 and 13]. With somewhere in the region of 60% of the coating man-hours being utilised for re-work (for a VLCC priced at $85 million USD this would add $1 million to the price).

The direct labour costs associated with coating re-work are easily identified but do not account for all the costs incurred by the shipyard and ultimately passed on to the ship owner. Costs associated with increase requirements for facilities, energy, consumables (including paint), equipment and supervision must also be assessed.

Facility investment - areas must be set aside for re-work to be undertaken. This may require the addition of an extra paint cell(s) depending on where repair work is to be carried out. Usually the cost of coating is cheapest at the paint cell, where it can be up to 3-4 times cheaper than carrying out the work later on in the production process. Alternatively additional areas could be set aside, although these would have to take into account weather protection and environmental issues as well as access of both men and equipment. A regulation compliant paint/blast cell can cost up to $15 million to install.

Environmental costs - if surface preparation and coating is to be undertaken in external areas. Then it is essential to protect both the unit from the environment and the environment form the surface preparation and coating activities i.e. spent blast media, Volatile Organic Compound (VOC) emissions, noise and liquid and other waste. The temporary covering of a unit to may cost in the region of $40,000. Additional costs would be incurred as a result of the required clean up and disposal of the supplementary consumables required to perform the re-work. The additional disposal costs for a VLCC can amount to $10,000.

VOC abatement for a primer line can cost up to $500,000 while the disposal of empty paint cans in Germany is now greater than the purchase price.
Disposal of grit from shot blasting operations is also subject to increased costs as hazardous waste. More and more of the work is having to be carried out under cover. In a recent case a yard spent $60,000 to coat the underwater hull of a

vessel in dock and had to pay $80,000 in settlement for environmental damage to nearby industry, as a result of over-spray.

Equipment costs - with an increase in surface preparation and coating man-hours of up to 60% for the re-work, additional equipment has to be supported and purchased.

Energy costs - These will rise in accordance with the additional work being carried out and can result in high levels of demand on services at critical points in the build programme (this is common if a lot of re-work is undertaken in dock, or alongside).

Material Costs - the increased consumption of blast media and paint due to re-work will be an additional expense.
An estimation of total cost of coating re-work for a VLCC (excluding energy and small plant costs) can be obtained from the following data:

Direct labour	= $1million
Indirect labour	= $0.25 million
Additional facilities	= $0.08million p.a. (1 paint cell)
Additional consumables	= $0.02 million per ship (assume 4 ships p.a.)
Blast media/ship	= $6,400 consumption
	=$6.500 disposal
Paint/ship	= $1,432,900
Total per ship	= $1.4 million or approximately 1,7% of the

ships price and a cost of almost $6 million per year for a yard building 4 ships p.a.

It should be noted that VLCC's are relatively simple vessels with relatively little outfitting, these figures could more than double for more complex ships.

If the ballast tank coating failed subsequently in service the cost of repair could be up to $13 million thus some additional investment at new building can save considerable costs through life.

TIME PENALTIES

The direct cost of coating re-work has been identified above. However these figures do not tell the whole story. The economic survival of a shipyard is governed by the amount of revenue it can achieve. The more ships it can build in one year the less the proportion of overheads each ship contract has to carry. Typically the cost structure of the yard is usually split as 60% materials, 20% direct labour and 20% overheads. Thus the more vessels the yard can produce per year the better its chances of survival. We have seen earlier how the steady improvement in steelwork production technology has resulted in a bottleneck at the coating process in the paint cells. Thus any time lost at the bottleneck is time lost for the whole facility. [14]

The time penalties of coating re-work often lead to a requirement for large areas to act as a buffer store for the units leaving the steel facilities and for the coating work to be completed. This adds overhead and causes delays to the production process and hence reduces the revenue earning potential of the yard as a whole.

IMPROVING THE COATING PROCESS

Types of Improvement

Improvements can be made both at pre-production and production. There is no doubt that the first step is to improve pre-production activities along the lines and in the areas outlined earlier. The first step must be to raise the perceived value of the coating process. When a part of the ship has been coated, value has been added and hence the coating needs to be protected. It is difficult to lobby for improvements when the cost of the paint is often less than 1% of the price of the ship, however it is one of the few areas where improvements can be easily and readily made. Typically up to 60% of coating man-hours are used on re-work and touch up, in no other part of the shipbuilding process would this be acceptable. The first step is to properly integrate the coating process into the shipbuilding cycle and to that end the development of a coating strategy should help to achieve this. To properly integrate the process the following key areas should be addressed: - Ship design - Facilities, equipment and technology - Production management - Product selection

Ship design

The design of the vessel must take more account of the needs of the coating process at new-building and the need for the coating to perform well through the life of the vessel. The performance of the coating should be considered as an integral part of the structural performance of the vessel through life. Premature failure of the coating could lead to corrosion and in turn premature failure of the ship structure [15]

Vessel designers should look at the use of other non-corroding materials for many of the outfit items such as pipes, door etc. as this would reduce the overall through life coating costs.

Facilities and equipment

The timing of when coating work is to be carried out is critical. It should not always be assumed that the best place is the paint cell (although it is the most efficient). Different yards face different problems and so the selection of when and where to paint different areas will depend on how the yard works and what are the more common forms of damage as well as what levels of investment the yard has for facilities and equipment. The impact of the environment must also be assessed.

The equipment selected has increasingly got to deal with not only its performance but also its potential to minimise the environmental impact.

Surface preparation techniques:

- Dry ice cleaning
- Combination nozzles (the so called u-jet)
- Dry grit blasting
- UHP water jetting
- Mechanical tools
- Etc.

Application techniques

- Electrostatic application
- Air shrouded nozzles
- Airless spray
- Brush/roller
- Etc.

Production Management

This can cover a very broad scope of management systems from financial control and budgeting to training and education. The build strategy and approach to ship building by the yard is the corner stone of all these activities. However one key system should be singled out:

Quality System - The use of a quality system to identify, quantify the occurrence of re-work and to systematically mange it and eliminate it is critical. Juran and Demming have advocated systems based on statistical tools for many years. Yet very few yards seem to use these in earnest even to monitor let alone control DFT. Yet the proper control of DFT alone can reduce VOC emissions and paint consumption by up to 50% in some areas.

Product selection

Talking to a number of yards it is always clear that a number of items are very high on their list of desirable features of a paint scheme:
Examples include:

- Fast drying products in tanks and on deck
- Low surface preparation requirements
- Low VOC
- Minimum number of products
- Minimum number of coats

In summary they are looking for predictability yet often when the decision is made to select one tender or another only two criteria are considered:

- Price
- Supplier

It is no longer true to say that the lowest bid always wins, but it is still quiet common. The technical support and reputation of the supplier is also very important.

Human Failings

Within many shipyards around the world, coating jobs are seen to be among the lowest of the low. This raises issues in terms of motivation, retention, and absenteeism. In many yards retention of a core of skilled employees is hard, resulting on considerable reliance on contractors. The motivation and skill levels of the workers have in some countries become a real issue. In the US, the retention and experience of the workforce appears to be above average, thus the other sources of inadequacies take on a greater importance. It is still seen as a dirty, dangerous and low paid job that does not merit real investment to get it right.

Environmental Challenges

The main challenge is to look at the impact of any changes on the total environmental equation rather than trying to optimise local or process specific solutions. The coating process impacts the environment in a number of ways:

- Air
- Land
- Water
- Human

Taking each of these challenges in turn:

Air

The main issues here are ;

- VOC management
- Over spray
- Open air grit blasting

VOC management is now to be controlled under the EU solvent directive [16] and the US Clean Air act [17]. Each yard is required to produce regular solvent emission reports and put forward management plans for the reduction of emissions driven from a base year. This is a very time consuming and labour intensive activity and has now been computerised [ibid].

Over-spray is an increasing issue as yards are more and more encroached by residential areas that will not tolerate the over-spray from the application process. Alternative technologies available (electrostatic spray) are as yet not reliable enough, too expensive or not productive enough to enable the yard maintain its production throughput.

Open air blasting generates considerable dust and this is also no longer tolerated by environmental agencies, resulting in yards having to either look at far less productive alternatives or building expensive paint/blast shops.

Finally, the new silicone based anti-fouling products raise a unique set of problems, not only do they require other coatings to be protected from them to avoid cross contamination, they also require dedicated equipment and a modified process of coating. So although offering some environmental benefits through life, these are not without penalty at new building. This again demonstrates the importance of considering the total environmental equation

Land

Land pollution is dominated by the surface preparation process and to a lesser extent the over-spray as well as the disposal of hazardous wastes.

The contamination of the adjacent land by wind carried by products of the surface preparation and coating processes, can be quite severe as many yards have been carrying out these activities for many years and so the build up has accumulated to often unacceptable levels.

The disposal of hazardous wastes needs some innovation. The waste consists of:

- Unused paint and solvents
- Used cans of paint,
- Contaminated grit and
- other waste products, such as rags, and other consumables

Some simple processes can be developed to eliminate some of these, such as incineration. For paint cans the use of liquid carbon dioxide should be considered to convert liquid waste into solid waste and leave a very clean empty can that could be re-used. Solvent recycling technology is well established but not widely used.

Bulk supply of paint is applicable to some vessel areas, where the coating system is applied in one go (such as anti-fouling). This can save considerable waste and fugitive VOC emissions. However, the economics of the supply of paint in this form has so far failed to convince shipyards and paint companies to adopt it widely (there are some notable exceptions).

Water

There are a number of problems for water pollution. The dominant factor has been the retention of TBT in the sediments around shipyards. There is evidence of a greater than expected accumulation of TBT at new building yards as TBT appears to have been leaching during the outfitting period. This has now been helped by the reduced outfitting times. However some of the newer technologies are still showing a similar affect, although this varies between salt and fresh water.

Run off water is having to be controlled, in particular from areas of surface preparation and coating, with collection and filtration s ystems increasingly being required.

Humans

The health and safety of workers is paramount and factors such as:

- Noise
- Fumes
- High pressure pumps
- Etc

All have an impact. In a study conducted into noise pollution, by the authors in the late 80's. One new building yard had to modify its complete coating strategy to reduce the noise pollution generated from the surface preparation process as it contravened local regulations to a residential area that had been developed some 150 years after the yard.

Conclusions

Shipyards face a real challenge to control the environmental impact of the coating process. If they are able to meet the challenge they can genuinely improve productivity and reduce costs.

Some simple steps can be taken to improve the environmental effects of the coating process such as a simple control of DFT during application.

It is not an area where considerable expenditure is needed to reap rewards, but it nonetheless needs investment to get the process right, from product selection to application.

The important factor in any assessment of a shipyard is to consider the overall environmental equation and not focus on local optima.

The problems with many current policies, regulations are that they isolate specific activities, for example you have to reduce VOC emissions as a stand-alone target. However, by using products with lower VOC, there is a general requirement to improve surface preparation quality and thus incur a penalty in surface preparation activities. Any assessment of a shipyard by authorities should therefore take into account the overall environmental balance rather than to be process specific.

The aim must be to reduce the environmental impact of the process while ensuring that the yard can maintain its competitive edge. This must be done through a proper coating strategy.

The imbalance in the application of regulations is quite large, with the USA and Northern Europe leading the way in the development of legislation and its application. For example, although Japan effectively banned TBT 10 years ago, it is only this year that they are considering implementing regulations regarding VOC emissions.

A balanced playing field much be achieved to ensure that while the environment is protected, no yards are unfairly penalised when compared to their competitors.

It is a challenge that is slowly being met by many shipyards, who have proven that they can improve productivity and reduce costs while minimising the environmental impact of these processes.

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Trends in propulsion and how they affect environmental sustainability

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SYNOPSIS

The stage will be set against a background of issues which are important in the shipping industry nowadays, such as the trend to (ultra) large containerships and very fast ships. The effects on fuel consumption, CO2 emission and other exhaust emissions will be evaluated. The paper will give some quantified results as well as an insight in fundamental relations relating to what is essentially a scale problem. On top of that, the paper will address some potential static and dynamic matching problems between ship and machinery in case of multi shaft installations that could be part of the solution both for the ultra large containerships as well as for the fast ships.

INTRODUCTION

Sustainable development according the Brundtland Commission United Nations 1987: *"A development that fulfils the needs of the current population without compromising the possibilities of future generations"*. This definition of sustainability though apparently clear is not very easy to translate into technical requirements useful to the designer of for instance a ship. Underlying the definition are assumptions as to what the 'needs' are of the current population and predictions about what will – turn out to – be compromising for future generations. Incorporating sustainability into the design will therefore require some further discussion and analysis. Added to this, a sustainability study is always difficult from a numerical point of view: relative weights and costs have to be estimated to a large extent, while the limitation of the reach of study influences the outcome considerably. Example of these are: is one kilogram NO_x more harmful than one kilogram of CO_2? What is the cost of one kilogram of CO_2 emission? Does the analysis include the machines and land area required to build a ship? Safe, albeit unrealistic, starting points are to use only renewable resources and produce only emissions that are indisputably harmless. The first starting point requires the use of only material from recycling and energy from wind, tidal or solar sources, the second starting point only allows for emission of clean water since almost all other emissions are in some way harmful for the local or the global environment. Clearly, in an environmental context sustainability is very difficult to assess, since little is known about the long term impact of emissions, let alone the costs that should be allocated to these emissions. To limit the scope and to be able to show some useful trends this paper focuses on the operational use of a ship, leaving out the building and scrapping processes. The main topic are the gaseous emissions of the propulsion and power

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Author's Biographies

Professor D. Stapersma, after graduating in 1973 at Delft University of Technology in the field of gas turbines, joined Nevesbu - the Dutch design bureau for naval ships - and was involved in the design and engineering of the machinery installation of the Standard frigate. After that he co-ordinated the integration of the automatic propulsion control system for a class of export corvettes. From 1980 onward he was responsible for the design and engineering of the machinery installation of the Walrus class submarines and in particular the machinery automation. After that he was in charge of the design of the Moray class submarines in a joint project organisation with RDM. Nowadays the author is professor of Marine Engineering at the Royal Netherlands Naval College and of Marine Diesel Engines at Delft University of Technology.

H.T. Grimmelius obtained a bachelor's degree in Marine Engineering in 1986, and sailed on merchant ships as engineer for a short period. In 1992, he graduated from Delft University of Technology in Marine Engineering, on a thesis on condition monitoring. He subsequently started a PhD. research project on condition monitoring for refrigeration plants onboard ships. In 1996, he also became assistant professor Marine Engineering at the Delft University.

plant that are influenced by the design of the plant (NO_x and CO_2). These emissions are closely related to the fuel consumption. Emissions that originate from the fuel quality such as SO_x and heavy metals are not considered. Furthermore, fluid and solid emissions such as oil, cleaning products and garbage are also not considered here.

ENVIRONMENTAL SUSTAINABILITY OF A SHIP AS TRANSPORT SYSTEM

In order to be able to assess the environmental sustainability of a system first a link has to be made between the harmful effects and the useful output of the system. In case of a ship as transport system the useful result is the transport of goods or people. In this study the harmful effects are limited to the gaseous emissions

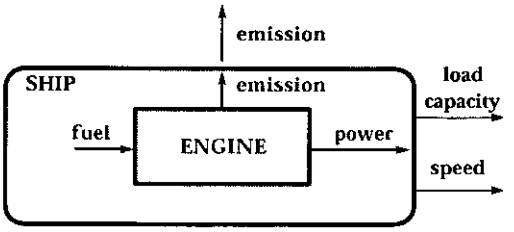

Figure 1 Ship system boundary showing emissions in relation with transport performance

Starting from the power specific emission (per) in g/kWh to relate emissions produced to distance covered the energy per mile (or km) must be known, this simply is power divided by ship speed. When making a prognosis this requires a further analysis of the ship resistance and propulsion characteristic. One step further is to relate the emission to transport performance in tonmile the result being tonmile specific emission, as illustrated in Figure 2.

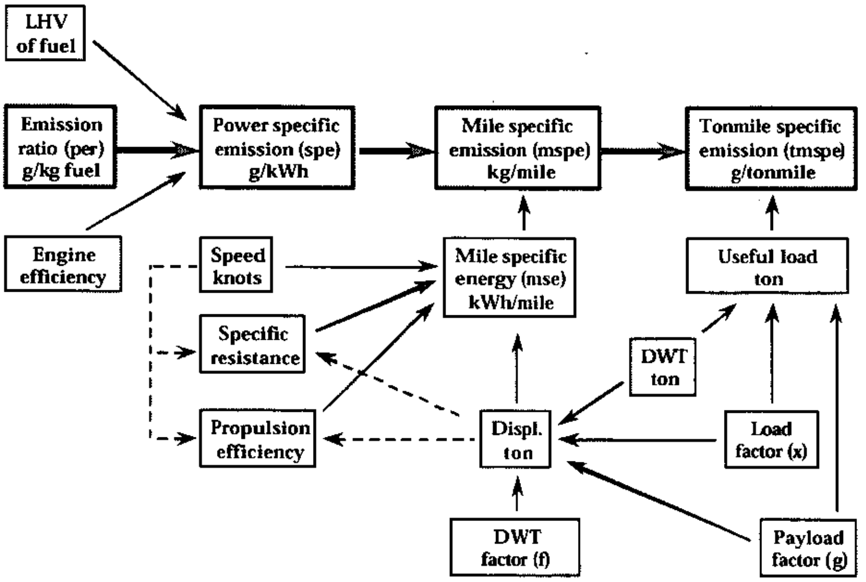

Figure 2 Units of expressing emissions and required data for a ship system

Putting together the chain from power specific emission to gram emission per tonmile transport performance results in the following 'master' equation:

$$\text{tmspe} = 49 \cdot \underbrace{\frac{\text{per}}{\eta_e \cdot \text{LHV}}}_{\text{Engine}} \cdot \underbrace{\frac{C_{bp} \cdot \rho^{1/3}}{DWT_{full}^{1/3}}}_{\text{Ship}} \cdot \underbrace{\frac{(1 - g \cdot f + x \cdot g \cdot f)^{2/3}}{x \cdot g \cdot f^{2/3}} \cdot v_S^{\,2}}_{\text{Mission}} \qquad (1)$$

If the *tonmile specific pollutant emission* (tmspe in g/tonmile) would be the basis for legislation rather then the power specific emission in g/kWh as selected by IMO, then not only the engine manufacturer would be forced to lower the emissions (per g/kg) and/or raise the engine's efficiency (η_e) but also the ship designer would get an incentive to lower the ship's resistance and/or raise the propulsion efficiency (C_{bp}, equation (3)). The scale effect is represented by the factor $DWT^{1/3}$: a larger ship will – all being equal – result in lower specific emissions. The ratio between displacement and DWT (f) is the result of the compromise between the wishes of the ship owner and the demands of the Classification Societies. The ship owner is also be involved in the selection of the fuel, through the Lower Heat Value (LHV) and his demands for endurance, the ratio between payload and DWT (g). When operational, the ratio between actual and design payload of course becomes very important (x). And, last but not least, the ship owner and crew together are responsible for the selection of the ship's speed (v_S) which, due to its quadratic power, heavily influences the emission per distance covered.

CONCEPT OF MODELLING SYSTEMATIC SERIES OF CONTAINERSHIPS

Dimensions and hull form

A systematic series of large to ultra large containerships is set up for further analysis. The main dimensions are presented in Table I .The resulting L/B and B/T ratios are shown in Figure 3.

Table I Main dimensions of systematic series of containerships

Nominal load capacity	*Length w.l.*	*Width*	*Design Draught*	*Propeller diameter*
4000 TEU	250 m	32.0 m	13.0 m	8.1 m
6000 TEU	290 m	42.0 m	13.5 m	8.4 m
8000 TEU	320 m	48.0 m	14.0 m	8.7 m
12000 TEU	360 m	58.0 m	14.5 m	9.0 m
16000 TEU	390 m	69.0 m	14.5 m	9.0 m

The displacement is fixed by assuming that the block coefficient is slowly increasing with ship length from 0.64 to 0.70 for single shaft ships, see Figure 4. Twin shaft ships (considered from LWL = 320 m onwards) have slightly lower block coefficients since the stern is not so full, in order to make room for the bracket mounted shaft lines. Since in particular the width of the ships and not draught is increased it could be possible to adopt two single shaft hull shapes adjacent to each other. This will produce a fuller aft ship (even fuller then the single shaft ship) and consequently larger displacement, but it is hoped that this hull form will exhibit the favourable hull efficiency of a single shaft ship. DWT has been roughly estimated by assuming the DWT/displacement ratio to slowly increase with length, see also Figure 4. The empty weight of the twin shaft ships is taken slightly higher than their single shaft counterparts, resulting in the DWT/displacement ratios as shown in Figure 4. The resulting displacement and DWT are shown in Figure 5.

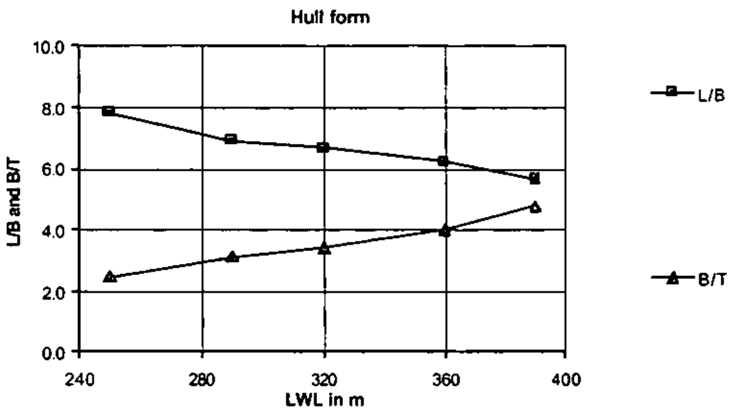

Figure 3 Hull form in terms of length/width ratio and width/draught ratio

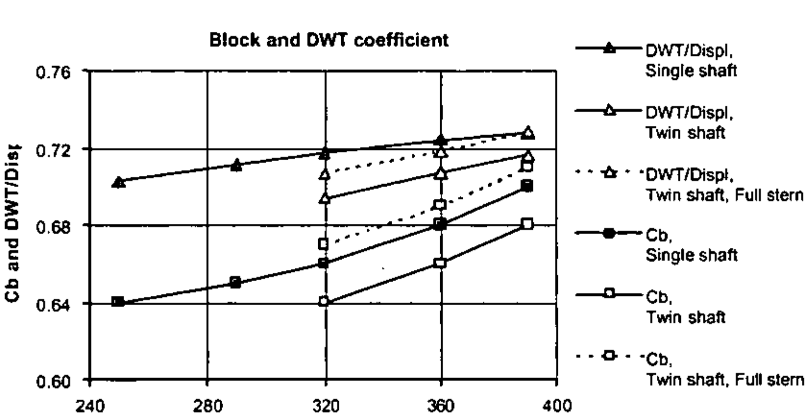

Figure 4 Block coefficient and DWT/Displacement ratio

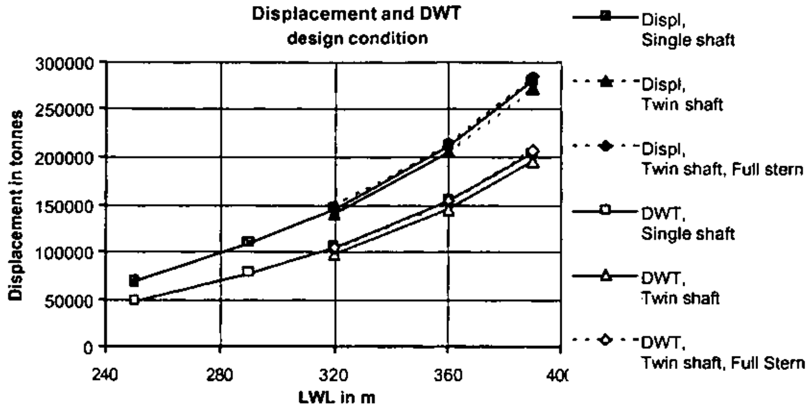

Figure 5 Displacement and DWT

Propeller design

The statistical method according to [Holtrop cs. 1978, 1982, 1984] has been used to estimate effective power for the systematic series of hull forms. For the design speed two cases have been considered, see Figure 6. At first it was assumed that design speed would increase with length, keeping Froude at approximately 0.22, which is a scheme that is based on technical feasibility. Then the design speed was kept constant at 24 kn, being a speed that is rationally selected with a view of the required trade.

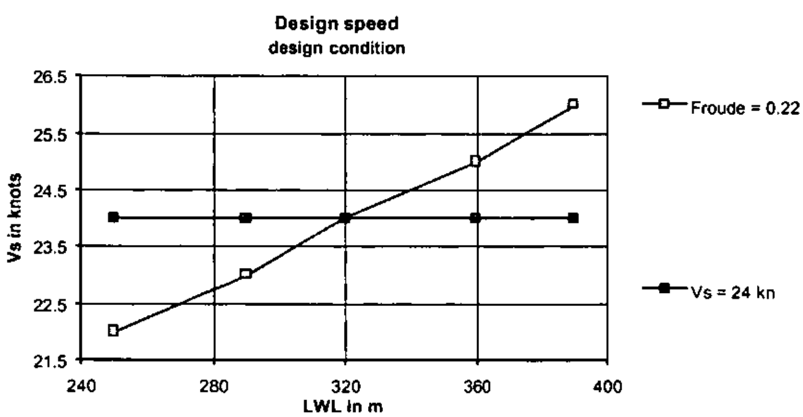

Figure 6 Design speed as function of length w.l.

[Holtrop cs., 1974] also gives regression formulas for wake fraction, thrust deduction and relative rotative efficiency; The latter together with the combined effect of the former (i.e. the hull efficiency) is shown in Figure 7 for the cases where design speed is kept at v_s = 24 kn. (the cases where Fr = 0.22 hardly give different values). A service margin of 15% has been applied, based on Sea State 3, one year fouling (3% added resistance per year) and reasonably deep water (200 meter). Then, based on the propeller diameters as restricted by draught according to Table I, the optimum shaft speed has been determined by selecting the appropriate propeller pitch for each case, see Figure 8. The resulting propeller efficiencies are shown in Figure 7 (again only for the case of a constant design speed of v_s = 24 kn). Note the dramatic drop-off of propeller efficiency as a result of the combined effect of the required power and draught limited propeller diameter.

Changing to twin shaft arrangement of course alleviates this, but then hull efficiency, at least in the case of A-brackets, is with a value around 1.0 much lower. The net effect on propulsive efficiency however is positive. This is even more true when a full stern is adopted. Hull efficiency and relative rotative efficiency then are almost equal to the single shaft arrangement (this is not shown in Figure 7). Propeller efficiency is somewhat lower but propulsive efficiency now comes up at very high figures.

It must be noted that the single shaft options for the larger ships are not feasible in view of cavitation criteria of the propeller. The expanded area ratio as required by Kellers criterion [Holtrop cs., 1974] is depicted in Figure 9. Since for 6 blade propellers an A_e/A_o value of 1.05 seems to be a maximum, above LWL = 320 m only the twin shaft options are feasible.

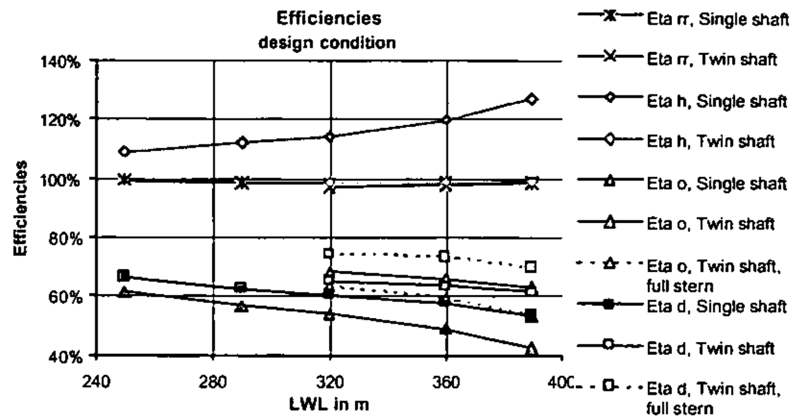

Figure 7 Hull efficiency (eta h), relative rotative efficiency (eta rr), open water propeller efficiency (eta o) and resulting overall (delivered) propulsive efficiency (eta d) for fixed design speed of $V_S = 24$ kn

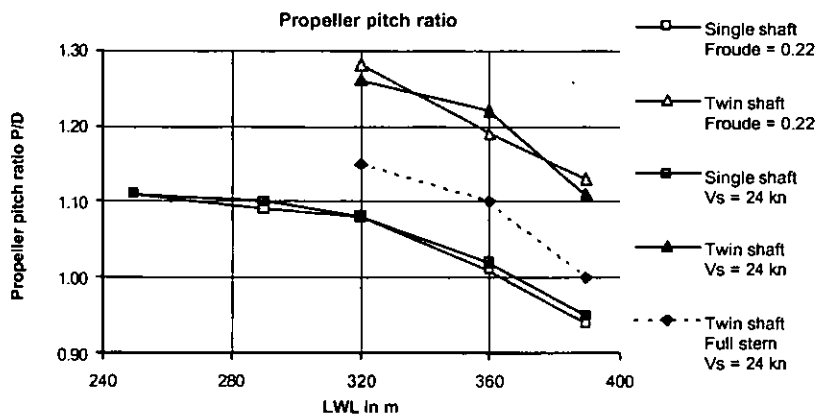

Figure 8 Propeller pitch/diameter ratio

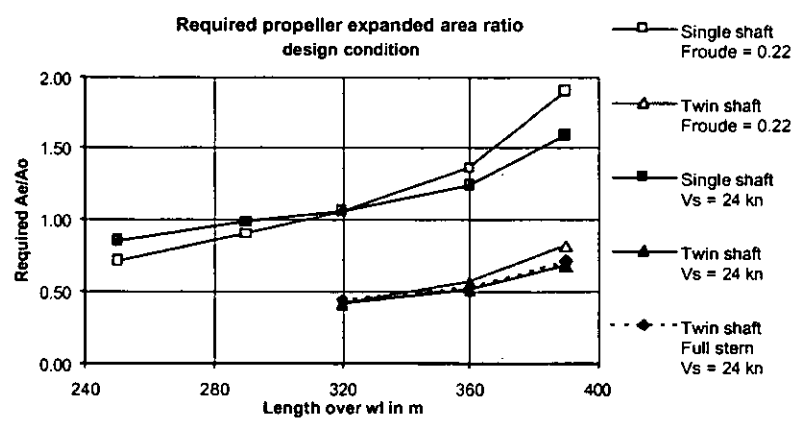

Figure 9 Required propeller expanded are ratio

Propulsion power for design condition

After applying a 2% transmission loss in the shaft line, the required engine power can be determined, see Figure 10. To have a better insight in the relative differences the Admiralty constant, defined as:

$$\mathrm{Adm} \overset{\mathrm{def}}{=} \frac{\Delta^{2/3} \cdot V_S^{\,3}}{P_b} \tag{2}$$

could be used. The authors prefer the inverse and non-dimensional version of this constant, the specific (brake) power coefficient (also used in equation (1)):

$$C_{bp} = \frac{P_b}{\rho \cdot \nabla^{2/3} \cdot V_S^{\,3}} = \frac{P_b}{\rho^{1/3} \cdot \Delta^{2/3} \cdot V_S^{\,3}} \tag{3}$$

This has been shown in Figure 11. Note the general trend of increasing specific power, particularly when Froude is kept constant. Analysis reveals that this is mainly caused by the drop of propeller efficiency, combined with a slight increase of specific resistance (effective power). Combining the relative good propeller efficiency of the twin shaft configuration with the hull efficiency of the single shaft ship (Figure 7) by applying two single ship sterns together (full stern) would result in a very low specific power coefficient (Figure 11) and thus the lowest value of required brake power (Figure 10).

Last but not least the engine speed as dictated by the choice of the propeller pitch and at the required power for design speed is shown in Figure 12. Note that engine speed would go up well above 100 rpm if the single shaft options would be viable for the large ships. As it is the twin shaft options exhibit much lower engine speeds, starting at 80 rpm for the 320 m ship.

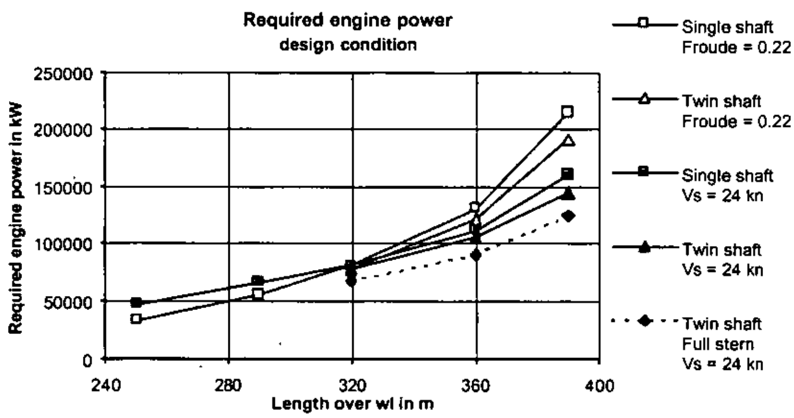

Figure 10 Required engine brake power

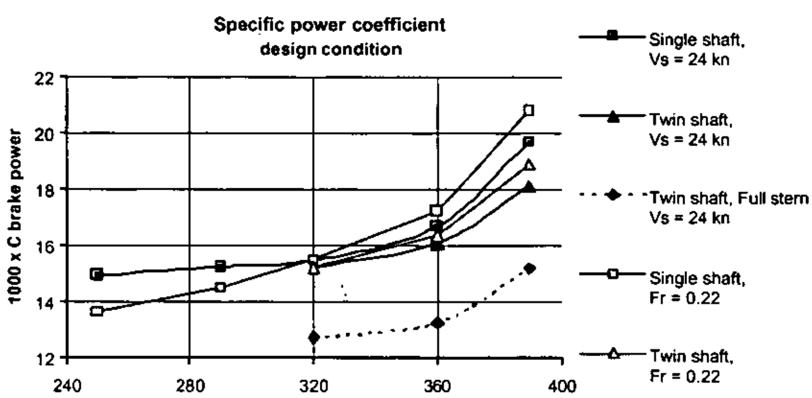

Figure 11 Specific (brake) power coefficient for fixed design speed of V_S = 24 kn

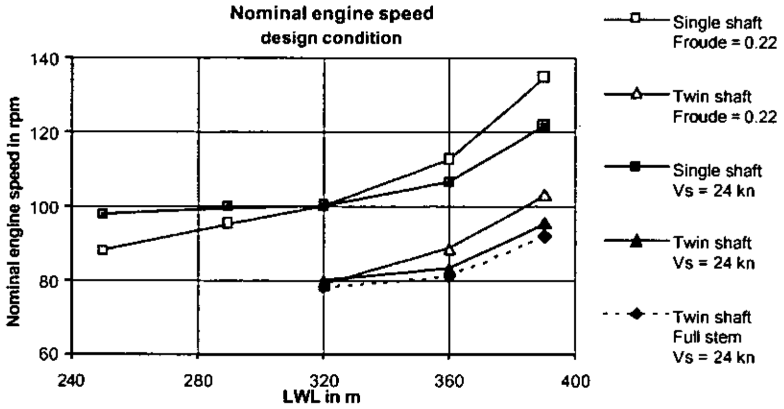

Figure 12 Nominal engine speed for fixed design speed of V_S = 24 kn

Auxiliary power/ lay out of power plant

The electric power for containerships has been growing fast with the number of reefer connections. In general auxiliary power for ships depends on main engine size and number of crew/passengers. The following expression was used:

$$P_{aux} = 100 + 0.55 \cdot P_b^{0.6} + x_{reef} \cdot Nr_{TEU} \cdot P_{reef} + Nr_{pers} \cdot P_{pers} \quad (4)$$

Installed brake power is known for all the cases. Assume:

$x_{reef} = 0.4$, $P_{reef} = 3$ kW , $P_{pers} = 3$ kW

The number of reefers dominates the picture, practically the same line is found for all cases. In Figure 13 the single shaft option with fixed design speed of 24 kn is pictured only. The installed auxiliary power is presented in Table II and is based on all shaft generators plus all diesel generators except one running at approximately 80% load.

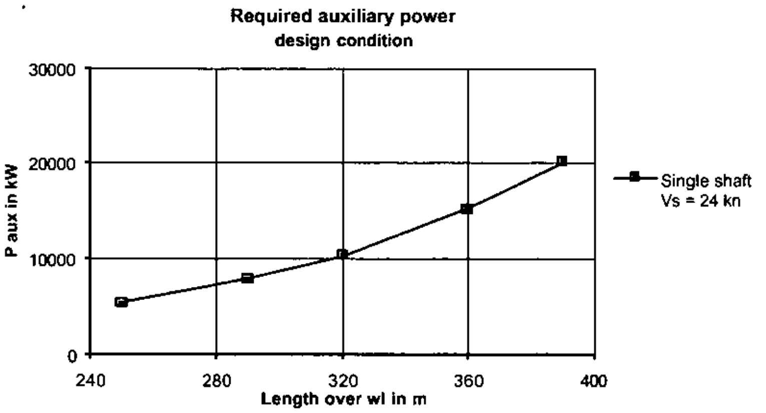

Figure 13 Required auxiliary electric power

Table II Installed auxiliary power

	Nr of shaft generators	*Power per shaft generator*	*Nr of Diesel generators*	*Power per Diesel generator*	*Total installed auxiliary powe*
4000 TEU, 1-shaft	1	2000 kW	3	2000 kW	8000 kW
6000 TEU, 1-shaft	1	3000 kW	3	3000 kW	12000 kW
8000 TEU, 1-shaft	1	4000 kW	3	4000 kW	16000 kW
12000 TEU, 1 shaft	1	6000 kW	3	6000 kW	24000 kW
16000 TEU, 1 shaft	1	8000 kW	3	8000 kW	32000 kW
8000 TEU, 2-shaft	2	2000 kW	3	4000 kW	16000 kW
12000 TEU, 2 shaft	2	3000 kW	3	5000 kW	24000 kW
16000 TEU, 2 shaft	2	4000 kW	3	8000 kW	32000 kW

The overall lay-out of the machinery plan is shown in Figure 14 for the single shaft plants and in Figure 15 for the twin shaft plants. Note that the latter offers the possibility to divide the engine room longitudinally in two fire-separated rooms.

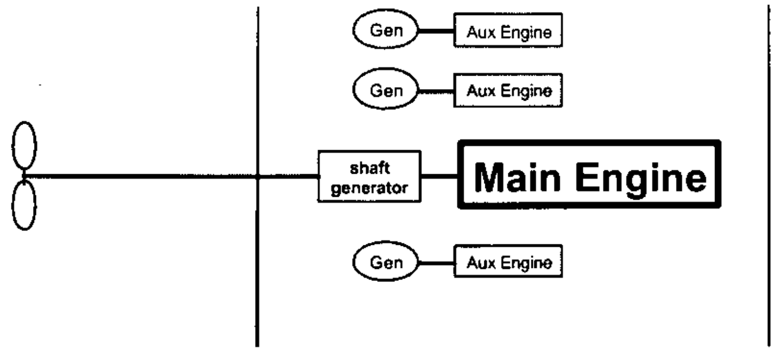

Figure 14 Lay- out of machinery plant, single shaft configuration

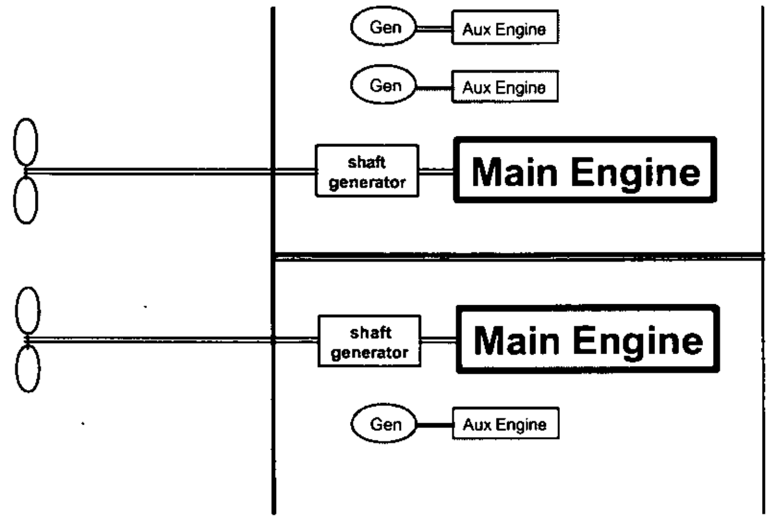

Figure 15 Lay- out of machinery plant, twin shaft configuration

Required fuel and payload

The required amount of fuel oil was determined by setting the ship's range at approximately 50 days at design speed for all cases. Then the faster sailing cases will require more fuel oil and have slightly less payload. The payload was determined from the DWT after subtraction of 1.1 times the weight of the fuel oil. The payload/DWT ratio is illustrated in Figure 16. Payload will be the usable amount of tonnes in the tonmile specific pollutant emission.

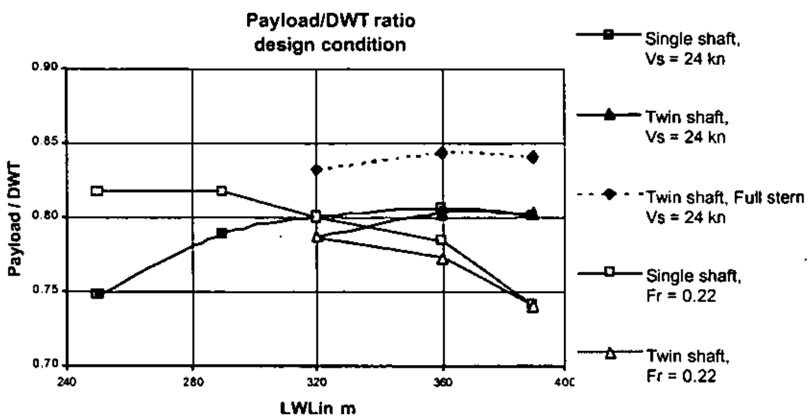

Figure 16 Ratio of payload and DWT (g)

SIMULATION OF OPERATION

Service condition

The draught in service condition is set at design draught minus 1 meter. In this condition it is assumed that the block coefficients and other hull shape factors have not changed much. For all designs it results in a useful payload of around 85-88% of the design value. Propulsion power of course is lower because of the lower displacement. However in this condition it is assumed that there is a requirement to run 1 kn above design speed in order to be able to make up for lost times during heavy sea states. All in all this results in engine margins between 0.85 and 0.88, which are values that correspond well with values adopted in practice. The part load power at the service condition then can also be calculated using the statistical method of [Holtrop cs., 1978, 1982, 1984], see Figure 17 for single shaft options and Figure 18 for twin shaft options (both for fixed design speed of $V_s = 24$ kn).

The large two stroke diesel engine has an engine efficiency of 52% at full load, slightly decreasing at part load[1]. The auxiliary power is supplied by the shaft generator plus 2 of the 3 diesel generators, apart from top speed where the shaft generator is disconnected and all diesel generators must be running. Efficiency of the diesel generators is 48% and for the engine 97% for the generator, both at full load and again slowly decreasing at part load. Efficiency of the slow speed shaft generator was assumed at 95%.

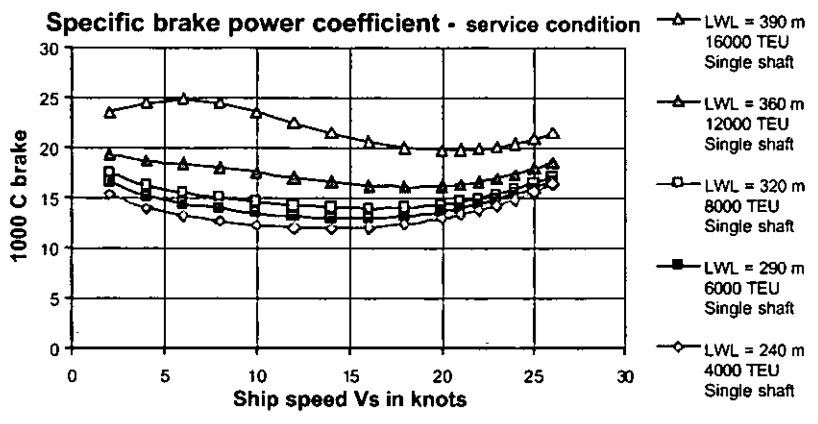

Figure 17 Required engine power coefficient over the speed range in service condition: single shaft with design speed of $V_S = 24$ kn

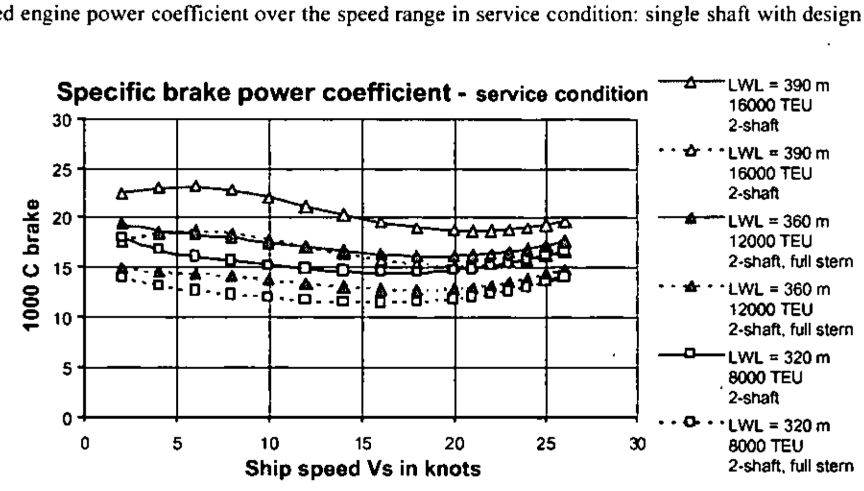

Figure 18 Required engine power coefficient over the speed range in service condition: twin shaft with design speed of $V_S = 24$ kn

Mission profiles

During a year, the ship runs at different speeds. For container vessels there is generally one dominating – service – speed. Higher speeds also occur, for instance to make up for unplanned delays, but for a fair amount of hours the ship runs slower for manoeuvring etcetera. The cases were run with a sharp mission profile around the service speeds of 22, 23, 24, 25 and 27 knots, all making 7500 hrs per year at sea, see Figure 19. The mean speed of advance (SOA) is plotted at the top. An

[1] for curves of sfc, being the inverse of efficiency, see Chapter 12 of [Klein Woud cs., 2002]

alternative profile was defined for ships capable of making 25 knots where the maximum number of hours was not made at 24 knots but at 22 knots. Also for this profile the hours were spread over a broader speed range. The idea is that in this mission profile with a lower mean speed it will be possible to sail much faster when necessary, thus providing a reliable time of arrival. Last but not least a very fast profile was defined around 30 knots, specifically for a small but fast feeder that will be discussed shortly.

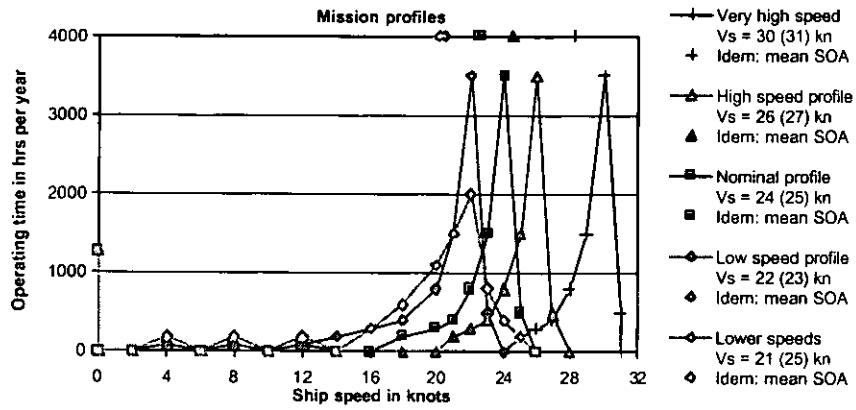

Figure 19 Mission profiles: speed of advance (SOA) against hours per year

Emissions

From the combination of required power and the mission profile the resulting emissions are calculated. Figure 20 shows the results for all concepts described in the previous section. Clearly, keeping the Froude number constant results in higher speeds and thus higher specific emissions. Keeping the speed constant shows the potential of increase of scale, but this effect is thwarted for the largest ships because of the less favourable hull shape due to draught restrictions and limitations to the propeller diameter (note that the largest single shaft designs are hypothetical!).
The twin shaft options generally are less favourable due to increased appendage drag and reduced hull efficiency, only for the largest design a small improvement is found. The twin shaft options with a full stern show a potential for improvement, due to the increased hull efficiency, with an optimum around 12.000 TEU.

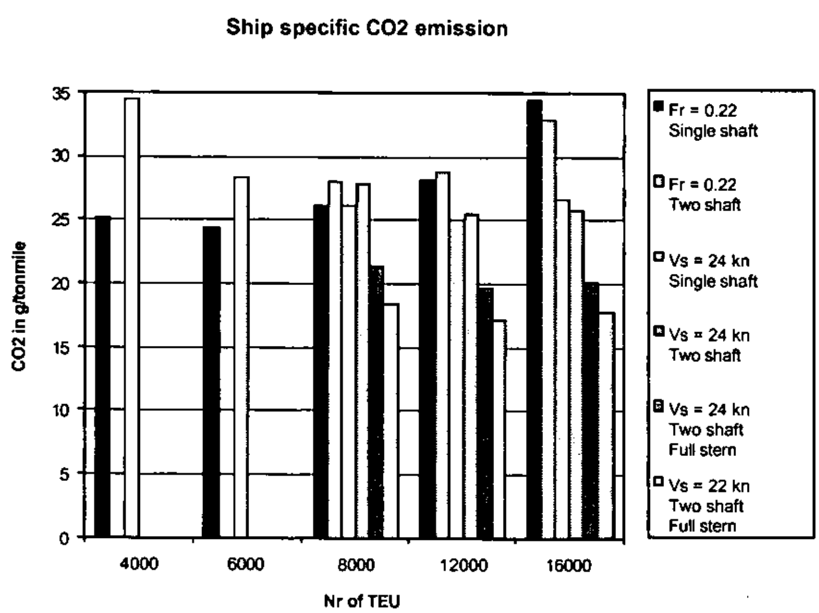

Figure 20 CO_2 emissions (note that > 8000 TEU the single shaft options are hypothetical!)

Specific fuel consumption follows exactly the same trend as CO_2 emission. SO_x emissions also follow the same trend, but are strongly dependent on fuel sulphur content. The trend in resulting NO_x emissions closely resemble the trend in CO_2 emission since for all profiles there is one prevailing engine load, and the effect of increased NO_x production at part load is suppressed.

HIGH SPEED CONTAINERSHIPS

Design data

In [Gee, 2000] the PEBOS ship project is reported from which the famous 1500 TEU pentamaran design evolved. This very slender hull with two stabilising sponsons on either side is a design with a payload of 13000 tons. The target speed was 30 knots to be achieved with only 30 MW power. No particulars of the hull size and form are given, but it can be estimated that the DWT/displacement ratio is 46 % while a specific brake power coefficient of 1000 x C_{bp} = 7.4 would be the target. Although from [Gee, 2000] it is reported that the speed target for this most interesting vessel has not yet been met, the tonmile specific CO_2 emission has been calculated for this concept on the basis of the very fast mission profile in Figure 19 as a "what if" case.

In the same paper [Gee, 2000] a more modest design is presented, the FFB design, which has actually been built. It is based on the PEBOS hull lines, but slenderness has been reduced in order to get enough stability without the sponsons. This ship is designed for 9000 ton payload, has a DWT/Displacement ratio of 46 % too, and must meet a design speed of 25 knots at 19 MW engine power. With the particulars given it is estimated that this ship has a specific brake power coefficient of 1000 x C_{PB} = 10.2, which is low indeed when looking at Figure 11. For this ship the tonmile specific CO_2 emission has been calculated on the basis of a 25 kn mission profile (falling between two profiles in Figure 19).

Lastly [Gee, 2000] compares the FFB ship with a conventional container feeder. It has 9500 tons payload, a DWT/displacement ratio of again approximately 55 % (only!) and requires 25.4 MW engine power to sail at 24.2 kn, which is equivalent to a value of 1000 x C_{bp} = 16.7. For this ship the tonmile specific CO_2 emission has been calculated on the basis of the nominal 24 kn mission profile in Figure 19.

Comparison of emissions

The three 1000 – 1500 TEU container feeder designs are compared on the basis of tonmile specific CO_2 emission in Figure 21. In order to be able to see the trend for fast ships and for large ships, two profiles for 4000 TEU and the best figures from the earlier investigation for the 8000 TEU and 12000 TEU large containerships (twin shaft, full stern) are entered as well.

The improved concepts show a remarkable trend as the specific emissions decreases with increased speed. For the pentamaran design the increase in speed (25 to 30 knots) is compensated by the combined effect of the much lower specific power target and the slightly larger hull (scale effect: 9500 to 13000 tonnes payload). The figure for the conventional 1500 TEU ship could be improved if the DWT/displacement ratio would be more in line with the larger containerships.

Compared to the large ships shown in Figure 21 the fast feeders do not come out favourably because of a combination of scale (DWT to power 1/3 in the master equation) and low DWT/displacement ratio, which do not outweigh their favourable brake power coefficient.

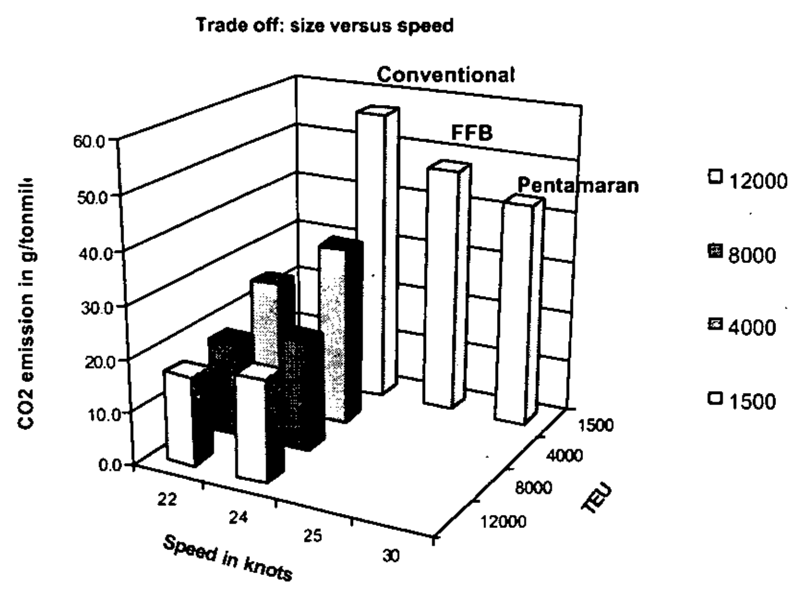

Figure 21 Trade off between size and speed for of tonmile specific CO_2 emission of containerships

The previous sections showed that a twin shaft solutions in combination with a full stern seems very attractive for the larger ships. The matching of the engines is shown in Figure 22, where for a nominal service condition maximum power and maximum speed are reached simultaneously. Under heavy conditions the maximum speeds drops to 20.6 knots, and though the margin between load line and engine limits is reduced, no static problems are to be expected. Under heavy conditions however the dynamic variations on the propeller loading could result in incidental engine overloads, forcing further speed reduction.

Improved reliability is often claimed to be one of the benefits of a twin shaft configuration. Figure 23 shows the load line of the ship with one operating propeller and the other stopped[2]. In service conditions there is no margin left, and the engine will overload under dynamic variations. It is important to note that a reduction in speed does not solve the problem here! Furthermore, in heavy conditions the engine is clearly overloaded, even in static conditions. Thus the reliability of the propulsion is not improved: if one engine fails, the other engine will have to be stopped to prevent damage. In fact, reliability has dropped because of the increased number of components!

A possible solution is illustrated in Figure 23: increasing the working area of the engine through the use of an 'advanced' turbo charger system (TC) (e.g. adopting sequential turbo charging similar to high performance four stroke engines or by adding an electric blower).

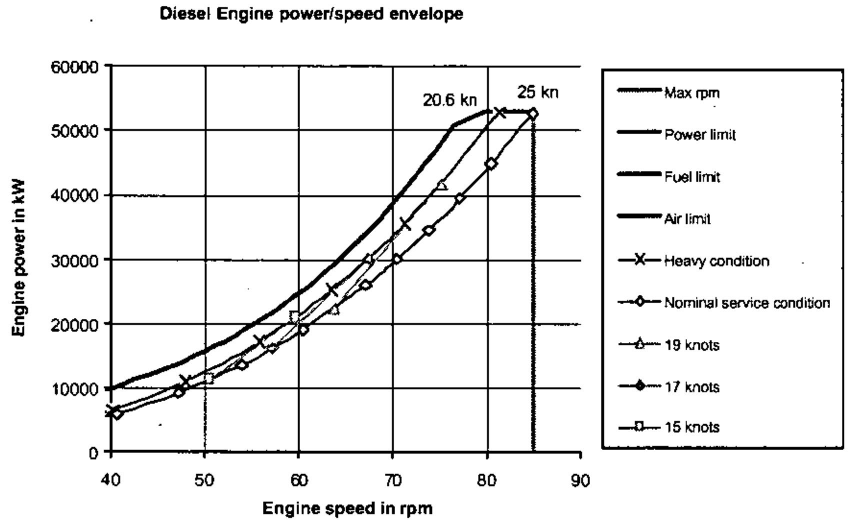

Figure 22 Twin shaft 12000 TEU ship, **2-shaft operation**, normal and heavy condition

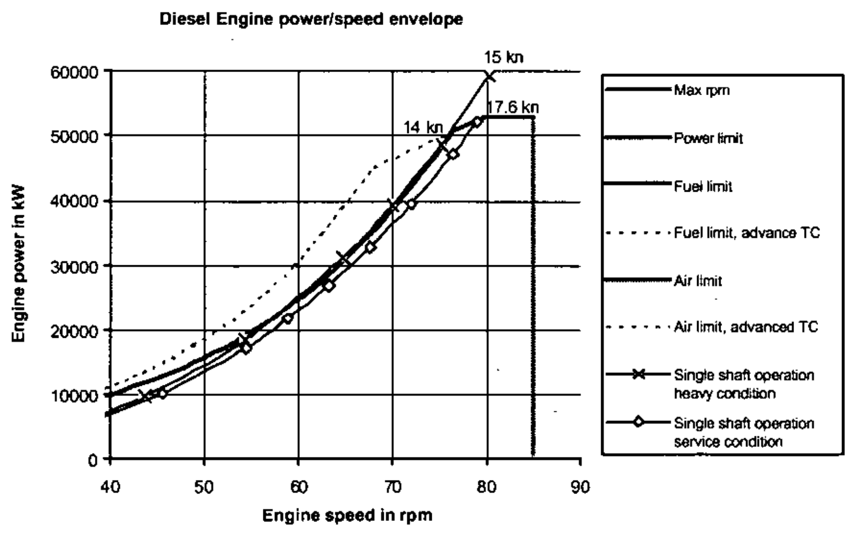

Figure 23 Twin shaft 12000 TEU ship, **1-shaft operation**, normal and heavy condition

[2] Whether or not the propeller is trailing does not significantly influence the outcome.

CONCLUSION

The tonmile specific CO_2 emission is a good indicator for the sustainability of the operational use of a ship design, and especially useful for comparing different designs. It is directly linked to specific fuel consumption (and thus to economy), and has a strong relation with other pollutant emissions such as NO_x and SO_x. The emission per tonmile is in many aspects comparable to the better known 'transport efficiency', but more suitable for comparison of designs from an environmental point of view.

For the container vessels analysed here, an increase of scale does not automatically lead to improvement. This is the result of a less favourable hull shape and the limited propeller diameter for the larger designs. For the largest vessels a twin shaft arrangement becomes a technical necessity, resulting in a further increase of specific emissions per tonmile. However, by adopting a different stern shape, and thus optimising the wake, considerable improvement is possible and a (weak) optimum emerges around 12.000 TEU. It should be noted that a twin shaft arrangement does not necessarily result in a more reliable design: sailing on one shaft is not an option if a common engine-propeller matching is adopted.

Clearly, no matter what design is chosen, any increase in speed will result in a penalty on the specific emission, while an increase in size, up to a certain limit, results in a reduction.

Another interesting approach is the adoption of a more 'robust' mission profile. By reducing the average speed, but maintaining the speed potential, the reliability of the arrival time increases while simultaneously the tonmile specific pollutant emission drops considerably.

NOMENCLATURE

Adm	Admiralty constant	-
C_{bp}	Specific brake power coefficient	-
DWT	Deadweight	tonnes
f	Deadweight (DWT) over displacement (Δ)	-
g	Maximum payload (W_{max}) over deadweight (DWT)	-
Nr_{pers}	Total number of persons on board	-
Nr_{TEU}	Total storage capacity in TEU	-
per	Pollutant emission ratio	kg/kg
P_{aux}	Required auxiliary power	kW
P_b	Brake power	kW
P_{pers}	Average power consumption per person	kW
P_{reef}	Average power consumption per reefer container	kW
sfc	Specific brake power coefficient	g/kWh
tmspe	Tonmile specific pollutant emission	g/tonmile
x	Payload (W) over maximum payload (W_{max})	-
x_{reef}	Number of reefer containers over total number of containers	-
∇	Volume displacement	m^3
Δ	Displacement	tonnes
ρ	Density of water	kg/m^3
η_e	Engine efficiency	-

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Ship emission and discharge inventories

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SYNOPSIS

A reliable and up-to-date inventory of key emissions and discharges to the environment is essential to gain a realistic insight into the impact of shipping on the environment. If we are not aware of baseline levels, neither the relative performance of shipping versus other modes of transport, nor progress toward reducing the environmental impact of shipping can be assessed. This paper presents an overview of published ship emission inventories for the operational phase, widely considered to be of greatest significance in terms of emissions and discharges to the environment. The assessment covers emissions to air, discharges to water and waste streams. Information on the level of emissions and discharges from ships is variable and uncertain for many components. More comprehensive information tends to be available in areas in which there is a high level of public interest. Hence the relatively good information on oil spills and, more recently, engine exhaust emissions. For other components, limited data is available. It is recommended that a baseline emission/discharge inventory is constructed with a breakdown into vessel types and operating mode. A mechanism for ensuring such data is regularly updated and made publicly available should also be put in place.

INTRODUCTION

Much progress has been made over the course of the last decade in raising the awareness of environmental issues in the shipping industry and much work aimed at reducing the impact of shipping on the environment has been undertaken. However information upon which to assess the overall impact of shipping on the environment is not readily available.

To assist work in determining the impact of shipping on the environment, a review of the current availability of information on the level of emissions and discharges from shipping to the environment was undertaken. This information is also key to:

- Targeting resources to tackle the key environmental issues;
- Identifying whether investment in technology is being reflected in improved environmental performance.
- Assessing the relative performance of shipping against other forms of transport.

All sectors of a ship's lifecycle from ship design and building through to scrapping impact on the environment. However, the overview is restricted to the day-to-day operational phase – widely considered to be of greatest significance in terms of emissions and discharges to the environment. Accidental pollution is largely excluded.

Assessment of the state of knowledge of shipping emissions and discharges to the environment is based around the following categories:

Emissions to air
- Exhaust emissions
- Refrigerant gases
- Fire fighting agents
- Cargo vapour emissions

Discharges to water
- Operational oil leakages
- Organisms carried in ballast water
- Antifouling coatings

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Waste streams
- Sewage
- Grey water
- Garbage
- Oily water

The availability of information as well as the levels of emissions/discharges are considered.

EMISSIONS TO AIR

Exhaust emissions

Discussion on exhaust emissions generally relates to diesel engines, currently the major provider of propulsive power in the marine industry. Emissions largely comprise nitrogen, oxygen, carbon dioxide, water vapour and smaller quantities of carbon monoxide, oxides of nitrogen (NOx), oxides of sulphur (SOx), partially reacted and non-combusted hydrocarbons and particulate material. Trace quantities of organic micropollutants eg. polyaromatic hydrocarbons (PAH), dioxins and heavy metals are also present.

Marine diesel exhaust emissions have been a focus for concern throughout the 1990's. This has been accompanied by significant progress in constructing inventories for key components. Internationally accepted emission factors have been established (Lloyd's Register, 1995). These have been recently reviewed (EPA, 2000; Cooper, 2002).

Detailed methodologies for constructing inventories of ship emissions have been developed by the UNECE Task Force on Emission Inventories and published in the Atmospheric Emission Inventory Guidebook (EEA, 2001). A number of ship exhaust emission inventories have been undertaken for key components on both regional and global bases (Table I). Variation is apparent between the various regional and global inventories. This may be attributable to use of different base years, calculation methodologies, emission factors, fleet segments and geographical limits for the different inventories. Published regional and global emission inventories have recently been reviewed (BMT, 2000).

Comparison of global emissions from shipping with those from all other sources indicates emissions of CO_2, NO_x and SO_x from shipping correspond to around 2%, 10-15% and 4-6% respectively of global anthropogenic emissions (Endresen *et al*, 2002a). Generally, most of the ship emissions take place in Northern Hemisphere. Corbett *et al* (1999) reported that 85% of shipping emissions occur in the Northern Hemisphere, with 52% in the North Atlantic/Northern Europe and 27% in North Pacific. However, Endresen *et al* (2002a) report lower emissions in the Northern Hemisphere and in the North Atlantic.

Some information also exists on regional/global estimates of other emission components of significant environmental interest eg. PAH, heavy metals and nitrous oxide (N_2O). However the emission factors on which these estimates are based tend to be derived from very limited data sets and/or adopted from other industries or transport modes and must be treated with caution.

Refrigerants and fire fighting agents

Emissions of chlorofluorocarbons (CFC) from the world shipping fleet were estimated at 3,000-6,000 tons for the year 1990 - equivalent to around 1-3 percent of annual global emissions. Halon emissions from shipping for the same year were estimated to be 300-400 tons, or around 10 percent of world total (IMO, 2002a). More recent figures are not readily available. It is anticipated that these would show a significant reduction in CFC and halon emissions on account of the phase out of these substances as a consequence of the Montreal Protocol on Substances that Deplete the Ozone Layer and subsequent amendments.

Ozone depleting CFC and halons are of key concern; although ''alternative'' fire fighting media and refrigerant gases are seldom without environmental impact and should also be included in any inventory. However, with the exception of the above 1990 figures for CFC and halons, little data appears available for global or regional emissions of refrigerant gases or fire fighting agents in the shipping industry. An alternative approach of assessing refrigerant or fire fighting media sold for use in the marine industry may provide a useful approximation; however this was outside the scope of the current review.

Table I Summary of Shipping Emission Statistics (in Mtonne/annum)

		Base Year	NO_x	CO	HC	SO_2	CO_2
Worldwide	Endresen *et al*, 2002a	1996/2000	10.8/11.9	1.0/1.1	0.33/0.36(NMVOC)	6.1/6.8	461/501
	Ship & Ocean Foundation, 2001	1997					387
	Skjølsvik *et al*, 2000	1996	10.3	1.0	0.33(NMHC) 0.04(CH_4)	5.8	438
	Corbett *et al*, 1999	1993	10.1			8.5	
	Olivier *et al*,1996	1990	8.6*	0.1	0.02(CH_4)	4.9	350
	Lloyd's Register, 2002	1990	11.3			6.4	
	Bremnes, 1990	1986	5.085			4.58	
European Area							
North Sea/Baltic	Whall *et al*, 2002	2000	1.074		0.039	0.763	41
North Sea	Jerre *et al.*, 1994	1990				0.269	
Southern North sea	CONCAWE, 1994	1992				0.206	
NE Atlantic, Black & Mediterranean Seas	Whall *et al*, 2002	2000	2.543		0.095	1.815	116
NE Atlantic	Lloyd's Register, 1995	1990	1.94	0.17	0.04	1.37	
Baltic sea	Alexandersson *et al* , 1993	1987	0.163			0.084	
Baltic Sea	Lloyd's Register, 1998	1990	0.35	0.03	0.008	0.23	
Mediterranean & Black Sea	Lloyd's Register, 1999	1990	1.73	0.15	0.04	1.25	

* Amended figure, Olivier, 2002

Cargo vapour emissions

Emissions of volatile organic compounds (VOC) from oil and chemical tankers are of increasing concern due to the part they play in the formation of photochemical oxidants. Estimates of global emissions of VOC when handling and transporting crude oil and oil products are in the range of 1.7-1.8 million tonnes per year, equivalent to 0.1-0.15% of all cargo transported (Martens, 1993, Endresen *et al*, 2002a). Higher emission estimates also exist (Telle, 2000). Emissions are generally geographically limited, on account of oil transport taking place within a fairly well defined system of international sea routes and since most of the evaporation takes place during loading.

EMISSIONS TO WATER

Oil

Data for 1990 indicates that approximately 0.56 million tonnes or 24% of the global input of oil into the marine environment was attributable to oil transportation and shipping (Table II). The major anthropogenic flow into the marine environment was from land based sources including refineries, municipal wastes and river run off (Offshore-environment, 2002). Of this, it has been estimated that 70-80% of oil entering the sea from marine transportation is attributable to normal ship operations (Table III); however, this percentage is likely to have changed over time (see later).. It will also be highly dependent upon the occurrence or absence of large oil spills within the period for which the estimate is made.

Table II Inputs of oil to the marine environment, 1990 (Etkin *et al*, 1998)

Source	Tonnes
Municipal/industrial	1,175,000
Transportation	564,000
Atmosphere	305,000
Natural sources	258,500
Offshore production/exploration	47,000
Total	2,350,000

Table III Estimates of oil entering the marine environment from shipping in 1989/90 (IMO, 1990)

Source	Discharge (tonne/year)	Discharge (%)
Operational discharge of oil cargo from tankers		
- Crude oil: Long haul	45 600	8.0
- Crude oil: Short haul	20 300	3.6
- Product oil: Long haul	20 800	3.7
- Product oil: Short haul	71 900	12.6
Subtotal	158 600	27.9
Dry docking	4 000	0.7
Marine terminals (eg. bunker operations)	30 000	5.3
Bilge and fuel oil		
- Machinery space bilges	64 400	11.3
- Fuel oil sludge	186 800	32.9
- Oily ballast from fuel oil tanks	1 400	0.2
Subtotal	252 600	44.4
Accidental spillage		
- Tanker accidents	114 000	20.0
- Non-tanker accidents	7 000	1.2
Subtotal	121 000	21.2
Scrapping of ships	2 600	0.5
Total	568 800	100

Although only 20-30% oil input from shipping into the marine environment is from accidental spills, in terms of public perception, this is the most important pollutant resulting from shipping operations. As a consequence, more information on the level of discharge to the environment tends to be available. For example, The International Tanker Owners Pollution Federation Limited (ITOPF, 2002) makes available a regularly updated database of oil spilled from tankers, combined carriers and barges to the marine environment. This covers all accidental spillages except those resulting from acts of war.

The database contains information on both the spill itself (amount and type of oil spilt, cause and location) and the vessel involved. For historical reasons, spills are categorised by size (<7 tonnes, 7-700 tonnes and >700 tonnes) although the actual amount spilt is also recorded.

Information is gathered from both published sources, such as the shipping press and other specialist publications, and also from vessel owners and insurers. The figures for amount of oil spilt in an incident include all oil lost to the environment, including that which is burnt or remains in a sunken vessel. The Oil Spill Intelligence Report (Cutter, 1996) also provides information on accidental oil pollution from maritime transport.

Table IV Number of spills and total quantity of oil spilt (ITOPF, 2002)

Year	No. of Spills 7-700t	No. of Spills >700t	Quantity of oil spilt (tonne x 10^3)	Year	No. of Spills 7-700t	No. of Spills > 700t	Quantity of oil spilt (tonne x 10^3)
1970	6	29	301	**1985**	29	8	88
1971	18	14	167	**1986**	25	7	19
1972	49	24	311	**1987**	27	10	30
1973	25	32	166	**1988**	11	10	198
1974	91	26	222	**1989**	32	13	178
1975	97	19	342	**1990**	50	13	61
1976	67	25	369	**1991**	27	8	435
1977	65	16	298	**1992**	31	9	162
1978	54	23	395	**1993**	30	11	144
1979	59	34	608	**1994**	27	7	105
1980	51	13	206	**1995**	21	2	9
1981	49	6	44	**1996**	20	3	79
1982	44	3	11	**1997**	27	10	67
1983	52	11	384	**1998**	22	4	10
1984	25	8	28	**1999**	19	5	29
				2000	18	3	12

Data on the quantity of oil entering the marine environment from normal shipping operations is less certain; however advances in estimating the volume of individual operational oil discharges (Koops and Huisman, 2001) should help improve data availability and reliability.

Operational oil pollution tends to be focused on shipping and oil transportation routes. The two largest single sources of oil entering the sea from marine transportation activities are due to operational tanker discharges and discharges of fuel oil sludge and machinery space bilge (Etkin, 1998).

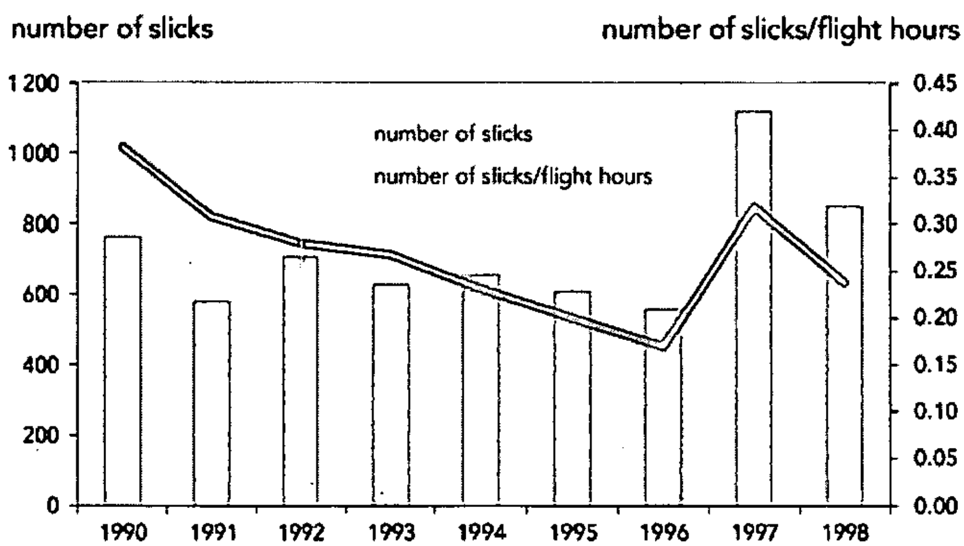

Figure 1: Annual number of oil slicks from illegal discharges observed by aerial surveillance in the North Sea and Baltic Sea (EEA, 2002a)

Improved engine design and international regulations such as MARPOL 73/78 (segregated ballast tanks /double hull tankers, introduction of special areas in which no oil discharges are allowed) have led to declining oil inputs from operational activities. Operational oil pollution is estimated to have fallen from approximately 1.4 to 0.56 million tonnes between 1981 and 1990 (Offshore-environment, 2002). However, the annual number of oil slicks between 1990 and 1998 attributable to illegal discharges in the North and Baltic Seas does not show a consistent decline (Figure 1).

Recent estimates of the volume and number of individual operational oil discharges observed on the Dutch Continental Shelf between 1993-1999 are given by Koops and Huisman (2001).

Antifouling coatings

Antifouling systems are applied to the wetted surface of ships' hulls to prevent fouling. These are generally paints containing one or more biocides which act to kill organisms attempting to settle on the hull. The environmental impact of these coatings generally relates to the biocidal components – primarily tributyl tin (TBT), copper and organic booster biocides such as triazines, although VOC emissions during coating application can also be of significance. Conventional coatings emit biocides constantly, and 80 - 90 percent of these biocides will leach into the sea within 3-5 years. It is estimated that TBT-based antifouling paint is used on 70 percent of the world's fleet (Mayell and Swanson, 1998).

The global input of TBT into the marine environment from the ocean-going merchant fleet is estimated to be in the range of 750-1500 tonne for year 1996, with a leaching rate of 2–4 $\mu g/cm^2$/day and estimated total wetted area of about $148x10^6$ m^2 (Endresen and Sørgård, 1999). The main contributing vessel categories are oil tankers, bulk carriers and general cargo vessels. Isensee *et al* (1994) used a different calculation approach and estimated annual TBT input to 1400-2400 tonnes. However, the input of TBT into the environment should gradually decrease due to adoption of the IMO International Convention for the Control of Harmful Anti-fouling Systems on Ships (IMO, 2002b).

Little data appears to be available on the input of copper and other biocides into the marine environment from antifouling paints. Attention has been focused on TBT. With the phasing out of TBT based paints it will be important to monitor increasing inputs of other biocides into the marine environment from antifouling coatings.

In a similar manner to that proposed for refrigerant gases and fire fighting media, it may be possible to derive an approximation of antifouling/ biocide inputs to the environment from industry statistics on paint sold for marine application and associated biocide content. Such an exercise, however, is outside the scope of this review.

Ballast water

Ballast water is unique amongst the environmental issues associated with shipping in that it is associated with detrimental effects mediated by living organisms. The densities and composition of organisms in ballast water carried by individual vessels are extremely variable and there is no simple relationship between quantity of ballast discharged and environmental impact. The origin of the ballast water, the environmental compatability of uptake and discharge ports and the interaction of organisms discharged with native species are also of key importance in assessing the risk of establishment of non native organisms translocated in ballast water. Risk tolls for estimating potential risk for introducing alien species have been recently developed (Behrens and Haugom, 2001; IMO, 2002c).

For commercial reasons, vessels will strive to operate with maximum cargo and minimum ballast at all times. Ballast water capacity varies as a function of cargo carrying capacity and ship type with typical values ranging from 25 - 40% of the dead weight tonnage (Carlton *et al*, 1990; Carlton *et al*, 1995; Hay *et al*, 1997; Endresen *et al*, 2002b). However, the capacity is normally only partially utilised. Assuming ballast water carried on average amounts to 30% of annual cargo transport, global ballast water transfer quantities are estimated to be approximately $2.7x10^9$tonnes (Endresen *et al*, 2002b). Published estimates of annual global ballast water volume of $10x10^9$tonnes are likely to be too high, since this figure exceeds the cargo volume transported by the merchant fleet (Endresen *et al*, 2002b).
The majority of ballast water discharge is geographically limited due to the well defined system of international sea routes. Information on estimated quantities of ballast discharged nationally and worldwide is presented in Table V. Information is also available on typical quantities of ballast discharged by the various ship types (eg. Hay *et al*, 1997; Carlton *et al*, 1990). Additional information may be found in Endresen *et al*, 2002b. Variation between the estimates may be attributable to the use of different base years, calculation methodologies and fleet segments.

Table V Ballast water discharge statistics

	Volume discharged (10^6 tonnes/annum)	Reference
USA	79	Carlton *et al.*, 1995
	101	Endresen *et al.*, 2002b
Australia	66	Australian Bureau of Statistics, 1986-87
	58	Jones, 1991
	98	Endresen *et al*, 2002b
New Zealand	3.7 – 5.0	Hay *et al*, 1997
Netherlands	7.5*	Gotje *et al*, 1998
	26	Endresen *et al*, 2002b
Worldwide	3,000-5,000	IMO, 2002d
	2,700	Endresen *et al*, 2002b

* Stated to represent 42% ballast water discharged in Europe

WASTE STREAMS

Quantification of ship generated wastes – sewage, grey water and garbage – is reasonably well covered. Figures are available from several sources on wastes generated per person per day for the various ship types (Norwegian Environmental Department, 1994; Schnitler, 1995; EMARC, 1999).

Table VI Total quantities of waste generated annually by shipping in Europe (EMARC, 1999)

	Oily wastes* ($m^3 \times 10^6$)	Sewage ($m^3 \times 10^3$)	Garbage (tonne x 10^3)
Eastern Mediterranean	0.04	916	12
Iberian Peninsula	4.73	3437	44
Northern Europe	8.00	4141	51
Southern Europe	4.94	9300	112
Scandinavia	1.37	4887	61
UK/Eire	3.52	3667	45
Total	22.6	26348	325

* includes oily bilge water, oily residues resulting from purification of fuel and lubricating oil, deteriorated or contaminated oils and oil cargo residues

Waste factors in combination with time spent at sea, ship size and type, and crew and passenger numbers have been used to derive annual figures for waste production by shipping on a regional basis (Table VI). Some information is also available on the amounts of washing agents, biological oxygen demand (BOD) and nitrogen and phosphorus nutrients discharged in sewage and/or grey water in the Baltic Sea (Swedish Shipowners' Association, 1995).

Although some wastes will be discharged directly to the marine environment, particularly outside of coastal or various "special areas", some wastes will be actively managed. Oily wastes, sewage and garbage may, for example be discharged to reception facilities ashore, treated prior to discharge or incinerated. Grey water is exceptional in that its discharge is not restricted by international law and it is most commonly discharged directly to the environment.

CONCLUDING REMARKS

The aforegoing review represents the first emissions and discharge inventory for ships in service. Information on the level of emissions and discharges is variable. More comprehensive information tends to be available in areas in which there is a high level of public interest. Hence the relatively good information on oil spills and, more recently, engine exhaust emissions. Ironically, data on oil entering the marine environment fromnormal shipping operations – widely believed to be the dominant input - appears poorly documented in comparison.

For other components, limited data on environmental inputs is available. This is particularly so in the case of antifouling coatings. With international regulations set to restrict the use of TBT antifouling coatings, it will be important to monitor declining TBT input alongside a probable increase in alternative biocide components.

A complete inventory of key emissions and discharges to the environment is essential to gain a realistic insight into the impact of shipping on the environment. If we are not aware of baseline levels, neither the relative performance of shipping versus other modes of transport, nor progress toward reducing the environmental impact of shipping can be assessed.

Developing a complete inventory is likely to be a considerable task. Periodic updating once methodologies are established should be somewhat easier. It is strongly recommended that consideration be given to initiation of a ship emission/discharge inventory project at an early date. The EC CORINAIR programme (EEA, 2002), which established an inventory of emissions of air pollutants in Europe and has led to regular undertaking of atmospheric emissions inventories, may well be a suitable model for such a project.

ACKNOWLEDGEMENTS

This work was carried out within the TRESHIP (Technologies for Reduced Environmental Impact from Ships) thematic network, under contract to DG-XII of the European Commission. The contribution of the network participants to the work reported herein is gratefully acknowledged.

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Integrating environmental performance in a logistic approach to short sea shipping – a case study

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SYNOPSIS

Transport by road is the most dominant mode of transportation in Europe today. An increased use of short sea shipping can balance the European transport system and contribute to a better environmental situation. The aim of this study is to identify and explore some characteristics of short sea shipping and to find general logistic weaknesses in the concept. By using a total logistic management approach, this study shows how short sea shipping is a competitive option with high environmental performance.

We present a comparative study between different modes of transportation. A fictitious case of transportation of cargo between the Lake Vänern area in Sweden and Duisburg in Germany is set up and evaluated. The intermodal network between these two regions includes road, rail and shipping. The logistic quality of the total transport chain is measured as a weighted sum of performance parameters such as transport time, transport cost, frequency and flexibility, reliability, logistic management and service, environmental impact and political acceptability.

The scope of the study is narrow, but by employing systems engineering techniques, interesting conclusions regarding a strengthened role of short sea shipping in a future European transport system has been made possible.

INTRODUCTION

A precondition for this work consists in a greater importance of ships in the future European transport system. This assumption relies on the benefits of scales in shipping, their positive impact on congestion and their environmental benefits compared to road transport. The study is incorporating environmental aspects as a logistic parameter.

The logistic service is complex and consists of several parts, both physical and non-physical, which in the following will be referred to as performance parameters. For the outline of this study seven parameters were considered most important and were included in the analysis. Through interviews different system stakeholders were invited to give their opinion on the weight of each respective parameter as input to a trade-off analysis. In a case study, different transport concepts were then evaluated against the preferences stated by the stakeholders. The weaknesses and strengths of each concept are visible, and the concepts can after this analysis be refined for improved performance.

The models for evaluation of the transport system are taken from the systems engineering discipline. Difficulties arise when assessing and comparing qualitative performance parameters. The methods used are found in literature but have been slightly modified to suit the purpose and scope of this study.

Daniels, Werner et al., 2001 shows a useful method for trade-off analyses. Measures of Effectiveness (MoE) are quantifiable measures that help describe how stakeholders value important system characteristics. (Sproles 2000) They are solution independent and derived from stakeholder requirements. The absolute numbers of the MoEs (e.g. engine effect as expressed in kW) are denoted figures of merit (FoM) and are unique for each candidate solution. These are translated to normalised values, normally in the range 0-1. FoMs of different character can thereafter be evaluated against each other. The normalised value shall be multiplied by a normalised qualitative weight assigned by the system stakeholder on different performance parameters in the same product (e.g. acceleration vs. fuel consumption). The trade-off analysis then helps in designing the system according to the wishes of the customers. (Daniels, Werner et al. 2001) In this study the MoEs are referred to as logistic performance parameters.

The methodology is validated in a case study relying on an existing market need between Sweden to Germany.

FRAME OF REFERENCE

A model of the logistic network used is brought forward and explained. The performance parameters are introduced and defined and finally the hypothesis is presented.

Model of the logistic system

To put the system under study and the following discussion in its context we propose a model of the logistic situation encompassing it. Systems on different hierarchical levels pose constraints and offer possibilities for the transport solutions that we are suggesting. The *infrastructure system* consists of roads, railroads and rivers, canals, locks and ports. This system is assumed to be existent without change. The *transport system* includes the different modes of transportation and will apart from the shipping activities remain without changes. The transport market is therefore only marginally influenced by our system. Focus will instead be on the *material flow systems*, where the functional decisions concerning planning and design are made. (Rohani 2000) The political framework will not be seen as a dynamic factor.

The network in which goods and information flow, can be seen as an interconnected system of nodes and links, where the nodes are terminals and the links are transport relations. Most transport chains involve node handling; this is specifically true for transport by rail and ships where reloading activities in port or station are necessary. Intermodal connections are in this respect more complex than a direct truck relation. In the following definition, the difficulties that are connected with intermodal transport are pronounced;

> *Intermodal transportation can be thought of as a process for transporting freight and passengers by means of a system of interconnected networks, involving various combinations of modes of transportation, in which all of the components are seamlessly linked and efficiently combined. (Jones, C. Richard Cassady et al.)*

The interfaces have to be carefully managed to provide a seamless chain and a high logistic efficiency.

Defining logistic performance

To make a comparison of different logistic services a balanced set of parameters reflecting different aspects of the total performance of that service has to be defined. In many comparative logistic studies, only one parameter is evaluated such as cost or transport time. (Beuthe, Jourquin et al. 2001), (Hagman 1998) A one-dimensional analysis can comprehensively examine this particular aspect but does not reflect the complex assessment a cargo owner has to make to choose logistic arrangement.

The seven parameters chosen for this study are believed to give a representative picture of how quality aware companies assess and chose their transports. The parameters are logistic management and service, transport time, frequency and flexibility, reliability, price of transport, political acceptance and environmental impact. For the definition and selection of the parameters there are mainly two references that have been used as support; (Lumsden 1998), (Wijnolst, Hoeven van der et al. 1993).

The characteristics of each performance parameter will be described and a suitable figure of merit will be suggested.

Logistic management and service

Logistic management and service is defined as the ability to conduct and communicate a smooth service integrating transport, information and administration.

This parameter embraces many of the non-material elements of the transport assignment. The more complex a task is the more essential is the management and service facilitating it. In an intermodal arrangement with many interfaces this dimension increases in importance. The development of overall services is enhanced by the growing use of information technology and EDI between the interacting parties.

This dimension is to a greater extent depending on organizational policy and computerization than on the rough outlines of the transport solution. Therefore, no FoM was established and the parameter was excluded from the trade-off analysis.

Transport time

Transport time is defined as the time for transport from warehouse/factory to arrival at buyer's facility. Other examples of definitions can be found in literature, Korpela and Tuominen uses the total order lead time as time measure. (Korpela and Tuominen 1996)

The FoM for transport time will be the time from source to sink, including both links and nodes, expressed in hours.

Frequency and flexibility

The definition used states frequency as the number of departures per unit time and flexibility as the ability to adjust to changes in incoming flow and size, composition etc.

Both rail and ship uses economies of scale to bear the high investments costs. This generally has a negative impact on frequency, or has to be compensated by large goods flows to keep the frequency at a satisfactory level. A low frequency increases the average time in the nodes due to long waiting hours for departure.

The connection between frequency and flexibility is based on the ability to adjust frequency to changes in incoming flow, size and composition.

No absolute measure of frequency has been defined. Instead a comparative figure based on the largest shipment size is used, assuming that the other concepts will have a frequency inversely proportional to the decrease in shipment size. The FoM for frequency and flexibility will thus be a measure of load capacity.

Reliability
Reliability in the sense of a logistic parameter is defined as the ability to provide the goods undamaged and in accordance with the agreed time schedule.

Reliability is a dimension that has increased in importance during the last two decades as a consequence of the just in time concept and the low stock levels in lean production. (Lumsden 1998)

The FoM have been taken from a statistical study of quality requirements that affect shippers' freight choices in the Nordic countries. Intermodal solutions were compared to single modal solutions. (Ludvigsen 1999)

Price
Price is traditionally considered the most important decision parameter when choosing transport arrangement, but has during the last 15 years diminished in favor for other qualities such as reliability and frequency (Lumsden 1998). One reason could be the increasing interest in monetary assessment of intangible costs of other factors such as reliability and environmental impact. For many types of goods this is still the conclusive factor especially bulk products and raw materials (EUROPEAN-COMMISSION 1996).

The financial context of the transportation modes differs in several aspects. Basically the ship and the rail alternative have high investment costs and low cost per kilometre travelled, while for the truck it is the opposite way. The infrastructural costs differ between the modes in the sense that the shipping sector carries its own costs to a greater extent than do the rail- and truck sectors. These costs also differ notably between countries.

When intermodal transport solutions include either transport by rail or by ship, reloading terminals is a must. The total cost consists of three principal cost types for intermodal solutions;

- "Distribution costs" - they are the costs associated with transport of goods to and from the terminals of departure and arrival respectively
- Handling costs in the "nodes".
- Cost for transport in the main transport leg.

For the direct transport with truck neither handling costs between transport legs nor distribution costs are relevant.

To be competitive with the truck and rail transport, the total costs of the shipping alternative have to be less than the price paid for the equivalent service on road or rail, and still contain profit margin for the ship owner. Reduction in costs are accomplished by high fill rates in the main leg, efficient handling equipment in nodes and the scope is set by the possible reach of the distribution leg.

In this study ship design is focused. Therefore the FoM of the price parameter differ between the transport modes in this study. For the land transports the FoM is the assessed price while for shipping it is the calculated costs.

Political acceptance
When a customer is to establish a new logistic arrangement an important decision factor is the future political direction e.g. if new dues and taxes are to expect or if the infrastructure is likely to be affected. This dimension can be summarized as political acceptance, expressing the compliance between the cargo owner's decision and the political will and approaching acts.

In this study the external costs of the transport has been chosen to serve as a figure of merit for political acceptance. These are the costs that are imposed on the society by the different transport sectors and the cost figures used are taken from a study by INFRAS/IWW that were used in the EU white paper on European transport policy (EUROPEAN-COMMISSION 2001). These figures include external costs from congestion, accidents and environmental impact.

Environmental impact
Environmental impact is defined as a change in the state or prospects for a natural, social or technical system. This impact will then contribute to a change in an observable variable, such as the number of species present in a habitat or the yearly increase of growing stock or cancer mortality per 1000 habitants. These changes can be denoted environmental effects.

Environmental impact from the transport sector has been identified and discussed in several earlier assessment studies and not at least Life Cycle Inventories (LCI) and Life Cycle Assessments (LCA). (Blinge, Arnäs et al. 1997; Magerholm Fet, Michelsen et al. 2000) It has often been shown that the consumption and combustion of fuel and the subsequent emissions are clearly dominant as contributor to environmental degradation.

In a future European transport system, environmental issues will be more in focus according to several reports from the European commission (EUROPEAN-COMMISSION 2001; EUROPEAN-COMMISSION 2002). The value of environmental assets is a delicate issue. We have chosen an evaluation method commonly used in life cycle assessments to address values to damages to ecosystems, human health and resources. The method is called Eco-indicator-99, the resulting one-dimensional value from the weighting procedure is used as FoM (Bengtsson 2000). Only emissions from fuel combustion are regarded in the weighting.

Interconnections between parameters

Several interconnections exist between the parameters. An example is how short lead time can have negative influence on cost, environment and sometimes even reliability as the time margins shrinks. On the other hand it may promote flexibility, if the planning horizon also can be shortened. The relation between environmental impact and political acceptance is another example of this.

In this study no thorough analysis on this matter has been conducted. The issue of defining an aggregated measure has been addressed in a. o. (Korpela and Tuominen 1996), (Ludvigsen 1999) and (Wijnolst 1993).

Hypothesis

An increased use of short sea shipping can balance the European transport system and contribute to a better environmental situation. The competitiveness of short sea shipping is dependent upon improved logistic efficiency including high environmental performance.

CASE

The case study consists of a comparison between short sea shipping transport and transport by road and rail. The transport departs from the area surrounding the lake Vänern in Sweden for Duisburg and the Ruhr area in Germany. The Väner area is an important supplier of grain and forest products. The three counties surrounding Lake Vänern accounts for 22% of the Swedish GNP. The Ruhr area is one of Europe's most densely populated and industrialized areas. The federal state Nord Rhein Westfahlen accounts for more than a fifth of the German GNP.

This route is chosen because it pronounces interesting ship design problems. The channel from Vänern to Gothenburg contains seven locks allowing the maximum dimension of length 88.0m and beam 13.2m. The passage between Gothenburg and Rotterdam goes in open water and the river Rhine has a very fluctuating water level with a median level of 4.25m. This implies that a ship built for this trip will be restrained in all dimensions but still operate safely in open water.

Altogether five different transport concepts were evaluated.

Logistic concepts

The first concept is the one most straightforward; direct truck from source to sink. The truck used is a Euro 1 long haul truck carrying a 20.4ton container. EC3 (Environmental Class 3) diesel is used. These presumptions are based on information from Schenker BTL (Schenker-BTL).

The second concept is an intermodal truck-ship-truck transport. A Euro 1 truck carrying 20.4 ton performs the short distance truck legs. In Sweden the fuel is EC1 diesel and in Europe EC3. A ship with main dimensions to fit the locks in Trollhätte channel performs the main leg. The draught, 5.85m, only rarely allows passage through Rhine, therefore the goods is unloaded in Rotterdam and further transported by truck.

The third concept is substantially the same as the foregoing, with the exception that the ship is modified for shallow water. The draught, 3.6m, is a compromise between load capacity and navigability in Rhine and statistically permits passage to Duisburg 237 days per year. The remaining part of the year it will have to unload in Rotterdam and continue with truck from there to the end destination. The distribution from the port of Duisburg is conducted with Euro 1 truck.

The fourth concept is a further modification of the ship. The draught is 2.55m, allowing passage in Rhine on average 353 days a year. It is assumed to be operating the route on a regular basis all through the year. A Euro 1 truck carrying 20.4 ton performs the short distance truck legs.

The fifth concept consists of intermodal rail and truck transport. It is assumed that rail is used between Karlstad and Duisburg passing through Denmark. A Euro 1 truck carrying 20.4 ton performs the short distance truck legs.

Cargo

In the study containerised goods have been in focus. The container has an intermodal interface and can be handled with standardised equipment.

The goods flow is assumed to be sufficient to operate three ships on the route allowing departures every second day. The optimal frequency for the main leg was set to one daily departure.

The return flow is not considered in this study. Due to trade unbalances an overcapacity in the return flow can be assumed and will affect the over all efficiency of the system.

Evaluation method

First an evaluation base is established; cargo owners from the Väner area gave their judgment on the performance parameters listed above. Ship owners and transport companies made the same assessment, but in the aspect of how they experience the values of their customers' requirements. In total, representatives from six companies took part in the study. The parameters were assigned a value from one to ten, ten being the highest score. The resulting weights were then normalised.

The FoMs for the different concepts were calculated as described under *defining logistic performance.* The quantitative values were then transformed according to a linear function delimited in the upper bound to the value of the best performing concept and in the lower bound to zero. This transformation scaled the FoMs to a range between 1 and 0, 1 being the highest score.

These comparative numbers are then multiplied with the weighting factors and a total performance measure for each concept is obtained.

Results

The weightings assigned to the logistic parameters by the system stakeholders are presented in Table I. Due to the number of participators in the survey the values are not statistically supported but can be seen as a rough indicator of the customers' requirements.

WEIGHT / PARAMETERS	*Transporter A*	*Transporter B*	*Transporter C*	*Customer 1*	*Customer 2*	*Customer 3*	*Average*	***Normalised weight***
Transport time	1	5	8	10	1	10	5,8	**0,14**
Frequency and flexibility	6	6	10	10	2	10	7,3	**0,18**
Reliability	10	9	9	10	9	9	9,3	**0,23**
Price	8	10	8	7	10	8	8,5	**0,21**
Political acceptance	3	-	10	0	3	8	4,8	**0,12**
Environmental impact	4	4	9	0	7	9	5,5	**0,13**
								1,00

Table I Stakeholders' judgments on performance parameters and the resulting normalised weight

The normalised weights were transferred into the concept evaluation matrix Table II.

MODE / PARAMETERS	*Truck*	*Ship 5,8*	*Ship 3,6*	*Ship 2,5*	*Rail*	*Normalizied weight*
Transport time	1,00	0,42	0,39	0,37	0,31	0,14
Frequency and flexibility	1,00	0,43	0,57	0,86	1,00	0,18
Reliability	1,00	0,93	0,93	0,93	0,93	0,23
Price	0,38	0,90	0,89	1,00	0,41	0,21
Political acceptance	0,32	0,72	0,89	1,00	0,91	0,12
Environmental impact	0,45	0,79	0,62	0,50	1,00	0,13
Total	**0,72**	**0,72**	**0,74**	**0,80**	**0,76**	

Table II Total concept evaluation according to the weighted figures of merit

According to the stakeholders' evaluations of the parameters, no dimension is distinctly most important.

The results show that the most suitable transport service for the route investigated is the intermodal ship concept using the smallest ship.

It is also clear that the difference in total performance is small among the different concepts. Individual parameters on the other hand show great variation between the concepts.

DISCUSSION

The trends in Europe point towards more regulations on environmentally degrading activities and regulations to avoid road congestion. If these parameters would receive a higher importance score from customers, the balance between the transport modes will be shifted towards rail and shipping.

The results imply that truck transport is the least favourable of the transport modes. This is not in accordance with the transport situation today in Europe. This discrepancy can be attributed to the fact that the parameters political acceptance and environmental impact are not as highly valued in reality as was stated by the interviewees. An extension of the model to include capital costs for the goods would further promote concepts with a short transport time.

The same weighting factors are used regardless of goods type. Depending on goods value, the cargo owners have different priorities for the logistic service. To obtain a higher precision in an analysis like this, a variation between different customer groups might be required.

As far as possible computational models and input data established in the branch are used. For the qualitative performance parameters environmental impact, reliability, flexibility and political acceptance, the evaluation basis is subject to preferences and needs further support among expertise and stakeholders to the system.

In a continuation the best performing concept should be further refined to identify additional opportunities to strengthen its competitive ability. Compared to truck transport the concepts employing rail and ships have environmental benefits. Shipping still has opportunities to efficiently improve its environmental performance

CONCLUDING REMARKS

The total performance differs only slightly between the concepts but can vary significantly for each parameter. This shows that the concepts have very different characteristics but still attain the same level of service.

The results pronounce the value of systems thinking in logistic services. The effectiveness should be measured in several dimensions on the basis of the whole transport chain. The concept using the largest ship shows an example of how sub optimisation can damage the system performance. The ship is optimised according to economies of scale resulting in long hinterland truck transport with subsequent high cost and environmental impact.

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Responding to top-down pressure for environmental integration and mainstreaming in marine-related projects.

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Future States

SYNOPSIS

Environmental integration and mainstreaming is the process that ensures consideration of environmental sustainability in development projects. The agenda for promoting environmental sustainability has been firmly set at the local, regional and national level through a variety of conventions and legislation. This top-down pressure has seen widespread institutional uptake. For example, all major international aid agencies are attempting to embed such "green accountability" into their activities. This is demonstrated by the World Bank in which all projects from all sectors, not just environment, are now environmentally mainstreamed – this has increased bank funding in the core and allied environment sector from <1US$b in 1990 to >16US$b in 2000. Besides the aid arena, environmental integration and mainstreaming is becoming institutionalised. Following on from the Cologne Report on Environmental Integration, the European Community has developed guidelines on environmental integration which link into policy, programming and project cycles. In addition, they identify a set of tools, which can be used to support environmental integration, the specialist sectors of which include shipping, fisheries and ports and harbours. For the business sector active in the marine environment, this top-down pressure for uptake of environmental integration and mainstreaming is coupled with the commercial pressure for business excellence. It has recently been suggested that environmental sustainability should be addressed as a core competence within the strategic learning architecture of any firm with aspirations of excellence. In response to a growing need for practical mainstreaming good practice, Future States Ltd. and the Centre for Coastal Management have worked together to attempt to provide the framework of a practical tool kit for the management of environmental integration and mainstreaming for marine-related activities.

INTRODUCTION

A plethora of efforts and initiatives have been advanced over the last few decades to try to improve the state of the environment. However, the early approaches to this pro-environmental agenda tended to be issue-specific and largely fragmented. More recently the environmental agenda has changed considerably, possibly initiated by the Rio Summit and the associated signing by many global states of Agenda 21 in 1992. The broadening of scope encompassed in Agenda 21, and other sequential union, state or regional and local initiatives, has manifested itself in a new wave of approaches towards improvement of the environment. Many of these approaches to this extending agenda are robust in themselves, however, overall they generally only address certain aspects and the links between such sectoral approaches are commonly not evident in the documentation. This paper uses a strategic approach to attempt to draw together many of these approaches to environmental improvement and provide a framework for meeting the contemporary agenda.

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THE ENVIRONMENT AND SUSTAINABILITY

Riding on the wave of environmentalism over the last 10 years, many products have identified themselves as "environmental", ranging from recycled toilet paper and pollution-free washing powder, to lead-free petrol and hydroelectric and wind power. Such products were endorsed by the increasingingly aware public and championed by commercial companies as well as governments. However, the wider societal benefits might be questionable. For example, was the UK governments tax support for lead-free fuel maintaining the environmentally damaging car culture? Was the removal of livelihoods and displacement of many indigenous or local people in large hydroelectric power schemes socially acceptable?

Agenda 21, and other following initiatives, encapsulated the concept of sustainability. This remit was wider than the previous environmental initiatives, for two reasons:

1. The inclusion of not just environmental considerations, but also social and economic aspects.
2. The planning horizon into which sustainability fits is conceptually infinite.

Consequently, this broadening of the agenda moved the attention away from solely the "green" product but to a "greening" of the wider process. However, most activities taking place in society, be they from those in commercial factories to organisations involved in governance, also have processes associated with them. To fit the Agenda 21 remit, the processes of all activities, not just those directly associated with "green" products, have to be carried out in a sustainable way.

ENVIRONMENTAL MAINSTREAMING

Environmental mainstreaming is a tool that can be used to help "green" the array of processes occurring in society. A working definition of environmental mainstreaming is that it is a tool that ensures the consideration of environmental sustainability in "non-core" environmental activities. "Non-core" activities represent the full portfolio of activities of an organisation, except for those sub-projects that holistically and specifically endorse environmental sustainability in terms of both process and output. Consequently, most projects are non-core because they are either producing something that is not intrinsically -environmentally sustainable , or the process is not within environmental best practice.

However, something like building of an offshore wind turbine in an EMS/ISO14001 audited factory which included upstream controls and lifecycle aspects, and an EIA of final siting of turbine would be a "core" environmental project, because both product (wind turbine) and process (making of it) have full environmental consideration.

Recently, many organisations have taken on environmental mainstreaming as an overarching and strategic tool for the promotion of environmental sustainability. For example, the World Bank now mainstreams all projects from all sectors, not solely the environmental sector (Acharaya, 2000; Acharya & Abuyuan, 2001). The World Bank recognises not only its core portfolio of stand-alone environmental projects, amounting to $5.1 billion in 2001, but also its "broad" portfolio of projects with environmental components in the areas of agriculture, electric power and energy, urban development and water supply and sanitation. Total lending, for core and environmentally mainstreamed broad projects was estimated to amount to $18 billion in 2001. At present there are few indicators that can be used to measure the success of this mainstreaming, however the World Bank are presently developing systems for environmental mainstreaming to permit them to utilise an environmental mainstreaming scorecard for development projects. As part of this process there is an institutional realignment taking place and cross-sectoral environmental skill training taking place of non-environmental specialist staff (Anon, 2002).

Other organisations are also in the early stages of mainstreaming. For example the UNDP (United Nations Development Program) has reported to the GEF Council (Global Environmental Fund) about environmental mainstreaming. The UNDP has a Programming Manual for project development and Country Program Outlines have been modified to ensure environmental mainstreaming. The UNDP presents the central objective of environmental mainstreaming as "the building of capacity and awareness within the programme countries necessary for them to independently pursue policies that are representative of the needs of their citizens while being responsible for the global environmental shared by all" (UNDP, 1998).

The European Union (EU), as an OECD/DAC member, has adopted International Development Targets, one of which states that "there should be a national strategy for sustainable development in the process of implementation, in every country by 2005, so as to ensure that current trends in the loss of environmental resources are effectively reversed at both the global and national levels by 2015" (EU, 1999). The EU has produced the "Cologne Report on Environmental Integration: mainstreaming environmental policy" as a working paper which was endorsed by the EU (SEC {99}777). As part of the process of ensuring early integration of the environment in the project cycle it has developed a manual for

Environmental Integration, which is expected to be finished in 2003 (EU, 2002a). Within this manual it identifies three cycles within the EU: policy making, programming and project cycles. The policy cycle operates at the level of the EU, whereas the programming cycle is national or regional and the project cycle focuses on environmental management of specific projects. A number of specialist sectors were addressed in the Environmental Integration report including shipping, fisheries and ports and harbours.

IMPLEMENTATION OF ENVIRONMENTAL MAINSTREAMING

Although there appears to be considerable top-down pressure for environmental integration, methods for carrying out and implementing environmental mainstreaming remain scarce to date. Implementation will partly depend on the continual top-down pressures for environmental mainstreaming and a developing bottom-up recognition of its intrinsic value (Fig. 1.).

ETHICAL STANCE

		Legal minimum	Ideological
DRIVERS OF STRATEGY	Internal managers	**Secretive**	**Evangelical**
	External stakeholders	**Regulations and procedures**	**Political**

Fig. 1. The relationship between the drivers of strategy and the process of implementation (adapted from Johnson & Scholes, 1999).

Whatever the strategic drivers for environmental mainstreaming, there already exists a number of tools available for organisations to aid environmental mainstreaming.

- Strategic Environmental Assessment is the systematic process for evaluating the environmental impacts of proposed policies, plans and programmes.
- Environmental Impact Assessment is the systematic evaluation of the potential adverse and beneficial environmental effects of a proposed development or activity.
- Environmental Audit aims to monitor environmental impacts, through a multidisciplinary process of objectively reviewing an operating company policies and practice. The practice would include processes such as, material storage, operating procedures, energy conservation and so on.
- Environmental Management Systems (e.g. EMAS [though not strictly speaking an EMS], ISO14001) ensures effective and ongoing implementation of an environmental management plan with procedures, and compliance with environmental objectives and targets of improvement.
- Environmental Management Plans are a planning tool at the regional, national, local, or sector-specific scale that give clear guidelines on strategic and policy environmental issues.
- Environmental Risk Assessment is an objective and scientific process of identifying and evaluating the adverse risks associated with a hazardous substance, activity, lifestyle or natural phenomena that may detrimentally affect the environment and/or human health.
- Life Cycle Assessment is for assessing the environmental aspects and potential environmental impacts associated with a product, processes or activity and identifying opportunities for environmental improvement.
- Green Accounting is a way of measuring the environmental performance of an organisation in economic terms.

Environmental mainstreaming requires selection and execution of the tools in this toolbox in a strategic and informed way at the policy, programming and project cycles. An environmental mainstreaming toolbox matrix, related to the policy, programming and project cycle is shown in Fig. 2. This matrix displays the tools appropriate for the various levels of environmental mainstreaming from policy down to project.

It can be seen that different tools are appropriate for mainstreaming at different levels, and awareness of this provides the ability for organisations to select appropriate tools for mainstreaming. Taking a theoretical example of a port and harbour complex sited in an estuary the potential set of tools to mainstream the harbour complex can be identified. At the highest level (policy) environmental mainstreaming assesses the activities and environmental impacts of the national and/or regional policy on activities within ports and harbours, such as a policy of commercial development and expansion. An appropriate tool for such an assessment is Strategic Environmental Assessment. At the more local estuary scale, the governing body (e.g. the Port Authority or the Harbour commission) should environmentally mainstream all activities within the estuary using tools such as Environmental Impact Assessment, Environmental Management Systems and Environment Management Plans. Within the estuary a number of enterprises, be they oil refineries or coastal tourist activities, should environmentally mainstream using tools such as Green Accounting, Environmental Audit and Environmental Impact Assessment. At the within-organisation project scale, Environmental Impact assessment, Environmental Risk Assessment and Lifecycle Accounting could be used.

MAINSTREAMING LEVEL	MANAGEMENT PROCESS	SCOPE	ENVIRONMENTAL TOOL							
			SEA	EMS	EMP	GA	EA	EIA	ERA	LCA
POLICY	Governance	*National/International*	4							
PROGRAMME	Strategic	*Local*	4	4	4					
PROJECT	Operational	*Organisational*				4	4	4		
		Project based						4	4	4

Abbreviation	Full title
SEA	Strategic Environmental Assessment
EMS	Environmental Management System
EMP	Environmental Management Plan
GA	Green Accounting
EA	Environmental Audit
EIA	Environmental Impact Assessment
ERA	Environmental Risk Assessment
LCA	Life Cycle Assessment

Fig. 2. Environmental mainstreaming toolbox matrix for selection of environmental mainstreaming tools for the policy, programme and project level.

The vertical hierarchy implicit in such an approach provides an opportunity for policy to be linked to strategy and then down through to operations. However, in addition to the implicit vertical hierarchy, processes ensuring horizontal integration are required. In light of the need for cooperation and communication between users of the coastal zone, many coastal areas have developed such voluntary and innovative partnerships (e.g. The Forth Coastal Forum, The Norfolk Coastal Partnership). In some areas partnerships have been explicitly developed for the purposes of achievement of Agenda 21. For example, the Partnership Local Action Network in Ireland is formed from 38 Partnership companies, each with an integrated area action plan, but together they also take on a more strategic role in local and regional development. A recent report entitled "Mainstreaming for Sustainable Development" highlights the need for suitable mechanisms to assist in mainstreaming successful processes and actions (Leogue, 2000).

RESPONSIBILITIES FOR ENVIRONMENTAL MAINSTREAMING

The responsibility for achieving the goals set out in Agenda 21 for sustainable development rests with the state policy and governance organisations of the signatory states. Further top-down pressure is provided through various EU policies and directives such as the Cologne Report mainstreaming environmental policy (SEC {99}777) and the implementation of Integrated Coastal Zone Management in Europe recommendation (EU, 2002b). Such top-down pressure is unlikely to achieve the wide scale requirements of the sustainability agenda as most activities take place at the operational and project level where such top-down pressures fail to affect changes in practice. However, recent work has suggested that there could be a commercially beneficial side to environmental mainstreaming.

Ferrone (2001) argues that enduringly successful commercial organisations will be those that begin as early as possible to define and embody in their activities a unique competitive advantage. The development of such strategic assets and consequent corporate architecture leads to the development of core competencies (sensu Prahalad & Hamel, 1990). It is only through the development of core competencies that permit a commercial organisation to survive in the competitive commercial world. Ferrone (2001) suggests that the environment can be used by a company as a core competence, to maintain its place in the market. Further work by the WWF (WWF-UK, 2001) has shown that the environment and sustainability can be used as a source of competitive advantage and reports on links between environmental performance and business performance (e.g. Volkswagen). Furthermore it provides a route map for managers to build a business case around sustainable strategies. It is suggested that there is potential for innovative and flexible companies to achieve defendable success in the commercial world, through following a strong sustainability agenda. Developing robust environmental mainstreaming activity is an initial item on that agenda.

CONCLUDING COMMENTS

Following a path of sustainability requires both core and non-core environmental considerations to be made. Clearly, strategic change is occurring in many organisations to advance sustainability through environmental mainstreaming. Much as the necessity for the approach is apparent, implementation is problematic. A matrix for selection of a variety of tools for environmental mainstreaming has been presented which provides a framework for mainstreaming, from high-level policy down to operational activities. However, this does require facilitation of the vertical, and probably more especially, the horizontal linkages for a holistic and effective approach. The development of such vertical and horizontal partnerships is not without precedent. It has also been shown that environmental mainstreaming could be built into innovative commercial organisations, to separate them from competitors in the market place. Although environmental mainstreaming is a relatively new collective toolbox for a range of existing tools, recognising its vertical architecture provides a coherent framework for developing both "green products" but also "green processes".

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A tool for deciphering user conflicts in the coastal zone.

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SYNOPSIS

The coastal zone often becomes a zone of conflict with multiple users competing for limited space and resources. A Department for International Development, UK Government funded project Integrated Coastal Zone Management and Training (ICZOMAT) has been seeking to investigate ways in which officers from different Government departments in India spanning the natural, social and economic realms can come together to attempt integrated coastal management. Capacity building is one tool that can lead to an increase in the awareness of stakeholders perceptions by coastal managers. However, much training in ICM is focussed on increasing scientific knowledge, rather than providing a robust framework for management. This paper describes a more holistic approach, encompassing not just science, but socio-economic and governance issues. In addition, the capacity building has been led through a "virtual scenario" case study approach. An ICM matrix is used to provide a framework for understanding the coast and the impact of management interventions. However, it can also provide a model for the conflicts of interventions on stakeholder groups. This "virtual scenario" approach coupled to experience of conflict reduction matrices has been shown to provide coastal managers with a wider appreciation of stakeholder conflict in the coastal zone.

INTRODUCTION

Concepts of coastal management first appeared in the early 1970s in the United States, initially as a framework of *coastal zone management* (CZM). They were initially designed for environmental protection, to avoid development mistakes and to mitigate against misuse and over-exploitation of coastal resources[1,2]. By the 1990s, CZM had evolved into *integrated coastal management* (ICM), conceived as a holistic management tool working across sectoral, disciplinary and institutional boundaries[1,2,3,4,5,6,7]. The goal of ICM is to promote economically efficient and sustainable uses of costal resources that balance conflicting resource demands of stakeholders. It has been recognised, however, that in practice ICM has failed to live up to its holistic ambitions[1,8]. Subsequent projects and policy approaches have tended to reflect the particular interests of the particular proponents of the analysis.

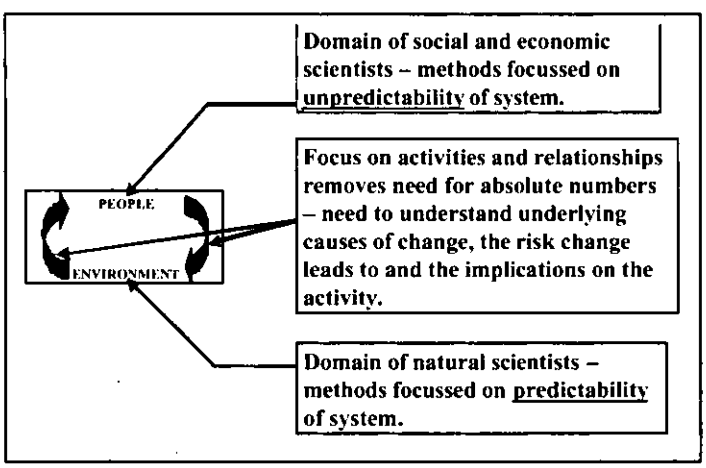

Figure 1. The source of conflict between sectoral groups studying the coastal zone arises because of a focus on either the provider (environment) or the user (people). A focus on the interactions and activities that that link the two creates greater understanding of the dynamics of the coastal zone.

The principle focus of most Integrated Coastal Management (ICM) programmes is to develop a knowledge-base of the natural processes that affect and impact the coastal zone. While it is vital to understand the natural processes at work in the coastal zone, ultimately management policy is seeking to control, constrain, encourage or modify the behaviours of people whose welfare and livelihoods are dependent on the resources of the coastal zone. Sophisticated scientific understanding of the coastal zone cannot in itself achieve ICM and can cause further coastal conflict. Perceptions of coastal resources between groups can be varied, diverse and conflictory. Natural scientists seek to predict changes in coastal resources embedded in a numeric and reductionist framework[2,9]. In contrast, social scientists seek to describe the patterns of interactions of people in networks of social relations, their maintenance and the conflict that arises from competing interests[10, 11, 12] (Figure 1). ICM should seek to determine a holistic view of stakeholders' perceptions of the coast in order to identify sources of conflict to which appropriate knowledge from all disciplines may be employed to resolve solutions[9].

Capacity building is one tool that can lead to an enhanced awareness of the diversity of perceptions of stakeholders and lead to a re-evaluation of the nature of knowledge and understanding required by coastal managers[13, 14]. However, training

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in ICM is often focussed on increasing scientific knowledge, rather than providing a robust framework for management, leading to negligible impact as scientific focussed solutions are rarely practical, socially acceptable, implementable or sustainable. Recent publications have promoted a view that education and training should adapt to both appropriate cultural contexts and the education needs of teachers/trainers, as well those of the students/trainees[15, 16, 17]. Additionally, the need for multidisciplinarity is consistently advocated, but this is usually set within a setting of sophisticated, high-tech specialist approaches rather than a generalist approach that might provide the skills to disseminate holistic management approaches[16].

THE INTEGRATED COASTAL ZONE MANAGEMENT AND TRAINING PROJECT

A recent project undertaken by the Centre for Coastal Management has explored capacity building for ICM from the perspectives of (i) skills in training and (ii) the course requirement for developing capacity in ICM. The project sought to develop capacity in State level Indian Government environment officers to write and implement coastal management plans under their 1991 Coastal Zone Notification (http://envfor.nic.in/legis/legis.html). The project goal was to develop a programme that would promote a holistic approach to environmental management, encompassing socio-economic and governance issues as well as natural sciences, within a tradition of specialist single sector management. The training process was designed to lead trainees through a "virtual scenario" case study approach, in which groups of trainees are required to develop a strategic ICM plan for a local 20-40km stretch of coast during the duration of the course (Figure 2). Case studies permit role-playing in an environment that simulates the work situation found in an ICM programme, they are safe and do not impose penalties for "wrong"' answers, and can help improve decision-making skills under conditions of scientific uncertainty and competing interests[18]. Central to the project goal was the development of training ability within India in order that capacity building could continue beyond the life of the project: Training teams were established at two Universities – Anna University at Chennai and Jadavpur University at Kolkata.

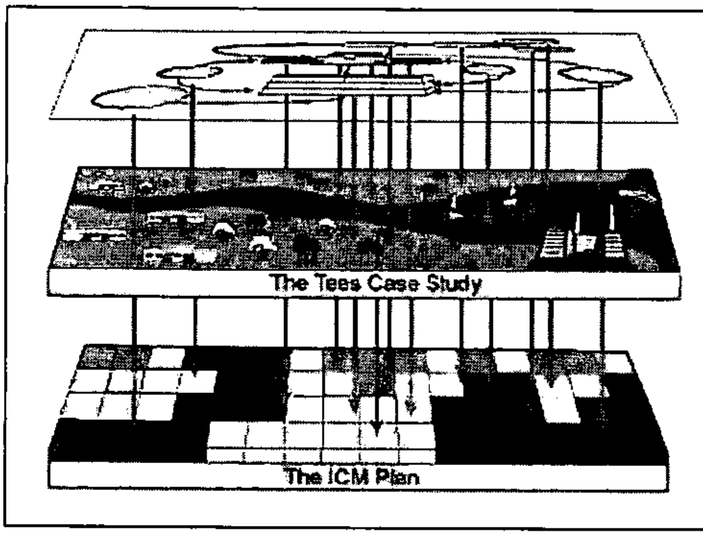

Figure 2. Conceptual outline of the "virtual scenario" case study approach. The First Layer is a conceptual model of how the various dynamics of integrated coastal management commonly interface (see Figure 2). The Second Layer represents the various case studies, tasks and exercises which illustrate or codify various of the dynamics of the First Layer, in real life. The Third Layer represents the outputs of the Second Layer by populating an resources, responsibilities, institutional elements, time scales etc. etc.).

Training-of-trainers

The project required trainers to develop new skills in order to support a sustainable training approach. A major objective of training in ICM must be to remove existing discipline-biased perspectives in favour of approaches that promote an open and inclusive process in order to contextualize the various, and often conflicting, values and perceptions of the many stakeholders in the coastal zone. Traditional teaching techniques, such as class lecturing and research assignments cannot attain such learning objectives[17,19]. Furthermore, it is unlikely that a coastal manager can ever be an 'expert' in the many disciplines and sectors that have inputs into ICM. Indeed, one might argue that the role of a coastal manager is as an executive coordinating and managing knowledge inputs rather than being the source of the knowledge itself. Thus, ICM is a team effort requiring individual inputs from a wide variety of sector and disciplines. Our approach was to develop training teams whose composition included expertise in the range of natural, social and economic disciplines and from the range of sectors to have a role in an ICM initiative (e.g., University, NGO, Institute and Government). The training teams were given a course based on the Certificate of Learning and Teaching in Higher Education given to new lecturers at Newcastle University, that included Models of learning; Training needs analysis; Content, structure, format and materials for training; Assessment and evaluation; Course organization; and Experiential training. This programme provided the necessary skills to conduct case study-based training (http://www.ncl.ac.uk/qsu/qsuintro.htm, see also Fletcher[20]). In order to guide trainers, and trainees, through the process of ICM encompassed within the course structure a formulaic model was constructed (Figure 3).

Course design

In order to provide a framework that guided both trainers and trainees through the ICM process, and support a "virtual scenario" case study approach, a three module approach was designed:

Module 1 – The role of information and knowledge in ICM. Facilitated by trainers and supported by seminars from experts, the range of disciplines and sectors that bear upon the case study area are introduced with the objectives of:

- illustrating the place and relevance of each subject area within integrated coastal management,
- the relationship between each subject area and other sectors of ICM, and
- the approach that should be employed when considering that discipline/sectoral interest in ICM issues and problems.

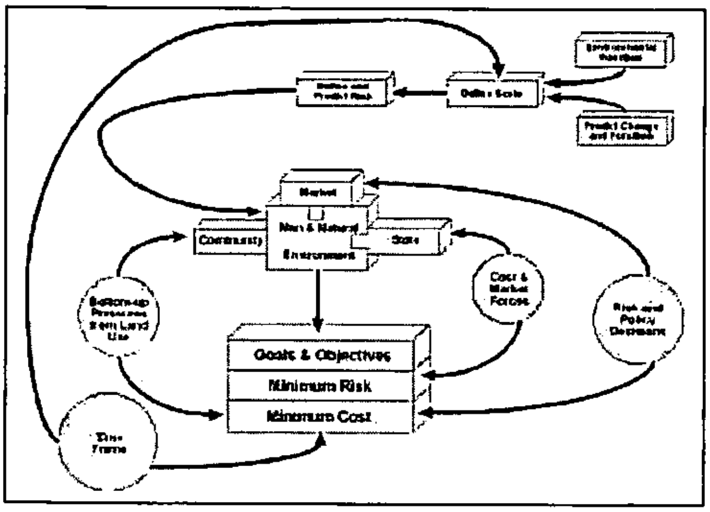

Figure 3. The above model seeks to identify and describe the bio-physical and human components, and their dynamics, of the coastal environment. The aim of coastal management is defined as *"To reduce risks to people and property and productivity, by maintaining and enhancing a functional coastal system; including the maintenance and enhancement of ecologically important areas"*.

Module 2 – Fieldwork. General information on the case study area is provided and trainers and trainees discuss likely issue/problem areas and identify stakeholders. Trainees then design their own programme of fieldwork that includes selection of sites and stakeholders to visit under the guidance of the trainers. The objective of the fieldwork is that trainees identify issues and problems that exist in the case study area and develop an appreciation of the differing perceptions of the various stakeholders to those issues and problems.

Module 3 – Writing an ICM plan. With an emphasis on demonstrating understanding of the dynamics, issues and problems within the case study area, trainees write a team report that takes the form of an outline management plan for the case study area.

The goal of the ICM plan was to work towards a sustainable coastal environment that minimised risks to people and property whilst minimising costs of sustained development. The task of the coastal management plan is to advise on ways in which coastal resource development can be integrated into such a dynamic, natural coastal system without loss of the resource or functional integrity of the environmental system. It is important to note that provision of least risk at least cost must result in a sustainable natural coastal system that maximises nature conservation objectives in order to reduce risks to people and property. Nature conservation must therefore be seen as synonymous with coastal defence rather than inimical to it.

An ICM matrix is used to provide a framework for understanding the coast and the impact of management interventions (Figure 4). However, it can also provide a model for the conflicts of interventions on stakeholder groups to be determined by the delegates. Using this matrix, delegates experience iterative searching for low conflict management solutions for the target coastline. This "virtual scenario" approach coupled to experience of conflict reduction matrices has been shown to provide coastal managers with a wider appreciation of stakeholder conflict in the coastal zone.

		COASTAL ENV.					LAND USE		PORTS & HARBOURS			INDUSTRY			LIVELIHOODS		
		Open shore	Estuaries	Old dunes	Frontal	Wet	Plantations	Agriculture	Creek Harbours	Beach	Constructed Ports	Tourism	Fisheries	Aquaculture	Nat. Material	Semi-Pakka	Concrete
COASTAL ENV.	Sea level change	√	√		√	√	√			√				√	√		
	Climate change				√		√	√			√		√	√			
	Local erosion	√	√		√					√							
	Local accretion	√	√							√							
LAND USE	Conversion of wetlands		√			√								√			
	Construction - tourist				√												
	Construction - general			√								√					
	Railway			√													
PORTS & HARBOURS																	
INDUSTRY	Pollution - aquaculture		√			√								√			
	Pollution - sewage											√					
	Pollution - litter																
	Failing aquaculture													√			
	Increasing tourists																
	Declining CPUE																
LIVELIHOODS	Urban [illegible]														√	√	√

Figure 4. An example of a completed matrix. The columns indicate system components categorised into functional groupings of the natural coastal and the human built environment. Rows identify forces of change originating from each of the functional groups. Where a change will interact with a component of the system it is recorded as a 'tick'. No attempt is made to qualify whether the impact is positive or negative, or its magnitude. Two primary stakeholders are identified; hoteliers and fisherman allowing changes that are threats to users and uses of the system to be revealed, and identifies principal foci of management needs against which the goals and objectives of the plan should be directed.

DISCUSSION

The training framework described here addresses a concern that training for development should be focussed on strengthening the capacity to practice, knowing how to proceed and how to find out what needs to be known using experience-based problem solving[21,22]. Provision of courses focussed on knowledge and intellectual competence run a risk of providing training that appears unproblematic and does not develop skills in engaging with the uncertainty of unknowns. Central to this approach is the notion that those engaged in management should make the best use of current information to formulate management options and put into place mechanisms to fill-in gaps in knowledge and information that can amend management practices as they become available. This is particularly important in many countries where coastal problems are both so acute and persistent[4] that there is not time to engage in long-term research programmes in order to decipher the perfect management solution.

Previous models for ICM, based on Gesamp[23] and Olsen et al.[4] have largely focussed on identifying the stages to the ICM process with little guidance to the nature of information required to support such a process. The framework described here aims to provide guidance in a training scenario that will allow coastal practioners to engage in the ICM process in a manner whereby information and knowledge used is relevant to the context of a management process and that is inclusive to all sectors and disciplines.

The system approach to training facilitates integrative thinking, active *versus* passive learning and unambiguous communication[19], as well as re-orienting attitudes towards a cross-sectoral and multidisciplinary approach that supports concepts of sustainability[24,25]. This ensures an inclusive process for all sectors and disciplines avoiding polarisation of different groups within the management process[26]. The focus on describing the system centred on function and change associated with each component also removes the problem that disciplines concentrate on describing the detail of a system prior to evaluating changes in it, which leads to a 'closed' language making it difficult for others outside of the discipline to find relevant data and be able to interpret it[27].

The use of a simple matrix has the advantage of reducing the complexity of information, provides a forum for all sectors and disciplines to display their findings and demonstrate understanding of the system without resorting to building separate and incompatible models[17,27].

Training programmes, using the framework described here, have been given to cadres of Officers from Federal and State Government in India over the past two years (2000 & 2001) and personnel associated with the Char development and Settlement Project II in Bangladesh in 2001. Immediately post-course, all participants were asked to evaluate the training provided using a scoring and comment format. Results showed that participants scored at least 70%, and as high as 93%, categories of Attainment of course objective, Relevance, Structure of course, and Presentation, and their comments suggested that the courses would be beneficial to their professional roles.

CONCLUSIONS

The programme seeks to guide the trainee to navigate ICM with a uniform approach placing emphasise on integration and interaction whilst retaining a generalist rather than specialist approach using case studies. The training provides guidance to solution formulation and a structured guide to coastal management plan preparation using a simple matrix approach. The project has demonstrated a means to achieve a number of key targets for capacity building projects:

1. A training team approach to curriculum development and methodology[17].
2. Built-in redundancy for international project managers[28].
3. The development of training that supports integrated thinking and analysis with a focus on the relationship of governance to ICM inputs and solutions[2].

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Naval Architecture: 100 years of development at Newcastle

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SYNOPSIS

In the north-east of England, formal teaching of naval architecture to degree level began in 1902 when a Lecturer was appointed to the Durham College of Science. This paper records and reviews the development since then of academic work in this subject at Newcastle. Difficult times up to WW2 were followed by rapid expansion, first in 1945-55 and then from 1965 when King's College became Newcastle University. Extensive development and diversification since then in both teaching and research are summarised. The merging in 1989 of naval architecture with marine and offshore engineering has created a world-class centre for maritime technology.

INTRODUCTION - NAVAL ARCHITECTURE EDUCATION IN THE 19TH CENTURY

In 19th century England, despite her emergence as a major naval power and the world leader in shipbuilding, the prevailing attitude towards formal education in naval architecture was, for the most part, discreditable. In contrast to France, where scientific and technological education was well established and highly regarded, and despite some shining examples such as Brunel (1806-1859) in demonstrating the value of applying scientific principles to achieve remarkable innovations in ship design, the leaders of 19th century shipbuilding did not generally value scientific training. Shipbuilding was seen as a craft, which depended more on practical training and the application of established arts and skills than on any science-based education.

What little enlightenment there was, during this 19th century, came from the Admiralty. The Navy Commissioners far-seeing report of 1806 led to the creation of a school for naval architecture at Portsmouth in 1811, but this was closed in 1832 "from motives of economy'. The same fate befell the Central School of Mathematics and Naval Construction, also based on Portsmouth Dockyard. which survived a mere 5 years, from 1848-53. Eleven years later, thanks in great part to an influential report from the recently-formed Institution of Naval Architects, a Royal School of Naval Architecture and Marine Engineering was founded at South Kensington, sponsored by the Admiralty and Education Departments. This school was transferred to the Royal Naval College at Greenwich in 1873, where for the next 95 years the members of the Royal Corps of Naval Constructors received education of high quality. This naval influence was to be an important factor in the subsequent and belated growth of civilian education and training.

By the last quarter of the 19th century, the north-east of England had become a world centre of shipbuilding. Yet so lacking in scientific and mathematical instruction was the training of apprentices in NE yards, that many recruited foreign draughtsmen - especially Scandinavian or German - who were more expert in ship calculations. They were said to be "rather cheap, but clever at figures". So it is ironic that the first recorded formal teaching of naval architecture in the area was by a Mr. Zimmerman, a German draughtsman at Jarrow. His classes were soon taken over by M.C.James; and in the closing years of the century night schools were teaching the subject first at the Library in North Shields, and later at Jarrow, Wallsend and South Shields. It is greatly to the credit of James and his mentor Dr. Rutherford, and his successors Baty and Hinchcliffe, that despite the disadvantages of night school work. the lack of good textbooks, and the demands of overtime working, naval architecture had at last established a foothold in post-school education.

In 1871 the Durham College of Physical Science was established in Newcastle "with primary consideration for the training of mining engineers". With its first professorial chairs in mathematics, physics, chemistry and geology, the new College testified to the growing recognition, especially by leaders of local opinion, that the future prosperity of industries in the north-east of England would benefit from a more structured and scientific scheme for the formation of its future engineers. The first B.Sc degrees (of the University of Durham) were awarded in 1876, with the first M.Sc and D.Sc being awarded in 1878 and 1888 respectively. Agriculture and mechanical engineering soon joined the trend; and with the creation of local institutions such as (in 1884) the North East Coast Institution of Engineers and Shipbuilders, where enthusiasts for their professions could meet and exchange ideas, the pressure - and, no less important - some financial support, for expansion of the College's work, gathered momentum.

The appointment of RL Weighton to a chair of engineering and naval architecture at the Durham College in 1891 brought marine work into its purview. The founding of this chair owed very much to the young NBC Institution, who not only persuaded Durham College of its necessity, and guaranteed significant funding in its early years, but also selected and nominated the new professor. Weighton had been chief draughtsman at Hawthorn Leslie's St. Peter's Works, and his interests and expertise were primarily in marine engineering. The College Principal, W Garnett, had invited H Rowell to lecture in naval architecture, but his contribution lasted only from 1889-91, and it was to be another 11 years before Weighton acquired more durable support in the person of a 32-year old naval architect, FH Alexander. The teaching of naval architecture to degree level at Newcastle thus dates from Alexander's appointment as lecturer, in the autumn of 1902.

1904 - 1937 NAVAL ARCHITECTURE AT ARMSTRONG COLLEGE

Francis Alexander (1865-1939) had held appointments at Hawthorn Leslie, Swan Hunter and as chief assistant to the naval architect at John Brown on Clydeside, before moving to the post where for the next 27 years his "extraordinary and infectious enthusiasm, his lucidity and his power of imparting knowledge" - to quote EVTelfer's obituarial words - benefitted many students from Britain and overseas; while his meticulous record-keeping has left an invaluable record of their attendance. He also left for posterity the "Alexander formula" for the block coefficient of ships, well known to many naval architects; but his papers on the mechanics of rowing are now less familiar.

Perhaps it was the quality of Alexander's teaching that helped to persuade local opinion that naval architecture was a subject of sufficient industrial, as well as intellectual, weight to justify the founding of a Chair in a separate department of naval architecture. Durham College of Science had, in 1904, been reconstituted as Armstrong College of the University of Durham. Thanks to the efforts of fund-raisers such as Principals Garnett and Gurney, land had been bought, and construction begun, of a purpose-built college, subsequently named as a memorial to the first Lord Armstrong and opened by King Edward VII in 1906. Expansion of academic work into other areas of science and engineering, and then into language, classics and music had already rendered obsolete the name of the College of *Science*. Armstrong College was almost a University in its own right, but remained, even when reconstituted as King's College in 1937, a constituent of Durham University until 1963.

The first Professor of Naval Architecture, Joseph Welch (1861-1950), came to head the new department in session 1906-7. He had been Senior Instructor in Naval Architecture at the Royal Naval College Greenwich, and then shipbuilding manager of Laird Bros. with responsibilty for the construction of many naval units. For the next 22 years, he and Alexander carried the burden of naval architecture teaching at Armstrong College. Student numbers were dominated by evening class entries, where large enrolments reflected the desire of local shipyard apprentices to obtain the qualifications of the Board of Education's examinations (the forerunners of National Certificates); whereas those who could afford the time and cost of daytime study for a Durham degree were very few. This was despite the availability of some competitive scholarships of £100-150, at a time when tuition fees were a mere £21-26. Typically in the first years of the new degree curriculum the day students might number around 15-20, while evening classes attracted an average of 70-80. Among the latter, two sons of a Tyne pilot - Amos and Wilfred Ayre - enrolled for evening study in the College; both were later knighted for their services to shipbuilding. Wilfred Ayre recalled the "exacting" nature of the five years' study he followed in order to obtain a degree by this route, which required him to sit special examinations in London. He observed that those few who succeeded in this onerous course "rose to the highest positions in the shipbuilding industry".

Evening class enrolments occasionally exceeded 100, and it is no surprise that Alexander, who bore the brunt of this work, needed part-time assistance, usually from local shipyard draughtsmen. R Hinchcliffe in 1910 was the first, followed by WRG Whiting, JL Scott and WJ Drummond, who had studied naval architecture at RNC Greenwich, and was later knighted for his work in the *mining* industry. Class enrolments peaked during WWI then diminished until Alexander's retirement in 1929, when evening work was discontinued.

Daytime study for the Durham BSc slowly began to attract more students after Professor Welch's appointment in 1906. With his naval background it was natural that instruction at Armstrong College followed closely that given to naval constructors at Greenwich. The course leading to a degree in naval architecture required the entrant to have passed the Durham University matriculation examination (or its equivalent); and then to complete 3 sessions, each of 3 terms and 3 months duration, as summarised in Table I. The general form of this curriculum, with its basis in science subjects, especially mathematics, and its heavy emphasis on drawing, was to become familiar to undergraduate naval architects- not only at Newcastle - for most of the next half -century. Such was the pervasive influence of the Admiralty system of higher education in naval architecture.

Table I Outline of the degree curriculum in naval architecture circa 1908

	Year 1	*Year 2*	*Year 3*
Science	Mathematics Physics Chemistry	Higher Mathematics	Additional Mathematics Physics and Physics Laboratory
Applied Science	Mechanical Drawing	Applied Mechanics Engineering Laboratory Mechanical Drawing	Lectures and Practical Work on Engineering Subjects
Naval Architecture	Introduction to Naval Architecture	Naval Architecture Ship Drawing & Calculations	Advanced Naval Architecture Ship Drawing, Calculation & Design

Today's students might be daunted by the demands made on the abilities of their early predecessors to perform endless numerical calculations and to produce the extensive drawings required by the course work. The 18th and 19th centuries had seen much development, especially in Europe, of the principal components of theoretical naval architecture:- the statics and stability of floating bodies; mensuration of ship shapes; wave mechanics; ship resistance, propulsion, powering and steering; ship motions; materials and methods of joining; and the strength of ship structures. The work of pioneers such as the Froudes was also generating much relevant data on ship behaviour. But the adaptation of this growing corpus of knowledge to the process of ship design required much ingenuity, and led to a rich variety of more-or-less approximate techniques. So it was judged important that students should be familiar with more than one such method of, for example, producing cross-curves of stability, or finding the position of the centre buoyancy. Names such as Attwood, Barnes, Morrish, Reech, Scribanti, Simpson and Tchebycheff still provide almost an alphabet of memories to those schooled in these procedures. So too do the draughting pens, long plans, lead weights and flexible battens - not to mention long hours of dedication - needed for the creation of comprehensive sets of ship drawings.

In 1913 a further year of study was introduced for students wishing, and qualified, to proceed to an Honours degree. But enrolments were badly hit by the war, when the whole College was taken over for use as a military hospital, and work had to be carried on in various local buildings. But the post-war intakes increased, and brought some brilliant Honours students, among them BV Telfer, JL Taylor, J Tutin and PH Todd, all destined for outstanding futures. Their careers were helped by valuable postgraduate scholarships, such as the 1851 and Sir William White awards of the Institution of Naval Architects. Postgraduate research in naval architecture at Newcastle had begun, despite an absence of research facilities. Indeed those early postgraduate students such as Telfer (the first Ph.D in NA) and Todd used the sea as their laboratory, spending much time on ships plying their trade.

The higher degrees of M.Sc and Ph.D had been available since Durham College days, but candidates in naval architecture were rare - only 3 in the period up to 1920. Also introduced in these early years were special and Diploma courses, for students unable to complete the degree programme. These were of particular benefit to students from overseas, especially Europe and China, whose early enrolments (in 1909 one in three students were from overseas) foreshadowed what was to become a distinctive feature of the student population in naval architecture at Newcastle. Another teaching commitment established in these first years was to provide instruction in naval architecture to students of marine engineering. These courses, with less emphasis on drawing office work, were introduced from around 1913.

Apart from mechanical aids such as planimeters, integraphs and the Fuller's Calculator, naval architecture students in these first decades at Newcastle seem to have had little experimental apparatus to hand. The exiguous financing of Welch's department is evident from its total annual cost in 1921 - a mere £2240. Marine engineers were better favoured, thanks to the generosity of local firms in helping to create an engineering laboratory where, for example, a quadruple-expansion steam engine not only gave students valuable hands-on experience, but also enabled staff such as Weighton and his assistants to carry out some of the first academic engineering research at Newcastle. But Welch and Alexander were not inactive in their efforts to advance the frontiers of their naval architecture knowledge. Both published papers on aspects of damage stability, and Alexander devised some new procedures for expediting various ship calculations. Following the Titanic disaster in 1912, Welch led the way in developing improved standards for the subdivision of ships through his work for the Committee of Inquiry.

In 1928, Welch retired, followed by Alexander in 1929. The second professor of naval architecture was Sir Westcott Abell (1877-1961) who had also studied, and later lectured, at RNC Greenwich. In 1909 he had been appointed to the new chair of naval architecture at Liverpool University, but two years later became Chief Ship Surveyor at Lloyd's Register. Knighted in 1920 for his wartime work, he went on to effect major changes to LR's work and organisation, showing particular interest in the strength and safety of ships, which continued during and after his 12 years at Armstrong College.

But Abell arrived there at a difficult time. Principal Morrison, seeing in 1927 that enrolments were so low, and that naval architecture seemed more attractive to foreigners than to the British, wondered whether the department should continue. Sir Westcott too must have wondered whether he had been wise to forsake his London office at LR for a small room on the top floor of the Armstrong Building, where he was flanked by the "Women's Staff Room" and the office of "The Normal Mistress" - whoever she was. And local opinion now seemed much less enthusiastic about higher education, no doubt influenced by the rapid decline in shipbuilding fortunes. From a peak of 949,000 tons in 1920, launches from north-east yards had slumped to 199,000 in 1926. Local unemployment ran at 47% in 1928; and worse was to come with the great depression of the 1930s, when despite pleas from such as Amos Ayre, now President of the Shipbuilding Employers' Federation, for urgent government assistance for the industry, launchings in 1933 were a mere 37,000 tons.

At Armstrong College, total student numbers were fairly static at 700-800 through these depressed years. In .1928 the Faculty of Applied Science separated from Science, and in 1930 students of Applied Science at Sunderland Technical College were allowed to qualify as internal candidates for the Durham degree. But Westcott Abell, now with JL Scott as assistant, could contribute little to these student totals; - enrolment into the undergraduate programme averaged less than 5 per year during the 12 years of Abell's tenure. It was true that among them were stars such as W Muckle (29-33) and A Emerson (30-34), later to become pillars of the department, as well as H Lackenby (31-35); and in 1932 the first female student, Susan Denham Christie, enrolled. But the dearth of students persisted; none enrolled in 1935; and little research was done. Here again, earlier attempts to gain support from local shipbuilders for a research association (of a kind much encouraged by the Government's Department of Scientific and Industrial Research) in the North-East had failed completely, - the matching local funding required was not forthcoming in these years of depression. The final years of Armstrong College saw its naval architecture department struggling for survival.

1937-1963 NAVAL ARCHITECTURE AT KING'S COLLEGE

The passing in 1935 of the University of Durham Act led in 1937 to Armstrong College and the College of Medicine becoming King's College, with its own government, Rector, Council, Senate and Academic Board. But it remained a constituent college of the University of Durham, thus perpetuating the right of graduates, having received their higher education entirely in *Newcastle*, to describe themselves as graduates of *Durham* University. Applied Science became one of 8 faculties at King's; and received the committed support of the first Rector, Lord Eustace Percy, who set about building on the considerable strengths on the Newcastle campus (which now included 6 Fellows of the Royal Society). But the Rector was uneasy about the future of naval architecture. Westcott Abell had reason to be grateful for the support of a Naval Architecture Standing Committee, consisting mainly of local industrialists, which since 1928 had led the triennial raising of funds to support the continuation of the Chair of NA. In 1931, for example, £1164 was subscribed, mostly in £100 donations from the larger shipyards; and this ensured the continuation of Abell's post for a further 3 years. Lord Percy felt that this was no way to sustain a University activity; and he also deplored the absence of research facilities and consequent failure to advance the frontiers of knowledge in the subject.

Under Professor Abell the teaching of naval architecture had continued in its now well-established form with 3 years to a Pass Degree and a further year to an Honours BSc, and with a special second year NA course for marine engineering students. The early war years were made more difficult by strained relations between Abell and Scott. Abell finally resigned in 1941, and the fact that the chair then remained unfilled for 4 years may have reflected the Rector's doubts about the future of this discipline. "We have a Chair, but hardly a Department", he wrote to the Standing Committee. The chair was advertised, but despite a seemingly strong field (including Telfer and Todd), no appointment was made. But a few students continued to enroll, so one of the Professors of Applied Mathematics, TH Havelock FRS (1877-1968) was asked to act as *locum tenens* for the intervening 4 years. A former Cambridge Wrangler, Havelock had in 1908 published the first of many papers (the last was in 1958) on the mathematics of ship resistance and dynamics in a seaway. Athough many students found Havelock's prowess in mathematics somewhat daunting, his theoretical work brought much benefit to ship research.

FH Todd agreed to act as a temporary lecturer for 18 months in 1941-42, then W Muckle and R Hinchcliffe joined the lecturing staff in the DNA to assist Havelock after Scott had died in 1942. But wartime enrolments to the course continued to be disappointing, making the outlook still uncertain. Again it was due to Lord Percy's efforts and the support of the NA Standing Committee (especially its Chairmen, JLBatey and EL Champness) that the future of the chair of NA was at last ensured by raising over £50,000 from industry. Contributions ranged from £3 (from Hunting) to £5,000 (from Sir Charles Craven on behalf of Vickers Armstrong); and the total sum met the Rector's aspirations to have at least £3,000 pa to meet the salary bill for a revitalised department of naval architecture.

Further powerful impetus came from the passing of the 1944 Education Act and the resurgence of post-war shipbuilding, and a dramatic change ensued, with first year numbers jumping from 5 in 1945 to 22 in 1948. But perhaps the major factor was the appointment at last in 1945 of a new Professor of Naval Architecture, LC Burrill (1905-65), who after completing the NA course at Newcastle in 1927, and postgraduate study as an 1851 Exhibitioner, had gained experience in the technical department of Swan Hunters, and then as naval architect and Technical Manager of the Manganese Bronze and Brass Company. Burrill skilfully rode the wave not only of post-war expansion in higher education, but also of a changed attitude by industry to research, exemplified ~ the creation in 1944 of the British Shipbuilding Research Association. Burrill's plea that a major academic research facility to support his growing expertise in propeller analysis and design should be located in King's College led to the construction, mostly from parts of a German research facility for acoustic testing of underwater weapons, of the Cavitation Tunnel in the nearby boilerhouse building at the College. With support from the Admiralty, DSIR andpropeller manufacturers, the tunnel was opened in December 1949, and A Emerson was recruited from the Teddington Laboratory as its Assistant Superintendent in 1950.

UGC funding for university expansion led to the opening in 1951 of the Stephenson Building, purpose-built for mechanical engineering; so that the engineering laboratories which had existed for sixty years on the ground floor of the Armstrong Building could be vacated. Burrill saw that the former hydraulics section of the lab. would be ideal for a ship testing tank; and thanks to his commitment and fund-raising energy, a 40m x 3.75m x 1.25m tank with centre-rail towing carriage was opened in 1951. These two substantial research facilities - tunnel and tank - needed workshops and model-making equipment, so space was found in the ground-floor lab., and a team of experimental and technician staff recruited, to service the growing research activity. Staff rooms and mo re teaching space became available as other departments moved out into new premises, to that most of the ground and first floors in the western side of the Armstrong building were taken over by NA, and remain so today.

From just 18 in 1945, the student population in the naval architecture department grew to over 90 in the next 15 years. The teaching staff had to increase; and Table ill records arrivals during this period, including former King's College graduates RL Townsin, EJ Glover and M Chilton, whose subsequent combined service to the department totalled 100 years. Marine Engineering too was strengthened ~ the appointment in 1956 of GH Chambers to a chair in that subject, with AW Jones as Lecturer. So when in 1957 the Institution of Naval Architects held a Conference on Education and Training, Burrill was able to report that activities at King's College had been transformed during his tenure.

The educational programme in place in 1957 for intending graduates in naval architecture is summarised in Table II.

Table II Outline of the degree curriculum in naval architecture circa 1957
(Bracketted figures are the hours allocated to the subject)

Year 1		*Year 2*		*Year 3*		*Year 4 (Honours)*	
Mathematics	144)	Mathematics	(96)	Mathematics	(72)	Mathematics	(72)
Physics	(72)	Economics	(24)			Language	(24)
Chemistry	(72)					Related Subject	(24)
Science Laboratory	(216)						
		Electrical Engineering	(24)	Metallurgy	(24)	Marine Engineering	(24)
		Mechanical Engineering	(72)	Mechanical Engineering	(48)	Hydrodynamics	(30)
		Engineering Laboratory	(144)	Marine Engineering	(24)		
				Engineering Laboratory	(108)		
Shipbuilding	(24)	Naval Architecture	(72)	Naval Architecture	(168)	Naval Architecture	(144)
Drawing Office	(144)	Drawing Office	(216)	Drawing Office	(216)	Drawing Office	(360)

Comparison with Table I (50 years earlier) shows the addition (from 1913) of the final Honours year; but the overall structure of the first three years is not greatly different, with the first year predominantly (75%) spent on science subjects, and mathematics continuing through all four years. Economics is now briefly introduced in the second year along with mechanical and electrical engineering, and there are third and fourth year courses in marine engineering. There are as yet no options in the course (except for the choice of language in year 4), and it is notable - and was a matter of some criticism at the Conference - that over a third of the total time on the NA course had to be spent in the drawing office.

Completion of years 1 to 3 led to the award of an Ordinary degree. Not shown in Table II is the course leading to a General Degree, introduced in 1955, in which the fourth year was spent on a broader range of studies, including economics and management, statistics, fluid mechanics and metallurgy, together with further work in naval architecture. Alternatively, the General degree could be obtained by spending the fourth year in another department, usually mechanical or marine engineering. The intention of these General degrees was to offer greater flexibility of study to suit a wider range of possible future employments, such as ship surveying or shipyard management. This move towards greater choice in undergraduate study recognised that naval architecture graduates might eventually make their careers in marine work other than ship design. It foreshadowed a great increase, in later years, in the variety of educational opportunities in the study of naval architecture at Newcastle University.

The programme outlined in Table n remained in place, with only minor changes, until 1967. Burrill and his team had now established, within the Faculty of Applied Science, a major university activity, in both teaching and research, for the final years of existence of King's College. Meanwhile, a proposal made in 1947 by Lord Percy, but opposed by the Government, for the separation of King's College from Durham University, had been revived. The Academic Board of the College in 1960 resolved that Newcastle University should be established in place of King's College; and after much debate over matters of organisation and management, on 1st August 1963 the change to Newcastle University took place.

1963 - 2002 NAVAL ARCHITECTURE AND MARINE TECHNOLOGY AT NEWCASTLE UNIVERSITY

So much has happened in the final 40-year period of this review that there is not ~ce to continue a detailed narrative of events, the more recent of which are in any case well known. Instead the main features of change and development are briefly reviewed with the help of summary tables. Worthy of general comment, however, is the paradox that over this period, in which the local and national commitment to ship design and construction has so greatly diminished, the size and scope of the erstwhile Department of Naval Architecture has greatly increased. This has resulted from a deliberate diversification into related areas of marine work, so that the demand for higher education and research in this widening field of marine technology has ensured Newcastle's continuing eminence in this subject.

Organisation and staffing

Professor Burrill died in 1965, and W Muckle headed the department until the Chair of Naval Architecture was filled by ill Caldwell in 1966. Like his predecessor, Caldwell was fortunate that demographic factors (the post-war birth-rate bulge in particular), together with a major expansion of univesity work heralded by the 1963 Robbins Report on Higher Education, provided an excellent climate for growth and change. The department of NA had already responded to a long-standing plea from its Advisory Committee that graduates should have more familiarity with ship construction as well as design, by adding Shipbuilding to its title and in its teaching. This and subsequent changes in the overall organisation of marine work within the Faculty are summarised below:

1963- Shipbuilding added to Department of Naval Architecture to become DNAS
1966 - Marine Engineering separated from Mechanical, to form the Department of Marine Engineering (DME)
1975 - School of Marine Technology (SMT) created, comprising DNAS and DME in a federal arrangement
1978 - Faculty of Applied Science became Faculty of Engineering, with corresponding changes in degree titles
1989 - Unified Department of Marine Technology (DMT) formed by joining DNAS and DME.

In 1966, headships of departments were regarded as permanent appointments, but this policy was changed in 1974 to fixed-term posts, not restricted to professors, and usually of 3-5 years. So when Caldwell became Dean of Engineering in 1983 after 17 years as head of DNAS, he was succeeded by RL Townsin, to be followed in 1989by I Thorp. Caldwell was also the first Head of the School of Marine Technology from 1975-80, followed by RV Thompson, who had succeeded Professor Chambers in the Chair of Marine Engineering in 1975. When in 1989 the 2 departments fused into DMT, it was headed by I Thorp (to 1993), G Hearn (93-95), P Sen (95-00) and A Incecik (2000-2002).

The staff of DNAS in 1966 comprised 1 Professor, 1 Reader, and 5 Lecturers, assisted by 8 technical, 3 experimental and 2 secretarial staff. There is not space to describe the many changes and additions to the staff during this period, but Table III below shows those for the academic staff in summary form. Because of the eventual coming together of the naval architecture and marine engineering departments, Table III includes both groups of staff.

Some indication of the widening scope of work in DNAS is seen in the following academic appointments, created to open up new and related areas of teaching and research.

1970 - Establishment of Lectureship in Marine Transport and Qperations (J King)
1974 -Readership in Marine Transport (IL Buxton)created with support from local shipowners and trusts
1975 - Leslie Lavy Chair of Ocean Engineering (B Denness) created through earmarked donations
1977 - Lectureship in Offshore Vehicle Design (PW Penney
1984 - Lectureship in Offshore Resource Engineering (MJ Downie)
1985 - Lloyd's Register Chair of Offshore Engineering (P Bettess) replaces Leslie Lavy Chair
2002 - Establishment of Chair of Marine Transport and Management

In addition to these specially created posts, members of staff directed their work into some new areas of marine work such as Small Craft Technology, Marine Production Technology, Marine Dynamics, and Marine Systems Analysis and Design; and the addition of marine engineering staff in the DMT from 1989 likewise brought new skills and specialisms. By the end of this review period, the academic staff in DMT numbered 16, which included 4 professors - of Marine Design and Construction, Marine Engineering. Ship Hydrodynamics, and Offshore Engineering. The disappearance of Naval Architecture from this list meant that Caldwell had been the last in this professorial line at Newcastle.

The vital part played by supporting staff in this period of expansion should not go unrecorded. The technician team headed in turn by Bill Vasey, George Flynn and presently Alan Buckham, the Information Officer Richard Carter and Computing Assistants, as well as the Administrative and Secretarial staff, headed first by Mabel Cummings and since 1979 by Kathleen Heads (now working for her sixth head of department), have all given excellent support. Among a small team of experimental staff, George Mitchell deserves special mention. From junior technician in 1957 to Senior Experimental Assistant with a wide variety of responsibilities, his record of 45 years dedicated service to the department still continues.

Table III Full-time academic staff 1902-2002

Name	*Appointed*	*Responsibilities*	*Left*
Naval Architecture			
FH Alexander	1902	Lecturer. Reader 1920	1929
JJ Welch	1907	Professor and Head of department. Dean of Science 1925-7	1928
WS Abell	1928	Professor and Head of Department	1941
JL Scott	1930	Lecturer	1942
W Muckle	1942	Lecturer. Reader 1953. Acting head of Department 1965-66	1976
TH Havelock	1942	Acting Head of Department 1942-45	1945
R Hinchcliffe	1942	Lecturer	1946
LC Burrill	1945	Professor and Head of Naval Architecture Research Laboratories	1965
JE McLachlan	1946	Lecturer	1951
BN Baxter	1950	Lecturer	1957
A Emerson	1950	Lecturer. Reader in Ship Hydrodynamics	1977
RL Townsin	1952	Lecturer. Senior Lecturer 1968. Head of Department 1983-88	1991
R Munro-Smith	1956	Lecturer. Senior Lecturer 1958	1963
EJ Glover	1957	Lecturer. Senior Lecturer 1973. Director of Cavitation Tunnel 1977-94	1994
M Chilton	1958	Lecturer. Senior Lecturer 1971	1983
JA Teasdale	1965	Lecturer. Senior Lecturer 1972	1989
JB Caldwell	1966	Professor & Head of Department 1966-83. Head of School 1975-80 & 1986-89	1991
P Atkinson	1969	Lecturer	2002
AT Ractliffe	1969	Lecturer. Senior Lecturer 1984	1989
J King	1971	Lecturer	1978
IL Buxton	1974	Reader in Marine Transport. Deputy head of Department 1993-2002	2002
B Denness	1975	Professor of Ocean Engineering	1985
PW Penney	1977	Lecturer	1991
GE Hearn	1978	Lecturer. Snr.Lecturer 1989. Prof. of Hydrodynamics 1991-1997, HoD 1993-95.	1997
P Sen	1980	Lecturer, Sbr, Lecturer 1992. Professor 1994. Head of Department 1995-2000.	
W Hills	1983	Lecturer. Senior Lecturer 1990. Director of EDC 1990. Professor 1996.	2000
MJ Downie	1984	Lecturer. Senior Lecturer 1995	
P Bettess	1985	Professor of Offshore Engineering 1985-95	1995
R Kattan	1986	Lecturer	1994
Marine Engineering			
AW Jones	1947	Lecturer. Senior Lecturer 1952	1976
GH Chambers	1956	Professor of Marine Engineering. Head of Department 1966-75	1975
I Thorp	1971	Lecturer. Head of School 1988-9. HoD of Marine Technology 1989-93.	1998
RV Thompson	1975	Professor of Marine Engineering. HoD 1975-86. Head of School 1980-86	1998
G Armstrong	1977	Lecturer. Senior Lecturer 1986	1989
A Fowler	1978	Lecturer	1991
T Ruxton	1984	Lecturer	1993
Marine Technology			
AP Roskilly	1990	Lecturer. Professor 1999	
M Atlar	1993	Lecturer. Senior Lecturer 1999. Professor 2001	
RW Birmingham	1994	Lecturer. Senior Lecturer 2000. Professor 2002	
PL Zhou	1994	Lecturer	2001
PNH Wright	1995	Lecturer	
E Mesbahi	1995	Lecturer. Senior Lecturer 2002	
A Incecik	1996	Professor. Head of Department 2000.	
D Clarke	1996	Lecturer	
GJ Bruce	1996	Lecturer. Senior Lecturer 2001	
YC Pu	1998	Lecturer	
CD French	2000	Lecturer	
RW Moss	2001	Lecturer	
HS Chan	2001	Lecturer	

Not included in the table are short-term appointments including FH Todd (1941-2), JL Taylor (1951-2), KR Chapman (1967-9), RG Woodhead (1972-74), and PW Marshall (1992-4).

Educational initiatives

In keeping with the policy of diversification through this 40-year period, the department has greatly expanded the scope and flexibility of its courses and curricula. Space precludes giving any detail of the content of these taught courses, but the subject titles clearly show the progressive diversification beyond the ambit of classical naval architecture into a much wider marine field.

Table IV overleaf summarises the main changes since 1967 and tells its own story of adaptation to the changing industrial and employment environment, and to the motivations of student applicants. The following section provides some evidence of the success of this policy.

Table IV Developments in teaching programmes 1967 – 2002

Year	
1967	First MSc course in Shipbuilding introduced
1968	Restructuring of BSc courses to include options in final year – ship design, ship hydromechanics, ship structures, shipbuilding science
1970	MSc course restructured to comprise 3 major and 2 minor options
1971	Marine transport and operations added as final year option
1972-79	MSc course major options increased to 8 including marine transport and marine engineering subjects
1979	Offshore vehicle design introduced as a final year option
1979	BSc course becomes BEng
1980	Offshore engineering added to MSc options
1985	MSc major options increased to 11 including Fluid-structure interaction
1986	MSc course "streamed" into 3 groups – Marine Technology, Marine Engineering, Offshore Engineering
1988	4-year MEng course in Marine Technology introduced
1989	BEng in Marine Technology offers 4 streams – Naval Architecture, Marine Engineering, Offshore Engineering, Small Craft Technology
1996	Master of Research in Marine Technology (MRes) introduced
1998	MEng course streamed into 4 options as for BEng course
2000	MTech in Marine Technology – a collaborative distance learning program – introduced
2002	MSc courses streamlined into 10 subject areas, now including Pipeline Engineering, Offshore and Environmental Technology and 8 others

Output of graduates and postgraduates

One clear measure of the activity and attractiveness of a University department is to be seen in the numbers graduating each year.

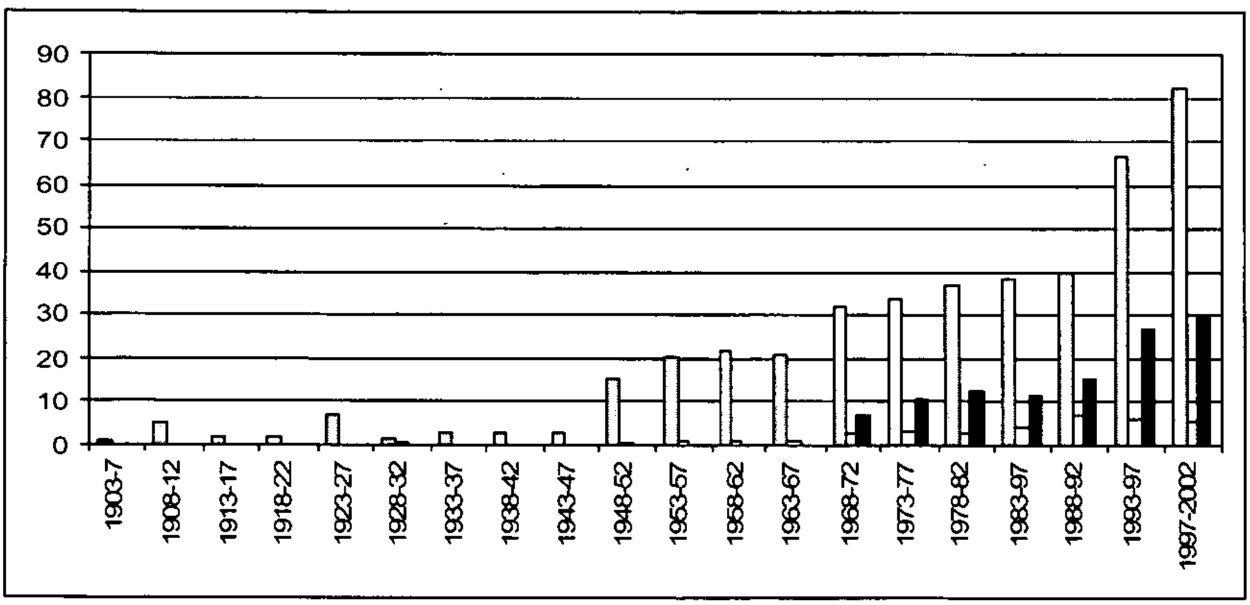

Fig.1 Numbers obtaining degrees – annual average over successive 5-year periods

Fig. 1 represents this "output" of DNAS and DMT over the whole 100-year period. To smooth out the considerable annual variations, the 3 bars in each period show from left to right the annual numbers, averaged over successive 5-year periods, of students who obtained *first degrees* (BSc, and later BEng and MEng); *higher degrees by research* (MSc, MPhil and PhD); and *higher degrees by course* (MSc and MRes). Clearly seen is the post-war expansion around 1950, with another increment from about 1970 in which higher degrees began to feature more strongly~ and from 1992 when the outputs of DNAS and DMT are aggregated. Also in this latter period the attractions of the multi-option MSc taught course and the new MRes have given a further fillip to postgraduate numbers.

Not included in the above are those students, often graduates from other disciplines wishing to "convert" to marine work, who have enrolled for 9-month Certificate, or 12-month Diploma, courses. These in one form or another have been available for much of the period under review and have attracted typically 1-5 students each year. Even without these, and even allowing for the effects of birth-rate changes and the great expansion of higher educational opportunities, the growth in numbers of marine technology graduates, now close to 120 per annum, is a considerable achievement when set against the great declineof one of the foremost industries in the north-east of England.

Research, development and industrial collaboration

This sector of academic activity has grown no less dramatically than the teaching work. Thanks to the efforts of Professor Burrill and his colleagues, the new Newcastle University in 1963 already had an active programme of basic and applied research in ship propulsion and hydromechanics. W Muckle was alsopublishing regular papers on the possible applications of aluminium alloys to ship construction. These departmental research activities benefited from the availability of the cavitation tunnel and towing tank, and the support of industrial partners including the propeller manufacturers and the Aluminium Development Association.

In the 1960s and early 70s the Government published a series of policy-making reports on the organisation of Civil Science and on the management of research and development. Significant organisational changes ensued, such as the creation of the Science Research Council (later to become SERC) and the Requirements Boards for various industrial sectors, including Ship and Marine Technology. One strong theme running through the emerging policy was that Universities should now be recognised as a major national resource not only for fundamental research, but also for applied research directed towards industrial needs and priorities. Funding was made available for the creation of "Industrial Units" in appropriate Universities such as Newcastle, where Caldwell's bid to establish a Marine Industries Centre (MIC) was successful. Opened in 1970, and headed by RV Thompson who had been working in America, the Centre won a number of contracts, particularly concerning the simulation and improvement of marine machinery systems, the emulsification of marine fuels and closed-cycle power units. Thompson succeeded GH Chambers as professor of Marine Engineering in 1975, and some members of the MIC staff also moved to the University payroll. One lasting result of MIC's 7-year existence was the creation of the "Jones Laboratory" for marine engineering research.

On the naval architecture side, research contracts and studentships stimulated increasing activity, especially in ship hydromechanics, propulsion and structural analysis and design. In 1973 the SRC published a report on Marine Technology, which led to the formation in 1976 of the Marine Technology Directorate (MTD) as a special unit of SERC to promote University R&D in this hitherto rather neglected (at least by SRC) field The successful bid by Newcastle University to become one of six "Marine Technology Centres" led not only to the award in 1980 of what was then one of the largest single research grants to be awarded - £1.5 million - to the University, but also to a stream of MTD funding for marine work which was to last for another 15 years. This was also one of the first grants for a multidisciplinary "programme" of work, and embraced more than 20 projects in 4 faculties - Engineering, Science, Medicine (on hyperbaric medicine) and Agriculture (on sea-bed ploughing and pipe-laying - work which later led to a world-leading company in sub-sea technology). The administration of this ambitious programme was vested in the School of Marine Technology, funds being made available for administrative support and an information officer.

The School of Marine Technology had now become the hub of a diverse research programme, with an increasing emphasis on offshore-related work. The Centre was able to attract substantial funding, and opportunities for postgraduate study, throughout the 1980s and much of the 1990s. During this time also, further initiatives by SERC (later to become EPSRC) enabled the School to become more closely involved with industry and its research needs. Successful bids were made for "CASE studentships" and for "Teaching Company" projects in collaboration with shipbuilding, ship repairing, and offshore companies. And in 1989, arising out of a growing interest and expertise in design, staff of the School were awarded a major grant to establish an "Engineering Design Centre", headed by W Hills. Space was found in the Armstrong Building to accommodate a rapidly expanding EDC staff and computing facilities, to work with a growing family of industrial partners, to promote improved practice in the design of large made-to-order products.

The high quality of such effort brought just rewards in the award to the Department of Marine Technology of the top rating in the 1996 Research Assessment Exercise. No doubt stimulated in part by the dictates of the "formula funding" of departments resulting from the increased accountability now required of Universities, there has been an impressive increase in the output of published work, and of funding for research, in this period. Staff have been quick to recognise funding possibilities, for example from EU initiatives (such as ESPRIT, BRITE and MOSES), with good research proposals, often in collaboration with other marine centres in Europe. That the Head of Department was able to report to the Advisory Committee in 2001 that research income was of the order of £70-75k per academic staff member, was a tribute to the continuing energy and high reputation of his team.

Premises and Facilities

When 50 years ago Professor Burrill bad the Towing Tank located in the Armstrong Building, and the Cavitation Tunnel erected in the adjacent boiler-house, he anchored the Department of Naval Architecture firmly to its original base on the university campus. From a single lecture room, a drawing office and professor's room before WW2, the DNAS (and now DMT) have since had the continuing problem of finding space to accommodate the expansion of teaching and research summarised above. Fortunately the original Armstrong Building was endowed with generous room heights and sturdily buttressed walls, so when The Department of Naval Architecture needed more floor area in the late 19608, some relief

was afforded by building intermediate floors in the ground floor spaces. Also it was clear that with the advent of computer-generated drawings there was no longer a need for so much time or space to be devoted to drawing work, so a large drawing office on the first floor was subdivided into staff rooms and lecture/conference areas. More rooms were added by building on top of the towing tank; and further mezzanining in the main laboratory accommodated the ocean engineering group as it grew after 1975. The compact, if Byzantine, geography of the resulting department has generally been beneficial.

But space limitations have curbed ambitions for new large experimental facilities; so alongside the growing provision of computing systems, the main emphasis has been on u pgrading existing equipment. Thus the capability of the towing tank has been much enhanced by new wave-making, measuring and observing equipment; and thanks to major grants from SERC (MTD), the University and Stone Manganese Marine, in 1979-80 the cavitation tunnel was substantially rebuilt with an enlarged working section and improved instrumentation. Re -opened by the head of MTD, M Adye, it was appropriately named "The Emerson Cavitation Tunnel", - a unique facility in British Universities.

In the large ground floor laboratory, various items of equipment, including a 2Oton structures test frame and a stability tank were much used for both teaching and research; and more recently a 9.6m flume with wave-making facility, a large U -tube for oscillating flow tests on offshore structural members, and apparatus for measuring resistance characteristics of different hull coatings, were added. The departmental workshops expanded into adjacent space vacated by the Chemistry Department while other contiguous areas have been annexed for a variety of purposes. Thus has life in the University's oldest building been one of timely adaptation and opportunistic expansion; while the proximity of departments such as Religious Studies and History, and the sound of music from Students practising in the nearby King's Hall, continue to preserve something of the ambience of a cultured university.

International activities The presence of overseas students, noted in earlier years, has maintained the international flavour of naval architecture, and of marine work generally, at Newcastle University. In the post WW2 expansion, there was a steady flow of students from Norway and Greece; and in the late 1960s and 70s some very talented students from Singapore were sponsored by their government by to return to outstanding careers there. Long-term links with Turkey and Egypt continued to bring students; and many more from countries who were developing their marine industries - Hong Kong, South Korea, Brazil and later Indonesia and the People's Republic of China -, ensured that the cosmopolitan mix of students was maintained. Over the years, typically 25-35% of undergraduates have come from overseas. At postgraduate level, a predominantly UK population in the 1960s has changed. as the difficulty of attracting home students to postgraduate work has intensified, to a situation where EU countries, other than UK, now provide the majority of students.

Naval architecture and marine technology have always drawn strength and interest from their international nature; and in many other ways Newcastle's links with the global community have prospered. An example was the formation, led jointly by Professors Caldwell and van Manen (from Delft), of the West European Graduate Education in Marine Technology (WEGEMT). The first of a continuing series of WEGEMT schools - on Advanced Ship Design Techniques - was organised at Newcastle by Dr. Townsin in 1978, attracting over 100 participants. Other collaborations have included exchange agreements in the 1980s and 90s with Universities in Poland and Indonesia. which have brought students and academic staff to Newcastle for research of mutual interest.

The increasing involvement of Newcastle staff in international groups such as ITTC, ISSC, and many others has further strengthened overseas contacts. It has led, too, to a number of successful conferences being hosted at Newcastle, recent exa mples including PRADS 92, PROPCA V 95, IMDC97, NCT 50 2000 and ENSUS 2000. Indeed the number of such events in the last 10 years has exceeded the total for the pre vious 90 years. In this and in other aspects of its work, it can surely be said that Marine Technology at Newcastle is now in very good shape; and all concerned can look forward with confidence to a second century of distinction.

ACKNOWLEDGEMENTS

For helping the Author to gather material against a very tight deadline, special thanks are due to Atilla Incecik, Kathleen Heads, Richard Carter, Gerry Dane and staff in the Special Collections department of the Robinson Library. This paper cannot claim to be the definitive history of this part of the Newcastle story, and any errors or omissions must be blamed on the Author. But at least it has placed on record some of the main events, vicissitudes and achievements of a remarkable century.

Establishment of UK's first School of Marine Science and Technology

A. Incecik, PhD
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SYNOPSIS

This paper describes the establishment of the UK's first marine school at Newcastle University, to provide a single base for all education, innovation and research related to the sea. The activities of the School of Marine Science and Technology cover marine biology, marine science, marine engineering, naval architecture, offshore engineering, coastal management and small craft technology. The School of Marine Science and Technology was formed on 1st August 2002 by merging the existing Department of Marine Sciences and Coastal Management with the Department of Marine Technology, both of which had 100-year histories and international reputations for teaching and research. The new School will continue with the current wide range of successful activities of the former Departments but will also branch out into new and exciting areas in the marine world.

INTRODUCTION

Marine Science activities at Newcastle include a one hundred year history of research into the flora and fauna of the shore and coastal waters. The wealth of knowledge arising from this has increasing relevance and importance in an environmentally conscious era. To enable sustainable use of the seas in the new century, the environmental issues of conservation of sea life and management of the marine environment and coastlines will be critical. Marine Science will play a pivotal role in establishing policy and supporting industry with research and the education of the next generations of scientists who will work internationally in this area.

This year we are also celebrating one hundred years of Naval Architecture education at Newcastle, which has been supporting the development of ships, offshore structures and other marine vehicles. Marine Technology education and research at Newcastle has been central to the development of new generations of ships, propulsion systems, offshore structures and small craft. The use of the sea and waterways for energy resources, transport and leisure is growing rapidly, and the knowledge base in Marine Technology will support this growing activity.

The School of Marine Science and Technology will take the lead in the development of new solutions for sustainable marine industries founded on a thorough knowledge of the sea and those parts of the environment that interact with it, including the atmosphere above the sea, substructures beneath it and the shoreline surrounding it. The research on marine environment at the School includes the following areas:

- Large scale monitoring and prediction of ecosystem change, and examination of the molecular and cellular mechanisms of organism' responses

- The marine contribution to climate change through studying the fluxes and production of important mediators which include: climatically active trace gas cycling and sea-air exchange; the measurement and quantification of the disproportionate contribution of fluxes in estuaries and oceanic upwellings; the role in the oceanic climate change of nutrients associated with major production sources (fisheries, kelp and mangrove).

- Development of technologies for reduced environmental impact from marine and offshore operations

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Author's Biography
Professor Atilla Incecik is Lloyd's Register Professor of Offshore Engineering and Head of School of Marine Science and Technology at the University of Newcastle Upon Tyne.

- Development of technologies for the production of environmentally acceptable renewable energy

- Development of techniques for the assessment of impact on the environment and society from production , maintenance, repair and operations of ships, offshore and oil and gas platforms and renewable energy devices.

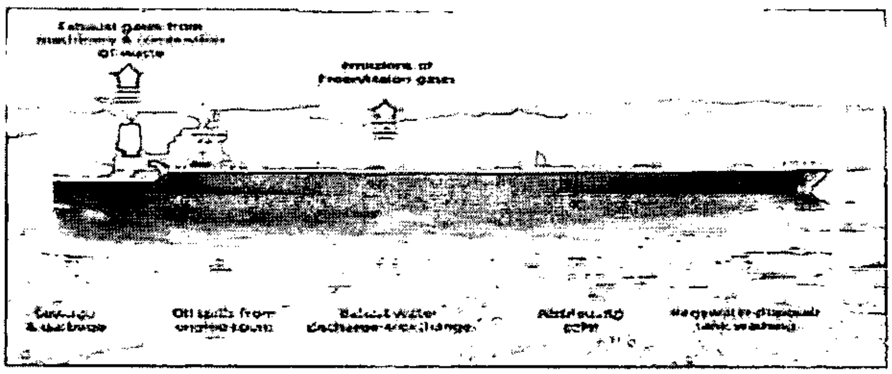

Figure 1. Emissions from a Ship

UNDERGRADUATE PROGRAMMES

The School currently offers four 3year courses leading to a BEng Honours degree in Marine Engineering; Naval Architecture; Offshore Engineering and Small Craft Technology as well as two 3-year courses leading to a BSc degree in Marine Biology and Zoology. It also offers five 4-year courses leading to the MEng degree in Marine Technology; Marine Engineering; Naval Architecture; Offshore Engineering and Small Craft Technology. In addition some new teaching areas (for example physical oceanography and ocean acoustics) will be established. Currently a new undergraduate degree level integrated course entitled: Marine Environmental Engineering is being established. This course will include the following discipline areas: transportation; coastal engineering; offshore engineering; recreation; fishing; waste disposal and emissions; global climate modelling; and engineering systems including acoustic sensing systems and biological sensors. The new course will integrate the existing courses offered in marine biology, coastal management and marine technology.

Current student numbers in the School's undergraduate programmes are summarised in the following Table:

Table I Student Numbers

	Marine Technology	*Marine Science*	*Zoology*
Foundation Year	16		
Stage 1	58	42	38
Stage 2	53	32	35
Stage 3	54	40	30
Stage 4	12		
Total	193	114	103

POSTGRADUATE PROGRAMMES

The School offers PhD and MPhil by research programmes in addition to MSc. and Diploma taught courses in Marine Engineering, Marine Technology, Pipeline Engineering, Offshore Engineering, Tropical Coastal Management, Naval Architecture, Marine Electrical Power Technology, Marine and Offshore Power Systems; Offshore and Environmental Engineering; Marine Transport with Management. Certificate courses in Marine Engineering and Naval Architecture are also available and are usually a preparation for the MSc. courses. There is also a degree of Master of Research (MRes), with a combination of research and taught elements. With the recent establishment of the Chair in Marine Transport and Management a new MSc course programme in Marine Transport with Management was launched this academic year.
Currently there are 107 students on our taught MSc programmes and 67 students studying for a PhD degree.
Brief aims for each of the MSc taught courses can be summarised as follows:

- **Marine Engineering:** This course is aimed at equipping students with a thorough understanding of existing and state-of-the-art technologies in marine engine design, modelling, control, transmission and electrical systems as well as ship's performance and propulsion.

- **Pipeline Engineering:** This course is aimed at equipping students with technical, environmental and managerial knowledge so that they are competent in design, construction, operation and maintenance of high-pressure offshore and online pipelines.

- **Offshore Engineering:** This course is aimed at graduate engineers who wish to specialise in design, dynamic and strength analysis of fixed and floating offshore oil and gas platforms, pipelines.

- **Marine Structures and Integrity:** The course is aimed at educating graduate engineers who wish to specialise in structural design and analysis of ships, fixed and floating offshore oil and gas platforms, and pipelines.

- **Tropical Coastal Management:** This course is aimed at providing knowledge and understanding of the disciplines underpinning coastal management, the principles of integrated coastal management and holistic overview of coastal management issues, together with a range of key practical and transferable skills.

- **Naval Architecture:** The aim of the course is to produce graduates who have developed well-founded knowledge, skills and understanding of Naval Architecture.

- **Marine Electrical Power Technology:** This course is aimed at equipping students with knowledge of some of the key electrical technologies of present and future markets so that the students can address the requirements of the modern Marine Engineering industry.

- **Marine and Offshore Power Systems:** This course is aimed at equipping students with knowledge of power and machinery systems on board ships and offshore platforms.

- **Offshore and Environmental Engineering:** This course is aimed at graduate engineers who wish to specialise in design and operations of offshore oil and gas platforms, production, process and transportation of hydrocarbons whilst developing awareness towards the need of the society and the environment.

- **Marine Transport with Management:** This course is aimed at graduates who wish to work in the marine transport and shipping industries, having an understanding of technical, financial and commercial issues.

- **Marine Technology:** This course is aimed at graduates who wish to have a broad knowledge and understanding of the marine technology discipline area and the course is comprised of various modules selected by the student from modules offered in the above technology courses.

- **MRes in Technology in the Marine Environment:** The MRes course is a Masters course in research set in the context of applied technology in the marine environment. It is aimed primarily for preparing students from a wide range of backgrounds for a career in an R&D environment in the marine related industries, either immediately on completion of the course, or after having continued to study for a Ph.D.

- **MTEC:** This programme is offered by a collaboration of six UK universities – Glasgow, Heriot-Watt, Newcastle, Southampton, Strathclyde and University College London. Newcastle is the co-ordinating university.
  The programme is designed to provide flexible, innovative training for graduates working full time in the marine industry.

  The MSc and Postgraduate Diploma are available in seven technology streams. These are:

  1. Naval Architecture
  2. Marine Engineering
  3. Offshore Engineering
  4. Small Craft Design
  5. Marine Classification and Survey
  6. Conversion and Repair of Ships and Offshore Structures
  7. Marine Technology for the Defence Services

- **The Integrated PhD in Engineering and Science in the Marine Environment:** It is aimed at enabling engineers and scientists to develop expertise and in-depth knowledge in a selected marine related area, and to gain detailed knowledge and experience of research methods and management. In addition an opportunity will be provided for engineers and scientists to widen their knowledge in areas that will be of relevance throughout their academic and professional careers including an introduction to teaching and presentational theory and practice and insights into international affairs.

RESEARCH PROGRAMMES

Research groups in the School have been extremely successful in attracting large sums of income from the research councils, the European Community and industry. The current research award value in the School exceeds £6 Million.

The School's current research programme includes the following areas:

- Evolutionary Computation and Decision Support Analysis
- The Environment, Safety and Reliability
- Design Methodologies
- Marine Powering and Propulsion
- Marine and Offshore Structures and Materials
- Marine Manufacturing Systems
- System Modelling, Control and Robotics
- Theoretical, Computational and Experimental Fluid Dynamics
- Renewable Energy
- Ecosystem change
- Interactions between the ocean, the atmosphere and land masses
- Organisms response to environmental signals
- Integration of research outputs into effective socio-economic management strategies and remedial actions for sustainable development of marine resources and coastal management

Some examples of current research in the School addressing problems related to safe and economic exploitation of resources and conduct of transportation in a sustainable marine environment include:

- Control, reduction and management of impact from marine and offshore discharges which include: exhaust gases from machinery and combustion of waste; oil spills from engine rooms; ballast water discharge; bilge-water disposal and tank washing; antifouling-paints; drill cuttings and flare gases. Members of the School are involved with two EU thematic network programs, which address the issues with regard to the development of technologies for reduced impact from ships, and the development of concepts for advanced marine machinery systems with low pollution. In addition, currently the School co-ordinates a EU sponsored project on 'Onboard Treatment of Ballast Water Treatment and Application of Low-Sulphur Marine Fuel'. There are 25 partners in the project representing the disciplines of marine science, marine technology, marine biology, shipping, chemistry and economics. The School is also active in research aimed at facilitating the development of TBT free marine coatings for International Coatings Ltd

- The School has recently been involved with a number of collaborative projects with CEFAS (Centre for Environment, Fisheries and Aquaculture Science) and the Dunstaffnage Marine Laboratory SAMS (Scottish Association for Marine Science).

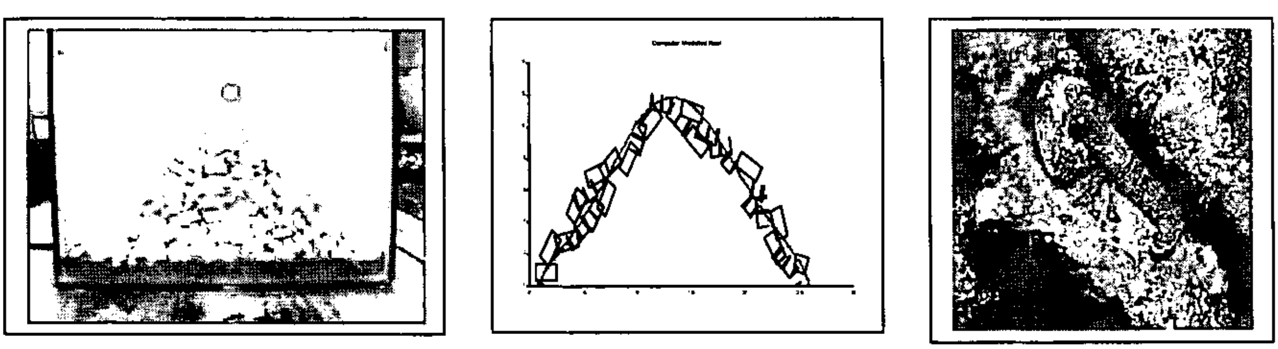

Figure 2. Modelling of Artificial Reefs

The projects involve impact assessment of TBT antifouling paints and their replacements, and modelling artificial reefs constructed of waste aggregate bi-products to determine the interactions with marine organisms and effect on the potential of commercial fisheries.

- Researchers in the School have recently completed a report for the Northern Offshore Federation so that the member companies involved in offshore decommissioning are informed of the environmental issues and technological provisions/limitations for offshore structure abandonment, re-use and scrapping.

- Development of design and analysis tools for wind and tidal energy generators. There are currently two EPSRC sponsored projects in the School aimed at developing analysis methods for the design and construction ofoffshore wind turbines and tidal power generators. The analysis methods being developed are validated through experimental measurements.

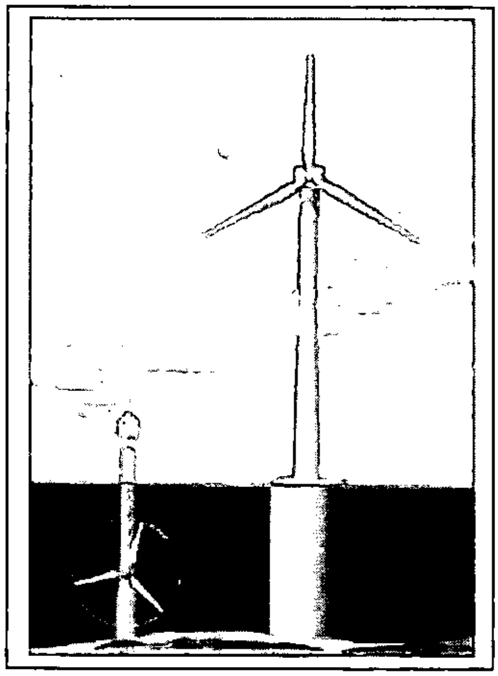

Fig. 3. Wind and Tidal Power Generation

- Reduction of wash effects and emissions due to fast sea transportation using high-speed vessels. The School is involved in three current EU supported projects aimed at the development of new high-speed vessel hull forms including integral electric pod drives to reduce the impact of waves generated by high speed craft on coastal lines and sea bed and of emissions to the atmosphere.

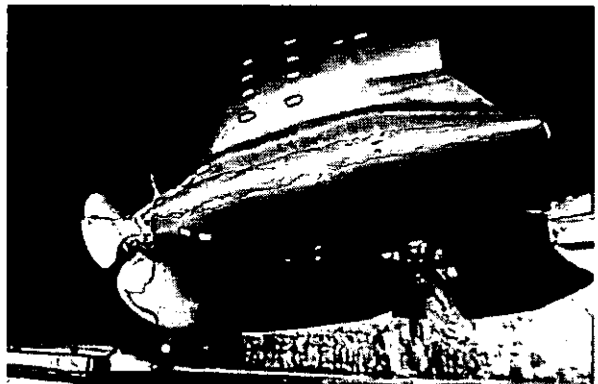

Fig. 4 Electric Pod Drives

- A new research project supported by the EU, concerns marine electric power management and power management system design and aims at improving fuel economy and reducing exhaust emissions.

- Another new project, with funding from the US Office of Naval Research, is on understanding chemical communication between fouling organisms. This project is aimed at underpinning the development of smart coatings to replace the present generation of biocidal antifouling (AF) and foul-release (FR) coatings.

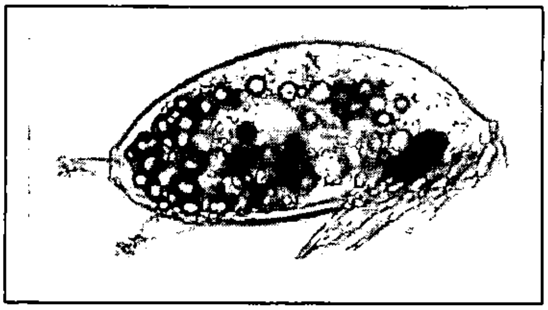

Fig. 5 Settlement-stage, cypris, larva of *Balanus amphitrite*

LABORATORY FACILITIES

Emerson Cavitation Tunnel

After the construction of the World's first cavitation tunnel by Parsons in 1895, the next major landmark in propeller cavitation research in Newcastle was the commissioning in early 1950 of the Newcastle University Cavitation Tunnel. During the ensuing 52 years the tunnel has adapted itself to the ever changing requirements of the propeller industry and has been able to survive as one of the living legends amongst the cavitation tunnels world wide

Since the modernisation of the tunnel in 1980, the tunnel was renamed as the "Emerson Cavitation Tunnel" and has an enlarged measuring section of 3.1m x 1.21m x 0.8m to test bodies at a maximum water speed of 8 m/s. The absolute pressure range of the tunnel varies between 7.6 and 106 kPa. Its large cross section and the main dynamometer provide the tunnel with the ability of testing model propellers up to 0.40m diameter in open water and 0.25 m diameter behind a dummy hull. Although no major structural alteration has been carried out on the tunnel itself since 1980, continuous improvements have taken place on the essential parts of the operating and the flow measurement system. These included the purchase of a portable system of equipment for the measurements and analysis of the wake and hull pressures as well as for acoustic measurements. A second dynamometer was also purchased for testing smaller propeller models behind hull models. Boosted by the recent three major EU sponsored projects, the tunnel has now acquired a new specialised podded dynamometer for testing the new generation podded propulsors. In parallel to the developments in computer technology the instrumentation, data collection and on-line data analysis of the tunnel have been improved using computer based environment. Although traditional still/moving photographic equipment is still available, this ability of the tunnel has been enhanced with the purchase of a high speed CCD video camera with a fast electronic shutter which can be triggered at any time yielding an imaging frequency of 0 to 50 frames/sec.

Although the tunnel is equipped with various flow measuring devices based on pitot tubes and small impellers, the major improvement in this area has been the purchase of the 2-D combined Laser Doppler Anemometry and Phase Doppler Anemometry (LDA/PDA) system in 1999. This equipment includes a 60 mm diameter 2-D submersible probe. It has a Multi-PDA signal processor, 3W water-cooled Argon-Ion Laser and a fully computer driven 3-D traversing system. The whole system is flexible enough to be upgraded for the third component in the future. The funding for this equipment was raised from the EPSRC and other industrial supporting companies, jointly with the Universities of Strathclyde and Glasgow. The accurate flow measuring systems of the Departmental facilities were enhanced further with the recent purchasing of the EPSRC sponsored 2-D Particle Image Velocimetry (PIV) system equipped with a 120mJ laser and a 1.3x1.0K MP Hi Sense digital camera

As part of the general maintenance programme, the dynamometer drive control and vacuum pump systems have recently been replaced with modern ones. In April 2000, the tunnel celebrated its 50th Anniversary by holding an international conference on propeller cavitation (NCT'50).

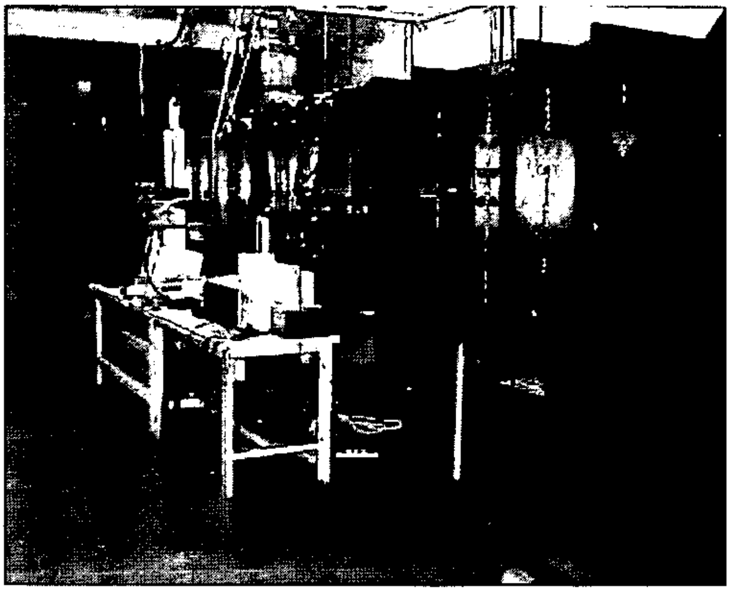

Fig. 6 Emerson Cavitation Tunnel

Fig. 7 Wash measurements on a catamaran model propeller using LDA equipment in the Emerson Cavitation Tunnel

Towing/Wave Tank

Calm water resistance, launching and seakeeping experiments are conducted in the towing/wave tank which is 37 m long, 3.70 m wide and 1.25 m deep. Models are towed using a monorail carriage system which has a maximum speed of 3 m/s. A rolling seal wavemaker is used to generate regular and irregular waves. The wavemaker is electronically controlled through the use of wave-generation software mounted on a micro-computer. Waves of up to 12 cms in height and wave periods of 0.5 seconds up to 2 seconds can be generated.

In the towing tank, calm water and added-wave resistance of the models is measured using uni-axial force transducers. The rigid-body motions of a model are measured using either potentiometers, or a set of light emitting diodes mounted on the model and monitored by SELSPOT cameras. Recently a new motion measurement system has been obtained. This comprises passive reflective sensors mounted on the model and two infra red combined emitting sources and cameras The system defines the X, Y and Z co-ordinates of each reflective marker which, when viewed from the two suitably disposed cameras, permits the rigid body motions to be determined. Rigid-body accelerations are measured using a gravity type accelerometer while the mooring forces are measured using uni-axial force transducers. Resistance-type wave probes are utilised for measuring the wave heights across the tank as well as in the vicinity of a model for wash measurement purposes. A miniature underwater camera and CCD system is used to observe and measure underwater behaviour of the models. The LDA and PIV equipment described earlier are portable and can also used extensively in the towing tank .

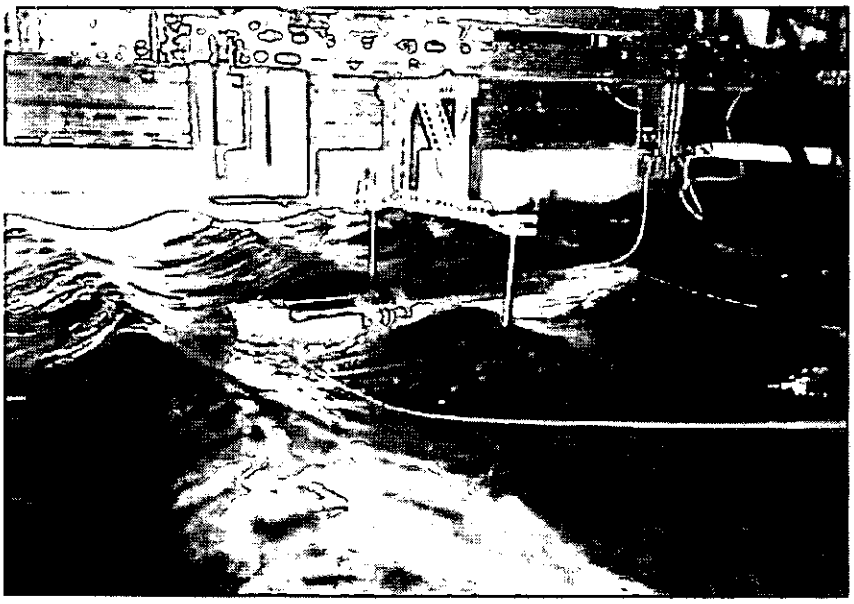

Fig. 8 Towing /Wave Tank

The U-Tube and Wave Flume

The U-Tube water tunnel has a 0.6 x 0.6 x 1.5 m working section. It is used for simulating wave flow about slender bodies and determining their fluid loading in planar oscillatory flow over a Keulegan Carpenter range extending to about 30. It is also well suited for flow visualisation experiments and flow field measurements using lasers. The Wave Flume is 9.6 m long and 0.305 m wide internally with a water depth of 1m. Two wave makers, one at each end, are incorporated. Both 2D excitation studies and hydrodynamic reactive coefficient studies can be carried out. A hydraulic actuator is available to force oscillate the model to determine the hydrodynamic reactive coefficients of added mass and fluid damping. Pressure distribution studies may be carried out simultaneously. The U-Tube and wave flume also take the advantage of the laser equipment as the ideal controlled test environment

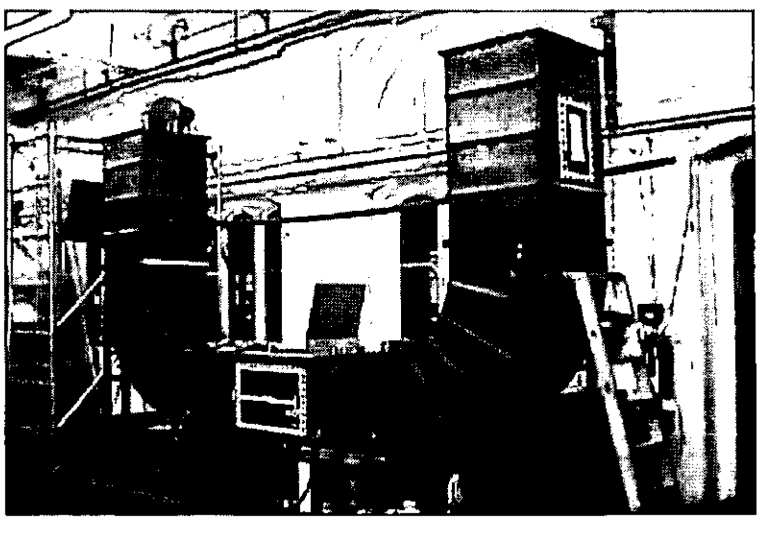

Fig. 9 The 'U' Tube

A New Combined Wave, Wind and Current Generator

A new combined wave, wind and current generator is currently under construction and will be installed in the School during February 2003. The new equipment is funded by the Regional Development Agency ONE North East and will be used for testing renewable energy devices and marine and offshore structures

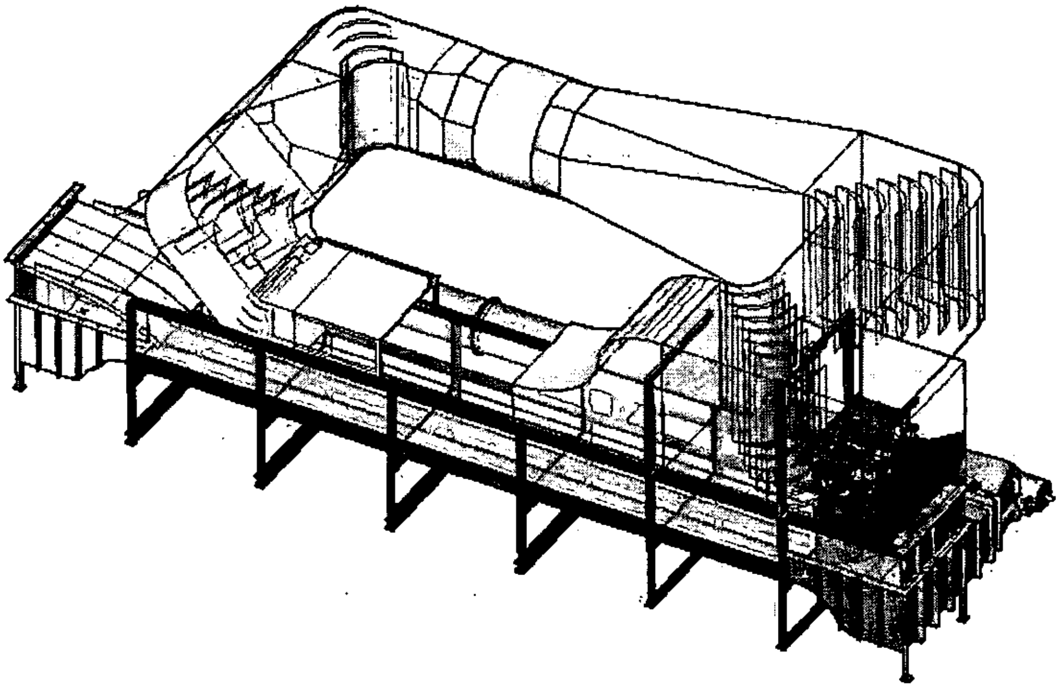

Fig. 10 Combined Wave, Wind and Current Generator under construction

The Jones Marine Laboratory

The Jones Marine Laboratory was established in 1976 and is primarily utilised for Marine Engineering undergraduate and postgraduate teaching, consultancy and research. The laboratory is fully supported by marine, mechanical and electronic technicians with facilities for fabrication and machining to allow test rigs and prototype equipment to be produced 'in-house'. The laboratory includes a number of marine diesel engine test beds providing a wide range of power outputs. Uniquely, a large medium speed engine is available which is fully instrumented so that parameters such as engine brake horse power, fuel consumption, cylinder pressure, fuel injection pressure, needle valve lift, valve temperature, cylinder liner temperature, etc. can be measured and analysed using an advanced data acquisition system. This engine has been adapted to enable one unit to operated using different fuels and is continuing to allow research into methods to improve engine efficiency, fuel consumption and emissions

A fuel atomisation test and measurement rig is available which has been specially designed to investigate and allow fuel atomisation to be analysed and modelled. In addition to those traditional instruments for engine tests, the Jones Laboratory has engine emissions measurement equipment capable of determining all kinds of species from the engine exhaust gases such as NO, NO2, HC, CO, SO2, CO2, O2.

Engine Specification:

- Ruston 6APC Diesel Engine - Rated power:735 kW at 1000 rpm
- Caterpillar 3116 Marine Diesel Engine - Rated power: 220 kW at 2800 rpm
- 2 x Perkins D3.152 Diesel Engine - Rated power: 36 kW at 2500 rpm
  One of the Perkins engines has been retrofitted as a close cycle diesel.

The Dove Marine Laboratory

The Dove Marine Laboratory was established on a small scale in 1897 by Mr. Alexander Meek, afterwards Professor of Zoology at Armstrong College. The laboratory was destroyed by fire in 1904. Fortunately it was agreed that the laboratory should be re-built, and the owner of the site, Mr. Wilfred H. Hudleston, agreed to build a laboratory on larger and better scale, provided that it should be named the Dove Marine Laboratory, after his ancestress, Eleanor Dove. The new building was formally opened by the Duke of Northumberland in 1908. Today the facilities of the Laboratory include a large open-plan aquarium with a flow-through water system. The seawater intake is situated in Cullercoats bay. Water is pumped into the building by an underground pipe entering the Laboratory on the west side and kept in holding tanks. It is filtered through sand and drawn off continuously. Fixed tanks include aquaria suitable for deep-sea species as well as shallow tanks for the maintenance and husbandry of coastal and shore species. The main aquarium has large wet benches with supplies of running sea water and air, allowing variable short term experimental designs for small tanks to be set up. There is also a closed recirculating seawater system with a capacity of 2000 litres and with temperature (3-20°) and photoperiod controls. In addition to sand filtration this seawater is filtered through biological filters and treated with UV. The constant volume of the system is continuously replenished in response to experimental demands.

The laboratory is an invaluable asset not only to the students and researchers in the School, but also to students, teachers and researchers from local schools, other universities in the UK and elsewhere around the world.

Fig. 11 The Dove Marine Laboratory

R/V Bernicia

The Research Vessel *Bernicia* is a multi-purpose ship of the stern trawler type. The vessel carries out a varied range of biological and other scientific programmes. These include: conventional surface, mid-water and bottom trawling using static fishing gear plankton sampling and bottom dredging water samples taken from a depth of up to 200 metres. Sea floor coring and rock dredging is carried out in water depths to 200 metres, soft sediment sampling and sea floor photography can also be undertaken in depths down to 200 metres. The vessel routinely works with scientists and divers deployed in an inflatable boat and is also fitted with diving ladders.

Ridley Building

The Ridley Building houses new research aquaria facilities in the form of 4 controlled environment rooms with independent re-circulating seawater systems. These were constructed in 2000 as a result of a successful NERC JREI bid. In addition there are 2 culture rooms for algae and invertebrate culture and a number of other constant temperature rooms. Research laboratories provide excellent space for modern marine biological research including molecular biology

SCHOOL STAFF

Academic Staff

Professor M. Atlar : Professor of Ship Hydrodynamics, Director of Cavitation Tunnel
Teaching: Marine and ship hydrodynamics, High speed and advanced craft hydromechanics, Powering marine vehicles, Marine vehicle performance and propulsion.
Research: Marine & ship hydrodynamics, Hydrodynamic testing. Marine computational fluid dynamics, High speed & advanced marine craft, Marine propulsors & cavitation, Marine renewable energy

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Bob Hindhaugh: Mechanical Technician
John Knowles: The Dove Marine Laboratory
Keith Laing: Computer Technician
David Lamb: Electronics Laboratory
Peter Mackintosh: Mechanical Technician
Tony Muse: Laboratory Supervisor
Ian Paterson: Cavitation Tunnel
Richard Preece: Laboratory Technician
John Price: Jones Laboratory
Alistair Simpson: Skipper- RV Bernicia
Kate Sutton: Deck Hand- RV Bernicia
Keith Taylor: Workshop Technician
David Willis: Electronics Laboratory

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Kathleen Heads: School Administrator
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Carol Weiss: Secretary

CLOSING REMARKS

The new School of Marine Science and Technology has been established on very strong foundations built over one hundreds years of excellence in teaching and research by the former Department of Marine Sciences and Coastal Management and the Department of Marine Technology at Newcastle. The new School is now set to lead the marine field for another one hundred years.

ACKNOWLEDGEMENT

This paper is compiled from various internal documents written by Prof. M. Atlar, Mr. G.J. Bruce, Dr. A.S. Clare, Dr. M. J. Downie, Kathleen Heads, Dr. C.L.J. Frid, Prof. P. J.W. Olive and Prof. A.P. Roskilly. The picture of the Dove Marine Laboratory was provided by Dr. Jane Delany. The Author is grateful to these colleagues for their assistance.

Possibilities of application of FSA methodology to safety against capsizing

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SYNOPSIS

During the last period much stress is put into increasing safety at sea. This is the result of increasing consciousness of the responsibility for the human life in the first line, sensitivity of the public opinion, and understanding of the hazards to environment. One of the important aspects of safety of ships at sea is safety against capsizing, in other words assurance of sufficient stability. Stability requirements are currently included in the IS Code developed by the International Maritime Organization (IMO). There are opinions expressed, that safety requirements of the IS Code are inadequate; they are mainly related to design and they do not take into account operational factors, including human factor adequately. Doubts are also expressed about the future philosophy of stability regulations. Quite recently, idea of application of Safety Assessment (SA) method was advanced which makes possible to take into account, apart design requirements, also human factor and operational aspects. Formal Safety Assessment being formalized procedure of safety assessment has been recently recommended by IMO. There are however serious difficulties in application of FSA methodology to stability problems. When considering application of FSA methodology to intact stability problems in the first step hazards that may lead to loss of the ship should be identified. In the paper various hazards related to scenarios of capsizing are considered and possible methods of assessment of risk involved are discussed.

INTRODUCTION

Although statistics of casualties shows that the probability of losing life at sea is not higher than in other human activities there is an increasing concern on the safety at sea. This is mainly the effect of serious disasters such as capsizing and foundering of large passenger ferries, HERALD OF FREE ENTERPRISE, ESTONIA and others that involved hundreds of fatalities. Therefore attention of maritime administrations and first of all of the International Maritime Organization (IMO) is focused at increasing safety at sea and adopting rational and presumably more stringent regulations. Casualties caused by insufficient stability do not constitute the large percentage of all casualties. However they usually involve many fatalities. Therefore the risk involved is high.

The first intact stability requirements comprising limiting values of stability parameters were adopted by IMO in 1968 by resolutions A.167(VII) (passenger and cargo vessels) and A.168(VII) (for fishing vessels). They were followed by requirements for some other types of ships and by inclusion of weather criterion. Ultimately in 1993 by resolution A.749(18) Intact Stability Code was adopted comprising intact stability requirements for all types of ships. This code is under constant review but still remains a recommendation.

The existing stability requirements are criticized because of the obvious shortcomings of statistical criteria and excessive simplifications in weather criterion. Analysis of casualties did show also that many ships satisfying IMO criteria capsized, whether others that did not were operated safely.[1] Taking this into account IMO in mid-seventies initiated work on so called "rational" (improved) stability criteria that possibly should be based on probability of capsizing. This task, however, had never been accomplished and ultimately the idea was abandoned.

There was extensive discussion since then on how to improve safety against capsizing. The opinions were expressed, that this could not be accomplished only by improving stability criteria, but by taking also into consideration operational factors including human factor[2]. Ultimately application of safety assessment methods was proposed.

Possibility of applying SA was discussed quite a long time ago[3]. Recently IMO considered formalized methodology of application of SA under the name Formal Safety Assessment – FSA. FSA was recommended by IMO as a methodology that should be applied in the future to the rule making process[4].

Author Biography
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FORMAL SAFETY ASSESSMENT (FSA) METHODOLOGY

FSA according to the definition is "a structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk/cost benefit assessment".
FSA methodology should comprise the following steps:

1. Identification of hazards
2. Risk assessment
3. Risk control options
4. Cost-benefit assessment, and
5. Recommendations for decision making

FSA methodology is thoroughly described in Ref. 4
Basically FSA methodology is intended to be applied to the entire ship safety system. However application of the relevant parts of this methodology to selected subsystems may provide useful tool to evaluate particular safety problems related to those subsystems. In the paper discussion is concentrated on the possibility of application of FSA methodology to stability problems and safety against capsizing. This obviously is only one of many aspects of safety of ships at sea, but within the scope of this paper only stability aspects are discussed.

Since adoption of the IMO recommendation few applications of FSA methodology to safety problems of ships are known, and the most thorough is trial application of FSA to high-speed catamaran craft. This was a very tedious work and the team working on the application of FSA to high-speed catamarans consisted of a number of experts and scientists and its results were presented in the bulky report[5]. There are also known some attempts to apply this methodology to stability problems[6,7,8].

Application of FSA methodology requires first of all identification of hazards and assessment of risk. This had been accomplished, further steps as mentioned above could be considered. The scope of this paper is limited to the consideration of the first two steps, i.e. identification of hazards and assessment of risk.

IDENTIFICATION OF HAZARDS

Before making attempt to identify hazards that may lead to capsizing it as necessary to define what is understood by the concept of capsizing. In common language, capsizing usually is understood as the passing of the ship from the upright position or zero degrees angle of heel to the upside down position or 180 degrees heel. The above concept of capsizing is, however, not satisfactory from the point of view of studying safety against capsizing.

The ship oscillates in a seaway under the action of waves and wind. With excessive rolling amplitudes, the ship may be in a situation where further handling is impossible. Water may inrush through openings in decks and superstructures. The rudder may be disabled and the ship may have to be abandoned. This situation may be described as loss of stability accident. When considering practical problems of safety from the stability point of view, it would be better to introduce a concept of loss of stability instead of capsizing although both concepts in the following discussion will be considered as synonymous, loss of stability, however, better describes situations occurring in reality when a ship considered as capsized may not necessarily be in the upside down position.

Hazard is defined as a situation which can potentially result in loss of stability accident. There are numerous hazardous situations that may affect stability and consequently lead to loss of stability accident. They could be categorised according to various principles. Krappinger and Hormann[9] divide all hazards into two groups:

1. Hazards, that at least in principle could be controlled and that could be avoided by applying suitable measures. Included in this group are factors such as shifting of cargoes due to faulty stowage, wrong distribution of cargoes, water inrush through unsecured openings, etc.
2. Hazards, that could not be controlled by the crew. Included in this group are factors such as wind and waves, water on deck, shifting of cargoes due to heavy rolling, icing, etc.

This classification is, however more suitable when considering risk control options.
It is proposed to classify all hazards into three categories:

1. Hazards related to heeling moments caused by shifting the position of the centre of gravity,
2. Hazards related to heeling moments created by external pulling forces,
3. Hazards related to the action of wind and seaway.

The first category may comprise loading and unloading cargoes and heavy equipment, free surfaces o water in tanks and holds, icing, crowding of passengers, loose goods, water in deck well, etc. To the second category belong heeling moments created by pulling of towing hawser, pulling of fishing gear or in turning. The third category comprises situations when sailing in confused seas including wind heeling moments, breaking and abnormal waves.

CAPSIZING SCENARIOS

Capsizing or loss of stability accident never is the result of a single cause. Always there is a chain of events that results in the accident. Possible capsizing scenarios must be investigated where simultaneous occurrence of various hazards has to be taken into account. One of the methods of creating such scenarios is the well known fault tree method. The difficulty with applying this method lies in the multitude of scenarios possible. One example of application of this method was presented in the Ref. 8 in respect of shifting cargo. Some possible scenarios of capsizing were listed in Ref.10. Identification of possible scenarios of capsizing could be best achieved by a mixture of different methods which should include descriptions and statistics of casualties at sea, model experiments and opinions of experts – experienced seamen, especially those, who survived casualties.

The largest data bank on stability casualties was collated by IMO[1] in the years 1963-85 where 166 loss of stability accidents were analysed. However, many casualties were described inadequately not enabling to reach definite conclusions. Aksyutin and Blyagoveschensky[11] described more than 200 loss of stability accidents. Those sources, as well as Ref. 12 and 13 provide excellent material that could be used for the intended purpose.

Model test constitute the other source that can be used to investigate capsizing scenarios. Model tests of capsizing are scarce. Some model tests were performed in open waters (lakes), some others were performed in towing tanks. Ref. 14 provides comprehensive description of model tests performed in various research institutions. Interesting conclusions could be drawn from observation of the model behaviour in waves, unfortunately other factors, as for example shifting of cargo, wind effect etc can not be reproduced correctly.

The analysis of stability casualties did show that in a great majority of capsizing scenarios, many factors were involved. Single capsize modes are rather rare in reality. As the most obvious cause of capsizing is action of waves and wind, single capsize modes could include:

- Beam wind in calm sea,
- Ship in waves from stern quarters. This includes pure loss of stability on wave crest, parametric resonance and broaching,
- Ship in beam waves, no wind effect. This includes simple and parametric resonance, rolling in steep and breaking waves, effect of wave groups,
- Abnormal very high and steep waves
- Ship in waves from bow quarter.

Many combined capsizing scenarios are possible. They may be developed from the above single modes by including the following factors:

- Wind effect in addition to waves,
- Effect of water on deck including free surface effect,
- Effect of water in the deck well resulting in pseudostatic heel,
- Effect of free surface of water in tanks or holds,
- Effect of shifting cargo,
- Effect of bow submergence,
- Effect of rudder action,
- Effect if icing.

The list is not exhaustive and, in particular, with regard to some special types of ships (fishing vessels, supply vessels, tugs, etc.), other factors also have to be included.

RISK ASSESSMENT

Risk is defined as the product of probability of an accident and its consequences, i.e. R = P x C. Probability P is the product of the probability of occurrence of the hazardous situation - C_k - and the probability of the loss of stability accident in this situation – PF_k. If the risk is calculated for all possible situations occurring during time t, then the overall probability would be:

$$PF_t = \sum_{k=1}^{k} C_k PF_k$$

The method that can be used to calculate those quantities is described *inter alia* in Ref.3 and 14.

Calculation of PF_k in cases when only wave effect (and possibly also wind effect) is taken into account could be performed by direct calculation method (mathematical simulation). Even in this case mathematical simulation of capsizing is extremely difficult because of a multitude of capsizing scenarios, because of the highly non-linear behavior of the ship in confused seas and because of the necessity to include six or even seven degrees of freedom simulation. In principle, however, the method allows to include factors of different nature and also even human factor, although the last possibility has not been yet fully investigated.

The other possibility to assess the probability of capsizing is performing model tests. Model tests are performed in order to check whether the ship may capsize in a seaway. Seaway is reproduced in towing tanks allowing only limited length of run, although runs are usually repeated several times each time with random realisation of the irregular seaway of assumed spectrum. If the model capsizes, then it is concluded that stability is insufficient, but if it does not, it does not mean that stability is sufficient and it will not capsize when the number of runs will increase. Moreover, in its lifetime the ship may encounter abnormal waves that are not reproduced in the tank. There are currently developed by ITTC Guidelines for Experimental Testing of Intact Ship Stability that provide uniform and sound basis for carrying out these tests. Still assessment of the probability of capsizing of the ship in long term on the basis of model experiments should be made with caution.

With regard to the second term in the risk equation, i.e. consequences the following could be said. Loss of stability accident usually involves considerable loss of life, *i.e.* it falls into the catastrophic category. Therefore only the acceptable level of probability of such accident should be considered. This is a problem requiring separate consideration. In this place it is suggested that the acceptable level of probability might be "remote, *i.e.* unlikely, but possible during lifetime of the ship", with corresponding number equal $1x10^{-7}$ or less.

CONCLUSIONS

From the above study it might be concluded that application of the FSA methodology to stability problems, although possible in principle, nevertheless requires extensive research effort that may take years. Basically there is sufficient material available to identify hazards and capsizing scenarios, but mathematical simulation of capsizing in those situations is far from providing practical results. Model tests of capsizing on the other hand are only limited to short term prediction of capsizing due to action of waves and assessment of long term probability of loss of stability accident on this basis is doubtful.

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Environmental Performance and Eco-Efficiency of Using Biodiesel in Recreational Boats

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SYNOPSIS

Biodiesel has been widely used to fuel diesel engines for onshore vehicles, particularly, for agriculture machinery. It has been recognised as viable option for environmental protection and rational use of energy resources. Application of biodiesel for merchant ships' propulsion in a large scale has been seen a non-near future option due to lack of availability and supply chains of the fuel. However, powering recreational boats with biodiesel has shown a potential market under the driving force of marine environment protection. Incentives of using biodiesel on recreational boats are clean and environmental-friendly operations which is one of the essential features of recreational boats sector. In addition the property of bio-degradation of biodiesel makes it suitable for waterborne application. These have clearly demonstrated the benefits of environmental protection by using biodiesel on creational boats. However, its environmental performance and eco-efficiency need to be examined.

This paper presents current trends and requirements for reporting environmental performance in industry. It gives a brief introduction to the use of indicators, especially environmental performance indicators and eco-efficiency indicators and describes the methodology to be used to assess the environmental impact of use of different fuels, ie. biodiesel and fossil diesel, in recreation boats. Different weighting techniques are used to present and evaluate the environmental characteristics of the two fuels' application. With assistance of cost factors, the eco-efficiency is demonstrated.

INTRODUCTION

There are different types of reporting systems on environmental performance and eco-efficiency. Eco-efficiency reports inform about economic performance in addition to the environmental performance while sustainability reporting encompasses social, economic and environmental aspects, the "triple bottom line". Today, a move has been seen from traditional environmental reporting to eco-efficiency reporting and sustainability reporting.

Indicators are frequently used to report the environmental performance. Fig. 1 shows the three pillars in sustainable development as the corners in the triangle, and indicates reporting at different levels.

Organisations like the United Nation's Environment Program (UNEP), the World Business Council for Sustainable Development (WBCSD) and the Organisation for Economic Co-operation and Development (OECD) have a strong influence on the requirements set to such reporting [1]. One of the initiatives by UNEP is the Global Reporting Initiative (GRI). GRI was established in 1997 with the mission of

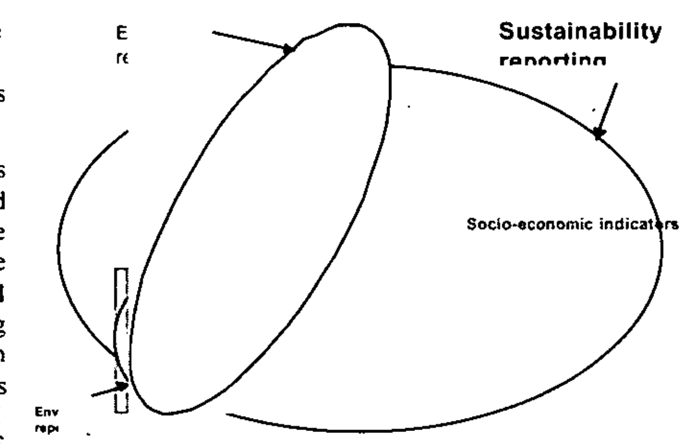

Fig. 1: Sustainability Reporting

developing globally applicable guidelines for reporting on economic, environmental, and social performance. The GRI's Sustainable Reporting Guidelines [2] represents the first global framework for comprehensive sustainability reporting. The latest version came in September 2002, which gives guidance to reporters on selecting generally applicable and organisation specific indicators, as well as integrated sustainability indicators. The development of eco-efficiency indicators is at the heart of the WBCSD's philosophy [3]. The word itself is a combination of economic and ecological efficiency. In order to compare with different systems, it is necessary to follow well known and standardises ways of reporting by means of a set of understood indicators.

METHODOLOGY

To decide upon the environmental performance, relevant data are needed. One way of collecting the data and selecting the most relevant indicators is to use the methodology described in the ISO 14031 code on "Environmental Performance Evaluation" [4]. The methodology is illustrated in Fig.2.

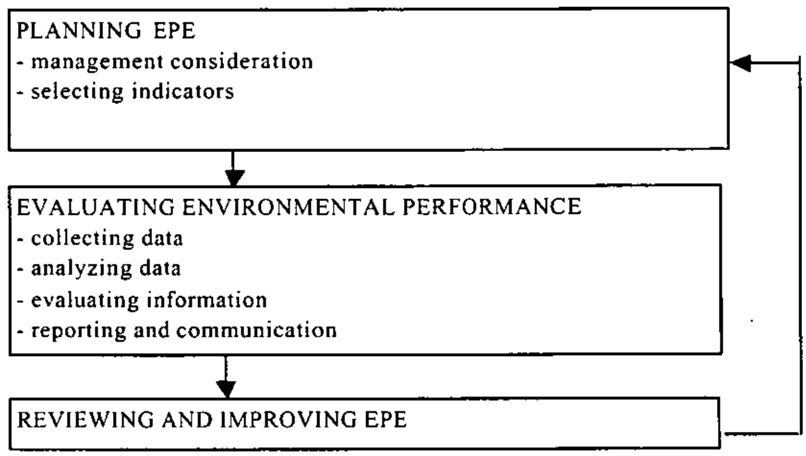

Fig 2: ISO 14031 methodology

To analyse the data and evaluate the information, that means to assess the environmental impact, the methodology recommended by ISO 14040 can be used [5]. The methodology consists of the main steps:

1. Goal and scope definition
2. Inventory
3. Impact assessment
4. Interpretation

In the step of impact assessment the following procedures are used:

3a: Classification; the step where the different substances are classified under the impact category they contribute to.

3b: Characterisation; the step in which the relative contribution of each substance within each category is calculated.

3c: Normalisation and evaluation; the step where the total contribution within each category is evaluated against the mean values in e.g. a country. Very often different weightings are used to compare the impact categories against each other.

To develop eco-efficiency measures, information on both the economic and the environmental performance is needed. By using the formula below the eco-efficiency can be calculated.

eco-efficiency = product or service value per environmental influence (1)

Information concerning the entire life cycle is also required to allow an evaluation of different systems on the background of their environmental and economic benefits. However, in this study only the user-phase is concerned.

CASE STUDY

Data collection

A case study was conducted focusing on biodiesel (rapeseed oil) production and market in recreational boats in the UK [6]. Biodiesel has been considered as a environmentally-friendly fuel which offers advantages of cleaner emissions, less pollution, less toxic, biodegradable, less soot, less smoke, less odour, pleasant to handle, safety, high lubricity, smoother operation and complete combustion. These make biodiesel an attractive fuel for recreational boats where clean environment is more sensitive. In addition, the low solubility and high biodegradation rate of biodiesel is absolutely an advantage for the boating environment since accidental spills of fuel is sometime inevitable.

It was concluded [6] that the biodiesel production rate in the UK would be about 430,000 tonnes per year if all UK set aside land were used for growing rapeseed corps. Table I shows the results of a survey conducted with 50 boat clubs in the UK on boats number, type, operation time and power range.

Table I: Fuel consumption by different type of boats

Boat Type	Sailing Dinghy	Sailing Yacht	Motor Cruiser	Sport	Total
Fuel consumption (%)*	2.2	4.5	26.2	15.3	48.2

*Percentage of rapeseed oil production from the set aside land in the UK

This study will examine the environmental aspects regarding the life cycle of fossil fuel and biodiesel from fuel extraction/production to transport and combustion emissions.

Characterisation and normalisation of data

Table II presents the yearly emissions from the sailing yachts in the UK and other parameters required for the analysis. Column 5 shows the characterisation values. It indicates that the contribution of NOx emissions to acidification is only 70% of that of SO_2. Column 6 shows the normalisation factors. They are developed based on total emissions per year in UK. The yearly emissions are then divided on the normalisation factors. This makes the figures comparable, see the two last columns in the table.

Table II: Life cycle emissions of fuel from sailing yachts operation in UK [7].

Impact category	Substances	Fuelled by Fos-D* (kg/year) [8]	Fuelled by Bio-D (kg/year) [8]	Characterisation	Normalisation factors [9]	Normalised values fossil diesel	Normalised values biodiesel
Climate change	CO_2	1.4×10^8	3.4×10^7	1	4.16×10^{11}	3.46×10^{-4}	8.17×10^{-5}
Acidification	SO_X	1.5×10^5	2.9×10^4	1,0	1.62×10^9	3.40×10^{-4}	3.45×10^{-4}
	NO_X	6.2×10^5	8.2×10^5	0,7	1.75×10^9		
Local air pollution	Particulars / soot	5.2×10^5	3.1×10^5	1	0.44×10^9	1.28×10^{-3}	8.26×10^{-4}
	CO	4.8×10^5	5.8×10^5	1	4.76×10^9		
Photo oxidant formation	NMVOC	2.9×10^5	1.5×10^5	1	1.96×10^9	1.48×10^{-4}	7.66×10^{-5}
Eutrophication	NO_X	6.2×10^5	8.2×10^5	1	1.75×10^9	3.54×10^{-4}	4.68×10^{-4}

* Fos-D represents fossil diesel fuel; Bio-D represents biodiesel.

Emissions of CO could also be included in the impact category of photo oxidant formation, but its contribution is insignificant after characterisation [8]. Other impacts categories, e.g. ozone layer depletion, and other substances in the selected impact categories are not included due to lack of reliable data. The chosen impact categories and substances are however sufficient to illustrate the method. From the state of the art knowledge in environmental performance study, it is safe to assume that the missing emission substances have little effect on the total results as presented in Fig.3. However, this is an area that needs further investigations.

Fig.3 shows the characterised and normalised environmental profile from sailing yachts in the UK fuelled by fossil diesel and biodiesel based on the figures in Table II. The results show that the use of biodiesel offers a better result within each impact category except for eutrophication, while the difference in acidification is insignificant. The adverse effect of eutrophication and acidification is due to the higher level of NO_X emissions of biodiesel. There is clearly an advantage in the contribution to climate change by using biodiesel (76.4 percent reduction), photo oxidant formation (48.2 percent reduction) and local air pollution (35.5 percent reduction).

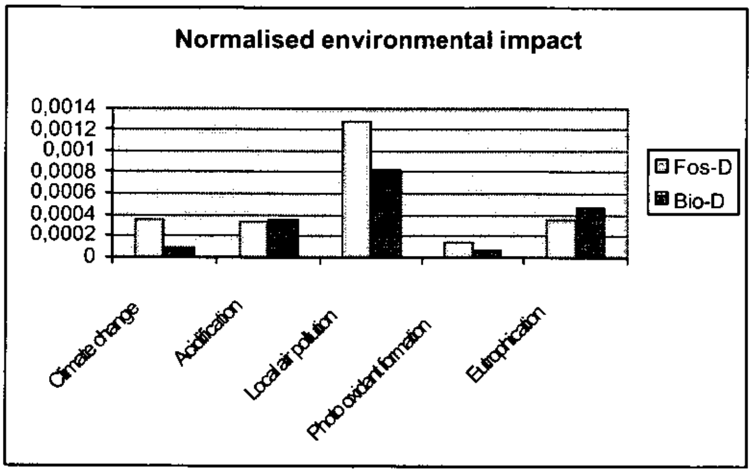

Fig.3: Characterised and normalised inventory results

Weight factors

Eight factors and valuation techniques are used for comparing the relative importance of different environmental impact categories, or to derive at a single index for comparison of the environmental performance of alternative systems when a decision with conflicting environmental targets is to be taken. In this study this is demonstrated by two different ways, weighted against political goals for improvement or weighting set by an expert panel. The highest number represents the most important category, see Table III. The normalised values in Table II are weighted and presented in Fig.4 and Fig.5.

Table III: Political weight factors and weight factors expressed by experts [10]

Impact Category	Weight factor, political goals	Weight factors, Expert panels
Climate change	1	19
Ozone depletion	1	12
Acidification	1,5	4
Photo oxidant formation	1,8	5
Local air pollution	1,5	4
Eutrophication	2	7

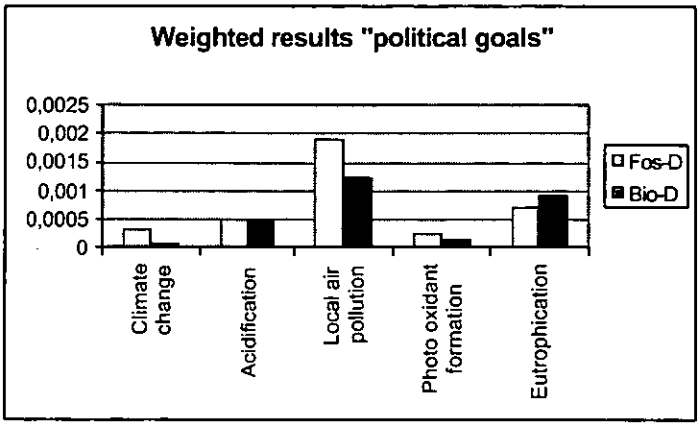

Fig. 4: Weighted results based on political targets.

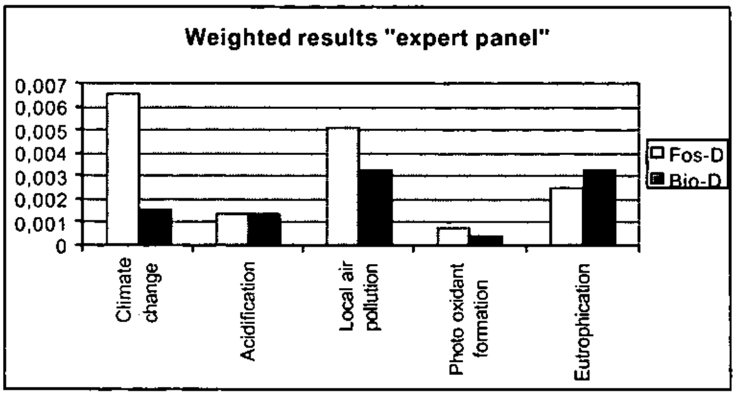

Fig.5: Weighted results based on expert procedures.

Eco-efficiency

In order to calculate the eco-efficiency, it is necessary to evaluate the economic values created by sailing activity (see equation (1)). However, it is difficult to obtain values/incomes on recreational activities, and one way to deal with this is to measure the value as the inverse of costs based on the fuel prices and yearly costs shown in Table IV and Table V.

Table IV: Fuel prices in the UK [11,12]

	Production	Retail profit	Tax	VAT	Retail price
Bio-D from used oil (pence)	40,48	3,00	25,82	11,60	**80,90**
Bio-D from fresh seeds (pence)	55,48	3,00	25,82	14,75	**99,05**
Fos-D (pence)	17,48	3,00	45,82	11,60	**77,90**
Red Diesel (pence)	17,48	9,00	3,13	5,18	**34,79**

Table V: Fuel cost per year by sail yacht [11]. Sensitivity study on fuel costs [13]

	A*	B	C	D
Bio-D	40632	90.2	874	**32032156**
Red Diesel	40632	34.79	852	**12043764**
Fos-D	40632	77,9	852	**26967783**
Bio-D, no tax	40632	50,56	874	**17955053**

*A = fuel consumption (t/y)
B = average fuel cost pence per litre
C= density of fuel (kg/m^3)
D = total fuel cost per year (GBP/y)

The environmental influence can be expressed by the impact categories as shown in Table II. The eco-efficiency of sailing yachts in UK on a yearly basis could then be calculated by:

$$\text{Eco-efficiency} = (1/\text{yearly costs}) / \text{environmental impact} \quad (2)$$

The values in Table V are used when the eco-efficiency figures are calculated. The results from the different scenarios are presented in Fig.6. They show that biodiesel with no tax has the best eco-efficiency for the impact categories climate change and photo oxidant formation For acidification normal priced biodiesel has the worst eco-efficiency. This is due to NOx-emissions. However, for other impact categories, fossil diesel shows a good eco-efficiency. For red diesel the environmental performance of fossil diesel is used, which is partly incorrect. By comparing Fig. 3 and Fig.6, the influence of costs on the eco-efficiency can be derived. However, the use of cost-factors is just for the purpose of demonstrating the method. Other pricing mechanisms and taxation systems could be included here. This is a subject for further studies.

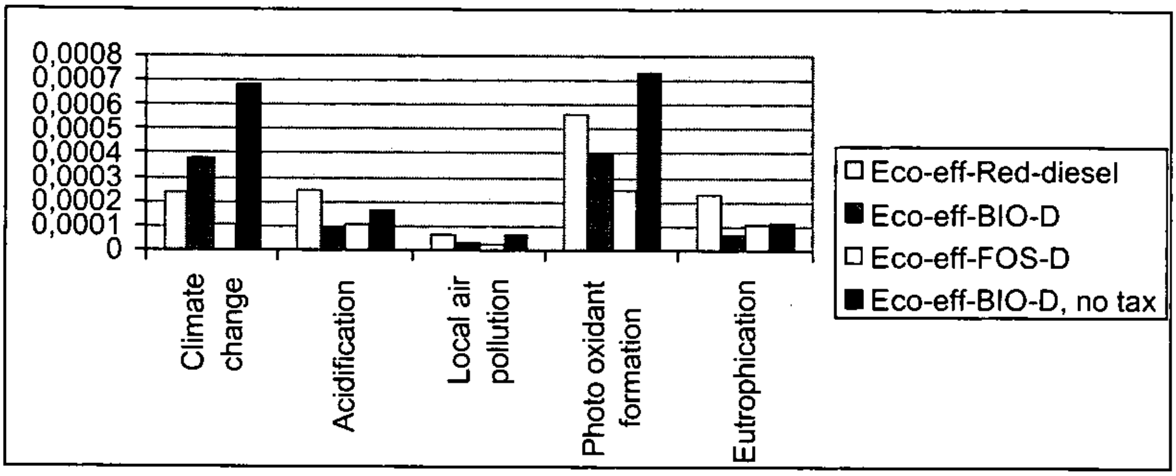

Fig.6: Eco-efficiency for different alternatives, see Table V.

CONCLUSIONS AND FUTURE CHALLENGES

The presentation has shown how to combine cost information and environmental impact information into eco-efficiency measures. The figures show the values of eco-efficiency indicators for each impact category. Such indicators can be used in eco-efficiency reporting, see Fig 1. There exist studies on how to add the different impact categories into one single score [14], which means that it could be possible to present the eco-efficiency for each fuel type and case by an aggregated eco-efficiency indicator. However, this requires weighting models between the different impact categories. This is a subject for further studies.

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The European marine fuel market - present and future

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SYNOPSIS

The MARTOB project has assessed the present status ofthe marine fuel market, and challenges related to changes to meet increased environmental requirements. New requirements including a stricter sulphur cap on marine bunker fuels have been proposed. The new legislation will include both distillate and residual fuel qualities, and affect all segments of shipping operating in European waters. Uncertainties related to the balance between future demand and supply of low sulphur fuel qualities have been assessed by the MARTOB project, and conclusions from these studies will be presented.

INTRODUCTION

In January 2002 the European Commission announced that it is preparing a Community Strategy on Air Pollution from Sea-going Ships, to be presented autumn 2002. It is expected to include a proposal for modifying directive 99/32/EC on the sulphur content on liquid fuels so as to extend its scope to include heavy bunker fuel oils, as well as proposals for the introduction of economic incentives.

The aims of the measures expected that the Commission will highlight are:

1. To reduce the overall emissions in the so-called SECAs (SO_x Emission Control Areas - the North and Baltic Seas) as well as in all EU port areas.
2. To establish a regulatory regime with which all seagoing ships will be able to comply by using only two different fuels.
3. To ensure that fuels complying with EU standards will be available in all EU ports.

Among the means for achieving these aims are the following, all of which are to be written into directive 1999/32:

- Member states bordering on the SECAs of the North and Baltic Seas must ensure that only marine fuels with a sulphur content of less than 1.5 per cent are used in their territorial waters, and possibly also, if applicable, in their exclusive economic zones. This shall apply to all vessels of all flags, either from the date of the MARPOL Annex VI coming into force or from January 1, 2005, whichever is the earlier.
- Only fuels with less than 0.2 per cent sulphur may be used in inland waterways and EU port areas. (It is suggested that the latter should be defined as extending from the "outer limit of territorial sea to the quayside.")
- By 2005 member states must ensure that all marine gas oil sold in their territories shall have less than 0.2 per cent sulphur. (A change in the definition of gas oils is suggested, so as to exclude the so-called DMB and DMC grades.)

The driving force behind new regulations related to the sulphur content in fuels consumed by ships, is the increasing relative emission of sulphur oxides from shipping in Europe if nothing is done. Assuming no change of the present marine fuel qualities and abatement measures being implemented on land sources, it has been predicted that shipping related sulphur emissions will represent two third of the total sulphur emissions in Europe in 2010.

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Several voices claim that the most cost efficient way to reduce sulphur emissions is to perform measures in the marine bunker fuel market[8]. In a study on behalf of the European Commission, BMT[2] concludes that the fuel cost for shipping in Europe will increase approximately 700 million USD annually if a cap in the region 1-1.5% is set on marine fuel sold in Europe.

Although several studies now have been performed to establish emission inventories and to assess effect of a sulphur cap in Europe, few have considered the availability of these fuel qualities and the supply/demand balance for these fuel qualities in European waters.

THE MARINE BUNKER MARKET

The international market

With 95% of world international trade transported by ship, the fortunes of the shipping industry are strongly linked to world trade. Marine fuels account for about 20% of total fuel oil demand, so the development of this market has important implications for refining industry.

Growth will continue in future, but increasing demand for bulk and general cargo trade will most probably be balanced by increased efficiency by tankers as newer, more efficient double-hulled vessels replace single-hulled vessels. Depending on world economic growth, energy use by marine transport is expected to grow by around 1.5 % per year until 2020, with higher growth rates in gas oil bunkers compared to fuel oil because of sulphur restrictions, particularly for coastal voyages.

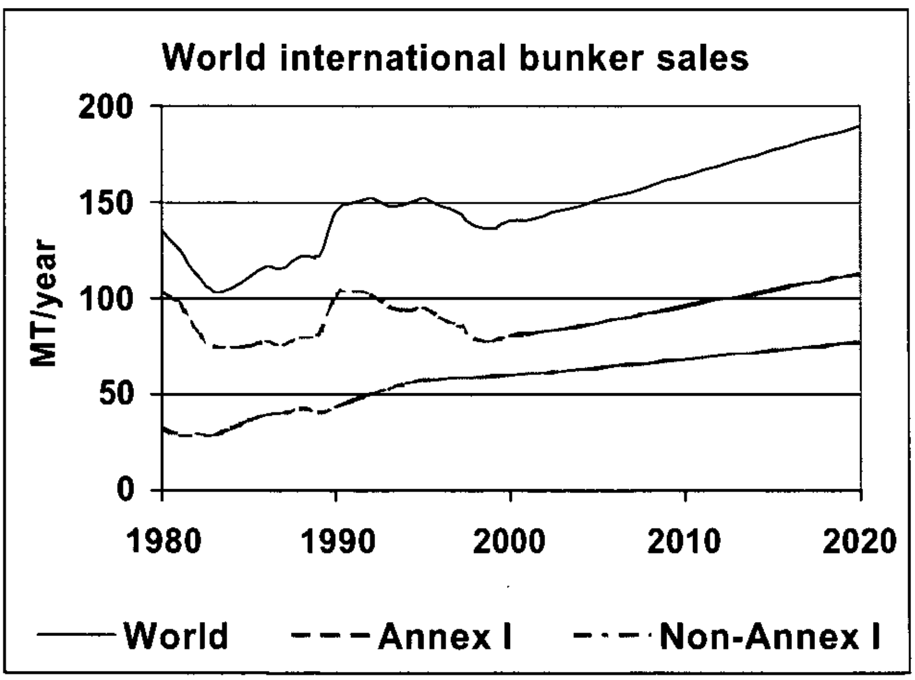

Figure 1 Development of world international bunker sales divided by Kyoto Protocol Parties (Source EIA, 2002)

As shown by figures 1 and 2 the world consumption of international bunker fuel is expected to continue to increase the next decade. The world total consumption of bunker is obviously significantly higher than indicated in figure 1, as sales to domestic consumption is not included in the figure. In order to establish a consistent understanding of the fuel consumption on a regional level, international bunker and domestic bunker fuel sale figures needs to be combined, a task which represents a challenge due to inconsistent reporting on marine bunker sales.

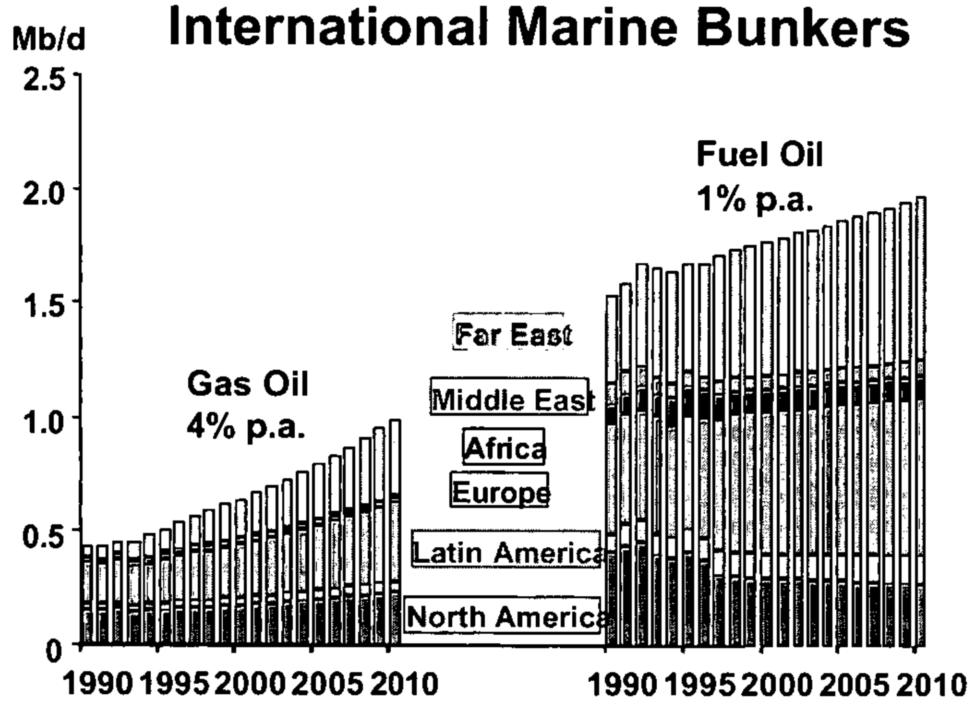

Figure. 2 Regional developments of international bunker sales [3,9]

The European market

Several assessments have been made recently to try to quantify the marine bunkers consumption in Europe. As seen from Table 1 the various studies does not provide consistent results, and this is to some extent due to different approach to the task, and how international/domestic sale and consumption have been considered.

Table 1 – Estimated sale and consumption of marine bunker fuel in Europe

Study performed by	Reference year	Total million tonnes
Bunker consumption		
BMT[2]	2001	33,5
ENTEC[5]	2000	49,5
Bunker sales		
BMT[2]	2001	40,6
Beicip-Franlab[1]	2000	43,6

[2] Source (BMT, 2000).
[5] Source (ENTEC, 2002) Fuel consumption is not presented in the study, but has been calculated based on the applied emission factor 3179 kg CO_2 per tonnes fuel consumed
[1] Source (Beicip-Franlab, 2002), Including 1999 figures for EU Accession countries

The most significant conclusion drawn from the comparison of different studies is that a significant uncertainty still exists with respect to the consumed volume of marine fuel oil in European waters. As a consequence of this it will be equally uncertain what effect new legislation will have on this market.

Based on sale figures collected in workshops arranged in connection with the MARTOB project, the sales in Europe of marine fuel oil have been estimated to be approximately 42.1 million tonnes (2001 figure). This figure does not include distillates, hence the figures found by Beicip-Franlab seems to be closest, but still somewhat low as this figure includes distillate sales.

With respect to low sulphur fuel oil (not MDO/MGO) with a sulphur content below 1.5%, the European supply has been estimated to be approximately 6.5 million tonnes, where the marine share represents less than 1 million tonnes annually.

Most inland consumption is moving to low sulphur fuel oil or natural gas. The IMO has proposed a reduction in the global maximum sulphur level in marine bunker fuel from 5% to 4.5%, which compares with the current global typical range in the order 2.8-3.5%, with only 0.02% of fuels used world-wide in shipping at a sulphur content over 4.5% and with the world average at 2.7%.

The proposed introduction of SO_x Emission Control Areas (SECA's), within which the sulphur content of fuel used on ships will be limited to 1.5% is expected to have a major impact on the supply side of the market. The Baltic and North Seas have been proposed as initial SECA's. Ratification by IMO members is not expected before 2005. More immediate are plans by the EU to impose sulphur limits on fuel oil used within EU territorial waters, probably set at 1.5% maximum. In either case, the provision of adequate quantities of segregated low sulphur bunkers does not currently exist.

AUGMENTING LOW SULPHUR FUEL OIL SUPPLY

The options

The options available to a refinery for increasing Low Sulphur Fuel Oil Supply to the bunker market are:

- Re-blending from the current HSFO market
- Switch to a lower sulphur crude diet
- Invest in Residue Desulphurisation (RDS)
- Redirect the low sulphur fuel oil destined for inland markets

Re-blending from the current HSFO market

A limited supply of lower sulphur content HFO could be available by re-blending current HSFO with MDO, or other components. This option presents a risk for producing unstable LSFO bunkers. Dilution of a thermally cracked residue with too high concentration of a paraffinic diluent ("cutter-stock") such as gas oil could result in an unstable fuel. It is consequently necessary to ensure that the aromaticity of any diluent is high enough to keep the asphaltenes dispersed. The addition of catalytically cracked cycle oils is one way of doing this, and so providing an adequate stability reserve.

Assuming properly done blending (right components from selected grades, and in correct order), the Beicip-Franlab report[1] suggests that around 4 MT of 1.5% S bunkers could be available in North Europe and about 0.7 MT in the south, as indicated below. The sulphur content of the remaining HSFO would increase to about 3.4 wt% in the North and 3.2 wt% in the South. Those figures and those for 1% S HFO case are presented in the table below.

Table 1 – Potential low sulphur bunker production by re-blending

POTENTIAL LSFO BUNKER PRODUCTION BY RE-BLENDING		
HFO Bunkers Sulphur Cont. wt%	**Atlantic/NEW/Other (MT)**	**Mediterranean (MT)**
<1.0	1.2	0.4
<1.5	4.0	0.7

This option may cover a small part of the market today, in SECA's (Sulphur Emission Control Areas) like the Baltic and North Sea where max. Sulphur 1.5% is required. But in general terms this represents a non-significant option, as it is not giving a viable solution in this problem. However, we need to be cautious as uncontrolled blending with feedstocks available in the market may give huge problems to the shipping due to unstable products. Stability is one of the critical parameters for handling fuel oil on board the vessels.

Switch to a lower sulphur crude diet

If we consider three different crude oils, Brent blend, Iranian Heavy and Arabian light, it is evident that there is a clear diversity in quality and yield, which will affect the refineries processing and output.

Table 2 – Crude oil data and typical output quality

Crude oil Analysis	**Arabia light (Saudi Arabia)**	**Iranian heavy (Iran)**	**Brent blend(UK)**
Density at 15C	0.860	0.872	0.830
Sulphur content %	1.90	1.89	0.35
Residue yield %	44.5	47.0	35.7
Atmospheric distillation			
(Residue) Density at 15C	0.959	0.972	0.923
(Residue) Sulphur Cont. %	3.28	3.02	0.78

Refineries will be constrained by their capability to handle more than a certain amount of a particular type of crude. This will depend on the configuration of the refinery to cope with the volumes of products created by crude processing and the constraints within which the refinery is allowed to operate, particularly in respect to environmental emissions.

Invest in Residue Desulphurisation (RDS)

Refinery processes for desulphurisation of HSFO are likely to be very expensive with each plant costing well in excess of $200 mln. At such levels, it is highly unlikely that the refining industry would be prepared to consider investments to support a low sulphur bunker business, without confidence in a significant and sustainable price increase for this higher quality product.

It is very difficult to indicate what the additional investment cost will be, but according the source "*Costs and benefits of controlling SO2 emissions from Ships in the North Sea and Seas to the West of Britain, May 1998, page 26*'[6], we will have following additional cost increase in manufacturing cost:

Table x – price premium on low sulphur fuel oil

Bunker Sulphur Content	Additional cost of producing low S bunker fuel compared with current high S bunker fuels (US$/t)*
2% Mass	35-50
1.5% Mass	45-70
1.0% Mass	55-85
0.5% Mass	65-95

The above figures are much in line with the figures provided by BMT[2] and Beicip-Franlab[1].

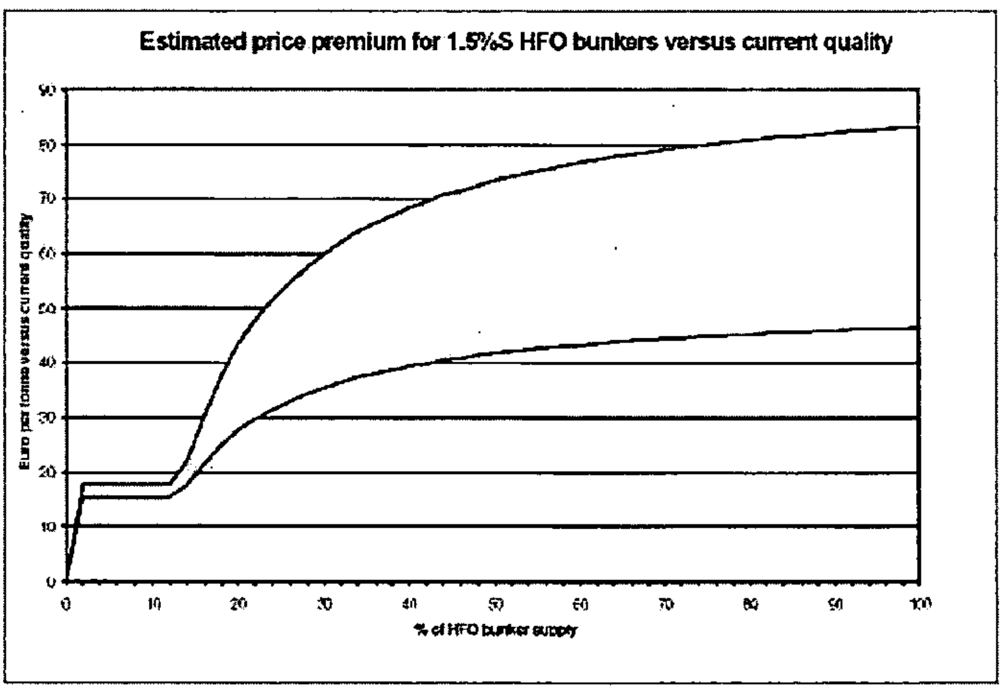

Figure 3 - Estimate of price premium for low sulphur fuel oil (from Beicip-Franlab, 2002)[1]

Redirect the low sulphur fuel oil destined for inland markets

The enforcement of the directive 1999/32/EC from January 1st 2003, will represent a significant increasing demand for LSFO 1% S max. and the contrary for HSFO. This will represent, on the base of the forecast for 2005 a deficit of about 8-10 MT LSFO, and a surplus of 12 MT for HSFO. This unbalance will be more significant for the Southern and Mediterranean refineries. In N.W.E and Nordic countries is being today produced a significant amount of LSFO, mainly diverted to the local ferry segment as bunkers, and exported to counties where they need LSFO for the utilities. This volume is already allocated, and if shipping wants this product they will have to bid it away from the inland market.

Main producers of LSFO are the refineries in Scandinavia, where the logistics for using North Sea crude are favourable. However the volume of this LSFO gone to the bunker market is linked up to long term contracts with the ferry companies, and hence not available for open spot bunker market. Therefore it is unlikely that the refiners there will ever put this product on the open market. As far as 1% avails are concerned the fact that 1% has blown out from a negative Low sulphur to High sulphur to +13-15usd/te suggests that the market believes it will become tight next year as the new legislation comes in. Key factors will be Portugal and Spain who rely on fuel oil when hydroelectricity is scarce. France is unlikely to change their demand. Italy is already mainly 1% and as they have moved over to gas but this has substituted it's HSFO demand not LSFO demand and if anything ENEL has increased its imports. Greece is the other big unknown as they burn vast amounts of HSFO.

Feasibility of increased low sulphur fuel oil supply

If tighter sulphur specifications are introduced for bunkers, this will reduce the capability of refineries to support the bunker market. The capability of the oil refining industry to produce more low sulphur fuel oil for both the inland and the bunkers market is limited through a combination of factors such as the availability of low sulphur crudes and the configuration of the refineries to cope with the different product volumes associated with high and low sulphur crudes.

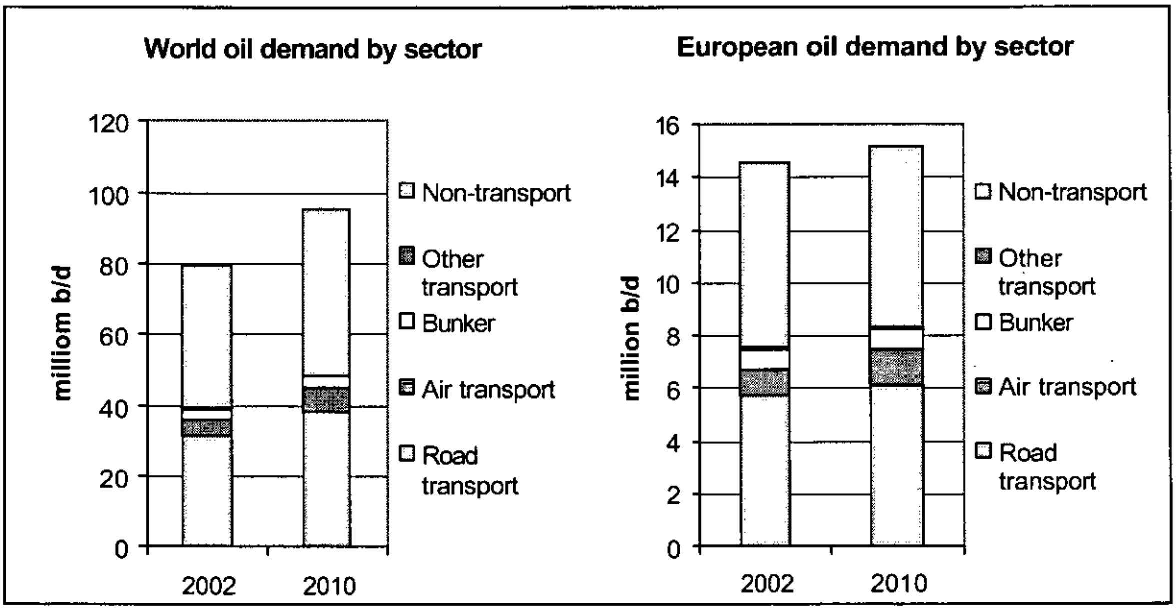

Figure 4 Demand of oil by sector (Source EIA, 2001)

The oil industry is unlikely to consider the bunkers market as a particularly attractive market within which to make substantial investments to convert high sulphur components into low sulphur fuel. In Figure 4 the position of the marine bunker market relative to the major oil markets are indicated. As indicated by the figure, bunker only represents approximately 5% of the European oil market in a situation where stricter requirements are expected in several sectors.

If the sulphur control areas were to be introduced including all consumption with fuel with maximum 1.5% sulphur, two options occur:

1. Operators would need to switch to distillates, and the distillate market redirected/increased to meet the increasing demand.
2. The availability of low sulphur fuel oil must increase. This would either imply increasing refinery output of these qualities, or redirect present LSFO market shares presently held by land-based consumers.

Due to the arguments above, it is considered most feasible in the short term to switch to distillates, and in the longer run changes are required in the present refinery structure to be able to supply a significant larger amount of LSFO.

SUMMARY AND CONCLUSION

The introduction of the Directive 1999/32/EC from January 1st, 2003 will limit the sulphur content of inland fuel oil to a maximum of 1%. This will create a disposal issue for the oil refining industry for high sulphur fuel oil components.

An alternative outlet for high sulphur fuel oil is the bunker market. However, if tighter sulphur specifications are introduced for bunkers, this will reduce the capability of refineries to support the bunker market.

The capability of the oil refining industry to produce more low sulphur fuel oil for both the inland and the bunkers market is limited through a combination of factors such as the availability of low sulphur crudes and the configuration of the refineries to cope with the different product volumes associated with high and low sulphur crudes.

The oil industry is unlikely to consider the bunkers market as a particularly attractive market within which to make substantial investments to convert high sulphur components into low sulphur fuel.

The required use of low sulphur (1.5%) bunkers within EU territorial waters, with even tighter sulphur specifications (0.2%) within port areas will present a major challenge for the marine business in terms of segregation of fuels both in ship and shore tankage and delivery systems.

More work needs to be done to quantify the impact of the above changes in respect to the ability of the refining industry to meet the changing demand, and to assess the overall cost impact on the business. This should take account of work currently being undertaken by Concawe into the impact on the European oil industry resulting from the introduction of lower sulphur specifications for both inland and marine fuels.

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Marine Fuel Cell Applications

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1 Summary

Fuel Cell technology (FC-technology) is on its way to find a market in the power supply sector. It will be introduced to merchant shipping beginning in parallel or short time after on shore applications. In the moment a large number of pilot applications are running, under design or erection. Existing first industrial applications besides the systems in space industry are the Howaldtswerke-Deutsche Werft (HDW) submarines of U-212 type. Engine manufacturers like MTU-Friedrichshafen are establishing fuel cell project groups. First research projects with marine focus are on the way in Europe and the US ministries of transport, energy and defence (DOT, DOE, DOD) also strongly support fuel cell development in the marine sector.

For merchant ships pilot projects can be expected in the next years. Driven by the strong environmental benefits combined with high efficiencies the FC-Technology will find its way into the shipping world. Safe use of gas, to date uncommon fuels onboard of ships and reforming of liquid hydrocarbon fuels will be key techniques. System costs will remain in the foreseeable future above the current level for diesel engines. The cost compensation due to higher efficiency will not be complete. Therefore FC-Systems in shipping will be used for special purposes and in cases where additional factors like environmental benefits are taken into consideration. Nevertheless a large market of some GW installed FC power per year is expected for the next decade.

2 Fuel cells and Fuel cell Systems

Fuel cells convert the chemical energy of hydrogen and oxygen directly into electricity and water. Similar to a battery a fuel cell consists of electrodes and an electrolyte. Based on this principle several types of fuel cells have been developed so far. Fig. 1 shows the available types with their operating temperatures. Hydrogen as fuel and oxygen or air are supplied to the fuel cell, react in the electrolyte and the reaction products and excess oxygen (if air is used also nitrogen) leave the fuel cell. The reaction produces electricity. The operation temperature is between 60 and 120 °C for Alkaline Fuel Cells (A-FC), 20-120 °C for Proton Exchange Membrane Fuel Cells (PEM- or PE-FCs), and 60 –220 °C for Phosphoric Acid Fuel Cells (PA-FC). The high temperature Molten Carbonate Fuel Cells (MC-FC) and Solid Oxide Fuel Cells (SO-FC) have operation temperatures above 600 and 900 °C respectively. Depending on the temperature level the heat can be used for different external purposes from heating for low temperature FCs to additional electric power generation for high temperature FCs.

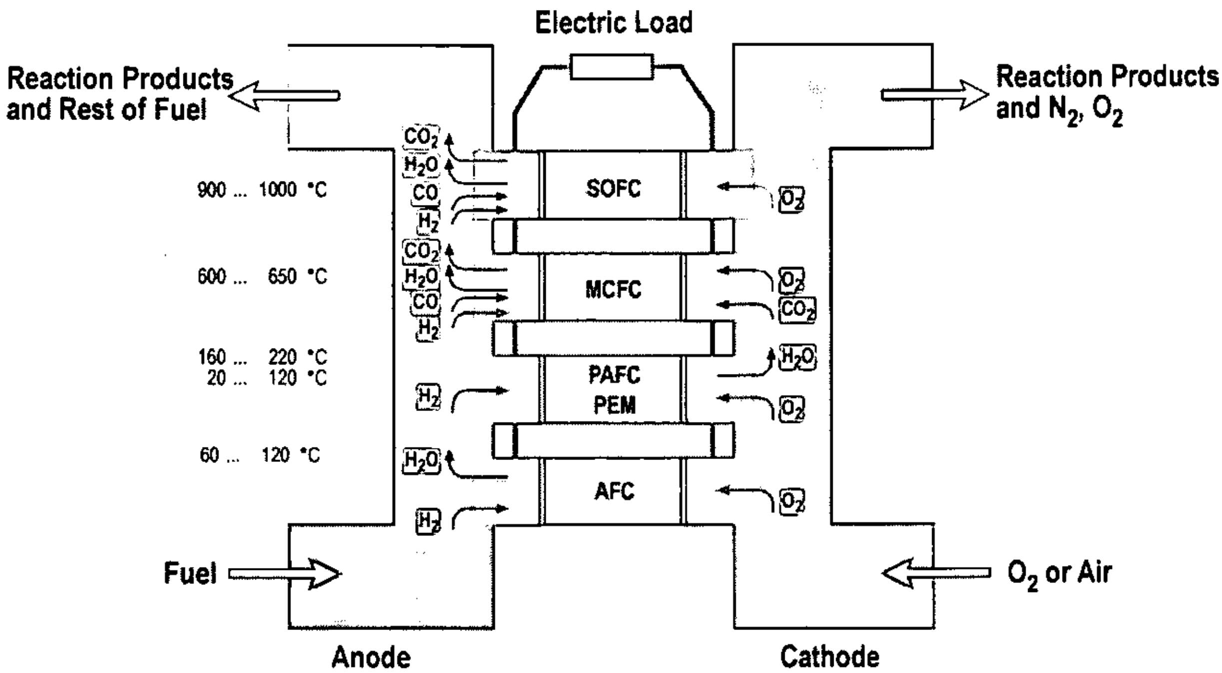


Fig. 1: Basic principles of different fuel cell types

A-FCs have been used in space industry and the ZeTek Power company tried to introduce the technology for transport systems until the summer of 2001. Nevertheless a disadvantage is that very clean hydrogen is required and that the potassium catalyst is reacting with the CO_2 content of the air.

FCs need a number of subsystems for operation. The subsystems depend on the type of FC and the available fuel. Taking a PEM as example Fig. 2 shows a simplified flow diagram for a possible application. Fuel and air are supplied to the reformer where they react with steam to hydrogen and CO_2. Excess hydrogen coming from the fuel cell is used as additional heat source. The gases are fed to the fuel cell after moistening up to saturation. After filtration and moistening ambient air reacts in the fuel cell with the hydrogen to water and direct current electricity, which is converted to alternating current. Excess air and nitrogen are directly emitted to the atmosphere. Excess hydrogen is burned in an excess gas burner and the heat is used for reforming. The water produced as reactant in the fuel cell is condensed and is used for the reformer and to a smaller amount for other purposes. Of course the heat generated in the fuel cell has to be removed to the environment and can be used for auxiliary purposes.

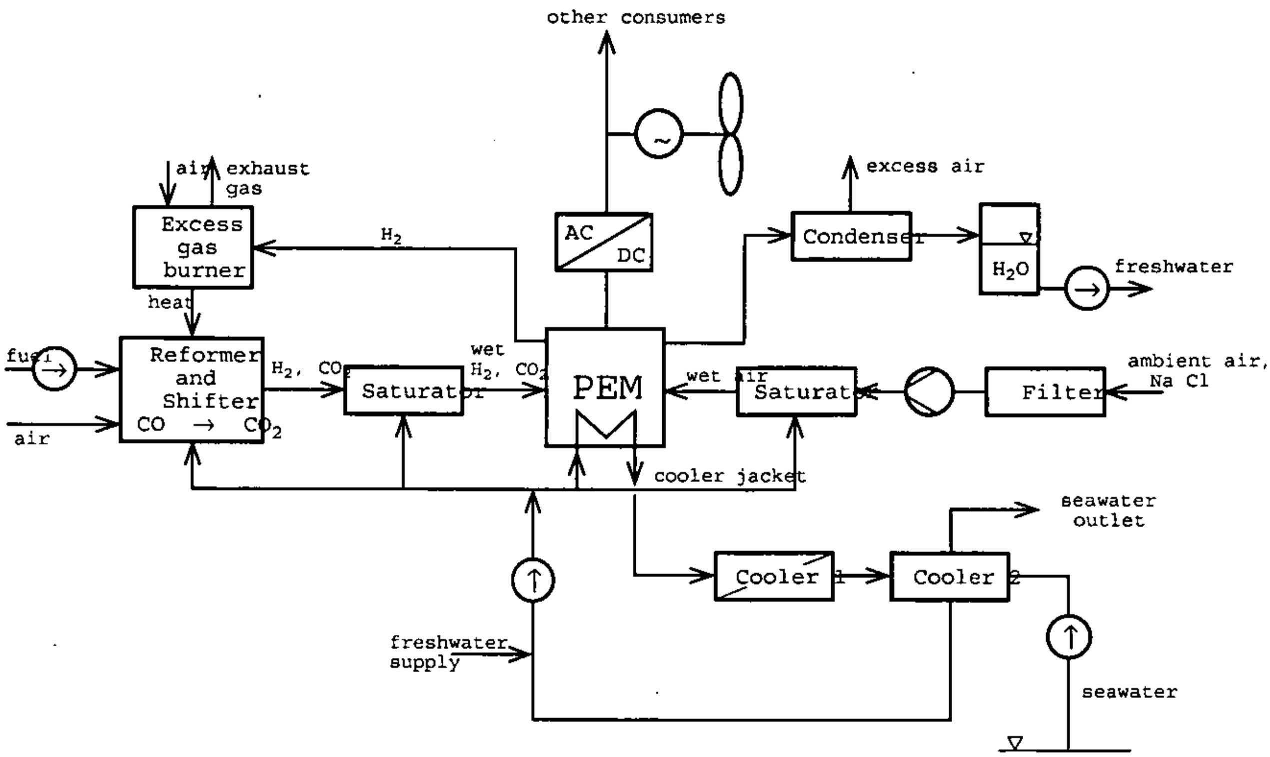


Fig. 2: Principle flow diagram for a PEM FC with reformer (marine application)

3 Land based installations

In most cases the civil marine market for power generating systems is a part of the overall market for the system manufacturers. With the exception of rudders and sails all propulsion technology for ships was first introduced in land based applications. This will be the case for FC-Systems also. Therefore, the development of FC-Systems for marine applications is closely related to the developments for land based installations. The focus for land based FC-Systems is laid on the car industry, stationary power generation, house heating and small applications e.g. for Laptops. In these areas a number of projects and pilot systems exist.

- The majority of car manufacturers run demonstrators based on PEM-FC in most cases. Fig. 3 shows some examples. The power range for these applications is up to 50 kW for private cars and 200 kW for buses.
- A large number of stationary installations operate with PA-FC. During the last years PEM-FC systems (e. g. Bewag project Berlin), MC-FC systems (e.g. Hot Module, Röhnklinikum in 2001) and SO-FC systems (Siemens Westinghouse Essen, Marbach) have been built. The largest system is the 1 MW SO-FC system in Marbach, which is shall be commissioned in 2003. Fig. 4 shows the PE-FC of Bewag in Berlin.

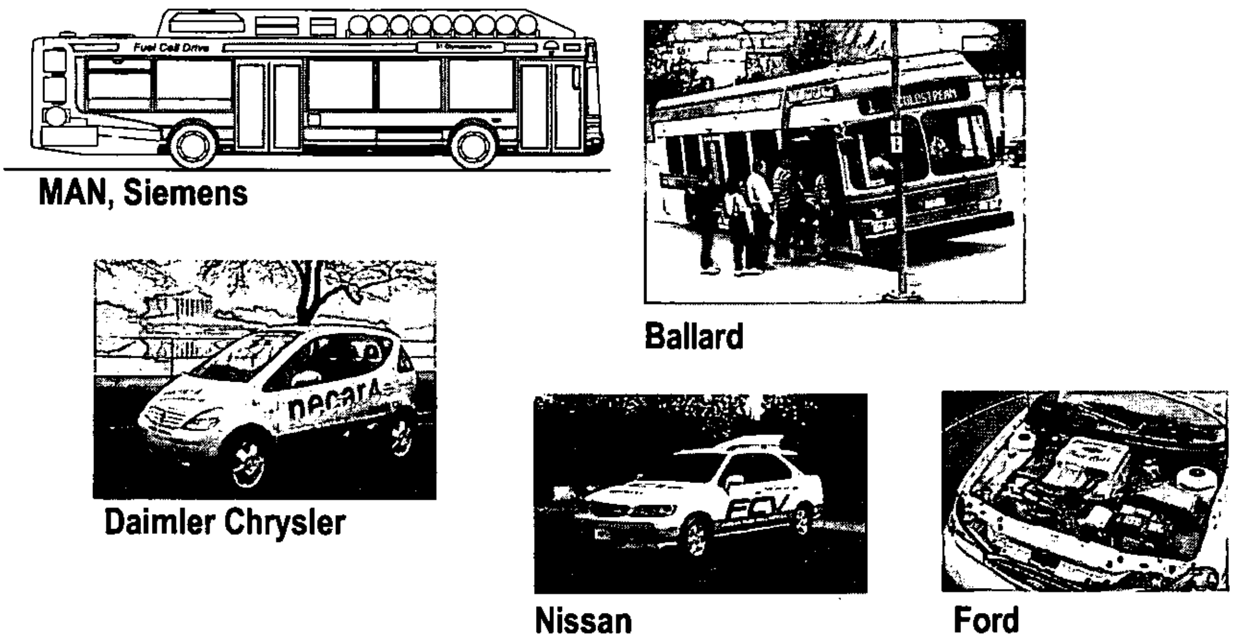


Fig. 3: Some Fuel Cell demonstrators in car industry

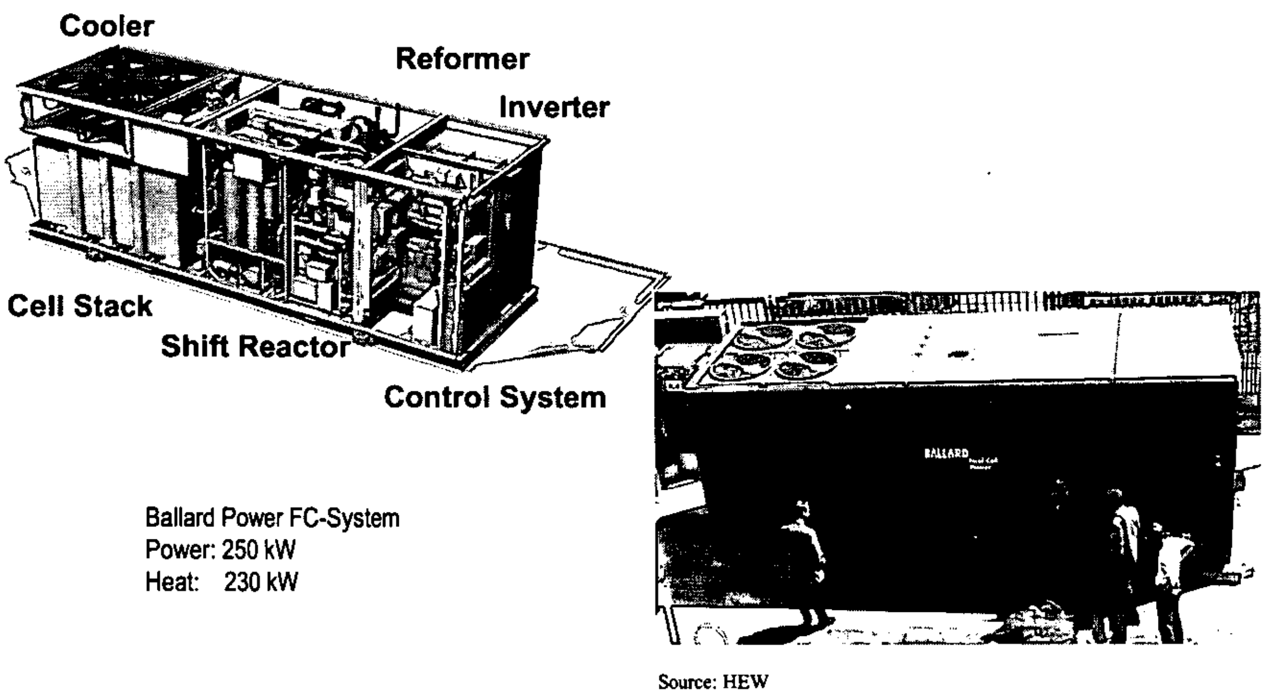


Fig. 4: PEM FC System of Bewag in Berlin (May 2000)

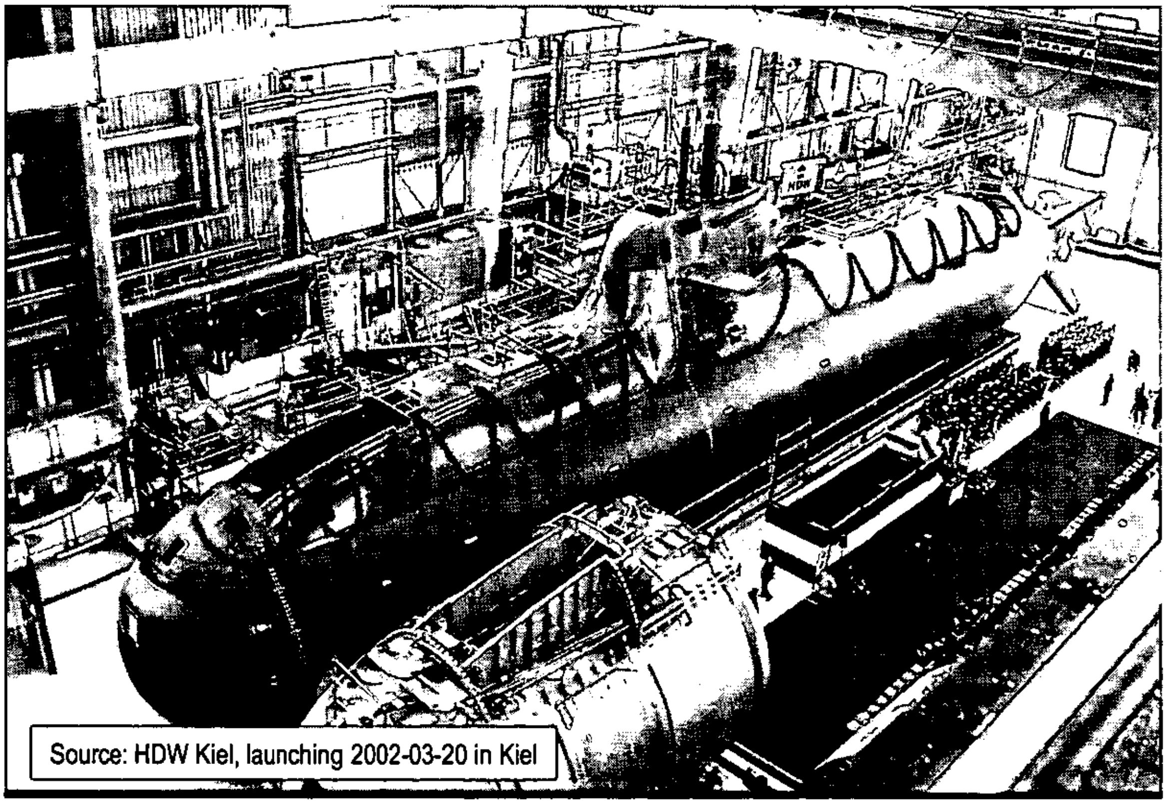
- A number of manufacturers are developing small FC-Systems for co-generation combining house heating and electrical power generation (e.g. Vaillant, Sulzer Hexis). These systems are based on PEM-FC and SO-FCs. The power range is between 5 kW and 1 kW. Field tests are announced for the near future.

- A number of small applications below 1 kW up to 8 kW have been presented. These applications focus on the market for battery substitution (e.g. Laptops, emergency power). Ballard Power recently presented a 1 kW PEM-FC unit (Ballard Nexa Module).

4 Current Status of Marine FC Applications

No FC-System has been tested on board of seagoing merchant vessels so far. As to the authors knowledge the current status of marine FC development is as follows.

- The most relevant marine application is the HDW/Siemens 250 kW hydrogen/oxygen PEM-FC System installed in HDW U-212 class submarines. Currently more than 10 submarines are on order (Fig. 5). HDW is working on a Methanol reformer for the next generation of submarine FC-Systems.



Source: HDW Kiel, launching 2002-03-20 in Kiel

Fig. 5: Launching of first HDW U 212 Class Submarine (U-31 of German Navy)

- Developments for civil marine applications are known from HDW and MTU Friedrichshafen. Wärtsilä and Danish reformer manufacturer Haldor Topseo recently joint their forces for the development of a high temperature FC-System for marine applications.
- A consortium around STN-Bremen is developing a autonomous operated vehicle (AOV) which will use a PE-FC developed by ZSW in Stuttgart (Fig. 6). The project supported by the German Ministry of Research named DeepC will be finished with the test of a technology demonstrator in 2004.

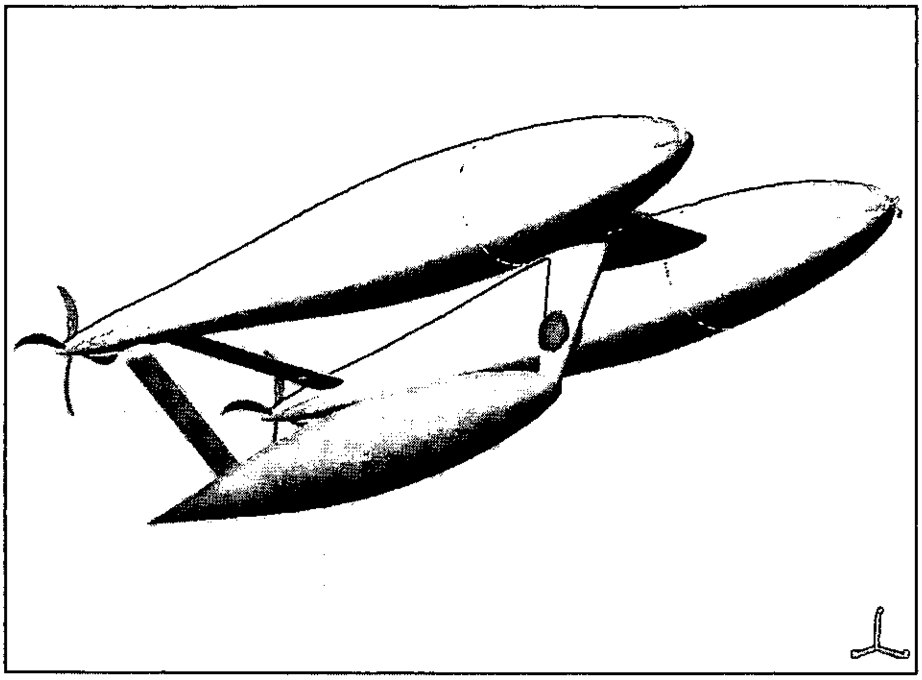


Fig. 6: Autonomous Operated Vehicle (AOV) of DeepC Project

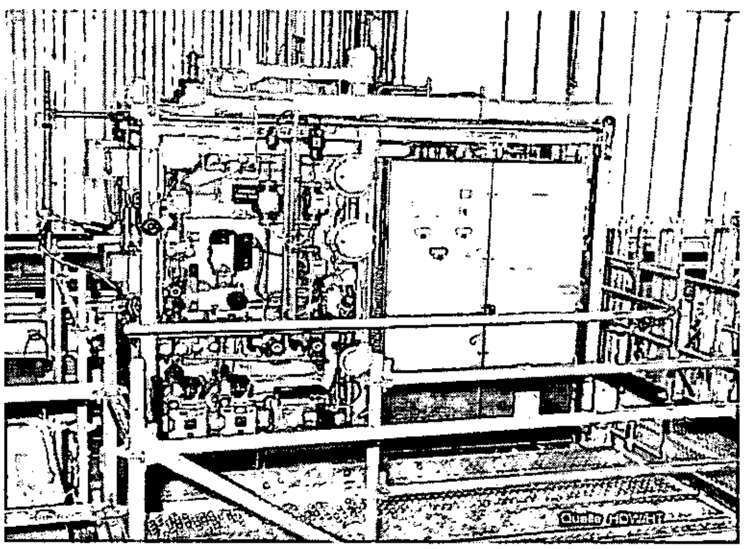
- The US Marine Administration (MARAD) supports the development of a power barge for the power supply of the hotel load for ships during port operation. In a first phase of the two phase project a test installation had been run with two 200 kW PA-FC. The electric loads of the ship were simulated during the tests. In phase two the erection of a demonstrator is intended.
- The US Office of Naval Research (ONR) proposed a demonstrator project to develop a 625 kW MC-FC system using diesel oil as fuel. In 2001 the R&D phase was announced to last 6 years ending with a demonstrator.
- In Iceland the government is intending to substitute fossil fuel by hydrogen produced from thermal energy available in Iceland at low cost. Projects with buses using hydrogen as fuel are running. The fishing fleet is one of the major fossil fuel consumers in Iceland. It is proposed to use hydrogen as fuel and FC technology instead of diesel engines for fishing vessel power supply. Currently a pilot project for the application of a 80 kW FC-System on board of a Icelandic vessel is under preparation (NAVIGEN Project)
- The European Commission (EC) is supporting a two year pilot study named FC-SHIP which was initiated by the thematic network TRESHIP. The project started in July 2002. More than 20 companies and institutions including the Fincantieri yard, engine manufacturer MTU and a number of the class societies are participating. The project is co-ordinated by the Norwegian Ship Owner's Association (NSA). It is intended to define a rational basis for the development of FC-Systems for merchant ships. Transfer of experiences from land based projects to marine applications, measurements of real life

load requirements, definition of basic safety and operational requirements, a conceptual ship design for a passenger ship and the assessment of infrastructure requirements are main topics.

5 Fuels required for Fuel cells

Fuel Cells can use hydrogen (A-FC, PE-FC, PA-FC) or hydrogen carbon monoxide mixtures as fuel (MC-FC, SO-FC). Fuels other than hydrogen therefore must be reformed to H2.

For ship applications petroleum fuels like natural, gas, methanol and diesel fuel seem to be the most likely solutions due to their prevalence and low costs. Diesel reformers have already been tested but no commercial application is really available on the market so far. In the scope of a DOD, DOT demonstration project the Danish manufacturer Haldor Topsoe tested a steam reformer and states that the technology is able to be used for diesel and kerosene. Fig. 7 shows the prototype of a methanol reformer for submarines.



product: H2 for 240 kW FC power
reformer efficiency: 90 %
dimensions: 2*1,8*0,8 m
steam reformer

Fig. 7: Methanol Reformer running at HDW in Kiel

The sulphur content of diesel fuel is regarded to be the major problem for the use of MDO or HFO in FC-Systems. Reformers operating with catalysts do not tolerate sulphur containing compounds like hydrogen sulfide (H2S) or carbonyl sulfide (COS). Also the platinum catalysts of low temperature FC do not tolerate sulphur compounds. Only high temperature SO-FC or MC-FC are more tolerant to sulphur. Nevertheless proposals for HFO reformers for SO-FC exist. To the knowledge of the authors all marine pilot applications currently discussed assume hydrogen or natural gas (LNG) as fuels.

6 Efficiency Potential

The highest efficiencies can be reached with SO-FCs. For combined cycles using the high temperature at the fuel cell outlet for a gas and steam turbine cycle electrical efficiencies of up to 80 % are expected. Current pilot plants of Siemens Westinghouse have 45 % efficiencies without and about 55 % with a gas turbine cycle.

The temperature level of MC-FCs is about 300°C lower compared to SO-FCs. The efficiency of the FC itself is comparable to the SO-FC efficiency. The temperature is still high enough for a gas or steam turbine cycle downstream of the MC-FC. The lower temperature level leads to lower system efficiencies. About 73 % are expected to be the maximum value. Hot Module pilot plants from MTU currently reach about 50 % (Fig. 8).

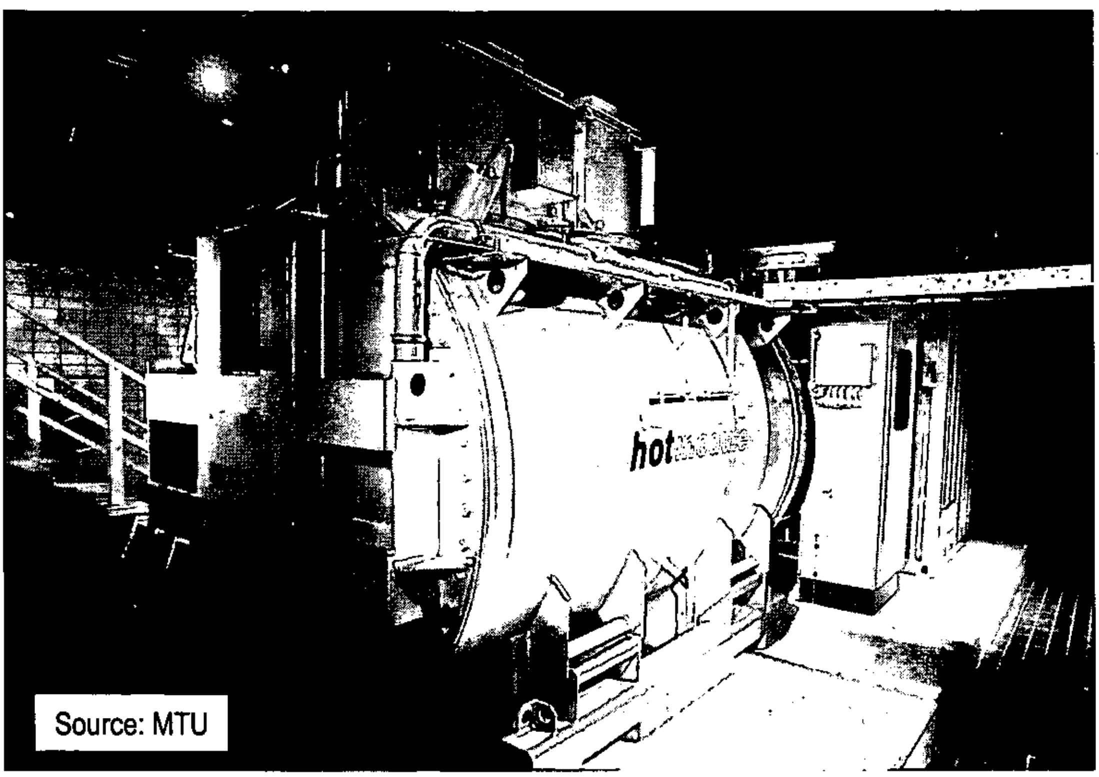


Fig. 8: Hot Module at Röhn-Klinikum

For low temperature PA-FC and PE-FC a separate gas or steam turbine cycle downstream of the fuel cell is not useful. For these systems the overall system efficiency is therefore equal to the efficiency of the FC itself. Pilot plants with reformers reach up to 40 %. If hydrogen is used directly the value increases to about 50 %.

7 Power Range

All types of FCs are of modular design. For marine applications it is important to note that power can be increased easily by installation of parallel systems. For high temperature FCs with gas-/steam turbine bottom cycles their additional power supply must be taken into account. The contribution of the bottom cycles is typically by the factor of about five below the FC power (20% of FC Power).

FC plants with 50 or 100 MW for power generation only are expected to be of SO-FC type. The expected power range of MC-FCs and low temperature PA-FC, PE-FC is related to the needs for combined production of heat and power. Therefore development targets are a few hundred kW to some MW.

The driving force of PE-FC development is the car industry. For this reason PE-FCs are currently developed for a power range below 1 kW up to 250 kW. The lower value is intended for battery substitution and the upper one for buses.

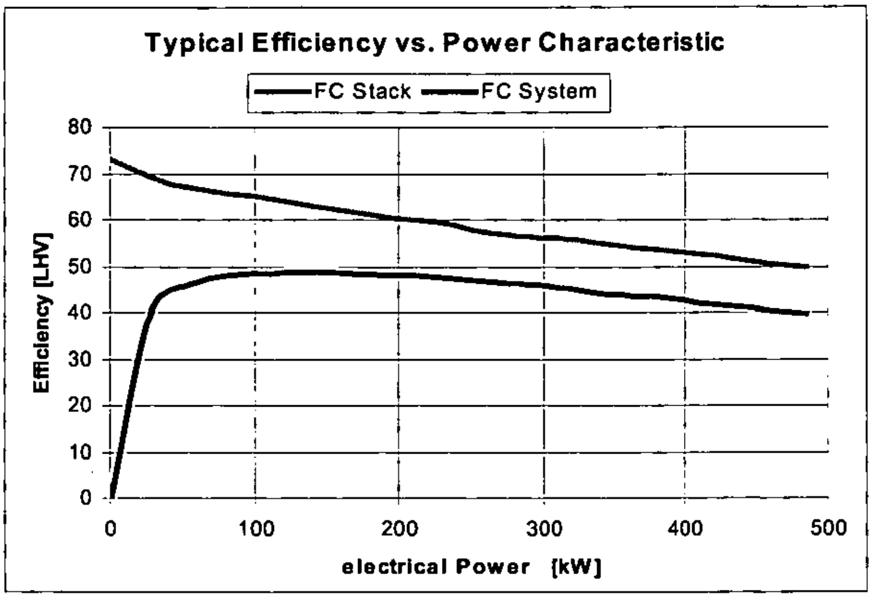
8 Stack Service Life

All FC developers aim of a service live of about 40 000 h. After this time the stacks must be exchanged due to reduced stack voltage and the corresponding low efficiency. From the current experience with FCs using natural gas as fuel it can be concluded that this value can be reached by all types of FCs. The values of reported service lives below 10 000 h for PE-FCs are caused by the main application of this FC type in the car industry. For cars a service live of 5000 h is sufficient because this is equivalent to about 250 000 km or 13 to 16 years of life time for a private car. Nevertheless it can be expected that PE-FC developed for stationary applications (e. g. Fig.4) will also reach the target of 40 000 h.

9 Operational behaviour

With the exception of MC-FCs all types of FC produce electricity directly proportional to the fuel gas flow into the cell. For this reason the response time under normal operating conditions mainly depends on the fuel conditioning system (reformer, shift reactor, gas supply). For MC-FC the system supplying the CO_2 to the cathode side must be taken into consideration also. However this is of minor importance because it is an internal transport of CO_2 which can be recycled from the anode side where it is built from CO_3 ions.

An other important factor is the different part load behaviour of FC compared to diesel engines, gas turbines or steam boilers. In principle the losses of the cell at operating temperature are constant. The cell voltage is constant or even increasing with decreasing load. Therefore the efficiency of FCs remains high down to very low part loads. Fig. 9 shows the part load behaviour of a PE-FC system with hydrogen as fuel and the PE-Stack.



Source: MTU-Friedrichshafen

Fig. 9: Part load behaviour of a PE-FC

This different system behaviour compared to conventional ship propulsions systems is important with respect to the operating regime. A modular diesel engine system is operated with optimum efficiency and therefore close to nominal power of the modules. Diesel engines are switched off if necessary. Contrary to Diesel engine a FC-System has a constant or slightly increasing efficiency at loads below nominal power. Therefore the modules of a FC-System will be reduced in power and if possible no module will be taken out of operation. The situation becomes more complex if conventional bottom cycles like gas- or steam turbines are included in the FC-System. The bottom cycles will only have about 10 to 20 % of the total power. Therefore their part load behaviour will be of minor importance to over all system efficiency. Also the system behaviour of the fuel reformer must taken into account. It can be concluded that a FC-System requires completely different operation and control regimes compared to existing diesel or gas turbine systems.

The start up time of the system is an other important operational aspect. PE-FC - developed for cars - already have acceptable start up times of a few minutes up to about 2 h. For PE-FC, PA-FC the start up time is mostly limited by the fuel processing system. It seems possible that the values for diesel engines (0.5 to 2 h) will be reached. High temperature SO-FCs, MC-FCs currently have start up times of more than 20 h which are not acceptable for ship operation. For these systems the FCs themselves and not the fuel reformers are the limiting components. The research targets for SO-FCs and MC-FCs are 2.5 to 5 h start up periods. With these figures ship applications seem to be realistic. Due to this behaviour of high temperature FCs and the sensitivity to load cycle frequencies the basic principle should be: "Reduce load but never switch them off!"

10 System Costs

One of the most critical points for any ship propulsion or power supply system are the costs. However, costs are currently the weak point of all FCs. The distance between target costs and known costs of pilot installations still equals the factor of 5 to 10. The next four to eight years are the time frame named by the developers to reach the cost targets. The cheapest FC-System is the PA-FC as produced by ONSI Company. From numerous installations of this approx. 200 kW modules world wide it is known that current investment is about 3000 to 4000 $US/kW and therefore unacceptable high for commercial shipping. Even the target costs of about 1000 $US/kW given for most FC-Systems are high values for ship propulsion systems.

For small installations up to about 250 kW the availability of cheap PE-FCs for cars and buses will pave the way for shipping applications. Bigger plants based on high temperature FC will be applied to naval ships and ships where investment costs are not the predominating factor.

With respect to investment and fuel costs it can be assumed that environmental reasons will be one of the key motivations for FC-Systems in shipping. FC-Systems also will be an interesting option for "all electric ships" and auxiliary power supply in combination with diesel engines or gas turbines. At the moment no comment can be given by the authors with respect to maintenance costs.

11 Safety

For land based installations the system safety of FCs is regarded to be comparable to the use of natural gas and therefore more or less technical standard for power plants, households and even cars. Nevertheless developers note that special attention must be given to the use of hydrogen which is related to the use of FCs.

For ship installations the comparison of FC-Systems to other ship board systems using gas and specially hydrogen gas is also valid. The difference is that for good reasons gas and nearly all other possible fuels for FCs are not allowed as fuels by IMO regulations. Having in mind that most safety standards are based on (bad) experience it should be accepted that FC technology including the related fuels and process techniques like fuel reformers represent a higher potential risk compared to common technology. To know and accept this is the first and most important step for the safe application of FC technology in shipping.

Gas as fuel is used on LNG tankers under the special regulations of the IMO IGC-Code. Furthermore a very limited number of vessels are using compressed gas. In 2000 a ferry boat fuelled with LNG for her four 675 kW piston engines went into service in Norway. A FPSO with a 6030 kW Wärtsilä gas-engine is under construction for a Norwegian owner. With the exception of the small pleasure craft HYDRA and a PA-FC system for a boat on the Lake Garda the only existing marine application of FC-Technology is the FC-

System installed in HDW class U-212 submarines which use Siemens PE-FCs stacks of 250 kW total power (Fig. 5).

Special regulations for FC-Systems on board of ships do not exist in the moment. Based on Germanischer Lloyd experiences with gas, liquefied gas tankers, liquefied hydrogen handling and submarine applications of FC-Systems we started the development of Guidelines for the use of FC-Systems on board of ships and boats in early 2001. These Guidelines are currently under final review. Germanischer Lloyd certification and classification work for FC-Systems and related components like storage, transfer systems and process equipment is supported by the Strategic Research Group Fuel Cell Technology which was established in early 2002 in Germanischer Lloyd. In the scope of the R&D-Project FC-SHIP the class societies GL, DNV, LR and RINA will work together to establish common basic safety recommendations for FC-Systems on board of ships.

Project Green Efforts for Existing Ships

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SYNOPSIS

The use of homogenisers in pre-treatment of heavy fuels is controversial, the major manufacturers of fuel separators advocate against installation of homogenisers upstream separators, arguing that it will strongly reduce separation efficiency of contaminants and water. On the other hand, suppliers of homogenisers claim 80 % reduction in sludge volumes, improvement in combustion, exhaust gas emissions and machinery maintenance by the use their equipment. A large number of ships are equipped with fuel homogenisers, however, the environmental and fuel consumption improvements and operational aspects have not been adequately documented so far.

The harmful environmental effects of organotin compounds were recognized by IMO in 1990. On 5 October 2001, a diplomatic conference adopted the IMO convention on the control of harmful anti-fouling systems on ships by consensus. This convention states a global prohibition on the application of organotin compounds which act as biocides in anti-fouling systems on ships by 1 January 2003, and a complete prohibition on the presence of organotin compounds which act as biocides in antifouling systems on ships by 1 January 2008.

Many ship owners have for several years tested tin-free antifouling paint systems, both in form of test patches and for full hull bottoms, with varying success. Some ships have experienced severe fouling and speed loss. Thus, there is a need for further testing and documentation on performance of TBT-free antifouling paint systems.

INTRODUCTION

The project "Green Efforts for Existing Ships" is part of a Norwegian national R&D program "MARMIL", initiated by the Norwegian Shipowners' Association and the Research Council of Norway, and with funding also from the thirty participating industry partners. The objective of the project is to establish and document operational experience from environmental efforts applicable for existing ships. Such experience and documentation is gained through implementation onboard sailing ships in normal operation. The project were started in 1998, and have pr today covered six different aspects:

- NOx emission rating of the main engine onboard a 6000 tdw paper carrier
- Exhaust gas emission measurements onboard Viking Lines' "Mariella", for evaluation of installed "Humid Air Motor", HAM technology
- Low sulphur marine fuels, effects on emission improvements and operational aspects
- Documentation of emissions from ship operation
- Fuel pre-treatment, fuel homogenisation and fuel/water emulsion
- TBT-free anti-fouling paint test programme

This paper will concentrate on the presentation of the two last part projects, test activities performed to identify possible effects from fuel homogenization and water emulsified fuel, and a test programme for documentation of performance of TBT-free anti-fouling paints.

EFFECT OF FUEL HOMOGENISATION

The effect of using homogenisers in pre-treatment of heavy fuels is controversial, and the experiences are differing. There are reports claiming reduction in fuel consumption and exhaust gas emissions, and reduction of deposit formation in the

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engine and exhaust boiler heat surfaces. The manufacturers are also claiming reduced sludge production and less filter clogging. Reduced sludge production means fuel savings and reduced incineration. In combination with water injection, a reduction in NOx-emissions is obtainable.

As important as to document the possible benefits of homogenisers is to investigate to which extent the homogeniser affects the separators ability to clean the fuel, and how it will effect the performance of the machinery through abrasive wear or other secondary effects. Leading manufacturers of fuel separators argue that use of homogenisers upstream the fuel separator will strongly reduce the separation efficiency of both water and other contaminants.

A considerable number of ships are to day equipped with homogenisers, and further more to be delivered. However, the environmental and fuel consumption improvements and operational aspects have not been adequately documented so far. This is the background why the project in 1999, in collaboration with two ship owners, established this test programme to investigate the possible effects of fuel homogenisation. In spring 2000 this group was extended to a total of twelve ship owners, with that in common of either operating ships with homogenisers or they will be in near future. The group also include the two major manufacturers of fuel separators, Alfa Laval and Westfalia, and the homogeniser manufacturer Ashland/Drew Marine Division. The group meets half-yearly for presentation of results and detailing further activities.

Several ship owners has offered test ships for the investigation. The onboard tests cover both fuel homogenisation and use of water-emulsified fuel. Measurements and recordings cover machinery performance parameters, fuel consumption, dynamic cylinder pressures, exhaust gas measurements and numerous visual inspections in addition to a comprehensive number of fuel and sludge samples and analysis. All visits onboard also comprise interview and discussions with the engine staff, who has also been involved in performed measurements and fuel sampling

The objective of the test activity has been to answer and document following questions?

- Do fuel homogenisation reduce sludge production ?
- Will fuel homogeniser situated upstream separators hamper the separator efficiency?
- Will fuel homogenisation improve the engine combustion quality?
    - reduction in fuel consumption?
    - less harmful exhaust gas emissions?

Reduction in sludge production

To be able to investigate possible sludge reduction potential, one has to clarify what exactly is meant by the term "sludge". Is it the total amount of material discharged from the fuel separator, or is it the part of the discharge with density higher than water?

The volume discharged from the fuel separator normally consists of three separate constituents or parts, the part with density higher than water, the water part, and the fuel part. The relative amount between them depends on fuel quality and on the type and adjustments of the fuel separator. All tests performed onboard the test ships verified that for to days normal ISO classified fuels the levels of contaminants, and hence the "Real Sludge" part with density higher than water, is fairly small. Tests performed onboard MT “Berge Stavanger”, equipped with Alfa Laval Alcap separators, evidenced just a spoonful of heavy sludge, the remainder being water. The tests were done with the sludge discharge line disconnected and the sludge collected in a bucket. Tests performed with and without SR homogeniser in operation gave identical results. This is confirmed by similar tests on other test ships. Consequently, for most ISO certified fuels the “real sludge” part represents a very small quantity, and loss of energy.

The major part of the energy lost through the separator discharge volume is therefore connected to the fuel part. Experience from several of the project test ships indicated fuel parts up to 50% of the total sludge volume. However, dependent on type of separator, if the separators are adjusted for a minimum of fuel discharge, the energy lost might be fairly small. This emphasises the importance of properly adjusted separators. On the other hand, if the sludge is incinerated containing large amounts of water, the fuel consumption for incineration will be high. Proper separation/drainage of the water from the remaining sludge is therefore of importance for the incinerator fuel consumption. Possible recovery/utilisation of all/parts of the sludge phase will be topic of further project investigation.

The main purpose of this part of the investigation has been to document whether the use of fuel homogenisation will reduce the amount of "real sludge", and maybe also if fuel homogenisation allows for prolonged discharge intervals. All the results from the onboard tests have been on ISO certified fuels with low content of contaminants, and have revealed no effect from fuel homogenisation. Still remains to establish if the effect is more marked on more contaminated fuels and for fuels with low stability margin. A project plenary meeting in June 2002 decided that a continuation covering such fuel qualities should be done more conveniently under controlled laboratory conditions. Such tests are planned this autumn.

Influence on separator efficiency

Separator manufacturers as well as several engine manufacturers are critical to homogenisers upstream the fuel separators, and strongly argument that it fosters low separation efficiency of both water and particles. A vital part of the project work has therefore been to document possible changes in separator efficiency when operating on homogenised fuel.

Influence on separation efficiency has been investigated by taking fuel samples from the fuel system with and without the homogeniser in the pre-treatment system in operation. All fuel samples were analysed by DNV Petroleum Services according to the standard "Veritas Fuel Quality Test Programme" parameters, with total sediment existent, total sediment accelerated and asphaltenes in addition. However, the major problem has been that the fuels content of contaminants has generally been very low, making exact establishment of separation efficiency hard to obtain.

Of special interest has been the separator's ability to remove particles like aluminium and silicon, so-called catalytic-fines. These small particles of powdered aluminium-silica based material, which are remainders from the refinery cracking process, can cause wear of fuel pumps, piston rings and cylinder liners. The combined amount of aluminium and silicon is limited to 80 mg/kg for all residual fuel grades by the ISO standard.
In addition, the separator efficiency regarding water removal has also been investigated.

Table I shows the results from analysis of fuel and sludge samples collected during a visit onboard MV "Probo Gull" during a journey between Taiwan and Japan. The samples were taken before and after the fuel separator on untreated reference fuel, R, and with homogenisers in operation, H1 + H2.

As comes forth from the results the level of sediments was reduced from 0.02 % m/m to 0.01 % when passing the separator, independent of homogenised fuel or not. The combined content of aluminium and silicon from the fuel samples was higher than from the other test vessels, but well below the 80 mg/kg limit (~40 mg/kg). A reduction in aluminium and silicon content was registered when comparing samples before and after the separator, both with untreated and homogenised fuel. The separation efficiency was in the range 50-70 %, and no significant changes in separator efficiency between untreated and homogenised fuel is evidenced.
The water content in the fuel samples was reduced from 0.5 % to 0.2 % for the reference case and from 0.4 to 0.3 for the case of homogenised fuel, indicating a lower ability to separate water from homogenised fuel.

A special test was performed onboard MT "Berge Stavanger" to further investigate the separator ability to separate water from homogenised/emulsified fuel. Onboard MT Berge Stavanger, the H1 homogeniser is arranged in an own circulation circuit connected to the settling tank. Just upstream the homogeniser a water injection unit was installed, and water injected and emulsified through the homogeniser until a water content in the settling tank of near 1 % was achieved. In this mode, fuel samples were collected before and after the fuel separator, shown in Table II.

Table I Results from analysis of fuel and sludge samples from MV "Probo Gull", with untreated and homogenised fuel

Sample no.		*F10000 9566*	*F10000 9567*	*N10000 1123*	*F10000 9571*	*F10000 9572*	*N10000 1127*
Date		10.11.00	10.11.00	09.11.00	11.11.00	11.11.00	10.11.00
Sample point		Before separator	After separator	Sludge sample	Before separator	After separator	Sludge sample
Operating condition		R	R	R	H1+H2	H1+H2	H1+H2
Density, 15 °C	kg/m^3	990.0	989.9		990.0	990.0	
Viscosity, 50 °C	mm/s^2	382.3	381.9		380.4	378.9	
Water	% V/V	0.5	0.2		0.4	0.3	
Micro Carbon Residue	% m/m	16.47	16.33		16.18	16.55	
Sulphur	% m/m	3.75	3.79		3.80	3.82	
Ash	% m/m	0.03	0.03	2.10	0.03	0.03	1.20
Vanadium	mg/kg	69	70	70	69	71	40
Sodium	mg/kg	22	18	1100	23	22	580
Aluminium	mg/kg	12	6	2600	15	5	1500
Silicon	mg/kg	17	9	3800	20	8	2100
Iron	mg/kg	5	3	840	6	3	500
Nickel	mg/kg	19	19	40	20	20	30
Calcium	mg/kg	4	3	220	4	3	120
Magnesium	mg/kg	1	1	110	2	1	60
Lead	mg/kg	< 1	< 1	30	< 1	< 1	< 10
Zinc	mg/kg	1	2	70	2	1	40
Total sed. potential	% m/m	0.02	0.01		0.02	0.01	
Total sediment existent	% m/m	0.01	0.01		0.02	0.01	
Total sed. accelerated	% m/m	0.02	0.01		0.01	0.01	
Asphaltenes	% m/m	8.0	8.0		7.6	7.5	

Table II Results from analysis of fuel samples from MT "Berge Stavanger", with 0.8 % water and homogenised fuel

Sample no.		*F19900 7824*	*F19900 7825*
Sample point		*Before separator*	*After separator*
Operating condition		H1	H1
Density, 15 °C	kg/m^3	956.5	956.5
Viscosity, 50 °C	mm/s^2	186.8	189.1
Water	% V/V	0.8	0.7
Micro Carbon Residue	% m/m	8.5	8.6
Sulphur	% m/m	3.29	3.3
Ash	% m/m	0.01	0.01
Vanadium	mg/kg	34	34
Sodium	mg/kg	6	6
Aluminium	mg/kg	< 1	2
Silicon	mg/kg	1	4
Iron	mg/kg	< 1	< 1
Nickel	mg/kg	9	9
Calcium	mg/kg	< 1	4
Magnesium	mg/kg	< 1	2
Lead	mg/kg	< 1	< 1
Zinc	mg/kg	< 1	< 1
Total sed. Potential	% m/m	< 0.01	< 0.01
Total sediment existent	% m/m	0.01	< 0.01
Total sed. Accelerated	% m/m	0.01	< 0.01
Pour point	°C	9	9
Asphaltenes	% m/m	2.5	2.5

As expected, the results clearly demonstrate the largely reduced capability in separating water when operating on homogenised/emulsified fuel. However, again due to very low content of other contaminants, the efficiency regarding other contaminants cannot be properly evaluated from these results.

The following conclusions might be drawn based on the fuel sample analysis from the case ships:

- For most of the fuels tested, the fuel content of contaminants was generally too low to establish exact values for the separator efficiency, hence comparison between untreated and homogenised fuel is unfair.
- For the fuels with higher content of contaminants, no significant changes in separator efficiency of cat. fines (Al/Si) is evidenced between untreated and homogenised fuel. However, the fuels content of water were fairly low.
- Special test with 1 % water injected upstream the homogeniser clearly indicated reduced capability of separating water when operating on homogenised/emulsified fuel.
- Further tests on fuels with high levels of contaminations are necessary to draw final conclusions regarding possible changes in separator efficiency when operating on homogenised fuel, such tests should also include fuels with high water content.

Improved combustion quality

In order to document possible improvements in combustion quality due to use of fuel homogenisers and water emulsion, the following parameters have been investigated:

- Specific fuel consumption
- Dynamic combustion pressure, rate of heat release
- Emission levels (NOx, THC, CO, smoke)
- Exhaust temperatures and cylinder liner temperatures
- Exhaust heat exchanger efficiency

Influence on specific fuel consumption

Figure 1 shows results from measurements onboard MV "Hual Trident" on voyage from Barcelona to Southampton. Measurements were performed during the following operation modes:

- Homogenised fuel (H1+H2)
- Reference, untreated fuel (R)
- Homogenised water emulsified fuel (H1+H2+W)

Each column is an average of several measurements in each operation mode.

The results imply that the fuel homogenisation and the actual water emulsion (ab. 5 % water) have no significant effect on fuel consumption. The dispersion of the values in each test mode was above the average difference shown in the figure. This result is confirmed from the other test ships.

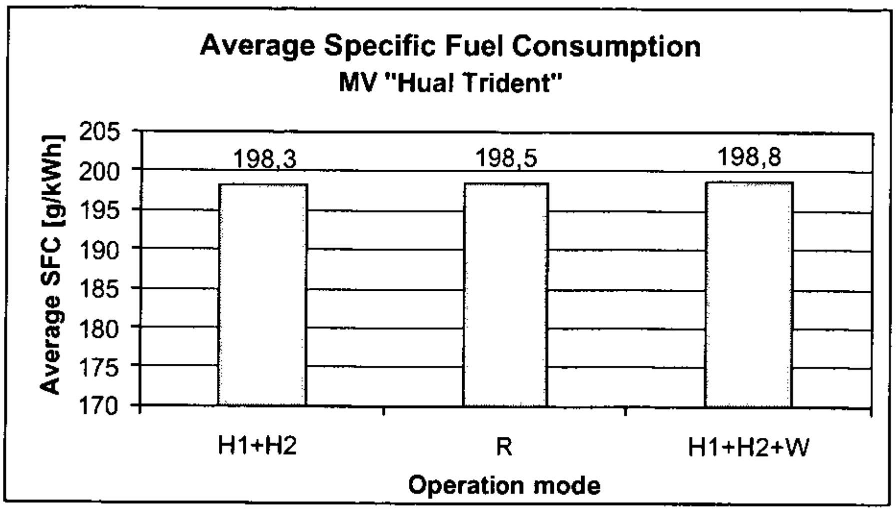

Figure 1: Average specific fuel consumption results from MV "Hual Trident", operation on homogenised (H1+H2), untreated reference (R), and homogenised water emulsified fuel (H1+H2+W)

Influence on dynamic cylinder pressure and rate of heat release

Any improvement in the engine combustion process, like reduction in ignition delay or accelerated combustion, always will be reflected in the dynamic cylinder pressure, and even clearer in the calculated rate of heat release. Investigation of these parameters was done as a supplement to the other measurements in order to substantiate possible effects of the fuel homogenisation. Figure 2 and 3 present results from the tests onboard MT "Berge Stavanger", reference condition on untreated fuel, R2, on homogenised fuel, H1+H2, and on homogenised water emulsified fuel (ab. 10 % water), H1+H2+W.

As comes forth, the diagrams for cylinder pressure and rate of heat release are identical between the reference case, R2, and the operation on homogenised fuel, H1+H2. Hence, the test evidence no significant change in the combustion process between untreated and homogenised fuel, this is also confirmed from the other test ships. However, when operating on homogenised water emulsified fuel, H1+H2+W, the ignition delay is slightly increased and the maximum cylinder pressure is reduced, but when the combustion starts the rate of heat release is improved compared to the case without water emulsion, and completion appears to be in the same range, about crank angle 395. This is in accordance with theory and earlier experience, and the reason for the lower NOx-emissions when operating on emulsified fuel.

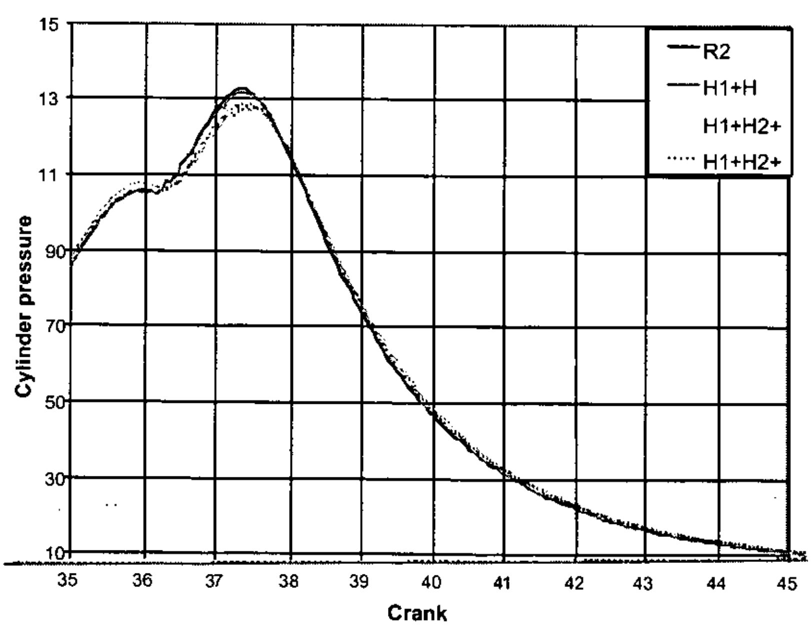

Figure 2: Dynamic cylinder pressure, MT "Berge Stavanger", from operation on untreated, homogenized and homogenized water emulsified fuel

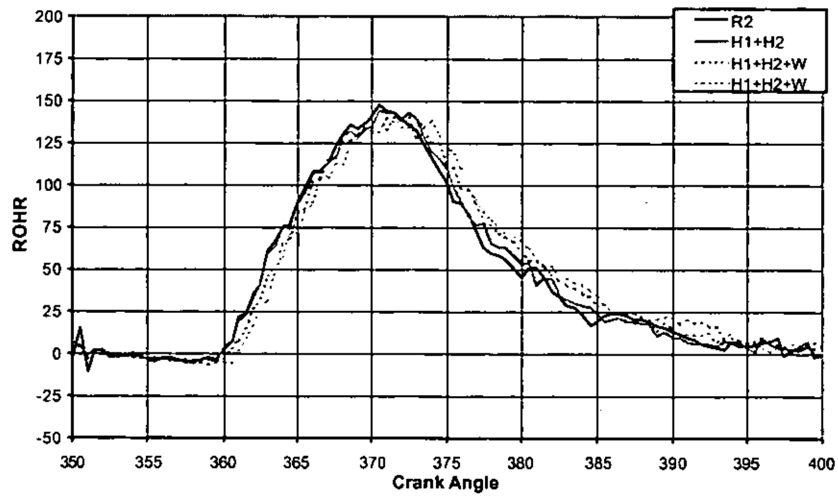

Figure 3: Calculated rate of heat release, MT "Berge Stavanger", from operation on untreated, homogenised and homogenised water emulsified fuel

Influence on emission levels

The performed tests also included exhaust gas measurements of NOx, CO, THC and smoke, as some homogeniser manufacturers claim that fuel homogenisation will reduce NOx formation during the combustion process.

Figure shows specific NOx-emissions from operation on various forms of fuel pre-treatment, adjusted according to ISO 8178-1 (earliest recorded data to the left, latest recorded data to the right).

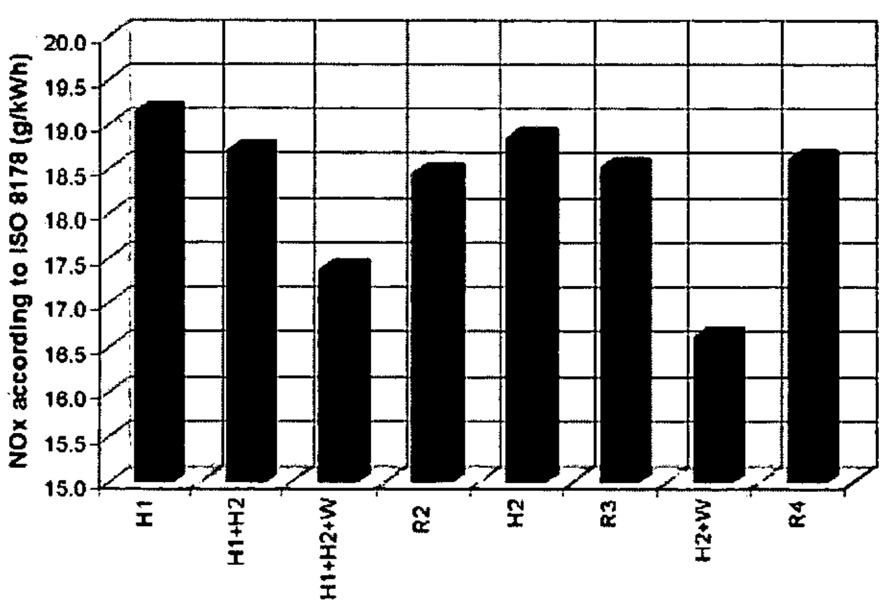

Figure 4: Specific NOx emissions from operation on various forms of fuel pre-treatment

- ✓ NOx emissions for the cases with untreated fuel varied between 18.5 and 18.6 g/kWh.
- ✓ NOx emissions for the cases with homogenised fuel varied between 18.7 and 19.1 g/kWh.
- ✓ NOx emissions for the cases with homogenised 10 % water emulsified fuel varied between 16.6 and 17.4 g/kWh.

The actual tests were done during a month voyage from Arabian Gulf to US, with corresponding variation in ambient conditions. The ambient conditions are parameters strongly influencing the NOx emission levels. Although the specific values have been adjusted according to ISO-8178-1, this correction factor is very general and does not give an accurate enough representation for the effects of ambient conditions on one particular engine. Therefore, only cases with similar ambient conditions are truly comparable. The ambient conditions for cases H2 and Hl+H2 are fairly similar to cases R2 and R3, and the NOx emissions for these cases are well inside 0.5 g/kW, which with mentioned uncertainties should be seen as insignificant. Hence, based on performed tests no effects on the NOx emissions were recorded when operating on homogenised fuel.

The ambient conditions for the case H2+W are very similar to those of the reference conditions. The NOx emissions are reduced from 18.5 g/kWh to 16.6 g/kWh, which are about 10%, and as expected. A smaller reduction is obtained in case H1+H2+W, but this may be due to lower ambient temperature and hence lower water to dry air ratio. Hence, based on the performed tests it might be concluded that water emulsified fuel has the expected effect on reducing NOx emissions.

THC and CO emissions were also recorded for the same operating conditions as above. No correlation between emission level and operating condition was found, indicating that THC and CO emissions were not affected by homogenised or emulsified fuel. However, as with the NOx emissions, the THC/CO level are also strongly affected by the ambient conditions.

PERFORMANCE OF TBT-FREE ANTI-FOULING PAINT SYSTEMS

Ships travel faster through the water and consume less fuel when their hulls are clean and smooth, free from fouling organisms, such as barnacles, algae or molluscs. In the early days of sailing ships, lime and later arsenical and mercurial compounds and DDT were used to coat ships' hulls to act as anti-fouling systems. During the 1960s the chemicals industry developed efficacious and cost-effective paints using metallic compounds, in particular the organotin compound tributyltin (TBT). By the 1970s, most seagoing vessels had TBT painted on their hulls.

The harmful environmental effects of organotin compounds were recognized by IMO in 1990, when the Marine Environment Protection committee (MEPC) adopted a resolution which recommended that Governments adopt measures to eliminate the use of antifouling paint containing TBT.

On 5 October 2001, a diplomatic conference adopted the IMO convention on the control of harmful anti-fouling systems on ships by consensus. This convention states a global prohibition on the application of organotin compounds which act as biocides in anti-fouling systems on ships by 1 January 2003, and a complete prohibition on the presence of organotin compounds which act as biocides in antifouling systems on ships by 1 January 2008. However, to be legally binding it need to be ratified by at least 25 states, the combined merchant fleet of which constitute not less than 25% of the gross tonnage of the world's merchant shipping.

Many ship owners have for several years tested tin-free antifouling paint systems, both in form of test areas and for full hull bottoms, with varying success. Some ships have experienced severe fouling and speed loss. Hence, many ship owner advocate against the ban, and ask for more time and thorough documentation regarding the performance of alternative paint systems. And in the same way, most nations are reluctant to ratify the ban. This is the background for the initiative to this programme. The test programme is part of a research project called "Green Efforts for Existing Ships", operated and managed by the Norwegian Marine Technology Research Institute, MARINTEK. The project is funded by the Research Council of Norway and the Norwegian Shipowners' Association in addition to support from all participating partners.

The overall objective of this TBT-free anti-fouling paint test programme is to perform testing and establish documentation on performance of last generation tin-free antifouling paint systems, based on application of test patches on ships in normal operation. Ship owners participate by offering test ships and arrange for test areas. The composition of test ships should be sufficiently broad to reflect operational conditions for the world fleet both regarding trades, trading waters, speed, activity levels, docking intervals etc, also most demanding operational conditions for anti-fouling systems to be *covered. All major suppliers of anti-fouling paint systems participate with their last generation products, designed for the actual ship and trade.*

A joint industry test programme

As mentioned in the introduction all paint suppliers do continuous testing of their products, also by means of test patches on sailing ships, in agreement with respective ship owner. What is seen as unique with this specific test programme is the extent of test ships and test patches, and even more the broad participation from most parties influenced by the actual TBT ban, from ship owners and the Norwegian Shipowners' Association, from all major suppliers of anti-fouling paint, from classification as well as research laboratories. A total of twenty-two companies has signed a Joint Venture Agreement and are directly involved in the test programme activities.

This broad cooperation is invaluably important, both regarding the objectiveness of results as for an efficient spread of information. Prior to dry-docking of each test ship when the test patches are applied, a meeting between paint suppliers and ship superintendent is arranged, for common data regarding the specific test ship, operation profile, docking interval as well as planning and positioning of test patches. Based on this each paint supplier make up his test patch specification, which are gathered by the programme manager before distribution between all involved parties. As the paint suppliers are fairly familiar with their competitor's products, this procedure ascertains that the paint systems specified are consistent with the test ship operation profile. With contribution from all partners the programme has elaborated standard report forms for paint application, divers inspection and final inspection in dry-dock, to ascertain comparable documentation between test ships. All paint suppliers are represented in dry-dock during the test patch application, and each fill in application data for his test patch together with comments regarding the quality of paint application as well as other relevant information. In addition wet paint samples are collected from all applied paint systems, for analysis of tin content and possible fingerprint test. All this data are gathered in an "Application Report" for each test ship, and is important for an objective evaluation at the end of the test period.

The wide participation of ship owners is similarly important to satisfy the programme objectives. The ship owner group represents a wide range of ship types, trades, trading waters, and docking interval, hence enable the selection of a set of test ships representative for the world fleet. As pr today test patches are applied on a total of sixteen test ships, and the first applied test patches have accumulated more than two years operation. The ship owners also play an active role in planning and follow up during test patch application, and further by performing intermediate in-water inspection as agreed between the partners.

DNV Section for Materials and Inspection Technology participates as specialist in Coating and Material Protection. They are prime responsible for all laboratory activities, wet sample analysis, spinning disc tests etc., in addition for all final dry-dock inspections and evaluation of obtained results.

Test programme discription

The project was formally established in June 2000, and the first test ship, the car carrier MV "Tancred" from Wallenius Wilhelmsen was dry-docked the following month and applied test patches. Since then test patches have been applied on a total of sixteen test ships. Of these fourteen has patches of last generation self-polishing (SP) anti-fouling paint systems, the last two has patches with biocide-free paint systems. The total test ship programme is presented in figure 5, also indicating the wide range of ship types/trades, when docked and applied patches and planned docking interval, as well as planned finalized test period.

Ship type	Ship owner	Ship name	Dock	Period	00	01	02	03	04	05	06	07
Car carrier	Wilhelmsen	Tancred	7/00	36								
Gas carrier	Bergesen	Helice	8/00	60								
Chemical	Stolt Nielsen	Stolt Egret	9/00	30								
Shuttle tank	Knutsen OAS	Vigdis Knutsen	10/00	36								
Chemical	StoltNielsen	Stolt Sapphire	10/00	60								
Tanker	Red Band	Knock Muir	12/00	60								
Open hatch	Billabong	Star Harmonia	12/00	36								
Coastal express	TFDS	Kong Harald	1/01	36								
Coastal express	TFDS	Polarlys	1/01	36								
Cruise ferry	Color Line	Kronprins Harald	1/01	24								
Cruise vessel	Red Band	Black Watch	3/01	24								
OBO carrier	Frontline	Front Breaker	4/01	60								
Bulk carrier	Høegh	SG Prosperity	8/01	60								
Supply	Farstad	Far Fosna	11/01	30								
LPG Carrier	Bergesen d.y.	Berge Ragnhild	2/02	30								
General Cargo	Grieg Billabong	Star Fuji	3/02	30								
	Klaveness	NN										

Figure 5: The total test ship programme

The participating paint suppliers goes forth from figure 6, also presenting which products are tested. The SP products all utilize copper-oxide as biocide, but in other respects the composition and properties between them are quite different compared to the existing TBT based technologies, which are fairly common in formulation. The biocide-free products are all based on silicone technology, but as Ameron at the time being doesn't have an available product in this category, they do not have test patches on those two test ships. The programme is still active in search of a third test ship for biocide-free systems.

Suppliers	SP-Products	Biocide-free Products
Jotun Paints/NOF Kansai Marine Coatings	SeaQuantum	Everclean
International Coatings/ Nippon Paint	Intersmooth Ecoloflex	Intersleek
Hempel's Marine Paints A/S	GLOBIC SP-ECO	HEMPASIL SP-EED
Star Marine Coating/ Chugoku Marine Paints	Sea Grandprix	Sea Grandprix ECO-Speed
Sigma Coatings	AlphaGen 20	Sigmaglide LSE
Ameron International	ABC#3	

Figure 6: Tested products by suppliers

The test patch areas are located mid-ship, for ships with single side loading arrangement preferably on the seaward side to reduce mechanical damages. Vertically the test patches goes from the bilge keel to the deep load line, and the horizontal width of each test patch is 3 – 5 m. For the best relative comparison between the test patches the sequence of test patches between the products are altered systematically from one test ship to the next. Figure 7 shows test patch layout during application on MV "Star Harmonia" from Grieg International/Billabong.

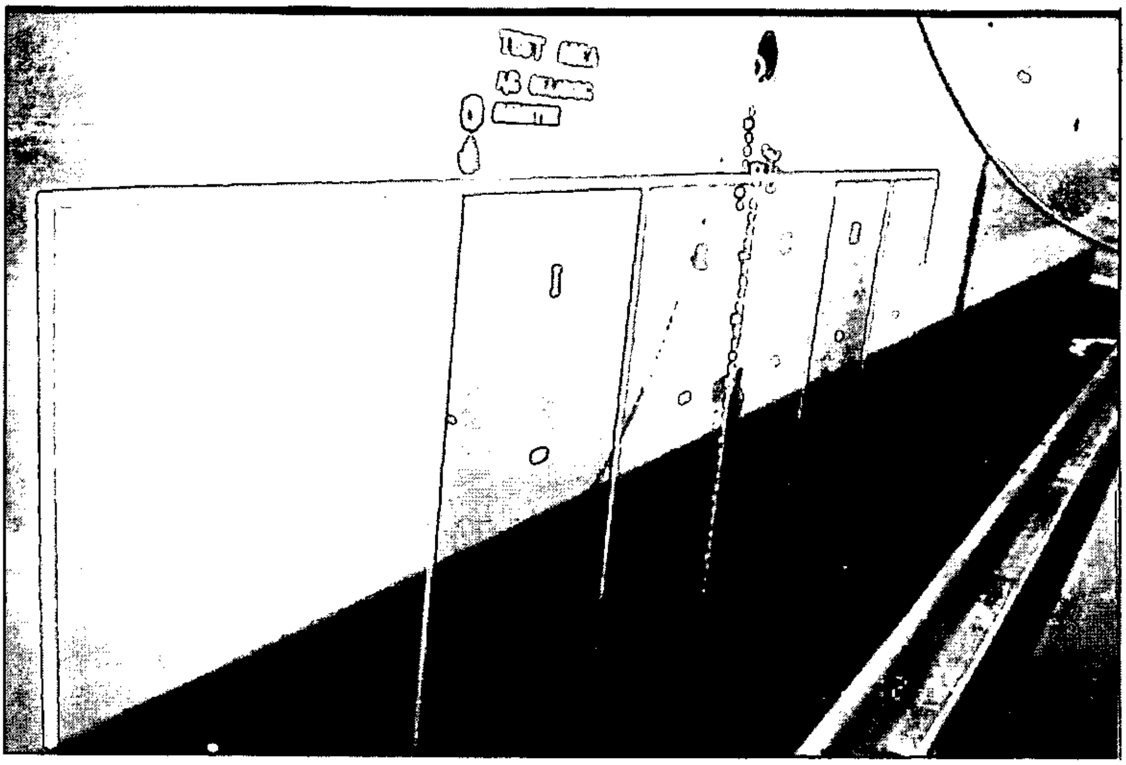

Figure 7: Test patch layout, MV "Star Harmonia"

The surface preparation of the total hull is decided by the ship owner. Several test ships is full blasted to steel and applied new anti-corrosive and TBT-free anti-fouling, in those cases one of the suppliers are main, the remainder have test patches as described above. However, the most common practice is still to do touch up of damaged areas and apply new TBT based anti fouling on top of existing paint system, eventually with a sealer in between. In those cases the surface preparation of the test patch zone are decided between the ship superintendent and representatives from the suppliers dependent on surface condition of existing coating. Even conditions for the total test area has been weighted, and for most ships in this category the upper half of the test area has been blasted to steel, then applied new anti-corrosive and possible sealer before specified anti-fouling test patches.

Since five of the ships have docking intervals of five years, the final results will not be available before the last ship has ended its test period by the end of year 2006. However, some early results valid for ships with the shortest docking periods are planned May 2003. Further an intermediate report is scheduled to December 2004, covering all but the 60 months paint systems.

DISCUSSIONS AND CONCLUSIONS

By the project execution the importance and superiority of the actual kind of joint industry research is clearly recognized. All results might not be of significant scientific importance, though of great value for the participating parties. First of all it is recognized as an highly efficient way of jointly generation and transfer of knowledge, experience and technology, important for a cost-efficient adoption of coming environmental legislation.

Waste Management at Sea: The Drive Towards an Environmentally Independent Ship

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ABSTRACT
Increasingly stringent marine discharge quality legislation is beginning to cause significant changes to the processes and practises of waste management on ships. Processes using membrane bioreactors (MBRs) are proving to be effective technologies for the treatment of shipboard black and grey water for reasons of compactness, simplicity and effectiveness of clean up. To further enhance environmental compliance, there is also a need to achieve remediation and/or volume reduction of other waste streams arising from ships. This approach has additional benefits including; reducing the volume required for on-board stowage; reducing the frequency of port visits (and reducing associated off-load costs); reduced manning requirements for waste handling; and improvements to health and safety conditions. QinetiQ Ltd's Environmental Sciences Dept has designed, constructed and trialled a full scale Integrated Waste Management System Technical Demonstrator (IWMS TD), in conjunction with Strachan & Henshaw Ltd and BMT-DSL Ltd. This new system processes seven waste streams that are typically produced on ships. The design of the system was aimed at treating the types and volumes of waste streams created by a future Royal Navy ship with a compliment of 204 personnel. More specifically the system will treat and dispose of; clinical waste, sanitary waste, food waste, bilge water, black water and grey water and garbage including metal, glass, paper and plastics. The black and grey water and the liquid effluent from sanitary waste processing are effectively treated using a proven submerged membrane bioreactor. Solid waste, including all garbage and pre-treated clinical waste, is shredded and combusted in a marine incinerator. Macerated food waste, oil from a bilge-water separator and excess sludge from the bioreactor, is burnt separately in the incinerator. The aim of this study is to demonstrate remediation of all ships' waste streams using an integrated approach to achieve the aims above. The results from the initial stages of this study are presented.

1. INTRODUCTION

1.1 Background and Legislation

There is a need to improve waste management practises at sea to meet anticipated changes to marine discharge legislation. The current standard for marine discharge legislation to control pollution at sea are set on an international level, with the consent of the maritime nations across the world, by the International Maritime Organisation (IMO). These standards are documented in the 1978-modified version of the 1973 'Convention for the Prevention of Pollution from Ships' that is collectively known as MARPOL 73/78 [1].

MARPOL 73/78 sets standards for liquid waste discharge to the sea for oil (Annex I, ratified 1983), and for sewage (Black water only, Annex IV), which although has yet to be ratified on an international level has been adopted by many of the 87 member states that have signed up to annex IV. More stringent legislation than Annex IV of MARPOL 73/78 is, however, appearing in various local areas around the world to curb the impact of the cruise ship industry, and affects all liquid discharges including both black and grey water. Dade County Florida, Alaska and the Great Barrier Reef all have considerably tougher effluent standards to comply with when compared to Annex IV of MARPOL 73/78. Garbage disposal at sea is also controlled by the 1988-ratified Annex V of MARPOL 73/78 and completely prohibits disposal of plastic waste at sea but does generally permit the disposal of metal, glass, paper and food beyond 12 nautical miles from land, except for special areas. It is the policy of the MOD to comply with international and local legislation so long as its operational capabilities are not affected.

In 1996, a NATO Industry Advisory Group (NIAG) conducted a pre-feasibility study into 'The Environmentally Sound Warship for the 21st Century' [2]. This study identified and quantified all shipboard waste streams, and made with predictions of future marine environmental legislation, recommending suitable technologies for the destruction or remediation of these wastes. The effluent quality predicted by NIAG is generally comparable to some of the more stringent local legislation that exists today (ie Dade County, Florida) and the UK MOD has set targets with the aim of achieving environmental compliance by 2005, with an environmentally sound warship design by 2015.

Annex VI of MARPOL 73/78 was recently established to control pollution from the gaseous exhausts of Diesel engines (ie acid rain precursors), but has yet to be ratified. Regulation 16 within Annex VI contains the only guidelines, though very limited, for running and monitoring a marine incinerator. Therefore in order to fully realise the quality of off-gases from a marine incinerator it is necessary to compare to current land-based legislation.

After commissioning a number of feasibility studies, the Royal Navy's specialist section Marine Auxiliary Environmental and Steam Integrated Project Team (MAES IPT) within the Warship Support Agency (WSA), which is funded by the Marine Engineering & Development Programme (MEDP), commissioned a project to design, construct and successfully operate a full-scale, fully integrated shore-based waste management system demonstrator for use on future platforms. It is intended that the demonstrator will prove the suitability for integration of currently available 'Commercial Off The Shelf' (COTS) equipment and advanced waste treatment technologies.

1.2 Project Drivers

The fundamental drivers for the Royal Navy and other shipping are to improve waste management practises at sea in order to:

a. Allow the RN world-wide operation in an environmentally-independent manor without legislative constraints;
b. Improve longevity at sea, whilst remaining environmentally compliant;
c. Help reduce the cost of off-loading wastes in ports and be independent of port reception facilities;
d. Reduce the burden on manning through system integration and automation;
e. Ensure onboard storage of wastes is kept to a minimum;
f. Provide confidence to ship builders and integrators thereby helping to ensure inclusion of such advanced waste treatment solutions into future ships.

1.3 Specific Project Requirements

The study had to demonstrate that the IWMS technical demonstrator could treat a total of seven waste streams produced by a Future Surface Combatant, with a typical compliment of 204 personnel (25 of whom are women), for a trial duration of 45-days, while making only compliant discharges and emissions during this period. These wastes included:

1. Black water (sewage, 3m^3 day^{-1}) collected from Type 23 Frigates in Portsmouth Dockyard;
2. Grey water (30m^3 day^{-1}) artificially prepared to a MOD recipe which included ~10 litres per day of various cleaning agents (laundry liquid, shampoo, disinfectant etc);
3. Bilge Water (2.09m^3 day^{-1}) artificially prepared to a MOD recipe which included 90 litres of 16 oils, lubricants and cleaning agents in 2m^3 of seawater;

4. Solid Waste (1.75m^3 day^{-1}) collected from municipal wastes (Onyx UK Ltd) which included metal (0.22m^3), glass (0.27m^3), paper (0.42m^3) and plastics (0.45m^3);
5. Food Waste (0.32m^3 day^{-1}) collected from a local hospital canteen;
6. Sanitary Waste (100 unused products day^{-1}) made up with sterile new products;
7. Clinical Waste (15 litres day^{-1}) made up of sterile bandages, swabs etc.

In addition to treating the correct amounts of waste per day, the waste loading profile was also of prime consideration to ensure that the equipments had sufficient buffering capacity to treat. For example, at the end of certain shifts significant changes to the amount of grey water generated onboard can alter from 1.9m^3 from 10am and 2pm to 13.3m^3 over the following two hours from 2pm to 4pm. Computer simulations were necessary to determine whether the IWMS system required additional buffering capacity to cope with certain peak waste loads over the course of the day.

2. THE IWMS TD PROJECT

2.1 Project Overview

The project commenced December 2001, is due to be completed January 2003, and comprises of five phases, which include:

Phase 1 Design of the system to be space-efficient and cost-effective for a fully integrated and compliant technical demonstrator. Commencement of various supporting studies such as project risk and safety assessment, environmental impact assessment (EIA) for both the land-based TD and ship fit, failure mode and criticality assessment (FMECA), a reliability and maintainability study, and finally, a ship installation study.

Phase 2 Procurement of the best commercial-off-the-shelf (COTS) equipment available using Value Analysis, where existing MOD-developed equipment was not available. The IWMS TD was constructed, integrated and set to work at the QinetiQ Haslar site.

Phase 3 Testing the IWMS TD for a total of 45 days with the waste streams provided in section 1.3 above, while monitoring all liquid effluents and gaseous emissions from the system over this period.

Phase 4 Project analysis, reporting and completion of all outstanding assessments and studies (Due Dec. 2002).

Phase 5 Remediation of the trial's site and final reporting.

2.2 System Design & Equipments Overview

The equipments selected for the IWMS TD included a combination of best available COTS equipment that could be readily integrated and automated into the complete system, in addition to specific MOD-developed systems that had been previously developed prior to the commencement of this IWMS study.

The main equipments included the MoD-developed: submerged membrane bioreactor; bilge water separator; sanitary waste pyrolysis unit. In addition, commercial off the shelf technologies were identified through value analysis and included a solids shredder and screw transfer mechanism; advanced marine incinerator; GDU food macerator; and standard bench top autoclave.

All equipments were controlled, managed and monitored using a fully interactive Supervisory Control And Data Acquisition (SCADA) software control system, which acted as the hub of the entire system. The SCADA system permitted remote access and understanding of the entire

IWMS TD, including both automatic and manual over-ride of pumps and valves with suitable sensors to activate alarms where necessary. The SCADA software also enabled full control of the daily liquid-waste loading amounts and profiles over the course of the day. An overview of the IWMS TD system showing the seven waste-stream inputs, integrated treatment processes and the three remediated waste product outputs are shown in figure 1. Figure 2 also presents a photographic overview of the IWMS technical demonstrator at QinetiQ Haslar.

2.3 Submerged membrane Bioreactor

The submerged membrane bioreactor was developed in 1999 at QinetiQ Haslar with MOD funding. The system was designed to be retrofitted onto a Type 23 Frigate to treat all black and grey water generated on-board. The existing 'collect and hold' tanks of a Type 23 Frigate were modified to incorporate the most appropriate membrane technology at that time, which met the maintenance criteria of the RN; flat sheet submerged membranes. The 'collect and hold' tanks were increased in volume within the ship's compartment and adapted to incorporate an initial black and grey water mixing tank, saddled between these existing two holding tanks. Suitable 6mm and 3mm strainers were added and one of the holding tanks was adapted to be an anoxic denitrification tank which recirculated directly to the second tank, which was adapted to included 220 half height flat sheet membranes (100m^2) in an aerated bioreactor [3]. The full-scale technical demonstrator remains at QinetiQ Haslar, and is currently incorporated into the IWMS TD, while a replica system is currently being trialled on HMS Grafton.

The submerged membrane bioreactor is currently used to remediate 3m^3 day^{-1} of black water and 30m^3 day^{-1} of grey water while also receiving the liquid effluent from the sanitary waste pyrolysis unit. The aerated bioreactor process promotes bacterial oxidation of the organic matter in the influent waste streams by developing an activated sludge ultimately producing carbon dioxide and water. The carbon dioxide vents out of the bioreactor with unused air from the aeration process while the water generated passes through the porous membranes (~<0.1μm with microfilm) as permeate and the membrane acts as an effective barrier to the bacteria in the activated sludge. Membrane fouling is minimised by creating a cross flow across the membrane surface using the aeration process and this process permits significant throughput of waste (33m^3 day^{-1}) through a 19m^3 capacity system without diluting the activated sludge or permitting the transfer of bacteria or solids into the clear effluent permeate. A small proportion of the suspended solids remains relatively non-biodegradable, which builds up in the bioreactor over time. Previous studies have shown that this bioreactor can run for over 54 days before the bioreactor would require de-sludging (ie suspended solids => 25000 mg.l^{-1}) [3]. However for this IWMS study once the optimum level of suspended solids has been achieved within the bioreactor (ie 13000 mg.l^{-1}) then small amounts of activated sludge are removed on a daily basis to the incinerator in order to maintain bioreactor efficiency.

In addition, the IWMS system is also exploring the opportunity of providing water re-use on board ships for a range of tasks including laundry and toilet flushing. A liquid polishing system has been added to the permeate line from the bioreactor to provide further sterilisation with an Ultra Violet (UV) flow through unit and an activated carbon filter to help reduce levels of tannins, the slight yellow colouration, that originate from the concentrated vacuum-collect black water. The clear permeate is monitored and passes from the bioreactor to the foul water drain for the technical demonstrator but would equally pass to sea for a ship fit.

2.4 Bilge Water Separator

The development of the bilge water separator was sponsored by the MoD. The system uses a preliminary weir separation process which separates the oil from the oily water while re-circulating to the sullage tank, the IWMS simulated hull of the ship. A secondary cross flow ceramic filtration process further purifies the water generated in the first preliminary stage to meet MARPOL 73/78 Annex I regulations (ie typically <15 ppm). The oil retentate is transferred to the incinerator sludge tank where it helps to increase the calorific value of the other liquid wastes to be incinerated (ie food waste and excess activated sludge). Whereas the oil-free water effluent from the ceramic membrane process passes to the sea (ie foul water drain) via an activated carbon filter to bring the water quality in line with the other determinands, besides oil, that require monitoring as part of the RN NIAG target.

2.5 Sanitary Waste Pyrolysis Unit

The industrial development of a sanitary waste treatment unit was sponsored by the MoD and uses pyrolysis technology. The unit consists of two holding/processing chambers, which accept feminine hygiene products including tampons, towels, applicators and bags. Each chamber automatically pyrolyses the sanitary products once the lid has been closed a total of three times and the 30 minute cycle includes stages of pyrolysis, air combustion and steam cleaning of the ash. Off-gases and bacterial sterilisation efficiency have all been monitored as part of previous QinietiQ studies for the MoD. As part of the IWMS study both the off-gases and liquid-ash product are pumped, via a small holding tank, to the bioreactor where further oxidation of the waste ensues.

2.6 GDU Food macerator

Food waste included the products of food preparation and meal wastage and was macerated by an industrial unit designed to minimise the amount of water usage to generate an appropriate slurry. The slurry was ultimately pumped to the incinerator sludge tank before being sprayed, via a lance with a swirl plate, into the incinerator with the other liquid waste (ie oil and activated sludge from the bioreactor). The food slurry was kept above a certain temperature using an immersion heater in order to prevent solidification of fats and greases in the pipe work. The food slurry was also continually re-circulated within the transfer pipe work to prevent blockages.

2.7 Shredder and Screw Feed

The shredder selected for the IWMS TD typically shreds the mixed solid waste, comprising of 1.75m^3 of paper, plastic packaging, metal cans and tins and other trash for the day, in approximately 20 minutes. The hopper that is located beneath the shredder can typically receive 1-days worth of solid waste for added contingency to the system if the incinerator should become inoperable for a day. The shredded waste (typically 2x10cm strips) falls from the hopper into a screw feed which transfers the solid waste to the incinerator at an appropriate speed as directed by the SCADA software, typically 49 Kg hour^{-1}.

2.8 Marine Incinerator

A range of thermal treatment technologies are currently being considered for the MoD, however, for the scope of this IWMS TD project the thermal destruction technology chosen was an advanced marine incinerator. The incinerator is a bespoke industrial development designed to fit within a single ship's deck space and able to incinerate both the solid and liquid waste streams described. The unit operates with a Diesel burner at between 850 and 1200°C, and significant dilution air is required via two large fans to reduce the temperature of the off-gas, and the ship's thermal signature, to typically <120°C. The incinerator uses a cyclonic system to increase the period of the waste products within the flame to typically 15 seconds thereby achieving increased oxidation. The dramatic temperature reduction on exit from the incinerator will also help to reduce potential dioxin formation. Drawing the combustion air though the outer cylinder sheath of the incinerator also helps to cool the outer surface of the incinerator. The automatic priority for incineration over the course of the day is to burn the shredded solid waste (1.75m^3 ~ 100Kg) before the liquid waste (450 litres) once the incinerator has risen over approximately 1.25 hours to its operating temperature of >850°C. The ash, which has yet to be analysed as part of this IWMS TD study, is significantly reduced in volume and will ultimately be assessed to determine the extent of the potential chemical hazard before recommending appropriate disposal on land. The off-gases are being monitored to US Environmental Protection Agency guidelines for a range of pollutants associated with both the gaseous and particulate phases of the off-gas.

3 RESULTS AND DISCUSSION

3.1 Liquid Permeate Monitoring

Initial data from the bioreactor during the IWMS 45-day trial are currently available and includes analysis of the sludge, permeate (pre-polishing) and permeate immediately after the UV and activated carbon polishing stages, as shown in table 1. Table 1 also includes a comparison of the IWMS data with the RN NIAG target [2] and also with the levels included in the unratified Annex IV of MARPOL 73/78 [1], which has so far been adopted by many of the 87 member states signed up to it.

It is evident from table 1 that the flat sheet membranes provide an effective barrier to the transfer of faecal coliform bacteria, suspended solids and many other parameters that are normally associated with the activated sludge. The high counts of faecal coliform bacteria and also of various other bacteria (data not shown) re-enforces the extent of the biologically oxidative nature of the activated sludge used in this process. Comparison of the permeate data, pre and post-polishing, demonstrates how the activated carbon filter helps to further reduce the organic matter content of the permeate, which may be required when considering ultimate re-use of the permeate water. However, it is also important to note that the initial permeate that passes out from the membranes (ie pre-polishing) is already easily fully compliant with Annex IV of MARPOL 73/78 and also meets all bar one of the target NIAG 2005 limits (ie TDS = 695 $mg.l^{-1}$). When considering the NIAG limit of 500 $mg.l^{-1}$ for total dissolved solids (TDS) it is important to note that this is equivalent to the Drinking Water Inspectorate (DWI) limit for potable and bottled mineral water. It is generally believed that this unrealistic limit set in NIAG is an oversight, especially as seawater typically contains 35000 $mg.l^{-1}$ TDS as discussed in [3]. When comparing this effluent quality to the 'Dade County', Florida legislation The IWMS also appears to be fully compliant, and would also generally meet the more futuristic target of NIAG 2015 , which is set as typically half the 2005 limits shown in table 1.

3.2 Off-Gas Emission Monitoring

Table 2 shows some of the gaseous pollutants monitored in the off-gas from the marine incinerator for the initial stages of the 45-day IWMS trial. The marine incinerator used in the IWMS readily complies with the dated soot measurements provided in regulation 16 of Annex VI of MARPOL VI [4]. However, for comparison it is useful to compare these off-gas results to more stringent land-based legislation. Therefore for comparison table 2 also includes some of the land-based incinerator legislation for generally larger incinerators than the one used in the IWMS project. More specifically, comparison is made with Part 'B' of the UK Integrated Pollution Prevention & Control regulations 2000, with current EC legislation EC/369/EEC, and also with what is deemed to be the most stringent legislation of all, the German '17 BimSch V' legislation.

Table 2 demonstrates that the initial gases monitored in the off-gas of the marine incinerator of the IWMS TD are readily within those limits set for larger land-based incinerators. These results may not be surprising due to the significant dilution of the incinerator off-gas in order to meet the required reduction in thermal signature emanating from the ship's stack. Results from the particulate-associated pollution in the off-gas of the IWMS TD were unavailable at the time of preparing this article.

4 CONCLUSIONS

The IWMS TD has demonstrated that it can treat and remediate seven waste streams produced by a future warship with a typical compliment of 204 crew, and produce three products including; off-gas for discharge to the atmosphere; clear permeate liquid for discharge to the sea. The volume reduction of the ash to be stored on-board ship has yet to be evaluated. To date, the results from the water discharge of the bilge water separator, the ash form the incinerator and the pollutants associated with the particulates in the off-gas have yet to be fully analysed and are therefore not presented in this article. However, the bioreactor permeate liquid and gases produced by the incinerator have been partially analysed and have been presented in this article. The results show that the bioreactor permeate easily meets the forthcoming international legislation of Annex IV of MARPOL 73/78 and, more importantly, meets some of the existing more stringent local legislation aimed to curb the environmental impact of the cruise ship industry. The data demonstrates that the NIAG targets set by the RN for 2005 and 2015 can realistically be achieved when modern waste management practises are applied to ship installations.

In addition, the partial off-gases monitored to date from the marine incinerator of the IWMS TD also easily meet the forthcoming marine incinerator legislation contained in Regulation 16 of Annex VI of MARPOL 73/78. More realistic emission targets set for land-based municipal incinerators were also readily achieved by the IWMS, including the most stringent German 17 BimSch V, which was partly as a result of the significant dilution air required to reduce the thermal signature of the incinerator when on a ship installation.

These initial results suggest that the integrated approach adopted in the IWMS TD is likely to help the RN achieve its goals of being environmentally independent within areas of the most stringent discharge legislation while reducing its reliance on port reception facilities. The designed system is considered to be at the forefront of current technology for ship installation that is currently available without incurring excessive cost. Also, the automated approach adopted by the IWMS is likely to help the RN to reduce its burden on manning. Finally, by designing, building and trialling the IWMS as a technical demonstrator and thereby recommending appropriate changes for a ship installation it is likely to provide increased confidence to ship builders and integrators when installing such advanced waste treatment technologies onboard future platforms.

5 ACKNOWLEDGEMENTS

The authors wish to acknowledge the project sponsor MoD, MAES IPT and the overall team members in QinetiQ, Strachan & Henshaw and BMT-DSL who have contributed to this study.

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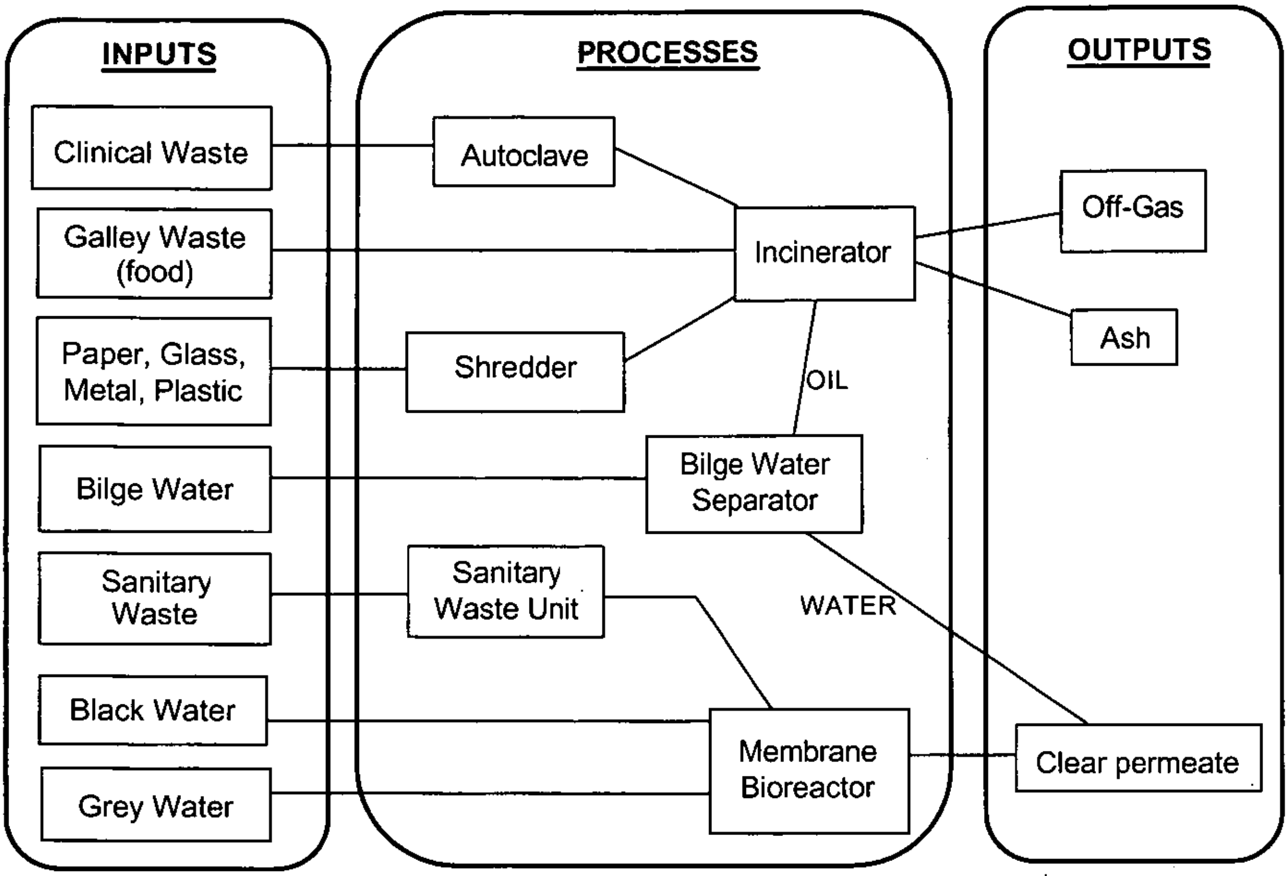

Figure 1. Schematic of the waste inputs, process technologies and outputs from the Integrated Waste Management System (IWMS).

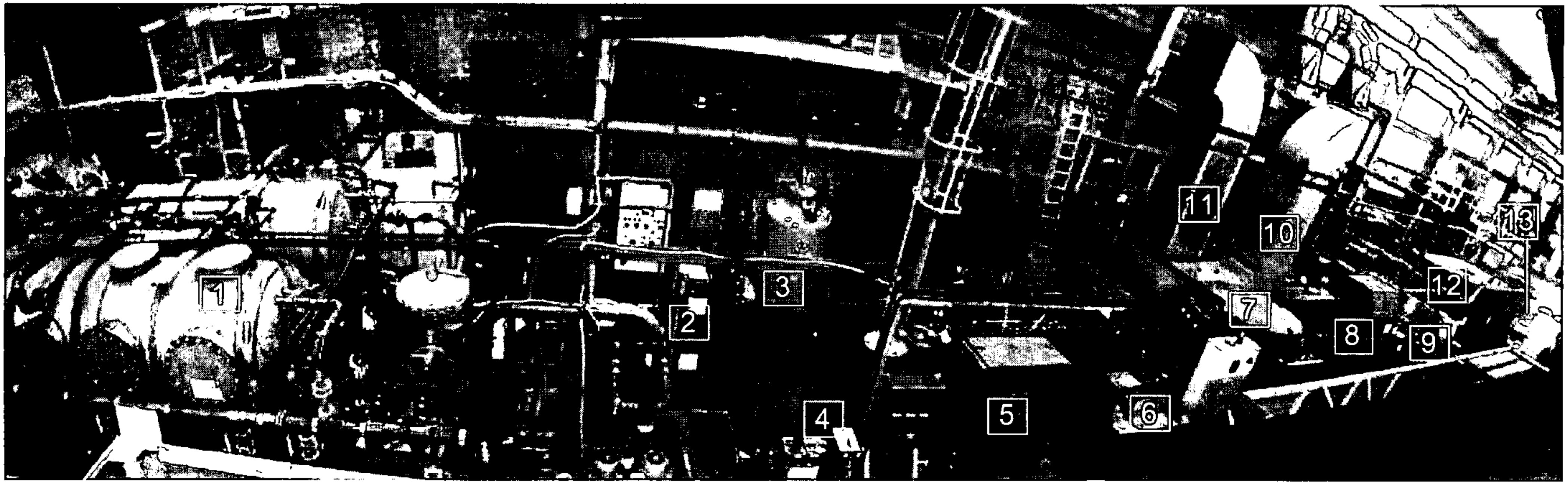

Figure 2. Photograph of the IWMS technical demonstrator at QinetiQ Haslar showing the key equipments listed.

1. Submerged Membrane Bioreactor
2. Ultra-Violet Permeate Polishing Unit
3. Activated Carbon Permeate Polishing Unit
4. Sanitary Waste Pyrolysis Unit
5. Bilge Water Separator
6. GDU – Food Macerator
7. Marine Incinerator
8. Shredder and Screw Transfer Mechanism
9. Control Panel
10. Off-gas Ductwork -Exit
11. Dilution Air Ductwork - Inlet
12. Grey Water Buffer Tank (18 Tonnes)
13. Control PC with SCADA software

Table 1. Initial results from the submerged membrane bioreactor used to remediate all black water, grey water and the product from the sanitary waste unit.

Determinand	Integrated Waste Management System			Royal Navy NIAG 2005 Target	IMO MARPOL 73/78 Annex IV
	Activated Sludge	Permeate (Pre-polishing)	Permeate (Post-polishing)		
Biochemical Oxygen Demand (BOD) ($mg.l^{-1}$)	1251	1.94	0.94	30	50
Chemical Oxygen Demand (COD) ($mg.l^{-1}$)	11867	65.1	14.7	300	-
Faecal Coliform Bacteria ($No.ml^{-1}$)	5.4×10^5	<1	<1	2	2.5
Suspended Solids ($mg.l^{-1}$)	10400	3.8	3.2	100	100
Total Dissolved Solids (TDS) ($mg.l^{-1}$)	695	nd	590	500	-
Metals (Combined) ($\mu g.l^{-1}$)	nd	nd	69	100	-
pH	nd	nd	7.9	6-9	-
Oil and Grease ($mg.l^{-1}$)	nd	nd	2.4	5	-
Total Organic Carbon ($mg.l^{-1}$)	30.6	12.4	3.23	100	-
Total Chlorine ($mg.l^{-1}$)	nd	nd	0.1	not allowed	As low as possible

'nd' = Not determined

'-' = Not monitored as part of MARPOL 73/78, Annex IV [1].

Table 2. Initial average off-gas measurements collected from the incineration of all types of wastes in the Integrated Waste Management System (IWMS).

Off-Gas Determinand	IWMS Off-Gas Concentration (with max and min levels)	IPPC Regulations (Part B) 2000 *	EC 369/89 †	German 17 BlmSch V ‡
NOx ($mg.m^{-3}$)	11.4 (<0.5 to 30.8)	-	-	200
SO_2 ($mg.m^{-3}$)	12.1 (<0.7 to 62.1)	300	300	50
CO ($mg.m^{-3}$)	10.1 (<0.8 to 64.4)	50	100	50

* Part B of the Integrated Pollution Prevention and Control Regulations (IPPC) 2000 for incinerators sized at a feed rate of 50-1000 Kg/hr.

† Current EC directive (EC/369/EEC) on new municipal waste incineration (>3 tonnes/hour)

‡ Stringent German government regulations for incinerator off-gases (Verordnung uber Verbrennungsanlagen fur Abfälle und ähnliche brennbare Stoffe – 17, BimSchV)

Future regulation of CO_2 emissions from ships - illusion or reality?

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SYNOPSIS

Legislation related to emissions from ship engine combustion is under pressure for further development. Emerging discussions in the early 1990s concluded in adoption of MARPOL Annex VI concerning air pollution from ships in 1997. Five years later, as Annex VI is still pending entry into force, questions are being raised over the shipping community's ability to act on the matter of emissions to air. In addition to this IMO has been challenged through the Kyoto Protocol as adopted by Conference of Parties to the UNFCCC in December 1997, to act as the body for cooperation between developed countries to reduce emissions of greenhouse gases from ships.

Greenhouse gas emissions from ships is a subject on the agenda for the Marine Environmental Protection Committee (MEPC) in IMO, and an assembly resolution on the subject was drafted at the 48th session in October 2002. Norway has been active in promoting that IMO should play an active role in defining the strategy on reduction of emissions of greenhouse gases from shipping. In cooperation with the Norwegian Maritime Authorities, MARINTEK and NTNU have participated in the development of a proposed approach based on environmental indexing of ships, and this approach has been presented for MEPC. Work undertaken has so far has focused on CO_2, this being recognised by MEPC as the main greenhouse gas emitted by ships.

In a future scenario where it is believed that CO_2 emissions will be regulated in line with other pollutants, it is not considered likely or beneficial that shipping will escape as the last unregulated business. Further for the benefit of the industry, IMO as the appropriate representative for the shipping industry should take the lead in providing the technical framework for future regulation on CO_2, as the organisation has done for other pollutants.

INTRODUCTION

As for other international bodies, greenhouse gas emissions have been in focus for the International Maritime Organisation (IMO) since the Kyoto Protocol[1] was presented in 1997. The Annex I parties to the protocol are urged to pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from marine bunker fuels, working through the International Maritime Organisation.

In 2000 IMO presented the Study on Greenhouse Gas Emissions from Ships[2]. The report, as presented to the Marine Environmental Protection Committee (MEPC), provided the basis for the work on an IMO strategy on the subject greenhouse gas emissions from international shipping.

Emissions to air are not a new or unknown subject for discussions in MEPC. Already in 1997 Annex VI[3] to the International Convention for the Prevention of Pollution from Ships (MARPOL) on the Prevention of Air Pollution from Ships had been adopted. MARPOL Annex VI limits emissions of sulphur oxides (SO_x) and nitrogen oxides (NO_x) from ship exhaust. The general limit for sulphur content of marine fuel (4.5% mass) is set far above the reported average of world sales[8] (2.7% mass). Annex VI also defines the special "SO_x Emission Control Areas" (SECA), as areas with a 1.5% (mass) fuel sulphur limit on bunker fuels, or alternatively to operate with exhaust gas cleaning system to limit SO_x emissions. In the adopted Annex VI, the Baltic Sea is designated as such a SO_x Emission Control Area, with the North Sea

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being the next area for the same designation. Based on information from IMO member states, MARPOL Annex VI is expected to achieve sufficient ratification by the summer 2003 to satisfy the entry into force and will do so in mid 2004[11].

A mandatory NO_x Technical Code, developed by IMO, defines how the defined limits for specific NO_x emissions (g/kWh) for new engines above 130 kW are to be complied with. The limit represents the state-of-the-art among the world major engine builders. Annex VI also prohibits deliberate emissions of ozone depleting substances including halons and chlorofluorocarbons (CFCs). New halon and CFC installations are prohibited on all ships, but hydrochlorofluoro-carbons (HCFCs) are permitted until January 2020.

In Europe the reduction of SO_x emissions from ships is a priority. Acidifications affecting fish, forest and groundwater, as well as historic buildings being eroded, are areas of major concern. As emissions from land-based sources of SO_x emissions already to a large extend are abated (e.g. emissions from large combustion plants and other modes of transport), ships' relative contribution is growing.

During development of MARPOL Annex VI, the discussions were limited to consideration of different pollutants in parallel. Formation of NO_x and SO_x, concurring abatement measures and development of new requirements, could be dealt with in parallel as measures affecting one to a very limited extent affected the other.

The introduction of the Kyoto protocol changed the possibility for further legislation discussions working along such an approach. The Kyoto Protocol invites industrialised countries to pursue the limitation or reduction of greenhouse gas emissions (GHG) working through the International Maritime Organisation. The IMO study on GHG emissions from ships clearly indicated the potential for improvements in this area, but also presents the challenge of trade-off between e.g. NO_x and CO_2 emission abatement measures.

In October 2002, the 48 session of the Marine Environmental Protection Committee (MEPC) of IMO were held, where an assembly resolution on greenhouse gas emissions was drafted. For MEPC the challenge is to balance the need for IMO to present a clear policy on GHG emissions in general and at the same time provide a basis for a strategy possible to implement within the framework of MARPOL. In doing so, IMO must not exceed or be contradictory to international law such as United Nations Convention on the Law of the Sea[12] (UNCLOS, 1982) or other international conventions. Article 1(a) of the Convention on the International Maritime Organization states that: "The purposes of the Organization are: To provide machinery for co-operation among governments in the fields of governmental regulations and practices relating to *technical matters* of all kinds affecting shipping engaged in international trade; to encourage and facilitate the general adoption of the highest practicable standards in matters concerning the maritime safety, efficiency of navigation and prevention and control of marine pollution from ships; and to deal with administrative and legal matters related to the purposes set out in this Article".

Present regulations related to components and equipment with focus on limit values on specific emissions (g/kWh) may not be the optimal approach to curb the total emissions from shipping. As design standards for components, such as main engines, the approach is well suited, but in way of describing the emissions from the ship operation the approach is incomplete. The system integration, choice of main parameters as speed and size, along with logistic planning and routing of a ship have significant impact on the overall emissions from operation of the ship. In the forthcoming legislation processes, it is expected that the overall energy efficiency of the ship as an entity will become the focus. Reduced emissions of one component may increase the emissions of another, while improved energy efficiency will reduce total fuel consumption and hence emission of all components.

In the following a possible strategy and implementation mechanisms aimed to curb CO_2 emissions from shipping will be discussed.

EMISSIONS TO AIR FROM SHIPPING

Emissions to air from shipping has been documented through several studies[2,4,5]. The various studies in general correspond well on the overall conclusions, although the estimated total figures vary significantly. Amount of emissions is often estimated by establishing an emission inventory. While some studies are limited to only European waters [4,5], others consider international shipping only[2]. In studies where scenarios for future development are made, these indicate further growth of ship-generated emissions to air in the future.

Emissions from ships, as shown in Figure 1, are distributed geographically in line with the pattern of seabourne trade. The majority of emissions occur on the northern hemisphere, with the highest concentrations in northern Europe, along the cost of the United States and the North Pacific. Based on this, it is not a surprise to find the countries in these areas among the most active in promoting stricter environmental legislation related to emissions to air in IMO.

Based on the number of studies provided on the subject, there should be sufficient material provided to agree that ship emissions contribute with a significant relative share of the world total emission inventories and hence that shipping could provide a meaningful contribution to curb global GHG emissions.

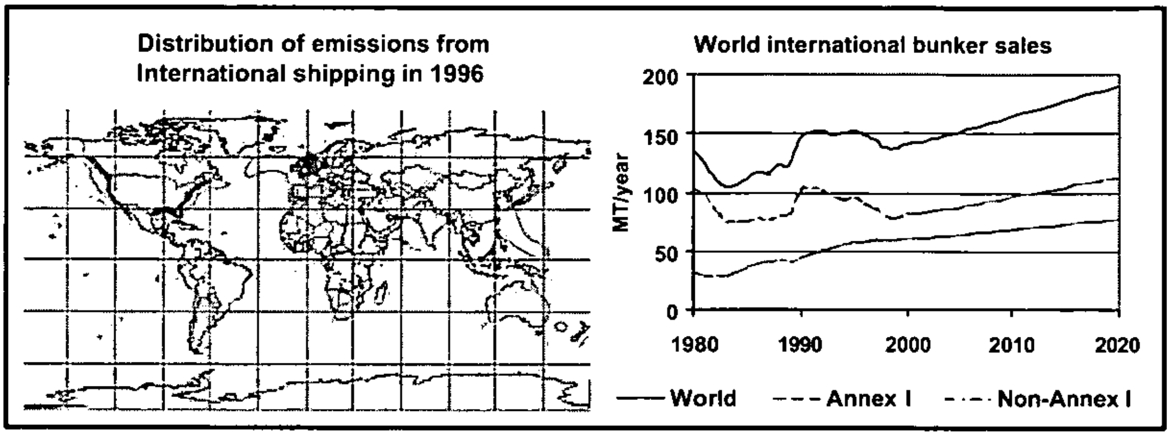

Figure 1 Distribution of emissions from international shipping and predicted growth of consumption[2,6]

With respect to pollutants UNFCCC defines greenhouse gases to be CO_2, CH_4, N_2O, HFC, PFCs and SF_6. Emissions of HFC, PFCs and SF_6 from ships are considered to be very small, and attempts to quantify these have so far yielded uncertain results. With respect to emissions of CO_2, CH_4 and N_2O from international bunkers, these emissions are included in inventory guidelines and reported by individual countries. Based on reported figures for 1998[14] from national greenhouse gas inventory data from Annex I Parties for 1990 to 1998, the relative contribution by CH_4 and N_2O (when considered in CO_2 equivalents) represents less than 0.3% and 1.9% of the total for the two components respectively. For comparison, the IMO Study reported that CH_4 and N_2O represented 0.2% and 0.8% respectively of the total emissions of CO_2, CH_4 and N_2O when considered in CO_2 equivalents. Based on existing inventories and degree of implemented regulations, it is based on this considered appropriate to focus on CO_2 in the initial phase of development of a GHG strategy for international shipping.

HOW TO CURB CO_2 EMISSIONS

In order to approach the core of the challenge of curbing emissions from ships, a basic equation for relationship between the main components affecting changes in carbon emissions may be considered[7]:

$$E = A \cdot I \cdot F \tag{1}$$

where E represents the emissions, A the activity in tonne-kilometres , I the energy intensity and F represents the specific conversion factor to convert fuel into emissions (e.g. kg CO_2/kg fuel). The energy intensity term will obviously be composed of several components (technical efficiency, utilisation), which in total express the energy consumed per unit transport work.

As the world economy continues to grow market analysis indicate that also the shipping activity will increase. This is based on experience from history, trade mechanisms and the clear correlation between economic growth and demand for transport. This basic assumption is applied in most inventory studies providing prognosis of continuing growth of emissions from ships. When considering (1), it is clear that an increase in A (activity) will require a corresponding reduction in I (intensity) or change of fuel (F) in order to curb the corresponding emissions (E).

The fuel element of the equation will only be able to provide marginal effect on all emission components with the traditional fuels. Application of natural gas or hydrogen may contribute to reduce emissions, but these alternatives are not expected to be feasible alternatives in large scale for at least the next decade or two.

The most feasible approach to reduce or curb emissions in medium term is, based on the above, to reduce the energy intensity of term in (1) by either improving ship design in this direction, and to further improve ship operation, or shifting from ship types with high energy intensity to those with lower intensity.

Assuming the strategy was to improve the energy efficiency of ships, critical elements would be:

1. A yardstick or scale defining energy efficiency for ships
2. An absolute or relative target for improvement
3. A market mechanism to implement a target for improvement.

Whether the mechanism chosen were to be applied only to new ships, or also to ships in operation, a measure for energy efficiency needs to be defined.

DEFINING THE ENERGY INTENSITY OF SHIPS

Based on data on existing ships, a large variation in design practice may be found even within one type of ships. As seen from figure 3 the installed propulsion power per DWT varies significantly even within on type of ships. If only new ships are considered, this large variation in design practice is not related to age alone. Based on this, work was started at MARINTEK and NTNU to consider how the energy efficiency of ships could be expressed, taking into account the particular of the individual vessels.

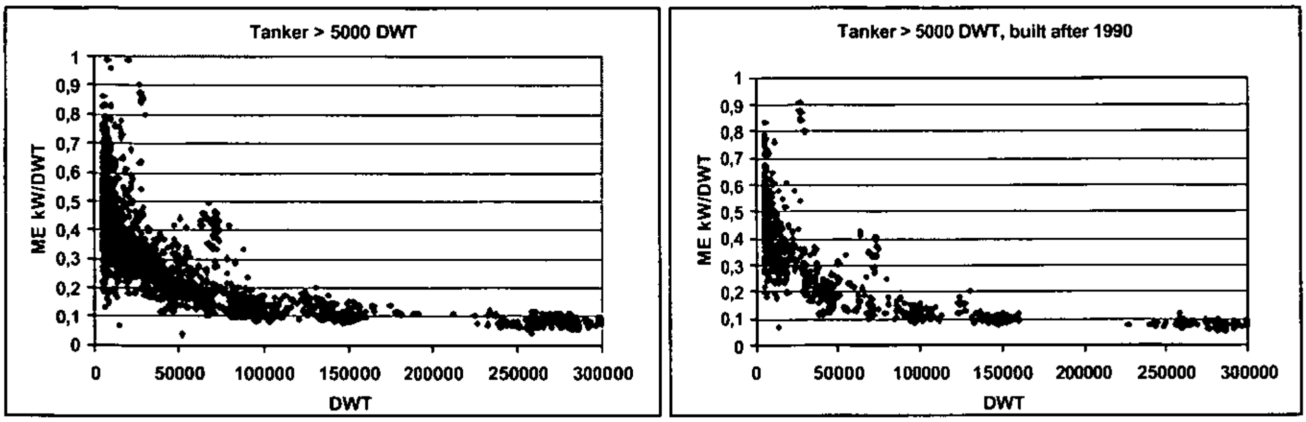

Figure 3 Variation in installed power for propulsion

The basic principle

An IMO correspondence group reported to MEPC48 that the majority of parties participating in the correspondence group supported a policy with the objective to reduce the unitary emissions from ships and through this define and obtain a target of relative reduction of emissions[10]. This was based on a Norwegian proposal[9] to MEPC46, which introduced the basic principle of a fuel consumption index (easily convertible to a CO_2 index) for ships as shown in equation 2.

$$F_{CO_2} = \frac{\text{consumption}}{\text{utilisation}} = \frac{\text{specific fuelconsumption} \times \text{installed power}}{\text{tonnage} \times \text{speed}} \quad \left(\frac{\text{tonn fuel}}{\text{tonn miles}}\right) \qquad (2)$$

The main arguments for equation 2 are:

1. An index should be transparent and easy to understand for those concerned.
2. Compliance should be possible to document, and preferably based on documentation already required for a ship.
3. An index should aim to establish an expression for the ratio between energy input and work performed, in order to promote development of energy-efficient ship systems and ship concepts
4. The same indexing should be possible to apply to both new and existing ships

The principle on a ship index for CO_2 could represent the basis for development of a standard for energy efficiency for different ship types. This could be obtained by an approach equivalent to that of the IMO NO_x code, where a limit value or target could be established based on the individual indexes from a set of ship data.

An example from some early case studies is indicated in Figure 4 where a set of ship data was applied. In this case a limit curve established based on a statistical mean value as indicated in Figure 4a). The required standard expressed as a target line was, as an example, set to a F_{CO2} value equal to the mean value of the fleet group in 2002. Figure 4b) illustrates a situation in which all ships in the group comply with the example target curve, e.g. by replacement of tonnage or de-rating of existing ships above the limit curve. All case studies were performed based on constant transport work performed by the fleet, and any growth of the fleet segment due to increased demand was ignored. The results indicated a long-term potential for reduced CO_2 emissions in the range 10-12% with a standard at the level chosen.

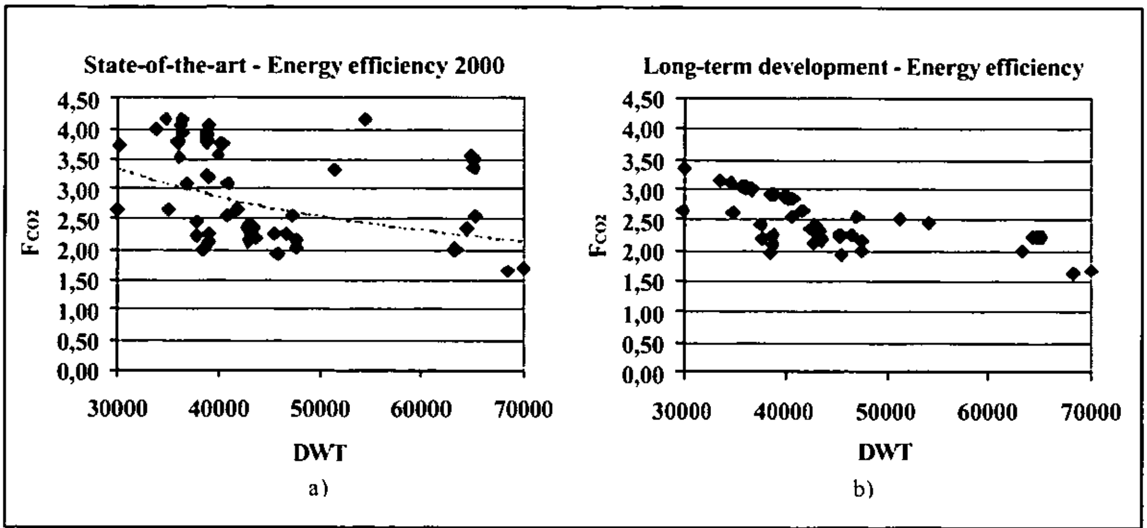

Figure 4 – Potential long-term development of energy efficiency for a fleet segment. Based on case study on 30-70000 DWT bulk carriers.

Based on these preliminary studies further studies were initiated to assess the robustness of the algorithm, the sensitivities of the parameters and extending the amount of ship data involved in order to further investigate the potential for this approach.

Equation (3) shows a potential extension of equation (2), refining the principle further for application in more detailed analyses. In Equation (3) efficiencies for the propeller ($?_0$), hull ($?_H$), transmission ($?_M$) and relative rotative efficiency ($?_R$) are included as well as using the total efficient power (P_e) as an alternative to initial studies where only installed engine power was considered (total efficient power in this context represents the product of total ship resistance and speed). The specific fuel consumption is kept as an expression for the thermodynamic efficiency, and a factor k added to take into account fuel type differences and incorporation of emission conversion factors if found appropriate.

$$F_{CO_2} = \frac{\text{consumption}}{\text{utilisation}} = \frac{k \cdot sfc \cdot \dfrac{P_e}{\eta_0 \cdot \eta_H \cdot \eta_R \cdot \eta_M}}{\text{tonnage} \times \text{speed}} \quad \left(\frac{\text{tonn fuel}}{\text{tonn miles}}\right) \qquad (3)$$

Equation (3) has been developed for the purpose of being able to perform sensitivity studies, consider importance of different parameters in development of algorithms and improve the understanding of relative importance of the various parameters that affect the energy efficiency of a ship.

The potential and need for further work

The work so far clearly indicates a gain by establishment of a design guideline related to energy efficiency of ships. As seen from figure 3 above the design practice even today still varies significantly for the ship types considered so far. A simple approach of a ship index and a design standard as presented here is favorable in ways of simplicity and the obvious clear promotion of minimum energy use to perform the task at hand. On the other hand it is obviously too early to conclude on the feasibility with respect to clearly define targets, absolute or relative. Applicability to different ship types, relevant parameters, and algorithms covering alternative propulsion system design and safety aspect still need further consideration. Obviously care should be taken to avoid introduction of an index promoting sub optimal solutions in order to ensure compliance with any new standard (e.g. "paragraph design"), or unwanted relationship with respect to other atmospheric pollutants (especially NO_x since NO_x emissions may exhibit an inverse relationship to CO_2 reduction). Further more ships which of various reasons need excess power installed should not be punished due to a static model not properly taking functional requirements into account.

Substantial work still needs to be undertaken to properly assess the approach as presented in this paper. The model used so far in the studies is far from complete, and several assumptions and simplifications applied so far needs more development work to further refine and improve the model. Future work will be needed to improve the ship database, assess the development of the fleet composition including trends on scrapping and newbuilding, performance of sensitivity studies on different parameters, and the impact of development of improved ship design and ship propulsion systems.

Assuming a scale and a target for reductions were obtained, this would still require a market mechanism for implementation to achieve long-term reduction of emissions.

RELEVANT MARKET MECHANISMS TO IMPLEMENT

Potential market based mechanisms to pursue to reduce emissions were considered in the IMO study[2], and the most relevant options identified to be:

- A voluntary agreements programme. Under this option, shipowners would agree to improve the emissions performance of their ships, agree to take certain measures to reduce emissions or they would agree to report emissions and efforts they make to reduce them.
- Carbon charges on bunker fuels. Such charges would have to be applied globally or at least among industrialised countries. Several alternatives for allocating such charges are discussed. One way to run a system of charges could be for the International Maritime Organisation (IMO) to administer the system.
- Emissions trading. Under this option, international shipping would be incorporated into the planned international emissions trading system that will be developed pursuant to Article 17 of the Kyoto Protocol. It would be very difficult to allocate emissions allowances to international shipping. However, they could be included in the trading system by allowing shipowners to sell emissions credits from measures taken to mitigate emissions from ships.
- Emission or efficiency standards. As with several existing IMO conventions, standards could apply to the design of new constructions, and possibly also to operational standards for existing ships, though the latter would be far more difficult.

Of the alternatives above, some are less realistic than others. The IMO study[2] presents the background on how carbon charge on bunker is not considered a viable option due to large evasion potential. With respect to voluntary measures, the opinions are divided on effectiveness of such market mechanisms. Often voluntary agreements represent a first step in a regulatory process, and if not proving to provide the achievements wanted mandatory measures are implemented. Emission trading systems are considered as a possible option, and attempts to establish such regimes have been initiated in local scale (e.g. trading on NO_x in Norway and SO_x in Sweden). The feasibility of an international trading system is however still very uncertain.

IMO may not be the appropriate organisation for determination of an absolute target for reduction of emissions from shipping. IMO may nevertheless take the lead in developing the necessary strategies and cooperate on implementation matters with regional authorities or internationally with Conference of the Parties to the UNFCCC. This could be achieved by the development of the proposed index and standard as indicated above, and inclusion in a wide indexing scheme for shipping.

An indexing approach

Environmental indexing has become a familiar expression within the shipping community after the introduction of several schemes based on this principle. The basic principle is differentiating the environmental profile of the vessels, and award those who are best. Ship owners are given credit either in way of reduced port fees or tonnage tax if they can show that their vessels complies with a standard beyond minimum mandatory environmental regulations e.g. as provided by MARPOL.

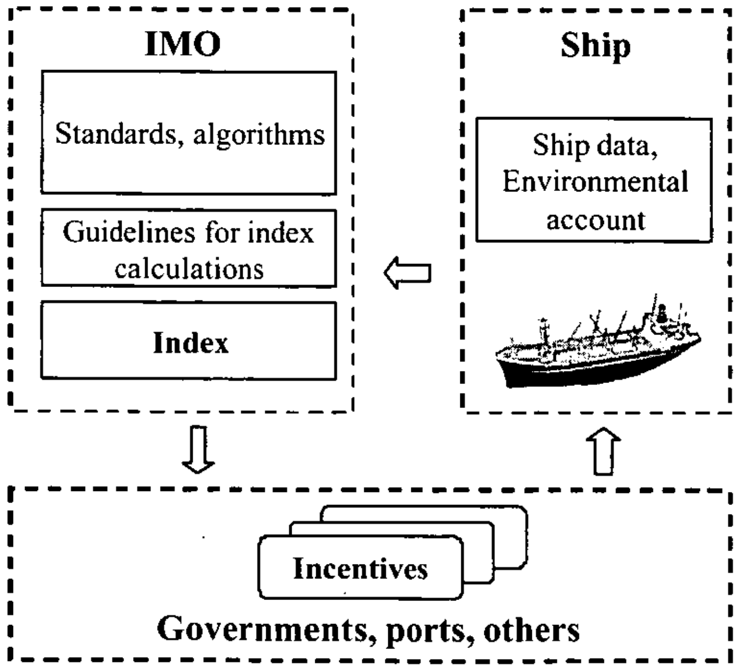

Figure 5 – An incentive based scheme to promote improved environmental performance of shipping

A CO_2 indexing approach with a defined target as presented here could be included in a wider environmental indexing scheme including several pollutants, even considering weighting the different pollutants relative to each other. By such an approach a market based incentive system could be established to promote both energy efficiency, choice of best available technology and fuel at the same time. Such a system will only have effect if it is internationally adopted and implemented, in order to achieve sufficient incentive for a ship owner. With a few local incentive schemes the economic benefit is presently not sufficient to invest in environmental friendly technology, but with incentives provided in many ports, this could be more attractive. It is in this perspective it is important that the development of such a system has a foundation in IMO and is implemented internationally.

DISCUSSIONS AND CONCLUSIONS

Today a process of environmental indexing of ships, combined with differentiated levies or taxes has developed, and it is not considered likely that this process is reversible. IMO may however in such a context represent a common denominator for further development, and provide a common framework that any kind of future "emission credit trading" or environmental differentiation system could be based on. This perspective may represent a win-win situation, where international cooperation is ensured to establish the framework for sound technical development based on requirements provided through technical standards, whereas different levels of ambitions may be expressed in national and regional application of the framework. The alternative is represented by different regulations on different levels, which would represent increased complexity for the ship operator with respect to compliance and documentation to be provided to different authorities.

IMO has recognised the responsibility and wish to take the lead in the matter of limitation of greenhouse gas emissions from ships, and is presently preparing an assembly resolution expressing the IMO policy in area[11]. Plans for further work, as being discussed in MEPC, points in the short term towards IMO guidelines related to voluntary emission reduction schemes. A key to successful work will however depend on the contribution from the IMO member states in the forthcoming process.

The development ahead related to the reduction or limitation of CO_2 emissions to air from shipping represent a significant challenge, as well as new opportunities, for the shipping community. As indicated above, increased energy efficiency is considered to represent the most favourable path forward. This does not only reduce emission of all components, but also represents an improvement in way of reduced fuel consumption for the operator.

In a future scenario where it is believed that CO_2 emissions will be regulated in line with other pollutants, it is not considered likely or beneficial that shipping will escape as the last unregulated business. Further for the benefit of the industry, IMO as the appropriate representative for the shipping industry should take the lead in providing the technical framework for future regulation on CO_2, as the organisation has done for other pollutants.

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Challenges on Marine Engine Manufacturers by new Emission Legislations

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SYNOPSIS

Today, climate changes and air quality are two major concerns. Governments on both sides of the Atlantic are committed to reducing the effects of manmade air pollutants. More stringent standards are being put in place, by a large variety of International Agencies, to limit emissions of noxious gases and particulates released by combustion engines.

This paper will address the challenges that an Engine Manufacturer has been facing, balancing the need for legislation compliancy with power output, with cost of operations and reliability.
Leading technology is the key solution to the ongoing need of limited emission engines, given the strict standards coming into effect in the near future. The paper will outline the current industry solution for "clean" fuel systems and will focus on the Caterpillar fuel system technology developments that will meet future requirements.

INTRODUCTION

Today, climate changes and air quality are two major concerns. Governments on both sides of the Atlantic are committed to reducing the effects of manmade air pollutants. Therefore more stringent standards are being put in place, by a large variety of International Agencies, to limit emissions of noxious gases and particulates released by combustion engines.
The aim is to reduce carbon dioxide emissions and greenhouses gases to 1990 levels, and reduce all other emissions including noise.
Many are the energy resources available in today's world (nuclear, gas, petrol, diesel, hydroelectric, eolic, ...), but the level of power provided by diesel engines remains of critical importance to our economies: electrical power is generated by diesel Generator Sets, highway trucks are massively equipped with diesel engines, diesel engines are the core of many industrial equipment and the base for machines (paving, construction, mining, ...). Last but not least the marine world is strongly dependant on diesel engines for powering ships that, throughout the world oceans ensure a safe and regular transfer of goods.
Today we are faced with legislation that is the major driver of product change in the Industry and this is bringing the product life down to 4-5 years timeframe. Investments have to be high and return on assets quick and high. Moreover, the Customer has to pay particular attention to the engine choice, considering the real cost of operation (through life cost) and the possible future updates if some new legal requirement becomes mandatory.

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CURRENT AND FUTURE LEGISLATIONS

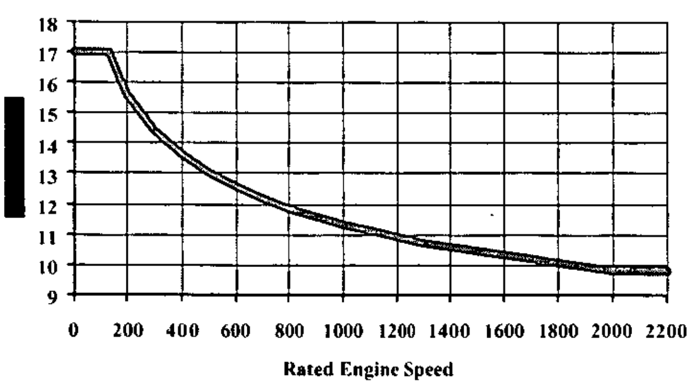
Current Legislation

Normally, most of the vessels are built under supervision of at least one major Marine Certification Society (MCS), like Lloyds Register of Shipping, American Bureau of Shipping ABS, Bureau Veritas BV, Registro Italiano Navale RINa, Germanisher Lloyds GL and many others: in this case, compliance to their rules is mandatory.
This implies that the engines and their components have been checked for safety and reliability, at least from a regulation standpoint.
Today, at least for the time being, instead of the MCS (that anyhow are in the process of amplifying their current regulations), other international Bodies are preparing and implementing standards that support the goal of emission limitation, that apply not only to marine engines but also to other equipments such as engines for Heavy Duty Highway Trucks, Buses, Locomotives and Machines.
Some of those - a short but not exhaustive list - are the US Environmental Protection Agency (EPA), the International Maritime Organization (IMO) and the European Commission (EC): all these Organizations have/are in the process of enacting similar, but not equal, standards that are leading to a staged regulation of diesel emissions.
Any current engine has therefore to be designed having in mind these new technical requirements and even the real possibility that in the future they will become even more stringent. Beside the technical challenges, engine manufactures are also facing the logistical difficulties posed by the fact that all these Organizations, while discussing, preparing and implementing their rules, have not the same requirements and testing procedures, even if close or similar: prioritising the choice of the approval processes is therefore something that should not be under evaluated as many test cells hours have to be spend and an incredible amount of financial resources allocated for.

IMO

International marine shipping has always been a hazardous industry and, in order to try to improve safety at sea, IMO (International Marine Organization) was established in 1948 and entered in force in 1958, as a UN (United Nation) organization.
The latest IMO legislation (Annex VI - NOx Regulation) is the regulation of NOx emissions in the exhaust gases of marine diesel engines (both for commercial and recreational applications) with a power higher than 130 kW. It will apply only to vessels built after January 1, 2000, however this legislation will not enter in force until it has been ratified by at least 15 States with at least 50% of world tonnage. As of December 2001, only 3 States (Norway, Sweden and Singapore) with 8.9% of world tonnage have actually ratified it. Once in force it will be applied retroactively to all vessels built (keel laid) after January 1,2000.

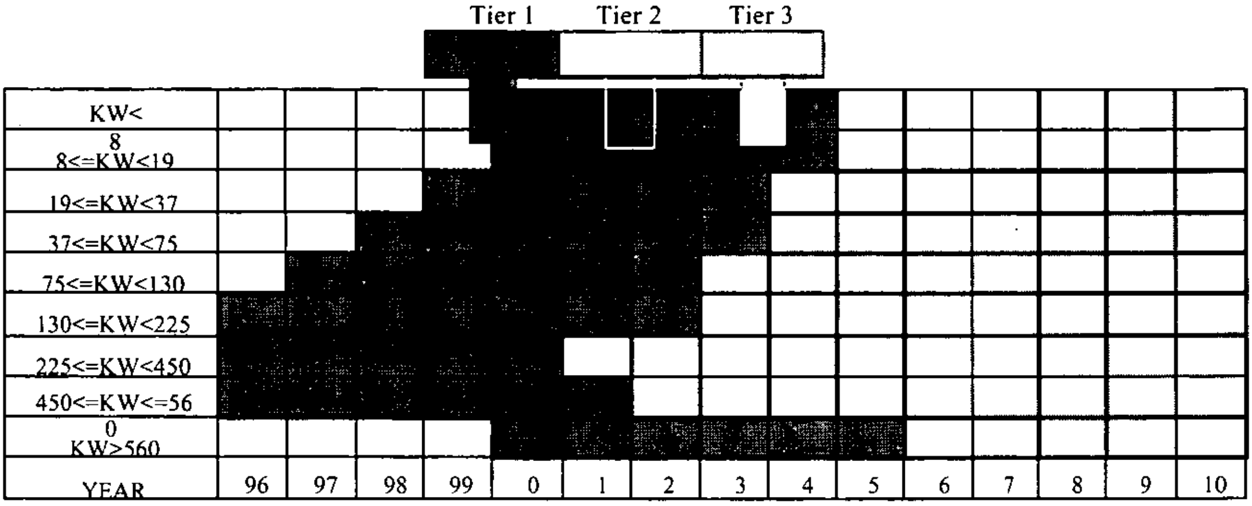
Fig. 1 Allowable Nox Emission (IMO 2000)

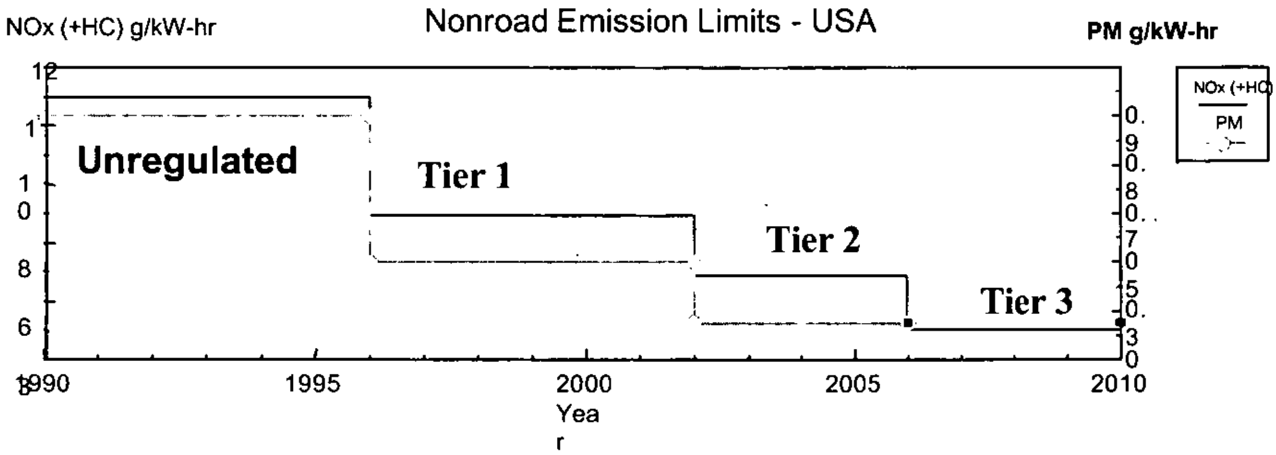


EPA

In the present study the weight factor in the long term prediction is the joint probability of significant wave height and zero There have been three stages of introducing limits on NOx and particles (PM), respectively called Tier 1, Tier 2 and Tier 3.

Fig. 2 Non Road emissions limits and implementations dates





The EPA Commercial Tier 1 limits have been set equal to the IMO – MARPOL Reg 13 (NOx only) and have become effective as of January 1, 2001.

The marine commercial emission Tier 2 standards and dates are regulated for power higher than 37 kW and for engine displacement.

Table 1. TIER 2 Introduction Schedule

ENGINE CYLINDER DISPLACEMENT (L)	*TIER 2 INTRODUCTION*
0.9<L<1.2	2005
1.2<L<2.5	2004
2.5<L<5	2007
5<L<15	2007
15<L<20	2007
20<L<25	2007
25<L<30	2007

On December 7, 2000, the US Environmental Protection Agency (EPA), following the current off road and the commercial marine regulations (Commercial Rule 40 CFR part 89), issued an advance notice of Proposed Rulemaking (ANPRM) covering recreational marine diesel engines and marine spark ignition (SI) stern drive and inboard engines, large industrial spark ignition engines over 25 hp and recreational vehicles using SI engines including motorcycles, all-terrain vehicles and snowmobile.

The recreational marine section of the ANPRM suggests that EPA is considering regulations patterned after the existing commercial marine engine rule.

Rhine River

The Central Commission for Navigation on the Rhine (CCNR), an organization of five European Nations along the Rhine River, has developed a regulation that will cover the emissions from diesel engines for ship propulsion and for auxiliary equipment installed on board boats operating on the Rhine River.

Also in this case CO, HC, NOx and particle levels are linked to the engine power:

Table 2. CCNR emissions limits

P_N [kW]	CO [g/kWh]	HC [g/kWh]	NO_x [g/kWh]	PT [g/kWh]
$37 \leq P_N < 75$	5,0	1,3	7,0	0,4
$75 \leq P_N < 130$	5,0	1,0	6,0	0,3
$130 \leq P_N < 560$	3,5	1,0	6,0	0,2
$P_N \geq 560$	3,5	1,0	$n \geq 2800\ min^{-1} = 6,0$ $500 \leq n < 2800\ min^{-1} = 30 \cdot n^{(-0,2)}$ $n \leq 500\ min^{-1} = 8,7$	0,2

Stage 1 regulations have been adopted and are tentatively scheduled to take effect January 1, 2002. The Engine Manufacturing Association (EMA) is protesting these regulations: however the application to auxiliary engines has been delayed due to allow more time to the engine manufacturers to comply with testing procedures.
The CCNR is considering, for year 2006, Stage 2 limits that may challenge technical feasibility.
There is a concern that CCNR is creating regional marine engine regulations that could be inconsistent with marine engine regulations issued by IMO, EPA and the EU.

European Union Directive – Exhaust Emissions

In Europe, the European Commission has introduced for non-road emission three stages of introducing limits on NOx and on particles (PM), respectively called Stage 1, Stage 2 and Stage 3.
Non Road emissions limits and implementations date are currently divided by power range:

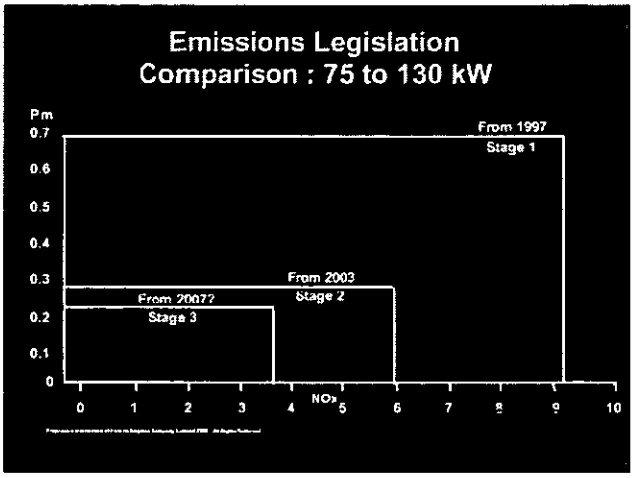
Table 3. STAGE 2 Introduction Schedule

ENGINE POWER BANDS (Kw)	*STAGE 2 INTRODUCTION*
Kw<8	2005
8<Kw<19	2005
19<Kw<37	2004
37<Kw<75	2004
75<Kw<130	2003
130<Kw<225	2003
225<Kw<450	2001
450<Kw<560	2002
Kw>560	2006

Stage 2 standards set unprecedented engine emission limits, in terms of particulate (g/kW-hr) vs. NOx (g/kW-hr): this regulation is still being strongly contested, especially considering the latest amendment regarding control of vessels in use on bodies of water used for drinking water consumption.

The reference NTE (Not To Exceed) values for CO, HC, NOx and particulates are linked by formulas to the engine power in kW and to the type of engine (spark ignition or compression ignition).

Fig. 3 EU emissions limits and implementations dates



European Union Directive – Noise Emissions

The European Directory 94/25/CE applicable to pleasure craft traditionally gave guidelines to prevent discharge of harmful organic and inorganic substances, gave limitations on exhaust emissions. In its and in its latest update, that will come into force in January 2004, it will include the maximum limit of passage noise (measured in accordance to ISO 14509) for all powered recreational craft of up to 24 m length of hull, including inboards, stern drives, personal watercraft (PWC) and outboard motors used in conjunction with a standard craft.

The limit is set at 78dB(A) for a boat passing at 25 meters from the microphone at maximum rated engine rpm. The test procedure described in ISO 14509 presents some challenges for repeatability and availability of the ambient conditions. There is still debate between all parties involved and until now only RINa took over the challenge of certifying Low Sounds Boats according to their close interpretation of ISO 14509.

The diesel engines exhaust represent a good portion of the overall noise of the vessel even with silencing system fitted on the vessel. All engine manufacture will be challenged to reduce their exhaust emission to help the boat builders with an easier installation.

Lake Constance (Bodensee)

This legislation covers only vessel on use on Lake Constance – Austria, Germany and Switzerland.

This Stage 1 was enacted in 1993 while Stage 2 applied from 1996. This legislates for NOx @ 10 g/kW hr and particulates on a sliding scale depending on engine power.

LOWERING EMISSIONS: TECHNICAL CHALLENGES

Technological changes brought about by these new standards represent the most important development in diesel engines for many years.

Increasingly, the latest diesel technology is being recognized as having environmental advantages over other combustion engines. As the most efficient internal combustion engine, diesel offers greater safety, more durability and reliability, more power and better fuel efficiency – up to 45/60% - than gasoline or natural gas alternatives. It also emits smaller amounts of CO, hydrocarbons, and CO2 than gasoline.

Great progress has already been accomplished in the reduction of Particulate Matter (PM) and Nitrogen Oxides (NOx), as improved fuel delivery and combustion chamber design, turbo charging and electronic fuel injection.

Various means to achieve lower emissions can be utilized:

- Lower the temperature at which combustion takes place;
- Burn the fuel using plenty of air;
- Use fuels with the lowest possible sulfur content;
- Burn the lightest, practical fuel;
- Very finely atomize the fuel;
- Have a slower burn;
- More accurately time injection of fuel and valve timing.

The various engine manufacturers use all these solutions, in many combined ways. Basically three can be the practical ways to lower the combustion temperature:

- Cool the incoming charge air with the coldest after-cooler water possible;
- Inject water to absorb the heat of combustion;
- Make the combustion occur all over the combustion chamber at the same time.

On the other hand, supercharging the engine poses certain challenges. Improving turbochargers requires a very good engineering in order to avoid flat spots at low speed but this effort prevents the use of water-cooled manifolds.
A roots blower, vice versa, gives great low speed power but chokes the engine at high speed, uses some shaft power to be driven and, last but not least, requires considerable maintenance.

Sulfur virtually should all come out from the exhaust pipe as particulate matter: so it is highly envisaged to burn fuel without sulfur to avoid smoke (or, better said, opacity vs. particles). Another obvious requirement is that fuel that is used should be as light and refined as possible (cost?).
All engine manufacturers put major efforts in making sure that fuel is as finely atomized as possible and in almost every cases this means that the fuel is injected at the highest possible injection pressure: furthermore, the more gradual and slow is the combustion (i.e. slower speed engines), the better are the emission values

LOWERING EMISSIONS: CURRENT TECHNICAL SOLUTIONS

Meeting tomorrow's stringent standards and delivering value in terms of performance, fuel efficiency, reliability and operating cost will be best (or only?) achieved with advanced electronic engine controls technology.
Capitalizing on the inherent flexibility of the electronic platform, leading marine diesel engine manufacturers developed electronic fuel systems that can be categorized as follows:

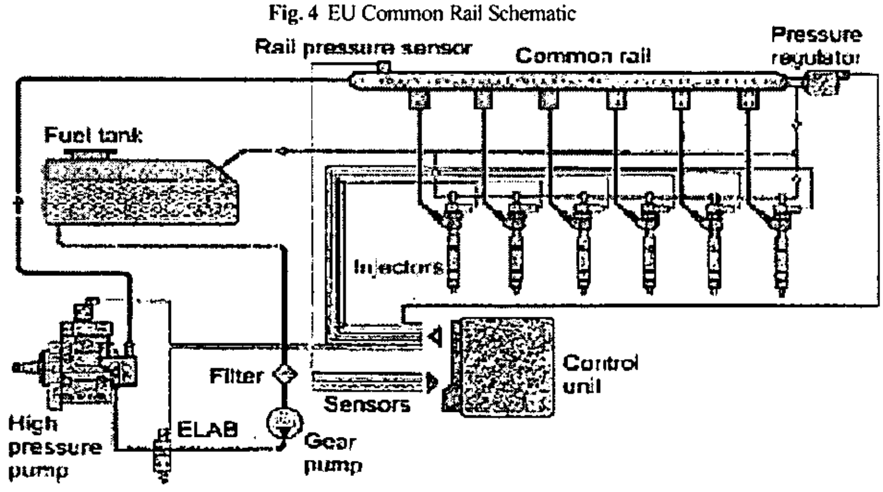
- Common Rail
- Mechanically actuated, Electronically controlled Unit Injection (MEUI)
- Hydraulically actuated Electronically controlled Unit Injection (HEUI[tm])

Common Rail

The common rail fuel system was first introduced in the late 1970's on medium speed marine engines with a mechanical control system. This eliminated the need for unit pumps for each cylinder thereby reducing the level of maintenance, and number of components on the engine. Today's electronically controlled version of the common rail system has the added benefits of establishing injection pressure independently of engine speed, and unlimited variable injection timing. Through these added features, the electronically controlled system offers much greater potential for added fuel efficiency, engine control, and reductions in NOx emissions.
The typical common rail fuel system consists of the following components (as shown in the diagram below):

- High-pressure fuel pump
- Sensors
- Rail or fuel manifold
- High-pressure fuel lines
- Electronic injectors
- Electronic control unit (ECU)
-

Fig. 4 EU Common Rail Schematic



The high-pressure fuel pump supplies an accumulator or manifold, called the "rail", with high-pressure fuel. The volume of fuel in the rail serves to dampen oscillating pulsations between the high-pressure pump and the injector nozzles. The high-pressure fuel, which can be as high as 180 MPa, is distributed to the injectors via high-pressure fuel lines connected to the rail. The pressure in the rail, as well as the start and end of injection events, are electronically controlled using the ECU. Through various engine sensor inputs, the ECU generates electrical pulses which energize each injector solenoid in sequence to start and stop injection.
To determine desired rail pressure, duration of injection, and correct injection timing, the ECU references its fuel map (software loaded on the ECU) with sensor input data and the external throttle input signal. The ECU then outputs command signals to the various fuel system components to achieve the desired engine performance.

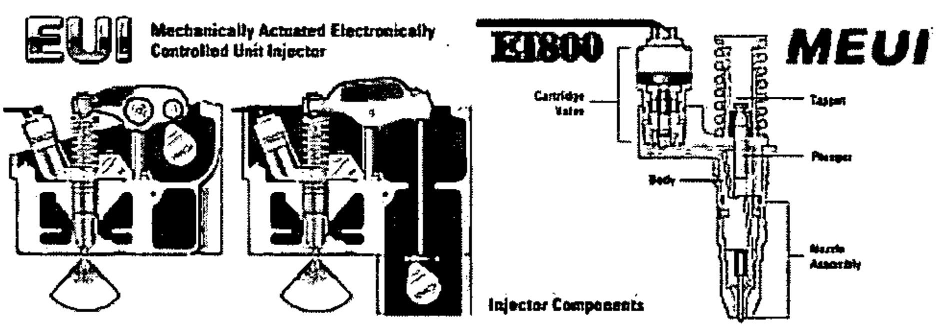
Features of Common Rail:

- Infinite variable timing
- Injection pressure control independent of engine speed
- Elimination of fuel cam, fuel rack, and drive linkage (lifter, rocker arm, pushrod)
- Replaces governor with multi-function ECU
- Electronic speed governing
- Provides platform for manufacturers to employ operation strategies
- Provides platform for increased engine control and monitoring via ECU

Mechanically actuated, Electronically controlled Unit Injection or MEUI

The MEUI fuel system incorporates a full authority electronic control system, electronic unit injectors (EUI), and low-pressure fuel system. The injectors receive low-pressure supply fuel at 4 bar and pressurizes it to between 70 MPa and 200 MPa. The injector contains the high-pressure pumping element and the fuel valve within the injector, hence the term "unit injector.
The mechanical energy required to generate high-pressure fuel within the unit injector is derived from the camshaft via the cam lobe, pushrod, and rocker arm assembly. Fuel from the lower pressure system is continuously circulated through the injectors via a common manifold. Injection cycle is controlled by current signals from the electronic control module (ECM) to the solenoid in the cartridge valve. The fuel is forced through the orifices in the nozzle at pressures up to 200 MPa, which provides for excellent atomisation and penetration of fuel for combustion.

Fig. 5 MEUI injection System



Some of the features of the MEUI fuel system include:

- High injection pressures up to 200 MPa
- Variable injection timing
- Electronic speed governing
- Electronic engine protection including derate strategies
- Operating strategies such as cold start mode
- Engine diagnostics and troubleshooting
- Adjustment free maintenance
- All measured engine parameters available via data link for monitoring, including engine fuel consumption rate
- Electronic control back-up option

Hydraulically actuated Electronically controlled Unit Injection (Caterpillar HEUI^{tm})

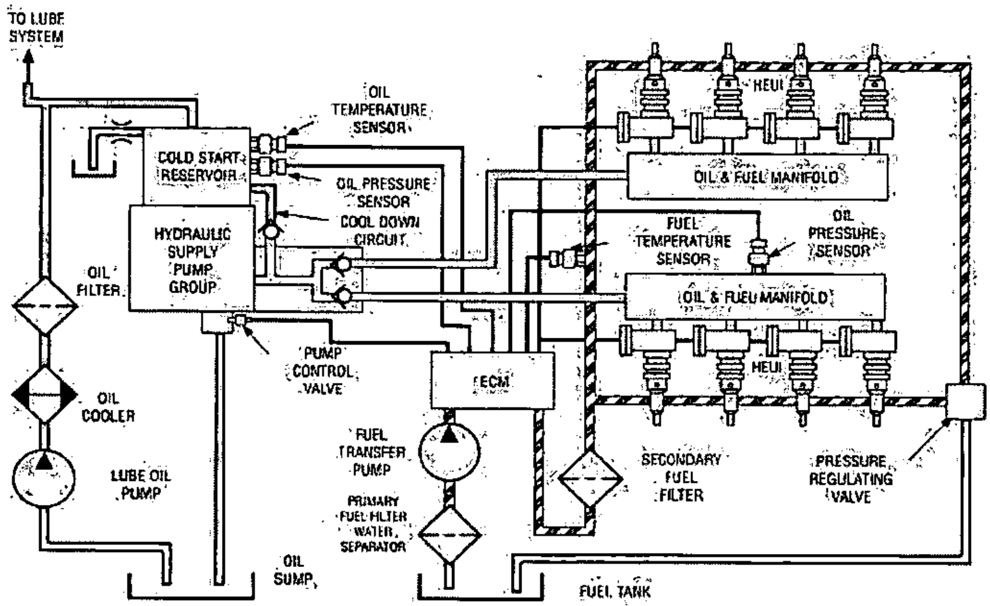
The HEUI system is a state-of-art fuel system that was designed and developed to meet the functional needs across a broad range of engine applications. HEUI was first introduced in 1995 on the 3126B 7.2 litre engine. Several years later, the HEUI went into production on the 3412E, 27-litre engine that is widely used today in various high-speed craft, work boat and fish boat applications.

HEUI is an acronym for hydraulically actuated, electronically controlled, unit injection. HEUI requires no mechanical actuating or mechanical control devices, and offers the marine customer many advantages over more conventional fuel systems. HEUI is capable of controlling injection pressure independent of engine speed and provides "infinite" flexibility in injection timing. This functionality was needed to meet future advances in emission reduction and enhanced engine performance.

The HEUI fuel system is comprised of the following subsystems:

- Injection Actuation system
- Injectors
- Electronic Control System
- Low-pressure fuel system

Fig. 6 HEUI Injection System Schematics



Injection Actuation System:

The injection actuation system takes lube oil from the main oil gallery and pressurizes it to power the HEUI injectors. This system replaces the gear train, camshaft and rocker arm used to power the MEUI's mechanical injector. The injection actuation system has two main functions:

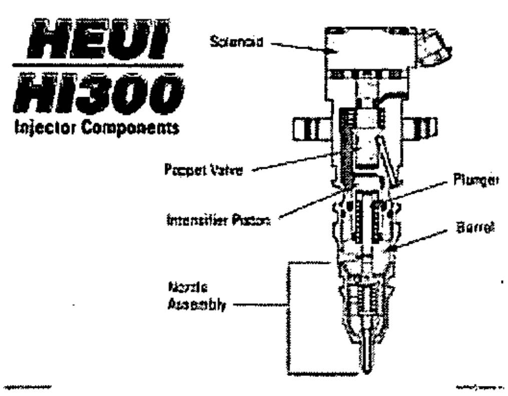
- Supplies high-pressure oil to power the HEUI injectors
- Controls injection pressure produced by injectors by changing oil actuation pressure

The axial-piston hydraulic pump is supplied with engine lube oil, at 4 bar, from the main oil gallery. The hydraulic pump increases the pressure of the oil to injection actuation pressures ranging from 6 MPa to 24.5 MPa. Actuation pressure is changed and regulated by the injection action pressure (IAP) control valve that maintains selected actuation pressure, regardless of engine speed, pump flow, and variable oil demand from the injectors.

The Injector:

The basic functions of the HEUI's injectors are nearly identical to the MEUI injectors. While there are some similarities in components, the method employed to generate high-pressure fuel for combustion is completely different.

Fig. 7 HEUI Injector



Five Stages of the HEUI Injection Cycle:

- Pre-injection
- Pilot injection
- Delay
- .Main Injection
- End of Injection

Electronic Control System:

The electronic control system is the management centre for not only the fuel system but for the entire engine. The system is comprised of various engine sensors, wiring harness, and the electronic control module (ECM). The ECM is common to both the HEUI and MEUI fuel system and provides the same features and functionality.

The ECM receives input from the various engine sensors as well as external input, such as the throttle signal. It processes the information and then references its software to provide outputs that achieve the desired control and performance of the engine. Furthermore, the ECM output includes complete engine monitoring data to proprietary and/or third party monitoring systems. As previously mentioned, the ECM has "full authority" control, meaning it has control over all engine functions.

Features of the Caterpillar HEUI fuel system include:

- High injection pressures up to 165 MPa
- Pilot injection
- Reduced emissions
- Infinite injection timing
- No high-pressure fuel lines
- Reduced noise (up to 50%)
- Electronic speed governing
- Electronic engine protection including derate strategies
- Operating strategies such as cold start mode
- E-trim (ECM electronically compensates for inevitable variations in injectors)
- Engine diagnostics and troubleshooting (via CAT software tool)
- Adjustment free maintenance

Advantages of the HEUI versus Common Rail

While both the common rail and HEUI fuel systems offer similar features, such as infinite variable injection timing capabilities, there are some clear advantages to the HEUI system over today's common rail system that are worth noting. They are as follows:

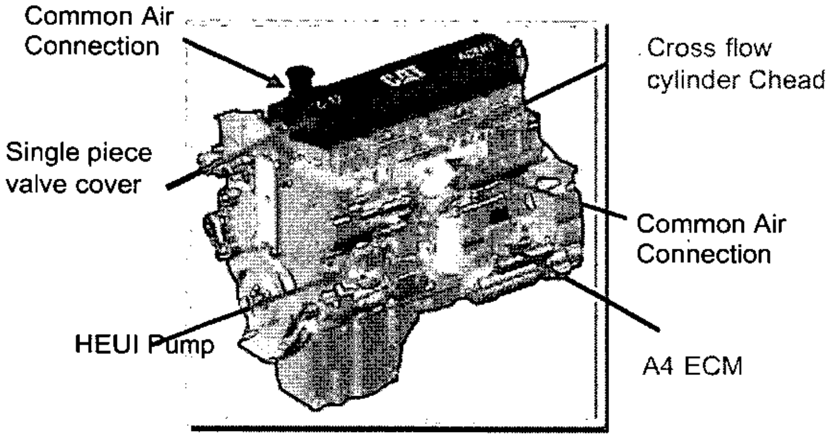
- The HEUI system does not have high-pressure fuel lines. The common rail system employs external high-pressure fuel lines with up to 180 MPa of fuel pressure. While the classification societies mandate that these lines be double-walled, additional hazard remains present.

- The HEUI system offers precise pre-metering injection through the groove in the plunger and spill port design. While pre-metering injection is possible in a common rail system, it is very difficult to accurately control, using single or multiple solenoids.
- The HEUI system provides "on-the-fly" rate shaping of the injection cycle for lower NOx emission levels and optimum fuel efficiency.

LOWERING EMISSIONS: FUTURE DEVELOPMENTS

Meeting tomorrow's stringent standards and delivering value in terms of performance, fuel efficiency, reliability and operating cost will be best (or only?) achieved with advanced electronic engine controls technology.
Electronics built into new diesel engines are the core component of an unprecedented system solution. With electronics, engines are capable of providing such features as integrated power management, improved fuel efficiency, easier maintenance and consequently reduced associated costs. The output and performance of all new, state of the art, engines will have to increase: yet, those engines must have reduced noise levels and the lowest emissions levels ever.
The need of a common, flexible platform to meet the various increasingly stringent emission rules forced all engine manufactures to plan another step forward in technology.
Caterpillar is currently developing all new high-speed engines with the new, CAT patented, ACERT, or Advanced Combustion Emission Reduction Technology. No visible performance advantages but serious emission reductions and decreased exhaust temperatures are the aims of introducing this advanced technology.
ACERT works to reduce the amount of emissions from the engine by using four core competencies: fuel systems (HEUI – Hydraulically Electronically-controlled Unit Injectors), combustion technology, Caterpillar electronics and after-treatment. These four core competencies can provide serious advantages when used synergistically, and Customer will still be provided with the best very reliable engines, as this is a technological evolution from existing current products.

Fig. 7 ACERT Core Design



FUTURE PERSPECTIVES

Specific research areas where major improvement are needed are foreseeable will certainly be noise prediction and reduction, combustion research and also alternative fuels.
CFD (Computational Fluid Analysis) and FEA (Finite Element Analysis), already used today, will be tools more and more used, with improved prediction capabilities. CFD will have to use advanced mathematical and physical models that also take into account the air motion, the fuel injection spray make up, the fuel combustion and the emission formation chemistry. On the other hand the extensive use of FEA will have to be concentrated on key areas with improved quality and reliability of results.
Air management is an area where efforts have to be placed and where adequate solutions have to be considered case by case, model by model, power by power: Naturally Aspirated, Turbo and Turbo Air-To Air charge cooled engines all find a place in the product offering.
Noise, Vibration and Harshness (NVH), analysis of combustion and mechanical noise are critical areas where today's technology has to focus on.
Fuel injection pressure and control, piston slap are key points where concentrated efforts have to be made. Typical Tier II engine will still have an aspiration choice, a medium swirl and fuel pressure plus a mechanical/electronic fuel pump. A Tier III engine will instead typically be TA, utilize high fuel pressure, mount an electronic fuel pump and be provided with after treatment.
For all the above improvement areas, electronics is the key words in order to cost effectively improve the performances and the behaviour of tomorrow engines.

SEAM - Measures to minimize environmental impacts from ships

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SYNOPSIS

New international legislation and rules in the environmental protection of the sea have regulated or will be regulating the use of some antifouling coatings, i.e. TBT (tri-butyl-tin), some types of marine fuel and procedures for ballast water management of seagoing vessels. This changing legal framework has prompted research activities such as the SEAM project with the aim of formulating safety and environmental alternative measures and the procedures to mitigate the impact of these key elements of shipping operations on the marine environment. SEAM is a Research Project partly funded by the European Commission (Directorate-General for Energy and Transport). The SEAM project started on the 1st of April 2001 and has a duration of 36 months. The SEAM consortium consists of 11 partners belonging to 8 European countries (including engineering companies, research institutes, universities, ports, shipping companies and stakeholders). Indeed, the European Commission aims to shift some of the increasing future freight and passenger traffic volumes from road transport to alternative modes, with beneficial effects to the environment, and hence an ever increasing use of maritime transport. This planned increase in maritime traffic brings forward the need to improve the environmental acceptability of maritime operations.

This paper will illustrate the key elements of SEAM, which is a policy-oriented project dealing with the formulation of measures to minimize risks caused by ballast water, antifouling paints and air emissions related to quality of fuel. The objectives of the project and its expected impacts will be described as well as the research methodology that is based on the use of the FSEA (Formal Safety and Environmental Assessment). The ultimate aim of the project - to outline recommendations to policy makers - will be shortly discussed. Some of the likely impacts of the first findings of the project will be outlined. Finally, an introduction to next SEAM workshops will be presented to open the debate to a wider community of end-users and stakeholders.

INTRODUCTION

The future of transport within the European Community, and especially in the maritime sector, will be governed by the development of a safe and environmentally acceptable maritime transport system. The volume of maritime transport in European waters is increasing and many European short sea-shipping initiatives aim to move freight from the land to the sea, with subsequent environmental improvements. This increased traffic, not only in ships coming into European waters but also in the increase in short sea shipping, indicates the need to improve the environmental acceptability of maritime operations.

In order to move towards these societal needs, the SEAM project focuses on formulating safety and environmental measures and procedures to mitigate the impact of three key elements of shipping operations on the marine environment: **ballast water management, anti-fouling paints** and **air emissions related to quality of fuel**. The proposed measures meet acceptable risk levels of shipping operations, taking into account the views of the main stakeholders (shipowners, ship managers, shippers, ports, terminals, regulatory bodies), and their economic viability is assessed. The project is organised around four main objectives:

1. To assess to which extend the environmental impacts of maritime operations can be minimised.
2. To identify available solutions for the mitigation of the impact of the above-mentioned three key elements
3. To verify to which extent the user requirements can be considered
4. To propose cost-effective alternative measures to both end-users and policy makers for mitigating environmental impact

The final results of the SEAM project will provide valuable input for the development of strategies for policy implementation to mitigate environmental pollution of the marine environment. It will propose cost-effective measures for new and existing ships to address the main environmental impacts from shipping caused by the three key elements. A major outcome of the SEAM project is to bring together all the stakeholders. Contact and consensus among stakeholders allow a real understanding of the needs and problems of all, from the engineers/scientists to the end users.

A CHANGING LEGAL FRAMEWORK AND ENVIRONMENTAL REQUIREMENTS

Environmental hazards

Ballast water

Ballast water has to be taken onboard to ensure the stability of ships at sea and is absolutely essential to the safe and efficient operation of modern ships. However, it may represent a serious environmental threat. Ballast water often originates from ports and other coastal regions, which are rich in organisms and planktonic species. It is variously released at sea, along coastlines, or in port systems. As a result, a diverse mix of organisms is transported and transferred around the world within the ballast water. In Figure 1 a cross-sections of a bulk carrier ballast tanks and ballast cycle are shown.

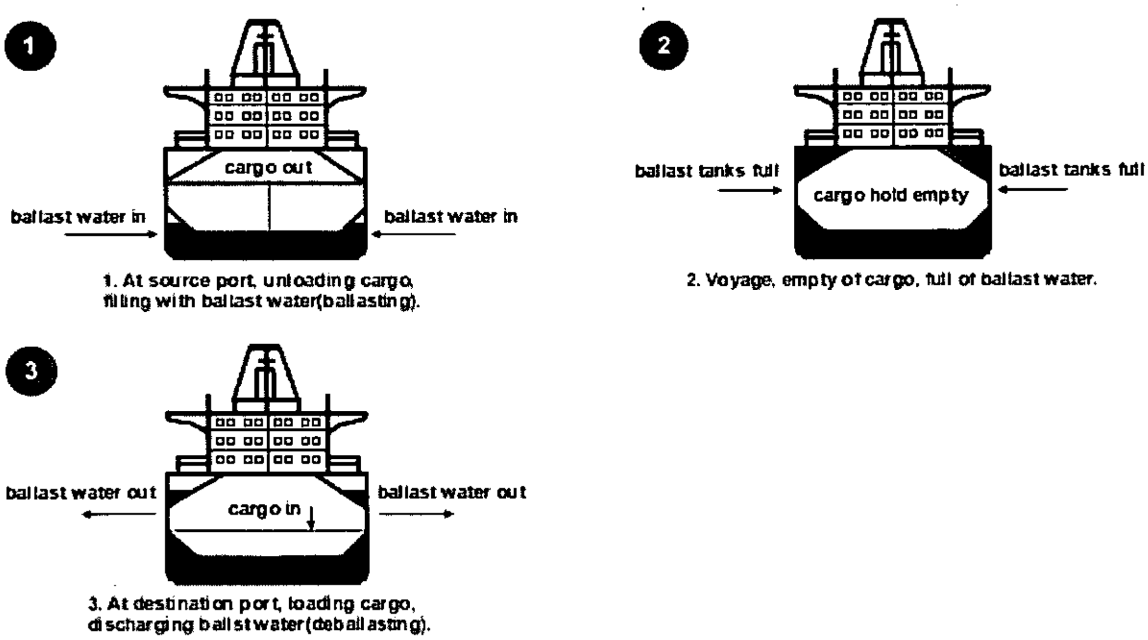

Fig. 1 Cross-section of bulk carrier ballast tanks and ballast cycle, *source: IMO website*

The transfer of organisms within ballast water has resulted in the unintentional introduction of non-indigenous freshwater and marine species into local ecosystems. Some introduced species that survive to establish a reproductive population in the host environment may become invasive, out-compete native species and multiply into pest proportions, which may result in significant economic and ecological impacts as well as human-health consequences. For instance, in the Black Sea, the filter-feeding North American jellyfish *Mnemiopsis leidyi* now comprises up to 95% of the biomass. It has depleted native plankton stocks to such an extent that it has contributed to the collapse of entire Black Sea commercial fisheries of anchovy and sprat [1].

Anti-fouling paints

Anti-fouling paints are used to coat the hulls of ships in order to prevent sea life such as algae and molluscs attaching themselves to the hull, thereby slowing down the ship and increasing fuel consumption. For example, a ship with less than 6 months unprotected exposure can accumulate sufficient fouling to increase fuel consumption by 50% [2]. The modern chemical industry developed effective anti-fouling paints using metallic compounds. Among these substances, organotin compounds are very effective anti-fouling agents for ships, the most widely used being tributyltin (TBT).

However these efficient organotin compounds have a severe impact on the environment. Environmental studies provided evidence that they persist in the water, kill sea life other than those attached to the hulls of ships and possibly enter food chains across the marine ecosystem and beyond. Specifically, TBT has shown to cause immune response, neurotoxic and genetic effects to marine species. Moreover, because TBT persist in sediments for years, wildlife continues to be exposed to it for long periods.

Air pollution

The potential implications of shipping emissions on regional air quality are apparent as nearly 70% of ship emissions occur within 400 km of land [3]. The air emissions related to the use of fuel are sulphur oxides, nitrogen oxides and carbon dioxide emissions, which have the potential to damage the environment (Table I).

Table 1 Index Shipping Related Emissions

Originators	So_x	No_x	*VOCs*	CO_2	*CFCs*	*Halons*	CH_3BR
Greenhouse effect				X	X	X	
ODS-Stratospheric					X	X	X
Ozone-ground		X	X				
Acid rain	X	X					
Linked-up with							
Fuel combustion	X	X	X	X			
Cargo handling			X		X		X
Ship's equipment					X	X	
Incinerators	X	X		X			

The oxidation of organic nitrogen in the fuel during the combustion process and the oxidation of molecular nitrogen in the combustion of air lead to the formation of nitrogen oxides (NOx), which continues after emission in the presence of hydrocarbons, ozone and sunlight. Sulphur oxides (SOx) are produced directly from the sulphur content of the fuel. Both NOx and SOx can be finally converted into acid forms, which contribute to acid rain. Soil acidification leads to leaching of the essential nutrients, which reduces the fertility of the soil. The acidification process also releases metals that can harm the microorganisms in the soil that are responsible for organic matter decomposition as well as animals up the food chain. Carbon dioxide (CO_2) is one of the main greenhouse effect gases, which contributes to climate change. The emissions of CO_2 linked to power consumption by the world's shipping industry are estimated to run to 420 million tons a year in 1996.

Finally, the deposition of nitrogen from emissions of nitrogen oxides and ammonia, can contribute to over fertilisation (eutrophication) of soils and water systems in certain regions of Europe. Excess nitrogen is also a problem at sea, where it causes algal blooms and oxygen depletion.

Existing legal framework

The main European and international legislations are described below.

Ballast water

In 1997, the member countries of IMO (International Maritime Organisation) developed voluntary guidelines for the control and management of ships ballast. However, the approaches recommended under the IMO guidelines are subject to limitations. For instance, reballasting at sea currently provides the best available risk minimisation measure, but is subject to serious ship-safety limits and is less than 100% effective in removing organisms from ballast water.

In recognition of the limitations of the current guidelines, the current lack of a totally effective solution and the serious threats still posed by invasive marine species, the IMO member countries have agreed to develop a mandatory international legal regime to regulate and control ballast water. The IMO's Marine Environment Protection Committee (MEPC) and its Ballast Water Working Group are working at developing this regime. This regime will take the form of an international convention, and it is hoped that member countries will agree it in late 2003.

Anti-fouling paints

On the 5 October 2001, the IMO's International Convention on the Control of Harmful Anti-fouling Systems on Ships (AFS-Convention) was adopted in London. This Convention will ban the application of organotin compounds which act as biocides in anti-fouling systems on ships from 1 January 2003, and will completely prohibit the presence of such compounds by 1 January 2008. By this date, ships should remove the organotin anti-fouling paints from the hull or apply a sealer coat. This convention will also establish a mechanism to prevent the potential future use of other harmful substances in anti-fouling systems.

One of the key problems in this matter is the lack of any powers of inspection or enforcement on the part of the IMO. The European Commission (EC) proposes in its Commission directive 2002/62/EC [4] of 9 July 2002 to prohibit organotin compounds used as active biocides on ships flying the flag of a Member State by 1 January 2003 and to ensure a complete prohibition of the presence of organotin compounds on all ships, irrespective of their flag, by 1 January 2008. This prohibition will also encourage Member States to ratify as soon as possible the AFS-Convention and contribute to an early implementation at international level.

Air pollution

In its annex VI, the IMO's MARPOL Convention establishes regulations for the Prevention of Air Pollution from Ships. This text, adopted in September 1997 but not yet in force, will set limits on sulphur oxide (SOx) and nitrogen oxide (NOx) emissions from ships exhausts and prohibit deliberate emissions of ozone-depleting substances. This includes a global threshold of 4.5% (by mass) on the sulphur content of fuel, which seems to be high as the average sulphur content of today's bunker oils is around 3%. It also contains provisions allowing for special "SOx Emission Control Areas" (ex: the Baltic Sea, North Sea) to be established with more stringent control on sulphur emissions. Alternatively, ships must fit an exhaust gas cleaning system or use any other technological method to limit SOx emissions. A Resolution invites IMO's MEPC to identify any impediments to entry into force of the Protocol, if the conditions for entry into force have not been met by 31 December 2002.

The United Nations' 1992 Framework Convention on Climate Change (FCCC) in its 1997 Kyoto Protocol, not yet ratified, adopted overall targets for greenhouse effect gas emissions by 2008-12. These targets are an 8% cut from 1990 levels for the European Union (EU), 7% for the USA, and 6% for Japan and Canada. Australia is allowed an 8% increase, while Russia has a target of 0% (i.e. 1990 levels). The Kyoto protocol also calls on Annex I Parties (i.e. most industrialised countries) to limit or reduce their greenhouse effect gas emissions from bunker fuels.

The European Union has already developed a strategy to diminish air pollution from route traffic and intends to set air quality standards. Concerning bunker fuels for ships, the Directive 99/32/EC sets [5], a maximum of 0.2% (by mass) sulphur content for gas oils from 1 January 2000, and of 0.1% from January 2008. Note that this Directive does not apply to ships crossing a frontier between a third country and a Member State and exempts the main sulphur pollutant i.e. heavy fuel oil.

SEAM APPROACH

The SEAM project uses Formal Safety and Environmental Assessment (FSEA) methodology as a rational structure for achieving its objectives. It will also make use of Environmental Impact Assessment (EIA) to assist in the scientific and technical evaluation.

SEAM addresses five principal areas of investigation:

- FSEA of the maritime transport system relating to ballast water management, use of anti-fouling paints and air pollution from ships
- Safety and Environmental Measures of existing preventive and consequence reducing measures (mitigation)
- Risk Analysis Evaluation Tool
- Life cycle engineering of the design New safety and environmental measures including management, procedures and operational tools verified by case studies and economic feasibility.

The figure 2 below shows the global framework of the project based around the FSEA methodologies, where the different steps are mentioned in the rectangles and where the corresponding actions within the SEAM project are listed.

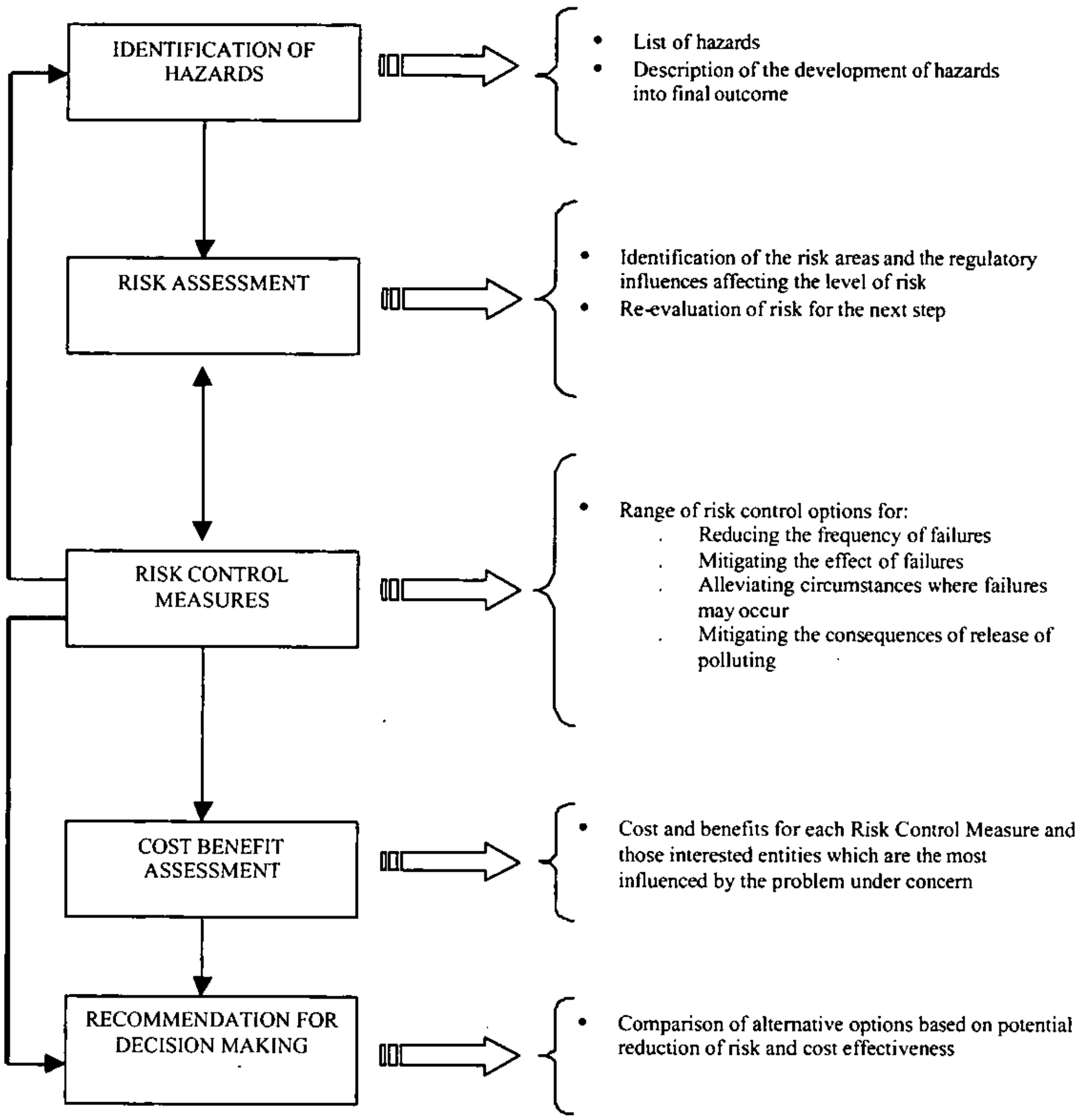

Fig.2 SEAM methodology

STATUS OF THE SEAM PROJECT

Environmental Risk Assessment of Maritime Transport Activity in the German Bight and the Gulf of Naples

The assessment of the environmental risks, which may be generated from extensive maritime transport activities in European waters, has been addressed in the SEAM project. Three fundamental modelling systems have been implemented and used for the prediction of the environmental risks caused by the release of anti-foulants, ballast waters and ships atmospheric emission around coastal waters [6]. The study has been carried out in two pilot European regions. These were the German Bight in the North of Europe and the Gulf of Naples within the Mediterranean Sea. Ships traffic networks around both pilot regions have been geographically identified together with the various standard shipping routes details that are adopted by all types of maritime vessels. The release rates of anti-foulants and atmospheric emissions have also been quantified in each route and across the whole networks [7]. Figure 3 shows a standard ship traffic network, which has been adopted for the modelling study of the German Bight.

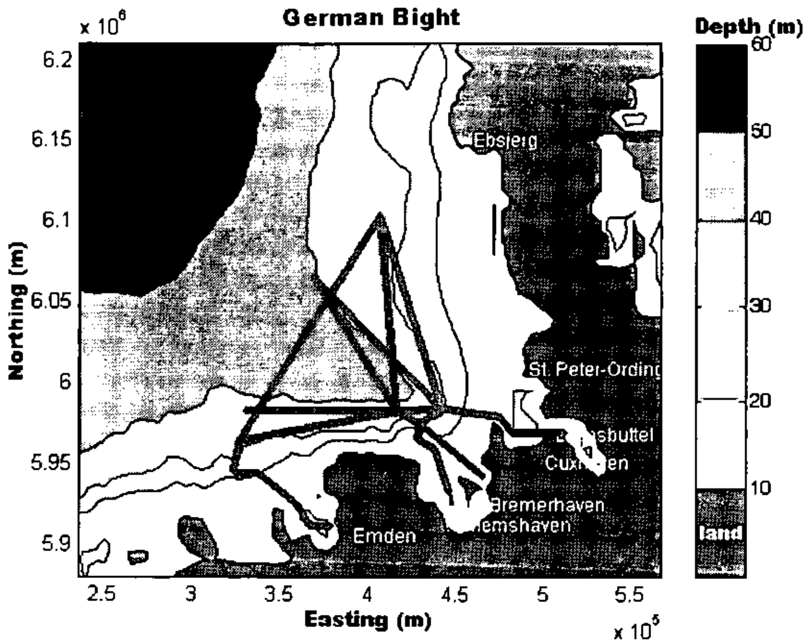

Fig 3 Shipping Traffic Network in the German Bight

The environmental risk evaluation from ship traffic activity around European coastal zones is dynamically modelled with time, since the environmental exposures are predicted in geospatial and temporal terms with the environment. The use of both marine and atmospheric environmental constraints in the models leads to the prediction of the environmental risks within a whole year period and zones which are most of concern. The environmental risks are computed from the ratio of the Predicted Environmental Concentrations (PEC) in time to that of the so-called No-Effect Concentrations (NEC). The latter is specific to a toxicity threshold above which a targeted marine species of concern is at high risk. Furthermore, the rate of occurrence of the PEC:NEC ratio levels within the region of study is predicted. In Figure 4, the exposure concentrations of TBT-based anti-foulants are shown in the German Bight region at various seasons of year for illustration. As a result, it is possible to identify the affected coastal zones and correlate it with specific marine species of concern in each coastal zone at various time periods of year. Furthermore, it could be compared with the use of an alternative anti-foulant within the same shipping routes and quantify the reduced environmental risk as a result.

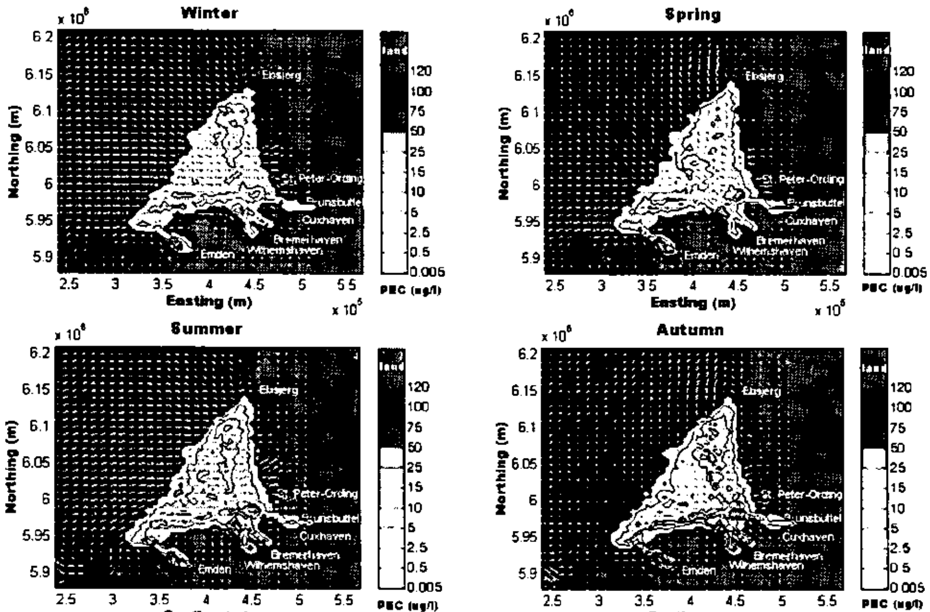

Fig. 4 Predicted TBT Exposure Concentrations (Conservative Case)

Similar concepts of risk ratio prediction apply to the atmospheric case study. The environmental thresholds are drawn from the European Union Air Quality Standards (EU_AQS) or indeed the World Health Organisation standards [8]. Atmospheric emission exposures of SOx and NOx are consequently compared in time with the EU_AQS threshold for instance. In figure 5, NOx exposures are shown during a year around the Gulf of Naples. NOx emission exceeds the EU_AQS threshold at around twenty metres above sea surface offshore but remains below the threshold throughout the year at higher altitude, as shown in Figure 6.

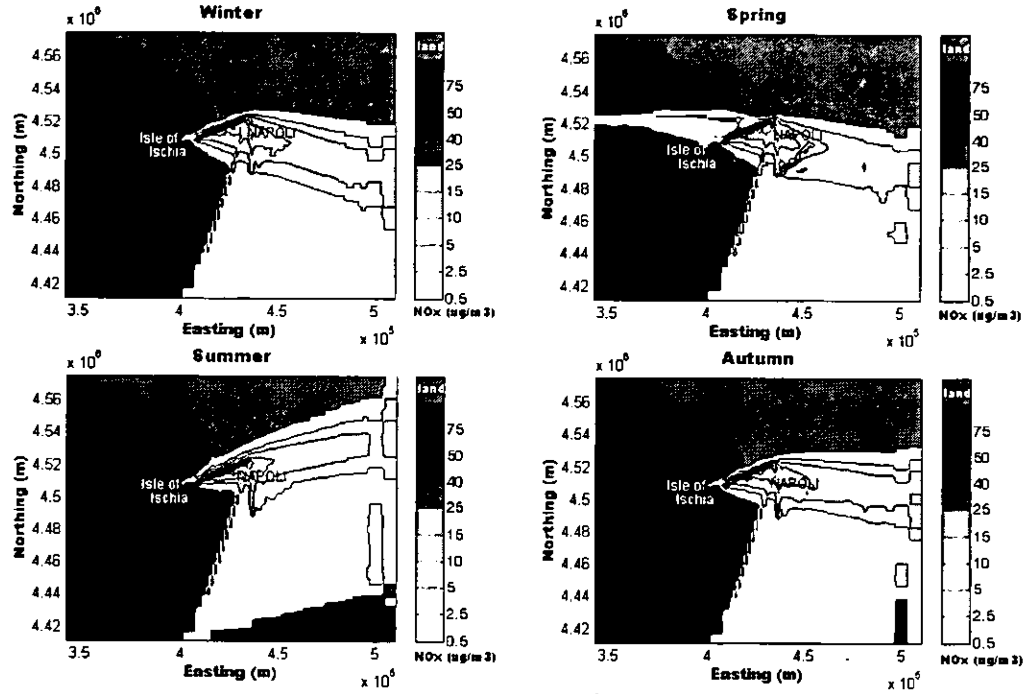

Fig 5 NOx Exposure Concentration (µg/m³) in the Gulf of Naples

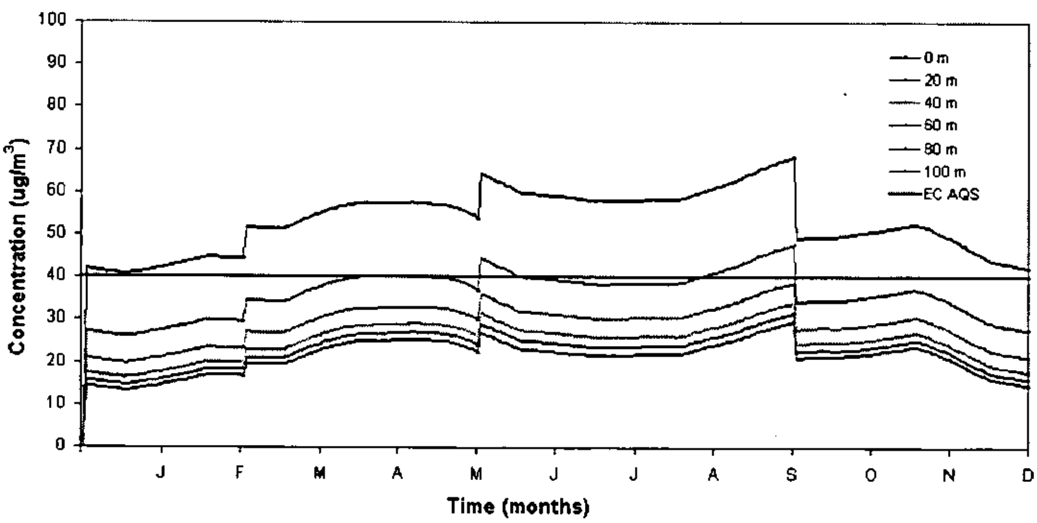

Fig. 6 Maximum NOx Exposure Concentration (µg/m³) Time Series in the Gulf of Naples

New modelling benchmarks for risk assessment and impact of contaminants from ship traffic activity vectors around two European coastal zones have been established during the SEAM project. These enabled the generic evaluation of the environmental risks that can be used for the assessment of maritime transport activity around other European coastal waters.

Mitigation Measures

Unquestionably, all shipping operations exert pressures on the marine environment. The acceptance of the hazards and risks associated with the use of TBT antifouling paints, the discharge of ballast water and emissions from ship exhaust has led to research and development into methods to mitigate these effects. Mitigation measures can be broadly divided into two categories: operational and technological. This project has identified both types of mitigation measures for all three of the addressed hazards.

Antifouling coatings

The need for an alternative antifouling coating to those containing organotin compounds has led to technological research and development in different areas. The modes of action of alternative coatings can be classified as follows:

1. The toxic approach uses other metals such as copper and zinc, or agrochemicals e.g. triazines, or a combination of chemicals in the paint base.
2. Fouling release approach systems does not reply on toxic chemicals but use the physical properties of low surface energy coatings to cause the very weak attachment of fouling organisms. These organisms then detach with the movement of water at a certain speed, over the surface e.g. silicone based coatings.
3. Fouling deterrents, as their name implies, are coatings that deter the settlement of fouling organisms. Many of the compounds under investigation are those that are extracted from or are analogues of chemicals from marine organisms which are known not to foul e.g. some corals, echinoderms, marine mammal fur.
4. Coating systems are also under investigation, in attempts to develop very efficient delivery systems that require less quantity of a toxic compound.

Operationally, there is little that can be done to mitigate the impacts of using toxic antifoulings. However the notion of not using any antifouling coatings and subsequently removing the fouling has been investigated and has even been operationalised. This requires fixed or mobile hull cleaning stations, e.g. divers or ROVs.

Ballast Water Discharge

Technological solutions that militate against the accidental introduction of species via ballast water fall into two categories:

1. Onboard treatment of ballast water is being extensively investigated and operationalised. Numerous approaches are described including chemical treatment e.g. chlorination, physical treatment e.g. UV, heat treatment. Filtration and cyclonic separation while under trial are also in service on some ships already. A combination of techniques is thought to give the most effective solution.
2. Onshore treatment of ballast water has not been seriously considered except in a few very specific circumstances.

Operationally, SEAM recognises two methods of mitigation:

3. Open Ocean Exchange involves an exchange of the ballast water held in tanks; this can be achieved by deballasting and then reballasting with new open ocean water or by flow through methods. The general principle is based on the biological differences between coastal and oceanic water, where coastal water is deemed to carry a higher risk of transporting species.
4. Ballast water management systems including decision support systems have been adopted by various countries and regions in an attempt to minimise the risk of introducing alien species via ballast water. Notably the Australian AQIS system was introduced in 2001.

Air Emission from Ships

SEAM has been concerned with NOx emissions that are usually associated with the condition and age of the engine and with SOx that are mostly associated with the fuel quality. Accordingly, mitigation takes different forms.

1. A reduction in sulphur emissions can be achieved either at source by reducing the level of sulphur in the bunker fuel or by flue scrubbing.
2. Reduction in NOx emissions can be achieved by the use of different propulsion systems or the good maintenance of fitted engines. Virtually all new builds of engines now comply with MARPOL Annex VI concerning NOx emissions.
3. Various systems fitted to the engine e.g. catalytic converters, water injection/emulsion, can also significantly reduce NOx emissions.

Operationally, various schemes have been proposed to reduce air emissions from ships. These include, at the simplest level, speed reduction, but also a range of market-based incentives and emission trading schemes. In port, "cold ironing" of ships reduces the emissions from ships by a switch to the use of shore-side power.

Next steps

The choice of any mitigation method cannot be made solely on the best available technology, but on a complex set of factors, including ship type, age, use, economics etc. As we have seen there is an increasing number of operational solutions available.

The next phase of SEAM will undertake a cost-benefit analysis of a selected number of mitigation methods for the three environmental problems. This analysis will attempt not only to consider shipping economics but also endeavour to incorporate environmental economic factors. Also important to the choice of mitigation method is the acceptability of that methodology to all stakeholders e.g. ship owners, environmentalists, regulators etc. The next phase of SEAM will also undertake an analysis of stakeholder needs and progress to a stakeholder dialogue leading to a resolution on the choice of the most acceptable solutions. These last stages of SEAM represent important socio-economic work, which has previously not been undertaken in the maritime industry.

Finally we hope that the SEAM work will lead to a methodology that will lead to the rapid resolution of future environmental problems that may arise in association with shipping.

DISCUSSION

Achievements

In order to achieve the global objectives of the SEAM project, the following actions have been carried out so far:

- To assess to which extend the environmental impacts of maritime operations can be minimised.

In order to provide the best understanding possible, activity description, hazard identification and data collection have been carried out. All these tasks have already been integrated for further research.

- To identify available solutions for the mitigation of the impact of the above-mentioned three key elements

This step, which has also been successfully achieved, was based on the risk assessment for safety and environmental measures through pollution risk evaluation, by models, and risk assessment for environmental options.

- To verify to which extent the user requirements can be considered

The user requirements are one of the key points of the project. In order to ensure seamless interoperability between our research and its application for end-users, a stakeholders group has been formed to support the entire study. The present situation has also been assessed and priorities identified through technical visits. Recommendations and the feasibility of our results will be assessed by the end-users and by means of full scale trials.

- To propose cost effective alternative measures to both end-users and policy makers for mitigating environmental impact

This last point is carrying out step by step during the whole research, according to the efficiency of the alternative measures. A focus group is currently being formed to provide recommendations about the SEAM accomplishments whilst a cost/benefit evaluation is being conducted.

The objectives of the SEAM project mentioned above will be achieved until the end of the project foreseen in April 2004. The next steps will focus on the mitigation measures based on the definition of risk acceptance level and directly approved by the stakeholders during our case studies, composed of full scale trials and evaluation of the potential measures. The final step for the achievement of all the objectives will be the cost benefit analysis and economics of operating ships.

Cost-benefit impact of SEAM

The second part of the SEAM project will concentrate on the cost benefit analysis and economics of operating ships. The main objective is to carry out a fundamental Cost Benefit Analysis (CBA) for the assessment of mitigation measures and procedures for environmentally friendly shipping operations. In addition to CBA, a financial assessment will be carried out in order to show the impacts of the measures on the parties involved.

The work will be divided into four steps, beginning with the definition of scenarios based upon the results of the development of risk control measures. The next step will be the identification of the cost elements and the expected benefit for the different risk scenarios.

The final two steps will be performed simultaneously, and aim at comparing the cost effectiveness for the different risk control measures and making the evaluation of the cost benefit assessment. The cost-benefit impact of SEAM will help to evaluate the mitigation measures that comply with the stakeholder requirements.

A stakeholder view: the Port of Rotterdam

Now and then it is useful to take careful thought at the question: What are we doing and why? In the context of the mission of the Port of Rotterdam it has been formulated as follows:

"The aim of the Rotterdam Municipal Port Management is to strengthen the position of the port-industrial complex in European perspective, at present and in the long run. It is positioning itself as port authority and international service provider".

Straight on it states the common port's main objective, which could be applicable to any commercial port: "Stimulation of activities in port and industrial areas".

However, NOT by all means, because the Port of Rotterdam is safeguarding one and another by two limiting conditions, being: A) a sufficient safety level on one side and B) acceptable environmental circumstances on the other side.

To the latter the SEAM project is developing policy measures for the shipping industry to minimize risks caused by ballast water and anti-fouling paint and to reduce harmful emissions related to the use of fossil fuels. The Port of Rotterdam is one of the SEAM partners and will incorporate the final results into consideration of its future policy development, whereby:

- First of all our strategic point of view and attitude in this field is to act pro-active and not defensive, thus being able to safeguard a sustainable development in a level playing field and preventing distortion of competition between ports on environmental and safety issues.
- Next to that we aim to keep a fair cost benefit balance between the limiting conditions environment and safety and the economic process and labour employment and
- Apart from that strive for the prevention of undesired disturbances in the Port Process.

Last but not least: Euro lateral uniformity on implementation, control and uphold of future regulations should be a 'sine qua non'.

CONCLUSIONS

Based on the research of this project, the following conclusions can be drawn:

1) Critical reviews performed on activity description, hazard identification and data collection indicated that there is a wide scope for devising improved measures.
2) A fresh approach has been put forward on the risk assessment and identification of environmental measures through pollution risk evaluation, by modelling, and risk assessment for environmental options.
3) Practical feedbacks with the end-users have demonstrated the need for recommendations on the feasibility of alternative measures.
4) The SEAM approach involves examining alternatives measures whilst taking into account aspects of science and technology, engineering, management, operations and cost-benefits in order to be useful to end-users and policy makers.

ACKNOWLEDGMENTS

The authors would like to express their sincere thanks to the European Commission Directorate General for Energy and Transport (EC DG TREN) for partially funding this research projects, in particular Ms. Astrid Schlewing and Mr. Arnaud Revel for their interest, guidance and constructive cooperation.

Moreover, it is impossible to acknowledge all the persons who over the time of this research have helped directly or indirectly. However, a special note of thank is entitled to our partners: Grimaldi Group, ISL, AMRIE, Bremen Senator (Ministry) for Economy and Ports (SWH), SAT, SAL, EMIL, as well as all the participants to our technical meetings and workshops. All of them have influenced to shape our thinking towards SEAM.

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Designing marine vehicles for environmental sustainability: including life cycle drivers during concept design

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SYNOPSIS

This paper discusses research in the areas of life cycle costing, environmental design drivers, upgradability, and risk analysis. The current issues surrounding these areas regarding the design of ships and offshore structures are outlined. It discusses recent research, including that of the EPSRC Engineering Design Centre for Marine and Other Made to Order Products (EDC) at the University of Newcastle upon Tyne, relevant to the current needs of the shipbuilding and offshore industries. It then moves on to suggest how such design drivers can be integrated for application in the concept design of marine vehicles in an environmentally conscious manner.

Author's Biography

Ian Ridley is a Senior Lecturer in Project Management in the School of Computing and Technology at the University of Sunderland. Prior to this he was a Senior Research Associate for five years at the Newcastle EDC where he worked on several research projects in the area of engineering design management. Before entering academia he spent many years working in industry within engineering management, including three years working overseas in the oil and gas industry.

Keith Hutchinson is a Senior Naval Architect with marine consultancy Armstrong Technology. He is responsible for the concept design and investment appraisal of a range of novel offshore and military vessels in addition to hydrostatic and dynamic evaluations of other commercial and military designs. He joined Swan Hunter Shipbuilders in 1990 and in 1992 was appointed Senior Designer within the Naval Architecture Section. Upon joining his current employer in 1995, he was seconded to the Newcastle EDC for three years as a Research Associate developing decision support tools for the evaluation, optimisation and selection of safer RO-RO ship designs and other marine vehicles.

INTRODUCTION

Over recent years the work of designers during the conceptual stage of the design process has become increasingly onerous and complex. This is, in part, as a result of enhanced client requirements for life cycle engineering to support the selected solution. Both clients and legislative requirements have caused whole life costing, environmental impact assessment, sustainability, the extension of working life and safety case analyses to gain significance during the development of compliant and optimal engineering design solutions.

Increasingly, many of the above considerations must now be incorporated into tender bids. In addition, such bid, documentation often has to be produced rapidly. Hence there is a perceived need for appropriate assessment techniques and tools to facilitate the rapid development of feasible and compliant designs in which the tenderer has confidence regarding performance, delivery and cost. Therefore, the availability of such tools will be of increasing benefit to the marine industry, especially to teams developing design solutions for an operational life in excess of twenty years

ENVIRONMENTAL CONCERN OR MAYBE NOT

The importance and need for the environmental management of shipping and other commercial marine activities comes to the fore of public debate generally every time there is some form of marine incident that results in the pollution of a stretch of coastline. The break-up and sinking of the *MT Prestige*, on the 19th November this year, off the coast of Spain has once again sparked off a debate on the need to ensure the risk of maritime commerce polluting the environment is kept to a minimum. While oil from the wreck continues to threaten the Spanish Galician coast then no doubt journalists will keep the topic at the front of public debate. But should environmental issues be driven by the emotion generated by such an event?

In 1995, it was argued by Smith[1] that an effective method of carrying out an Environmental Impact Assessment (EIA) on a ship would help to ensure the proper environmental management of shipping, as opposed to developing methods for dealing with pollution from ships, of which there was already an extensive literature. The use of an appropriate method of EIA within the shipping industry, that is acted on, should help to reduce the general impact of shipping on the environment as well as lessening the number of environmental disasters that can attributed to shipping.

Within the oil and gas industry the attitude to the environment varies from one oil company to another. This particularly true with regard to the impact of the use of fossil fuels on climate change. Hove et al[2] discuss how ExxonMobil still believe that the link between fossil fuels and climate change has not yet been conclusively proved and therefore restrictions should not be placed on the oil industry. Because of this they have been one of the most prominent forces driving the lobbying of the US government to ensure that the USA does not ratify the Kyoto Protocol.

BP Amoco on the other hand take the view that whether or not fossil fuel use is the major cause of climate change, it probably has some effect. Therefore, some form of action should be taken now, as if no action was taken until there was indisputable proof then the effort required to reverse the effect on world climate would be so much greater. BP Amoco along with Shell realise that there are commercial benefits to be gained by being seen to be taking sustainability and environmental impact seriously. Shell learnt this lesson during the very public confrontation with Greenpeace over the disposal of the Brent Spar. During this confrontation Shell experienced a dramatic drop of its petrol forecourt sales in Germany. However, the 'StopEsso' campaign cannot be said to have had the same effect and influence on ExxonMobil.

In general though, the trend world-wide is towards developing more environmentally friendly working practices. This has resulted in the need for methods, that can be applied at the concept design stage of marine vehicles, that can model both through life costs and benefits as well as environmental drivers.

THROUGH LIFE COSTING

Life cycle costing is becoming increasingly important when assessing the overall performance of a design, or existing, ship or offshore structure. The oil and gas industry have been developing Whole Life Costing (WLC) capabilities for several years. The application and results of such an assessment on concept designs of FPSO's (Floating Production, Storage and Offloading vessels) utilising emergent technologies for exploiting Stranded Gas Reserves are discussed by Mackie et al[3] and Mackie and Hutchinson[4]. With regard to shipping, both commercial and governmental organisations are active in this field. For example the United Kingdom Ministry of Defence (MoD) are interested in establishing not only Unit Procurement Costs (UPC – Capital Expenditure, CAPEX) but also the Through life Costs (TLC – Operational Expenditure, OPEX) for both front line warships and auxiliaries. In order to facilitate the capture of the relevant cost streams the MoD have sponsored several seminars with industry and commissioned the development of models which facilitate not only cost projections, but also updating as expenditure figures are returned.

As marine products become more complex it becomes increasingly difficult to model Life Cycle Costs (LCC). This is due to the corresponding increase in the complexity, number and underlying detail of the LCC streams. Other factors that add to the difficulty are the risks inherent in establishing the correct operational and financial assumptions to be applied. The uncertainty with these assumptions increases as the time period over which they are to be applied is extended. It is therefore inherently easier to develop a model for a five year operational life rather than one for fifteen to twenty years or more. In the latter model, issues such as refurbishment, upgrading, change of operational use or pattern need to be taken into consideration. Such requirements create the need for a more complex model and also require sensitivity to be studied which therefore involves numerous operational permutations to be evaluated. A point worth noting is that for specialised, complex vessels this can lead to the need to model a cost capture period, embracing preliminary concept formulation through to disposal/breaking up, of over fifty years.

The Newcastle EDC in collaboration with industrial partners set out to address some of the problems associated with the construction, population and application of LCC models. As a consequence a generic life cycle costing tool has been developed by the Newcastle EDC. To facilitate ease of use the tool is based around the utilisation of a natural engineering language for the development of LCC models rather than a financial one. Such an approach allows models to be developed by the engineers responsible for producing the concept design rather than by those whose main concern is producing and monitoring accounting information. This approach allows the designer to maintain control of the design, while being able to assess the LCC performance and hence investigate the impact of modifications to the design, within the specification, so as to meet the customer's life cycle requirements. A detailed account of the tool is described by Ridley and Stephenson[5] and Ridley et al[6].

The life cycle costing tool was designed to handle CAPEX, OPEX and disposal costs. Within these broad cost areas it was found that some costs were less difficult to establish than others, for example general capital and operational costs. However for other cost streams it was found to be quite difficult to establish the appropriate costing scenarios within the tool. In particular, upgradeability costs and environmental costs proved difficult to incorporate with any degree of certainty. This was due to the non-existence of appropriate methodologies to assess the suitability of various design scenarios with reference to these two cost streams. This resulted in two additional research groups being set up in the Newcastle EDC. The purpose of the first was to evaluate the issues surrounding design for upgradability and the second to investigate clean design and environmental factors pertaining to the design of large structures. The background and findings resulting from this research is discussed below.

ENVIRONMENTAL DRIVERS

When developing a concept design for a marine vehicle there are a great many environmental drivers that need to be considered. The consideration of these drivers when incorporating them within a whole life model is often further complicated by the interactive nature of the various drivers with each other. The level to which environmental drivers are pursued will depend on commercial requirements as well as the availability of appropriate data. The principle drivers that can influence a design are shown in figure 1. The drivers fall into a variety of categories. A number are within the control of those responsible for the design, some drivers will be driven by commercial pressures and concerns, while other drivers are dictated by various regulatory bodies.

Construction

There are three broad areas of concern during the construction of a marine vehicle, these are:

- Pollution
- Energy
- Resource Sustainability

The construction phase of a marine vehicle has the potential to produce air, water and land pollution. When developing a model it is relatively easy to include the obvious potential sources of pollution, for example the accidental discharge of a pollutant into the river on which the construction yard is situated. The difficulty for the designer at the concept stage is developing an understanding of how such things should be modelled. The designer is more likely to be an engineering modelling expert rather than an environmental modelling expert. But, this is only the start of the problem when considering drivers at the construction phase.

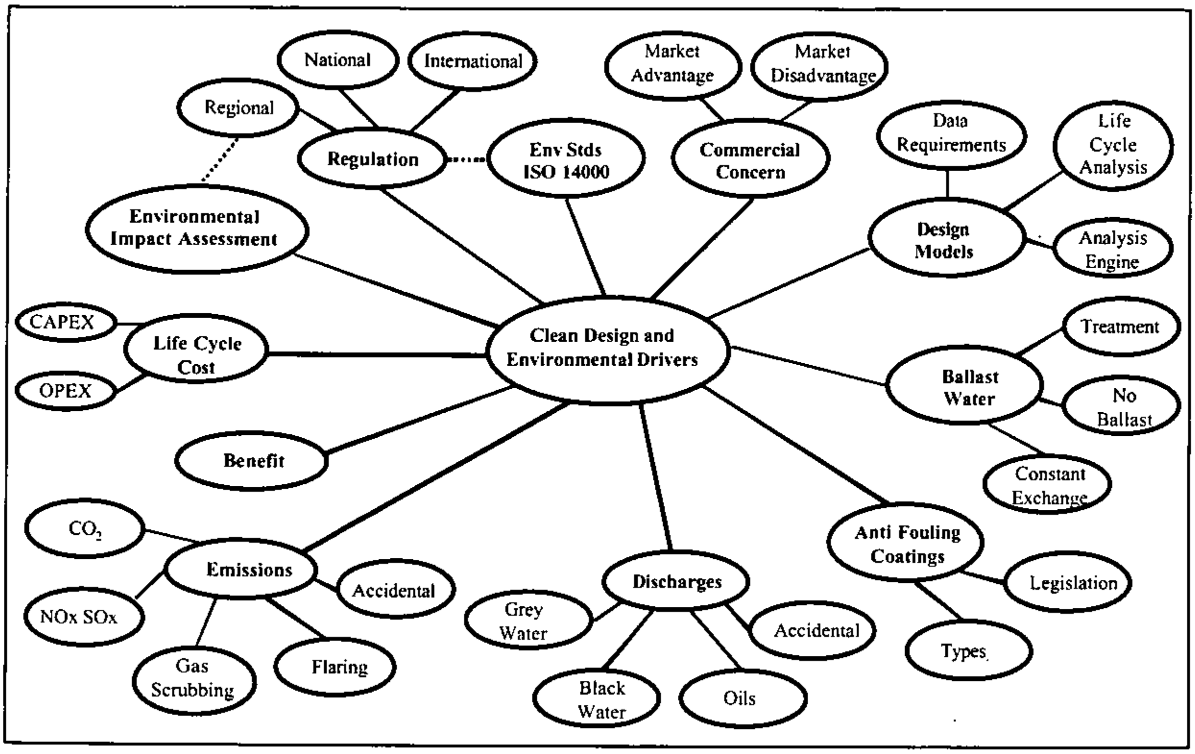

Figure 1: Principle Environmental Drivers that can Influence Concept Design

When the energy and resource sustainability drivers also have to be included then the modelling required gains another degree of complexity. When all three drivers are considered together it is found that these drivers impact on a products environmental impact long before any materials arrive at the construction yard.

As an example let us look at a requirement for aluminium for use within a ships superstructure. When considering the environmental impact it has been argued that numerous aspects will need to be considered. The following is a non-exhaustive list:

- method of extraction of ore and its environmental impact
- transportation for smelting
- smelting
- rolling
- transport of finished product to shipyard, etc.

Each of the above will have a variety of environmental and sustainability factors to be considered. However, it should be remembered that such issues should be looked at as a whole and not as isolated issues. For example, a major consideration when assessing the environmental impact and sustainability of aluminium is the method by which the electricity used to produce the aluminium is generated. In terms of electricity generation, hydroelectric power stations are more sustainable than coal fired ones. It would generally be thought that hydroelectric power was more environmentally friendly. However, this may not be the case if the water head for the hydro power scheme was created by flooding an environmentally sensitive area.

Environmental, or green, evaluation is not just limited to the method of production, but also to areas such as transportation. Take the aluminium example in the last paragraph. Let us say that the ship was being built in Finland and the choice was between aluminium produced in Japan utilising hydro electricity or aluminium produced in the UK utilising an on site coal fired power station. Such a choice adds yet another level into the environmental and sustainability evaluation, in this case transportation.

Therefore, when looking at green issues during concept design a reasonable level for the investigation has to be set, if the task is not to become un-accomplishable. As the example above demonstrated it is generally not possible to look at issues in isolation. In the case above there would be pollution issues surrounding the generation of electricity from a coal fired power station that would also need to be considered along with other energy issues.

When selecting resources of whatever nature, sustainability of that resource should be considered. The sustainability of some resources is much easier to determine than for others.

Operational

The environmental drivers to be found in the operational phase are no less complex than those to be found in the construction phase. But, at this stage the modeller is faced with the prospect of having to model an operating life often in excess of twenty years and where specialist vessels are concerned this may be upwards of thirty years. During the operation of a marine vehicle there are many broad areas of potential concern these include:

- Energy use
- Emissions
- Anti Fouling Coatings
- Ballast Water
- Discharges

Known Emissions

When considering known emissions a major problem in the oil and gas industry is the flaring of unwanted associated gas[3] and with shipping is the emission of NO_x and SO_x. A recent study by Isakson et al[7] into the atmospheric pollution in Goteborg harbour, Sweden, found that a large percentage of the SO_x pollution came from shipping. Their study found that the 12,000 yearly shipping arrivals contributed to 45% of the total SO_x emissions in the Goteberg area. Such data highlights the importance of modelling known emissions when considering their effect and cost within whole life modelling. When modelling the emissions over the whole life of a marine vehicle the possibility of changes in emissions legislation would also have to be considered as would how the design would cope with tougher regulation. On the positive side other things to be considered are the probability of changes in fuel technologies, which could produce a cleaner burn and lower emissions, along with improvements in gas scrubbing technologies. Other forms of emissions would have to be considered in a similar manner.

Antifouling Coatings

Another area of environmental concern is that of antifouling coatings. The use of TBT (trybutyltin) is now being phased out following legislation introduced by the IMO (International Maritime Organisation) which has outlawed its use by 2008. This is in response to the assessment of its impact on aquatic organisms. Hence, paint manufacturers are now developing alternatives.

It has been argued that while eliminating the use of TBT will allow certain areas of the marine ecology to recover, the ban may adversely effect other areas of the environment[8]. This is mainly because of the possible increase in the use of fossil fuel by shipping due to the replacement antifouling coatings not been as effective at providing a self polishing underwater hull. Any reduction in underwater hull smoothness will reduce the hull efficiency through the water. So, as with other areas discussed, the modelling of coatings is generally complex.

A problem currently for the designer wishing to model the environmental impact of antifouling that does not use not contain TBT is that very little is known about the possible effects on the marine environment of the alternative compounds that are now being used. Evans[9] points out that most of the compounds being proposed are organic booster biocides, which are highly toxic when used for to kill agricultural pests. As such toxicity is part of their make up it will be present when such compounds are used as the active ingredient of antifouling, but there is little or no published data on their effects on marine life.

As ship hull fouling is liable to increase with the phasing out of TBT, a problem that may increase is the introduction non-native marine life, which is transported on the fouled hull. It is often thought that the main method non-native marine life being introduced to a region is through ballast water, but Evans[9] points out that in UK waters more non-native marine life is introduced from transportation on the outside of the hull than in the ballast water.

Ballast Water

In recent years the impact of ballast water transportation then discharge on the aquatic ecosystem has grown in importance. The EU are currently partly funding a large Framework 5 investigation, the MARTOB project, into methods of treating ballast water to eliminate the effects of dumped ballast water on the environment. Mesbahi[10] when writing on the MARTOB project estimated that more that 10,000 million tonnes of ballast water is transported around the globe annually.

When it comes to modelling the effects of ballast water within the terms of whole life models there could be various scenarios that would need to be considered. At one extreme could be the modelling of costs associated with the operation of an advanced technology ballast water treatment plant. This modelling should present no greater a level of difficulty than is incumbent in modelling other plant and equipment. The modelling would consist of normal operational, maintenance, upgrade costs and the like.

The other extreme could be the modelling of the costs associated will not having any form of ballast water treatment. Here the main operation costs would the pumping costs involved in the loading and unloading of water ballast, which should be a none too arduous a task. But, if as part of a comprehensive Environmental Impact Assessment (EIA) the ecological and environmental costs of discharging untreated ballast water had to be modelled over the total working life, then the modelling complexity would be increased substantially. Also, the nature of the problem means that, as there may be many unknown effects due to the ballast water discharge, it would be very difficult to produce a whole life cost model. Hence, any model produced would have to allow for a great degree of uncertainty.

Deliberate and Accidental Discharge

Deliberate discharge is now regarded as unacceptable in certain areas of the world. This has resulted in the need to install plant to treat both black and grey water. When developing models the effects of treatment and non-treatment will need to be considered.

Accidental emissions by there nature can be difficult to model and to predict. But, any model should consider such scenarios if the model is to be valid.

Disposal

For many years disposal was generally though of something that only had to be considered when the vehicles operational life was drawing to a close. Over recent years such attitudes have been challenged, as the public has become aware of the potential for creating pollution during the disposal process. The initial disposal plans for the Brent Spar is a case in point. The high profile media attention seeking actions of Greenpeace caused Shell to reconsider its disposals plans for the Brent Spar. This particular case has probably done more than any other to bring the issue of large structure disposal to the publics attention.

Pollution and reuse are generally the main drivers that need to be considered when modelling disposal. As a long time period is involved between the creation of the model and the actual act of disposal the level of accuracy and validity of such models must be in question.

LIFE CYCLE ANALYSIS TOOLS

Over recent years there has been various research activities aimed at the development of a robust and reliable Life Cycle Analysis (LCA) tools. One particular project was the TEES (The Energy Efficient Ship) project funded by the European Commission[11].

A simple LCA tool was developed by Kane at the Newcastle EDC[12, 13]. Part of this study utilised the tool to investigate the uncertainties associated with LCA. It was concluded that there are two main forms of uncertainty:

- aleatory, and
- epistemic.

Aleatory uncertainty refers to inherent problems of variability of the various input data that is used. Epistemic uncertainty is caused due to a lack of knowledge in the area being modelled. The research concluded that the preferable way to move the body of knowledge forward within LCA would be to develop robust ways of managing epistemic uncertainty. It was felt that aleatory uncertainty would generally be always high in certain areas due to the effect of outside forces on data variables, e.g. market forces, economic models, etc.

While there is no doubt that there is a need for good, easy to use LCA tools, there was another study into the use of LCA carried out by Stoyell at the Newcastle EDC, that ran concurrently to the above investigation. This study concluded that elaborate life cycle tools would be of little use currently to many organisations[14]. It was found that for such tools to work complex data is required. Within the context of environmental issues organisation often have problems even with primary communication. Therefore, basic communication on environmental issues must be developed within an organisation before attempts are made to utilise sophisticated modelling tools. It was concluded that the development of an organisations environmental communication networks would be every bit as challenging as the effort that would be later required to build a LCA model of a sufficient depth to be of use when assessing environmental impact of large Engineered to Order (ETO) products.

Most LCA tools utilise reasonability simple analysis engines. It is possible that in the future such tools are going to have to increase in sophistication if they are to provide the level of modelling confidence that will be required if a LCA within a concept design framework is to be regarded as credible. It is felt that the inclusion of fuzzy sets and MCDM capabilities within the analysis engine will increase the level of certainty of the model output data.

FUTURE UPGRADING CONSIDERATIONS

As discussed earlier marine products and vehicles invariably have a long life. From concept design to commissioning can often take in excess of five years. An operational life of twenty years is typical and often this can extend to over thirty years. Finally, de-commissioning and disposal can often span over several years. With such a long life marine products require refurbishment at various times throughout their operational life. As new technologies become available, upgrading of the original equipment may be required so that economic viability is maintained. In addition, when a product has such a long operational life then the application / use of the product may change. Upgrading may also be required to increase a products operational capability due to the requirement to enhance delivery or production which normally occurs over time with changes in market needs.

The complex nature and extended time element surrounding upgradeability makes it challenging to model in a life cycle costing model with any degree of accuracy or certainty. Barber[15] ruminated that modelling upgradeability within a life cycle cost model was possible at the concept design stage, if an appropriate methodology was available to assist in the assessment of upgrade strategies.

The upgradability assessment methodology developed is based around the development of predictability scenarios for the various possible upgrade options. The need for upgrading is driven by five broad categories:

- changes to capacity
- changes in input
- changes in output
- technical changes
- regulatory changes

It is envisaged that in use these high level categories would be broken down into appropriate sub-categories. The reasons for upgrade are fed into an analysis engine, based on time and probability that would produce the predictability scenarios. The various scenarios would feed into suitable upgrade frameworks which result from the approach taken during the development of the design, such as:

- Bare Minimum Plant
- Added Space
- Added Services
- Margins on Ancillaries
- Margins on Major Equipment
- Most generous plant Capital can provide

It is envisaged that a commercially applicable analysis engine for such a methodology will need a reasonable degree of sophistication and data analysis power. A possible solution would be the inclusion of Multiple Criteria Decision Making (MCDM) within the analysis engine. The Newcastle EDC has pursued research in this area for a number of years. It has successfully proved the power of MCDM in various situations where there are a large numbers of main and sub-criteria (objectives, constraints and attributes) that can influence a decision. Examples for combinatorial problems are given by Todd and Sen[16, 17] and for parametric problems by Hutchinson et al[18, 19]. This is generally the case in upgradeability analysis at the concept design stage. Therefore, MCDM would be an appropriate way to move forward on the development of a commercial analysis engine.

RISK ASSESSMENT AND SAFETY CASE CONSIDERATION

The reality that the worse case predictions of quantitative risk assessment could actually happen were demonstrated with major tragic consequence when the Piper Alpha oil rig disaster occurred in 1988. This disaster and the subsequent report produced by Cullen[20] have had a significant impact on how risk and safety are considered within oil and gas operations in the United Kingdom (UK) and other European waters. Recently Brandsaeter[21] has outlined the use of a comprehensive quantitative risk assessment process by the offshore oil industry. He details the importance of incorporating a range of techniques such as Hazard and Operability studies (HAZOP), Structured What-If Checklist (SWIFT) and Failure Modes, Effects and Criticality Analysis (FMECA), if such an assessment is going to have the required level on comprehensiveness. The approach put forward by Brandsaeter[21] is echoed by Khan et al[22] in their discussion on the development of risk based safety assessment during the design of offshore process facilities.

Within the UK, Safety Case reports are a legal requirement for land-based and offshore process plant. In the UK the operator must submit the Safety Case to the Health & Safety Executive (HSE) for approval before processes can be commissioned. The Safety Case report details the substances and operations of a plant and presents quantitative and qualitative information relating to the likelihood for potential major hazards at the installation. Such reports require important information from process design as well as operational data, thus effective data management and exchange is necessary[23].

Risk assessment is also important when developing the concept design of a ship. Such an assessment should consider both normal operation and likely performance during and after an accident. An example of the subject matter for risk assessment during the normal operation phase of a ship would be that of hull maintenance and reliability, something that is of topical interest after the recent *MT Erica* and *MT Prestige* tanker disasters.

Casella and Rizzuto[24] have developed a model for determining the reliability of double-hull oil tankers. The model calculates a reliability index and failure point co-ordinates for the proposed hull design. With regard to risk assessment performance during and after an accident the American Bureau of Shipping (ABS) published the finding of a study of the state-of-the-art research in this area[25].

WHOLE LIFE ANALYSIS TOOLS

A Whole Life Analysis (WLA) tool needs to be able to combine the requirements of life cycle costing, upgradeability modelling and life cycle analysis. In addition, there could be a need to add safety case costing and modelling into the tool to give all round comprehensiveness.

With these needs in mind the model in figure 2 is proposed. This model is an enhancement of the life cycle cost model that was discussed earlier. Within this model it is acknowledged that a high degree of sophistication is required. The central spine of the model is still the annual net Cash Flows (CF) feeding into the Discounted Cash Flow (DCF) calculation that is then used to produce a Net Present Value (NPV) and an Internal Rate of Return (IRR).

Into the central spine is fed income from various sources, but the model now acknowledges the need to consider changes in the market over time along with the market risk factors. Also, feeding the central spine are the various costs associated with the life of a product. As with income, the model now acknowledges that there are certain considerations that need to be taken into account where costs are concerned. These are, performance changes over the life of a product for whatever reason, along with cost escalation over time.

One of the cost streams is upgradeability and this has been discussed earlier. Such a cost can be difficult to establish due to the many possible scenarios. It is now envisaged that a WLA tool should be able to provide the ability to assess upgradeability cost options utilising an analysis engine that can handle the level of complexity associated with the problem.

The central spine is also fed by a life cycle profile. This should be able to deliver a LCA at the required level of detail for the project being considered. To be of credible use, there should be various ways of building up the required data. Also, aleatory and epistemic uncertainty must be handled in a quantifiable manner. The analysis engine should start to provide the types of solution that would make LCA more reliable, possibly by including fuzzy sets and the like within analysis algorithms.

The completed WLC analysis of a particular design option is fed into a design comparator, so that various design solutions can be compared. As most large ETO products are complex by nature such comparisons can be difficult to undertake. To assist in the comparison process it is proposed that MCDM, specifically Multiple Attribute Decision

Making (MADM), would provide a powerful and robust methodologies for the process. To close the model loop a feedback is provided to the initial design to allow for revised designs to be created.

An area that requires further investigation is the manner in which the various risks associated with WLC modelling are handled. The ability to be able to properly account for modelling risks would help to ensure greater model integrity.

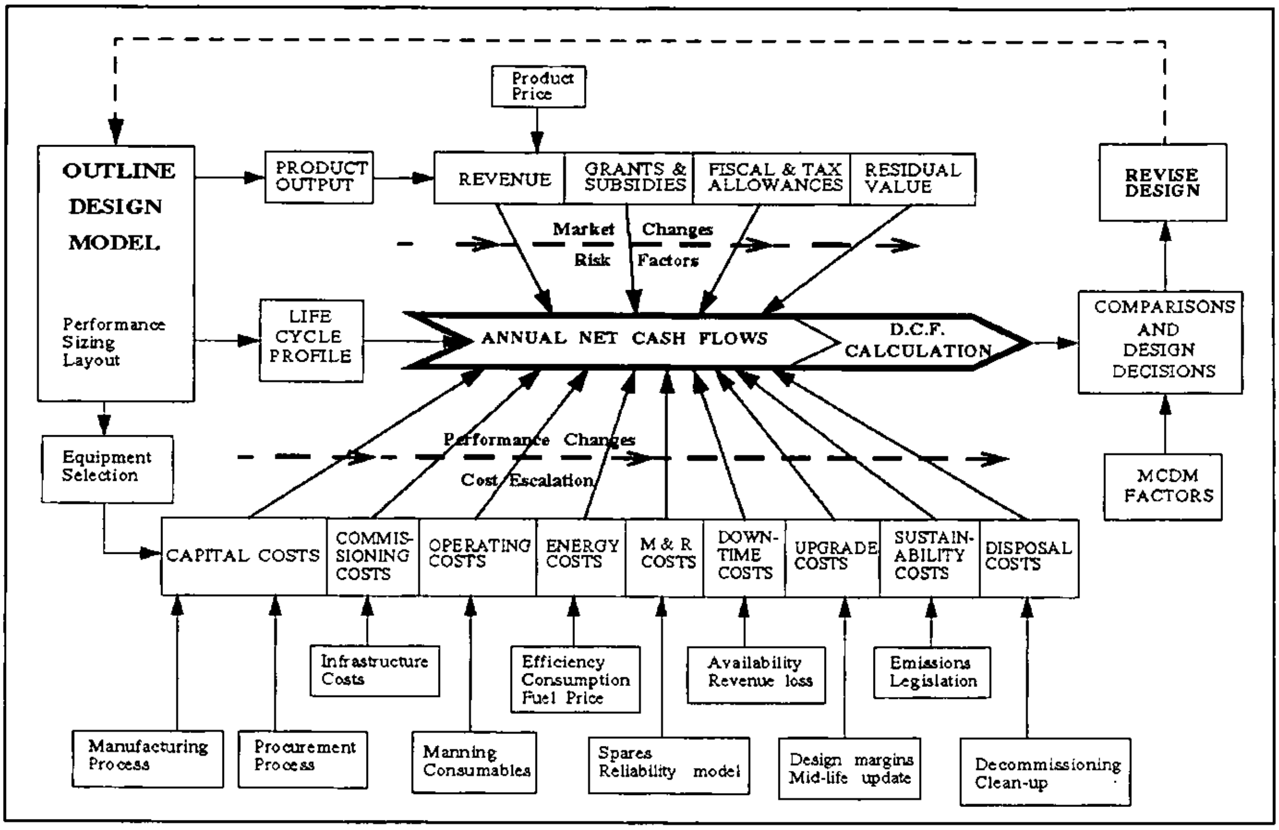

Figure 2: Whole Life Cash Flow Model

CONCLUSION

This paper has highlighted and discussed various design drivers and evaluation methodologies, which although by no means exhaustive, could form the foundation of a designer's "applications toolbox" in support of the formulation of environmentally sustainable designs. An approach has been described as to how these often conflicting design drivers, and hence the diverse and complex but robust analysis techniques, can be brought together as a coherent whole for practical application by industry at the concept design stage.

The consideration of such drivers and use of the discussed techniques at the outset of the design process will help placate the growing public concern over the environmental impact due to the manufacture, operation and disposal of all types of marine vehicles. This will be achieved through the design and production of more environmentally friendly ships utilising the latest technologies regarding construction and operation. As a consequence such designs will be, by definition, more energy efficient and hence should have reduced running costs. However, they may be penalised by the requirement for increased capital expenditure during the design and build phases. The application of the techniques described will facilitate the accurate quantification of both the technical and economic performance of a design over the whole life cycle.

The full financial and environmental benefits of developing and operating environmentally sustainable designs for all types of marine vehicles have yet to be realised. At present there is rarely a coherent strategy to the assessment of environmental drivers during concept design. Hence, at the outset of the design process there must be a change of emphasis from first cost to whole life cost and environmental impact assessment which, by definition, requires a change to the design process and the application of prescriptive rules etc. The assessment of the design drivers and application of the methodologies discussed in this paper may go some way to aid the development of environmentally friendly designs, thus reducing our impact on the ecology of our planet and hence maintaining our environment today and for future generations.

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Ballast water treatment and ship safety

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SYNOPSIS:

Following a presentation of the context, observations of non-indigenous species transferred from regions to regions by ballast waters, and of the resulting IMO actions, the ballast waters treatment principles are reviewed. Three families of treatments allowing to kill or eliminate harmful content from ballast waters are presented : without additive to waters (thermal and hydrocyclone methods), by additive to waters (chlorine, biodegradable treatment), exchanges of ballast waters (sequential, flow through and dilution). Then the ship and crew safety is analysed for each of these 3 families. The ship operation safety concerns trim, free-oard and stability, the ship resistance concerns both items: structural loads and corrosion. The crew safety is analysed with respect to operation and failure of the considered water treatment systems. The risks concern the handling of hazardous products, the ship spaces and/or crew contamination in case of system or piping failure, the increase of work load on board with risk of human errors increase. To conclude the obligation of a Ballast Water Management Plan for every ship is reminded, and the needs for efficiency and risk evaluations are brought out for the future.

INTRODUCTION

It has been clearly demonstrated that the introduction in coastal waters of unwanted aquatic organisms and pathogens from ships' ballast water and sediment discharges may pose threats to indigenous human, animal and plant life, and to the marine environment [1].

Just to illustrate we shall mention oysters disease in France, the origin of which has been proven coming from pathogens imported by a ship ballast waters and the cholera epidemic in Peru, also proven coming from pathogens introduced in the harbour waters by deballasted waters.

To prevent new cases in future, actions have been taken by international, national and local authorities leading to the development of recommendations, compulsory rules, and by the shipping world to develop efficient and economical methods for ballast water treatments.

We shall review the today activities in rules development and then the existing water ballast treatment methods, with a particular attention to their impact on the ship and crew safety.

RULES OF TODAY

The society becoming conscious of the risk link to ship ballast waters, various international and national authorities decided to develop and impose rules to prevent new contamination or at least limit transfer of aquatic organisms and pathogens from one world location to another one.

As no compulsory international rules exist, discussion around the development of rules follow at different authority levels.

Involved authorities and works in progress

Rules are today developed by international, regional, national and local (ports) authorities, not always in co-operation, which creates a very difficult context for ship owners and operators.

I M O (International Maritime Organisation)

The IMO adopted in Assembly on 27 November 1997 the Resolution A.868(20) "Guideline for the control and management of ship ballast water to minimise the transfer of harmful aquatic organisms and pathogens, but the observance of this guideline is not mandatory. However, a ship has a commitment to comply with the quarantine requirements of a port state, and cases of non-compliance with a request to carry out ballast management procedures may need to be explained.

The IMO/MEPC is very active and the reports shows several points:

First, the port states remain in a sense the sole authorities in that matter, within the IMO framework: *"...each country has the right to decide on restrictions, in accordance with criteria established by IMO, relating to the discharge of ballast water within waters under its jurisdiction, and in accordance with international law..."*

Next, *"vessels will be required to manage sediments."*

"Ballast water exchange should be regarded as an interim solution and the aim is to produce safe and more effective alternative ballast water treatment options that will ultimately replace Ballast Water Exchange".

A first MEPC/MSC Circular is now under development to consider ballast water and sediment management options when developing and building new vessels. According to MEPC timetable, work progression should lead toward a diplomatic conference on ballast water management before the end of the biennial 2002-03.

IACS (International Association of Classification Societies)

As water ballast treatment systems or methods impact the ship design and her operation safety, Classification Societies are directly concerned. Therefore, IACS has created a particular working group on the subject of hazard identification of ballast exchange at sea.

The objective of the study is to identify hazards that are unique to Ballast Water Exchange at sea, in order to assist with the development of rules and regulations by IACS or IMO.

The report issued in January 2000 comprises the HAZID-report on ballast water exchange (BWE) for bulk carriers. For that purpose, the 'Structured What-If checklist Technique' (SWIFT) was applied.

European Union

On 1st April 2001, the MARTOB Research & Development program was launched under the control of the European Union Commission, DG TREN (Energy and Transport). The objective is to investigate methodologies and technologies and to design systems for ballast water treatment, to assess their effectiveness and to produce criteria for selecting appropriate ballast water management methods versus ship constrains.

Port authorities

As no international rules are compulsory, many port states have introduced their own requirements which, though often differing in detail, generally call for ships to report in advance to the national monitoring authority, how much ballast water will be on board on arrival, where it was taken on board, and whether a ballast management procedure has been followed. In most cases, it is mandatory to make the report, even though the actual ballast exchange in mid-ocean (or other management procedure) remains voluntary.

Today, a number of port states, including Australia, Canada, Chile, Israel, New Zealand and the USA have introduced regulations intended to prevent ships which arrive in their waters from discharging ballast water which contains 'non-native, harmful species of aquatic life forms'.

Criteria for ballast water quality assessment

For the time being, there is no internationally accepted set of criteria assessing the ballast water quality. Criteria depend on each port state according to the targeted pathogens and the method used.

In general terms, inactivation standards should be agreed on for killing, removing or otherwise inactivating harmful aquatic organisms and pathogens in ballast water. The application of a ballast water management and relevant control options should be accepted whenever there is a demonstrated 95% inactivation or more of the targeted organisms.

Existing accepted criteria are, for example:

- potable water as ballast water
- remove at least 95% by volume of the original ballast water contained in a ballast tank
- on shore: ballast water heating at 90° C during 1 minute
- on board: ballast water heating at 65°C during 2 minute

HOW TO AVOID/MINIMIS E ORGANISMS AND SEDIMENTS TRANSFER

Various methods are possible, generally not exclusive: by using pure water for ballast, avoiding or minimising the uptake of organisms, by ballast water treatment to eliminate the unwanted organisms and sediments. Actually, the optimum method should involve several processes.

Referring ballast water treatment methods, they can be sorted out into two categories: shore-based methods and on board methods.

Uptake of ballast water

The first possible action is to prevent uptake of sediment and harmful organisms, not loading water ballast in coastal waters.

IMO Res.A.868(20) recommends, whenever practicable, the uptake of ballast should be delayed until the ship reaches open ocean waters, if not, uptake of ballast water should be avoided in areas such as:

- Areas with outbreaks, infestations or known populations of harmful organis ms and pathogens.
- Areas with current phytoplankton blooms (algal blooms, such as red tides).
- Nearby sewage outfalls.
- Nearby dredging operations.
- When tidal stream is known to be the most turbid.
- Areas where tidal flushing is known to be poor.
- In darkness when bottom-dwelling organisms may rise up in the water column.
- In very shallow water.
- Where propellers may stir up sediment.
- Areas with naturally high levels of suspended sediments, e.g. river mouths and delta areas, or in locations that have been affected significantly by soil erosion from inland drainage.

Shore-based ballast water management

A very efficient method is to use potable water or on-shore pre-treated water as ballast water. But this method is very limited by the availability of large quantities of these kinds of water in ports of call and cost.

Another method is to unload the ballast water in a specific shore installation where the water can treated by processes which are commonly used in the industry.

There are many different processes for water treatments such as filtration, oxidising and non-oxidising biocides, thermal, ozonation, electric pulse, pulse plasma, UV, acoustic, magnetic, deoxygenation, biological, etc., but most of them are specific and limited to a certain range of pathogens and some are still at the research or development level. In addition, as for pre-treated water, the availability of installations in ports of call is very limited.

On board ballast water management.

On board treatments are in fact the more commonly applied methods. They can be classed in three families of treatments allowing to kill or eliminate harmful content from ballast waters:

- without additive to waters: thermal and hydrocyclone methods
- by additive to waters: chlorine, biodegradable treatment
- exchanges of ballast waters: sequential, flow through and dilution.

Ballast water treatment without additives

The principles of on board treatments of ballast water are the same as those used on shore.

As an example we shall mention the thermal method that uses the ballast water in the main engine cooler, under development in UK and Australia.

Other examples are the use of hydrocyclone (centrifugal separator) with UV (ultraviolet) or US (ultrasonic) post-treatment under development in Netherlands and Norway.

The evaluation of all these methods is part of the above mentioned EU R&D MARTOB project.

Ballast water treatment by additives

The principle of these methods is the addition of biocides, ozone or nutrient solution, some of them being also used on shore treatment installations.

Addition of biocides or ozone addition aims to directly kill harmful organisms, when addition of nutrient solution aims to create a de-oxygenation of the water and consequently also kill the harmful organisms.

As an example we shall mention the requirement for use of chlorine by the Argentine port state authorities, biodegradable ballast water treatment in development in Germany, biological de-oxygenation in development in Norway.

Also the evaluation of all these methods is part of the EU R&D MARTOB project.

Ballast water exchange (BWE)

As it is commonly accepted that there is no harmful organisms nor sediments, and that coastal organisms cannot remain alive in deep waters, a method is to exchange ballast waters in open ocean, as far as possible from shore.

Today this method obtained a general acceptance internationally, it gains the owner favour and is extensively used. Three way of doing are considered:

- Sequential Exchange

  The ballast tanks are pumped out and refilled with clean water, when sailing in mid-ocean. It is a step-by-step procedure. During the operations, each relevant ballast tank has to be emptied until suction is lost, and then refilled.

- Flow Through Exchange

  The ballast tanks are simultaneously discharged and filled by pumping in clean water, allowing the water to overflow through air pipes or other deck openings. For each tank, it is necessary and required by IMO Res. A.868(20) to pump in 3 times the volume of the tank to achieve an estimated 95% change of water.

- Dilution Exchange

  The principle of this method is similar to the Flow Through method. The ballast tanks are simultaneously discharged and filled by pumping in clean water, but the filling levels in the relevant tanks are kept constant by simultaneously pumping out the diluted water. For each tank, the water may be considered as exchanged when the achieved dilution rate reaches 95%.

In general terms, each of the ballast water exchange methods are understood to "inactivate" the harmful aquatic organisms and pathogens in a ship's ballast water by removing at least 95% by volume of the original ballast water contained in a ballast tank

Methods status

All possible methods are not at the same level of development, use and understanding. A summary global view is provided in figure 1.

	Means	Feasibility	Applications	port State acceptance	Class Rules or Statutory Requirements
Shore-based	*Heat Treatment*	OK - depends on port of call	Process in course (Australia)	Process has been submitted to AQIS (Australia)	-
	Potable / Pre-Treated Water ballast	OK - depends on port of call	Australia	OK (Australia)	-
On Board Treatment	*Filtration*	OK	Trials have been carried out in USA (Great Lakes)	-	-
	Heat Treatment	OK	Trials have been carried out in Australia	Process has been submitted to AQIS (Australia)	-
	Hydrocyclones (centrifugal separators +UV)	OK	Already used in offshore	-	-
	Electrochemical Control	-	Tests planned in Japan	-	-
	Chlorine	OK	Argentina	OK (Argentina)	-
	Biodegradable Chemicals	OK	In development in Germany	-	-
Ballast Water Exchange	*Sequential Exchange*	OK (a priori)	OK	OK	YES
	Flow Through Exchange	OK (depending on vessel tanks)	OK	OK	YES
	Dilution	OK (a priori)	OK	OK	YES

Figure 1: Ballast water treatments status

SHIP AND CREW SAFETY

The introduction of a new equipment and process on board may modify the ship and crew safety context. Therefore risks attached to the different methods are reviewed versus the ship integrity, ship operation and crew.

On shore treatment

Excepting the installation of a dedicated piping and connection to the on shore installations, no changes are expected in the ship general arrangement, nor equipment. Also no impact on the crew at sea will exist.

On board treatment

The installation of an on board ballast water treatment system corresponds to the installation of a new equipment, and so must comply with existing rules and standard applicable to ship design, building and operation.

In fact there is no particulars with respect to ballast water treatment systems than to others, and with respect to corrosion risk increase it should be assessed if new materials or products are added in the piping network and if DC current is used. Any addition to the ballast water, or increase of the temperature, will modify the water characteristics or/and content which may impact the piping and structure integrity, the crew safety.

Referring water properties the main changes may concem conductivity, hardness, PH, redox potential, temperatures, and referring water content changes may be O_2 content, O_3 (ozone) content, CO_2 content, H_2S content, inorganic and organic substances, bacteria concentration.

All these parameters are directly impacting the risk of corrosion of piping, internal ballast tank structures, coatings, seals and gasket. In addition the added product should not pollute the sea water when released nor present any non controllable danger to the crew when handling or in case of a accidental release.

These questions are actually assessed within the EU R&D MARTOB project for 7 different on board ballast water treatment systems.

Ballast water exchange (BWE)

With reference to IMO Res. A.868(20), the ballast water exchange has to be done, when practicable, in deep water (IMO Res. A774(18): more than 2000 m deep), open ocean as far as possible from shore (i.e., 200 miles from shore).

The obligation to handle ballast water in open sea is clearly a new constrain not considered previously in ship design and it may impact the existing ship integrity in such a way that it is considered that it is not always practicable.

So requirements for the ballast water management plan consider that it should list the circumstances under which ballast water exchange at sea should not be undertaken, i.e. under specific sea states, hurricanes, typhoons, cyclones, heavy weather, icing conditions, ... Such information may prove to be the master's best defence if called upon to explain why he decided not to exchange ballast en route.

The reasons are that BWE has direct effects on the ship behaviour versus the selected technique, on stability, ship behaviour on waves, hull girder strength, local structures strength, piping operation, but also on the crew safety.

Intact Stability

During ballast water exchange operations, the vessel should comply at any stage with intact stability requirements (IMO Res. A.749(18)), and for the dilution process, the capacities of the suction and discharge water ballast pumps should be similar to assure a constant filling level.

EFFECTS ON INTACT STABILITY		
Sequential Exchange	Negative	Creation of free surfaces + changes in KG and GM.
Flow Through Exchange	Unchanged	Ballast tanks are either full or empty. No change in free surface, KG and GM.
Dilution Exchange	Unchanged	Ballast tanks are either full or empty. No change in free surface, KG and GM.

Ship behaviour on waves

The bridge visibility is modify by the trim and freeboard, so during ballast water exchange operations, the actual draught should comply with the seasonal freeboard mark and the Rule minimum draught (e.g. MARPOL,...).

Also during ballast water exchange operations, the trim of the vessel should remain within acceptable limits to assure a sufficient immersion (draught aft) of the propeller and the rudder, to assure a sufficient draught forward to avoid slamming and to comply with the required Rule minimum draught forward (e.g. MARPOL,...) and to assure a sufficient navigation bridge visibility (SOLAS-Part 1-Chap 5 Regulation 22).

EFFECTS ON TRIM AND FREEBOARD		
Sequential Exchange	Negative	Change in loading cases.
Flow Through Exchange	Unchanged	Ballast tanks are either full or empty. No change in loading case, thus trim
Dilution Exchange	Unchanged	Ballast tanks are either full or empty. No change in loading case, thus trim

Hull girder strength (bending, shear and torsion)

The loading changes should not increase hull girder bending, shear and torsion so that it could damage the ship structure. Still water bending moments (SWBM) and still water shear forces (SWSF) distribution along the ship's length should remain within acceptable limits according to the reviewed Loading Manual / Loading Computer (admissible values <u>at sea</u>).

Combined stresses including the additional torsion stresses (warping, etc.), if relevant, should remain within acceptable limits (e.g. for containerships, or ships with large deck openings).

EFFECTS ON HULL GIRDER STRENGTH		
Sequential Exchange	Negative	Change in loading cases, thus SWBM, SWSF and Torsion.
Flow Through Exchange	Unchanged	Ballast tanks are either full or empty. No change in loading case: SWBM, SWSF, Torsion
Dilution Exchange	Unchanged	Ballast tanks are either full or empty. No change in loading case: SWBM, SWSF, Torsion

Local scantlings of ballast tanks

Over and under-pressurisation of ballast tanks should be avoided. The local scantlings of the ballast tanks are to be able to withstand the actual loads within acceptable stress limits, depending on the applied BWE method.

EFFECTS ON LOCAL SCANTLINGS OF BALLAST TANKS.		
Sequential Exchange	Within design limits	The local tank structure is normally suitable for all transient local loading cases
Flow Through Exchange	Negative	Over pressurisation of ballast tanks.
Dilution Exchange	Unchanged	Over pressurisation if discharging pumps fail, filling pumps remaining active

Another question concerning local scantling of the ballast tank boundaries is the risk of sloshing as sloshing can appear during the sequential exchange when the ballast tanks or holds are slack.

EFFECTS ON SLOSHING IN PARTIALLY FILLED CAPACITIES.		
Sequential Exchange	Negative	Sloshing can occur.
Flow Through Exchange	Unchanged	No sloshing.
Dilution Exchange	Unchanged	No sloshing

Some piping aspects

The relative on board positions of ballast tank inlets and outlets can affect the exchange efficiency. For example, if the outlet and inlet of a ballast tank are close to each other, are located on the same side, and the outlet is forward of the inlet, then the water taken up by the inlet will contain a relatively important quantity of water originally from the subject ballast.

Referring flow through method and air pipes, they are generally not designed for continuous ballast water overflow in large quantities during flow through and so need to be adapted. The venting and tank overflow arrangements are to be such that flow through is a practicable alternative (ex. the locations of certain air pipes in enclosed spaces could prevent the use of flow through).

EFFECTS ON AIR PIPES OR OTHER CONCERNED DECK OPENINGS		
Sequential Exchange	Positive	Unchanged.
Flow Through Exchange	Negative	Air pipes usually not designed for the intended use.
Dilution Exchange	Positive	Unchanged

Crew safety

The BWE operations being rather long and complex depending on the size and type of the vessel, they require intensive crew attention. This could induce fatigue of the crew. Therefore, the crew training and familiarisation with the BWE procedures should be effective and checked by the appointed BWM Officer (see ICS / Intertanko Ballast Water Management Plan for the duties of the appointed BWM Officer).

During the flow through process, the access of the crew to the weather decks should be strictly limited due to serious safety risks caused by large quantities of water cascading on these decks.

Summary of BWE effects versus ship operation

Practical applications of sequential BWE procedures on board of different types of existing vessels allow to consider that:

- Referring sequential method, in most cases, it is difficult to match all the criteria (stability, hull girder strength, propeller immersion, draught forward and bridge visibility). However, in most cases it is possible to comply with criteria for stability, hull girder strength and propeller immersion, the latter actually corresponding to the minimum allowable draught aft. During the sequential process, the bending moments and shear forces (depending on the vessel) often approach the maximum allowable reviewed values.
- Due to the fact that during sequential exchanges the bending moments and shear forces (depending on the vessel) often approach the maximum allowable reviewed values, and considering the BWE operation required time, the fatigue of sensitive structural elements could be significantly increased.
- In most cases, it is difficult to achieve the required minimum draught forward, thus restricting the BWE procedures to favourable weather conditions (no slamming). Consequently, the bridge visibility is very difficult to achieve in most cases.
- The effect of variations in consumable on the loading cases and their corresponding exchange sequences are much more sensitive for smaller vessels than for larger ones.
- Referring flow through method, the corrosion of the weather decks and side shell could be accelerated when the method is regularly used.

A global view of the effects on the ship safety is given in figure 2.

EFFECTS ON	Sequential	Flow Through	Dilution
Intact stability	Negative	Unchanged	Unchanged
Trim and freeboard	Negative	Unchanged	Unchanged
Hull girder strength	Negative	Unchanged	Unchanged
Local scantlings of ballast tanks	Unchanged	Negative	Unchanged
Sloshing in partially filled capacities	Negative	Unchanged	Unchanged
Air pipes	Unchanged	Negative	Unchanged
Crew safety	Negative	Negative	Unchanged
Weather decks and side shell corrosion	Unchanged	Negative	Unchanged
Additional structural fatigue	Negative	Unchanged	Unchanged

Figure 2: BWE direct effects versus ship safety

CONCLUSION

With respect to the risk of transfer of pathogens by ballast waters, every ship carrying ballast water should be provided with a Ballast Water Management Plan to assist in the minimisation of transfer of harmful aquatic organisms and pathogens. The intent of the plan should be to provide effective procedures for ballast water management ensuring a safe operation of the ship.

The Ballast Water Management Plan should be specific and tailored to each ship, taking into account the used methods (exchange at sea, on board treatment, etc...) and be modelled on the Ship Ballast Water Management Plan referred to in IMO Res. A.868(20) that was developed by the International Chamber of Shipping (ICS) and INTERTANKO for the IMO.

Accordingly, a typical Ballast Water Management Plan should contain the following items:

1. Description of ship particulars
2. Explanations of the need for ballast water management and need for reporting to port states
3. Description of ballast water arrangements on board
4. Safety considerations concerning to ballast water management
5. Procedure for managing ballast water (if ballast water exchange is used, this section should contain the ballast water exchange plan. see 0)
6. Ballast water sampling points

7. Crew training and familiarisation
8. Duties of appointed ballast water management officer
9. Ballast water reporting form and handling log
10. IMO Resolution A.868(20)
11. Summaries of existing national or local quarantine requirements for ballast water management

But the review of the today knowledge and ship operation practices show that the subject cannot be considered in a stable state. Important questions have not been yet solved such as:

- the criteria to be respected for ballast water treatment to obtained an acceptable risk level
- the efficiency of the ballast water exchanges at sea
- the efficiency of the on-board ballast water treatments
- a common view and understanding amongst involved national, regional, national and port authorities.

Therefore a great effort is always required in R&D with respect to the methods and equipment, which is one of the targets of the EU R&D project MARTOB, and with respect to the development of unified compulsory rules.

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US Coastguard	http://www.uscg.mil/
ICS	http://www.marisec.org/
OptiMar Ballast Systems	http://www.optimarin.com/
Pacific Ballast Water Group	http://web.pdx.edu/~sytsmam/pbwg/pbwg.html
IMO	http://www.imo.org/imo/news/297/ballast.htm
BIMCO	http://www.bimco.dk/default.html
INTERTANKO	http://www.intertanko.com/
KLUWER	http://www.wku.lt/nemo/EuroAquaInvader.htm

Testing on-board ballast water treatment facilities in the laboratory scale

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Synopsis
Shipping has been found to be one of the main modes of transmission for *non-indigenous species (NIS)* today. Before the late 1990s there was no knowledge of the number of ballast and fouling species that are being brought into the European coastal seas. However, during the last decades a lot of scientific reliable data have been collected to show the obvious increase of introductions during the last 50 years through the world. In European scale, the new invaders have introduced themselves to all the main sea areas due to increases in the number, size and speed of ships, the successive opening of new trade routes in the post-war era and the expansion of aquaculture.

Tentative figures obtained during the study indicate high numbers of invaders in the Baltic Sea (> 105 species of which some 70 established) in relation to its low number of native species of plants and animals. For British waters, it was estimated that about 55% of primary introductions of all NIS had probably been introduced in association with shipping. In the Black Sea and the Sea of Azov there are more than 45 NIS recorded of which 16 are of North American origin.

A research project MARTOB (On Board Treatment of Ballast Water (Technologies Development and Applications) and Application of Low-sulphur Marine Fuels), partly funded by EU, was established in 2001 to find out solutions on the development of onboard ballast water treatment. The research program consists of various sub-projects and working packages among them the laboratory scale testing of the different treatment systems has been one of the most interesting tasks. The main aims of this study have been to investigate the various possible methods for controlling the transfer of non-indigenous organisms and bacteria through the ballast water. A lot of emphasis has been paid on the to development of cost-effective, safe, environmentally friendly on board ballast water treatment methods which have a minimum impact on ship operations.

This paper describes the laboratory test phase of the MARTOB project. Thermal, de-oxygenation, ultraviolet, ultrasonic, oxicide and ozone treatment methods were tested in the University of Newcastle in June 2002 by a group of scientists all over the Europe. The general objectives and the test principles of this test phase have been discussed, too.

1 Introduction
MARTOB is an acronym for an EU project entitled On Board Treatment of Ballast Water (Technologies Development and Applications) and Application of Low-Sulphur Marine Fuel. The main objectives of the project are to investigate methodologies and technologies for preventing the introduction of non-indigenous species through ships' ballast water. In addition to the Ballast Water treatment issues also the low sulphur fuels are studied in terms of assessment of the financial, technical and operational effects of a sulphur cap on marine bunker fuel in European waters.

Author's biography
Mr. Jorma Rytkönen is a group manager of the VTT Industrial Systems, Espoo, Finland. He has more than 18 years background in maritime and port engineering field. He is in charge of VTT's maritime operations and environment related research. He has also been a lecturer in the Helsinki University of Technology more than 10 years in the professorships of Hydraulics and Arctic Engineering.

The objectives for the MARTOB's laboratory testing phase were the design and development of the proposed treatment methods in laboratory scale and with computer simulation, the assessment of environmental, biological, economical, risk and safety aspects and the evaluation of subsequent long-term effect of the individual methods on the marine ecosystems.

The test trials of the proposed ballast water treatments included in the project were held at Newcastle University in early June, 2002, including the following technologies: high temperature heat treatment (University of Newcastle as the task leader), oxicide treatment (TNO of the Netherlands), ultraviolet, ultrasound and ozone methods (VTT of Finland), de-oxygenation (SINTEF of Norway), Advanced Oxidation Method (BenRad of Sweden) and combinations of the above technologies as the hurdle technology (BERSON of Netherlands). Before the Newcastle trials, various partners carried out preliminary test trials.

This paper gives a brief information on the various technologies tested in the laboratory phase. Some of the technologies presented here, have been described more detailed in the ENSUS Conference proceedings, and referred in the chapter 11.

2 Brief description of the test protocoll

As part of the search to find the best technique to treat ballast water, the MARTOB laboratory-scale trials were carried out from the 6^{th} to the 14^{th} June 2002. For reasons of logistics and consistency, all the devices were tested in the same location, in the facilities of the University of Newcastle.

The general objectives of the laboratory test phase were the following:

- to design and develop the proposed treatment methods in laboratory scale and with computer simulation,
- assessment of environmental, biological, economical, risk and safety aspects,
- evaluation of subsequent long-term effect of the individual methods on the marine eco-systems.

The treatments tested included: de-oxigenation, high temperature thermal treatment, oxicide, advanced oxidation (combination of ozone, UV and catalysts), ozone, ultrasounds (US), UV, as well as a hurdle methodology (different combinations of the above). The standard test protocol was applied in order to have a comparative and reliable assessment of the biological effectiveness of the different treatments. The test protocol for laboratory tests has been defined more detailed in (Quilez-Badia et al, 2002)

Standard seawater was prepared for all tests 24 hours before use. Deionised water (supplier) was added to Tropic Marine salt (35g/l) (Aquatics Unlimited, Bridgewater, Wales) in 4 mesocosms of 250 or 450l. Following the addition of water, the mixture was agitated continuously for 24h using compressed air to ensure that all the salt had dissolved. Salinity was checked using a refractometer (Bellingham & Stanley, Tunbridge Wells, Kent, UK).

Cultures were supplied in bulk, zooplankton every 2 days and phytoplankton every 5 days (apart from the 9^{th} and 10^{th} June, when *Acartia* was not available) They were stored in CT rooms in the aquarium suite at the Ridley Building, University of Newcastle, at 10 and 15°C respectively.

Information on supplied plankton density was available from the suppliers. Samples were measured out directly from the cultures, each species being stored in a separate bottle. The organisms were mixed with 70l of seawater that had been pumped into a tank, to create a sample of test organisms, the 'soup' (Table I). After pouring the samples into the prepared seawater the bottles used to carry them were rinsed twice in the same water and added to the mixture.

Table 1. Plankton species used in soup sample, showing numbers used per 70l sample and the amount of water added with each species.

Plankton	No/70l	Vol. of sample
1. *Nereis virens*	80	40ml
2.*Acartia tonsa*	200	350ml
3.*Tisbe battagliai*	80	50ml
4.*Alexandrium tamarense*	**10 x 10?**	**60ml?**
5. *Thalassiosira pseudonana*	**10 x 10?**	**60ml?**

(? preliminary - to be specified later)

Prior to pumping the soup into test rigs the mixture was gently agitated to ensure a homogeneous mixture. Following pumping to the test rigs the tank was rinsed with clean seawater to ensure removal of any residual organisms.

Before initiating the treatments, a 10l initial sample was collected from each test rig for laboratory analysis. Treatments were carried out and on completion a 50l sample was taken for analysis.

A control tank containing one sample was set up and left at room temperature. Sub-samples were taken at intervals to monitor background mortality. Three replicates were made during three consecutive days (12-14th June)

3 High temperature system design

Design of a thermal treatment system was conduced by the University of Newcastle (UNEW) The design objective was to integrate a two stage heating system (pre-heating and high temperature heating systems) with existing ballast and cooling systems.

Along with the system design, the temperature tolerance of different marine organisms will be studied under laboratory conditions, in order to produce a treatment protocol for targeted species. This will provide a scientific and technical guide for treatment temperatures to be used for different organisms and bacteria from different geographical regions.

A range of ballast water management guidelines and regulatory practices have been introduced by various countries in an attempt to minimise the risk of non-indigenous marine organisms being transported around the world in ballast water. Thermal treatment of ballast water is one of the many options that are receiving considerable research attention around the world. Since 1994, various organisations have conducted studies on the effectiveness of thermal treatment to kill unwanted organisms in ballast water. More detailed description of the system and the test results are given in (Vourdachas & Meshabi, 2002). Figure 1 gives a general principle of the thermal treatment method.

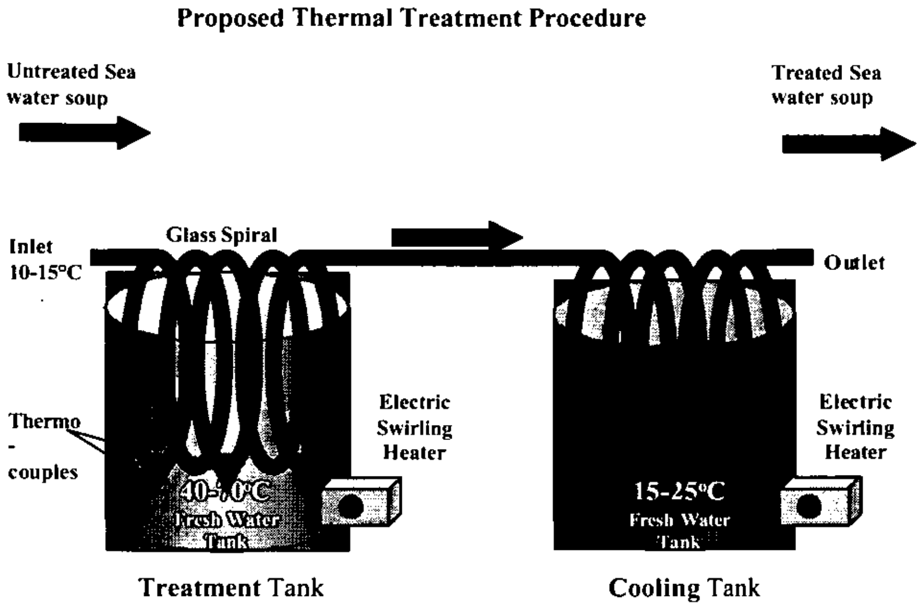

Figure 1. The general principle of UNEW's thermal treatment design.

4. Biological de-oxygenation

The de-oxygenation technique is based on the theory that addition of nutrients to ballast water will lead to a rapid bacterial growth that will consume the oxygen in the water. The resulting anoxic conditions will kill most higher organisms.

De-oxygenation studies was performed by the Norwegian Sintef using small reactors with temperature control, in the laboratory. Ballast water (4-6 different types) collected from ballast tanks of ships will be used. A nutrient solution suitable for addition to ballast water has already been devised, but further improvement may be possible. During the de-oxygenation process, dissolved oxygen, pH, concentration of aerobic, anaerobic and sulphate reducing bacteria was followed. Chemical analyses (primarily organic acids and sulphide) were also performed.

The effect of temperature on the process rate was examined. Repeatedly filling, treating, and emptying a reactor over a certain period will assess the effect of the treatment on corrosion and biofilm formation. The treated reactor will be compared with a non-treated reference. The effect of de-oxygenation on the survival of microalgae believed to be one of the more resistant groups of organisms, will be studied. This task will be performed in considering requirements of sea trials. Detailed description of the project is shown in (Josefsen & Marjussen, 2002).

5 UV/US treatment

A UV/US pilot unit consisting of both U/V source and U/S transducer was tested under laboratory conditions. Both units were based on the built in a chamber-techniques, which allows an optimum flow rate to guarantee the best possible U/V unit combined with an effective cavitation created by a high power U/S transducer. An optimised pilot model was designed to guarantee the most suitable U/V-light source and U/S-transducer with best possible power and frequency. The Dutch Company Berson provided the UV system. Ultrasound system was made of the Finnish Acomarin LtD. The test programme of both UV/US treatment system was performed by the VTT Industrial Systems of Finland.

Both technologies were tested first as single technology (US and UV) in order to determine the operational parameters for both UV and US treatment system. The testing was carried out in two phases, both in laboratory scale. In the preliminary test phase the devises were tested in Espoo in May 2002. In the second phase the devices were tested in Newcastle among all the other treatment systems.

Figure 2. The test rig for both Ultrasound and UV treatment systems.

The UV unit was be equipped with one lamp of 40 W (effective UV output at the end of life through the quartz sleeve) with power consumption of 350 W. The lamp has an output spectrum of covering 200 - 400 nm but not every wavelength is effective. Hence the Meulemans curve will be applied for germicidal effectiveness. The UV-device was able to handle 200 - 1.000 l/hour. The main effort in construction of the US device was focussed on the design of the transducer in order to achieve the best possible inactivation of the target organisms. Also the flow rates of US and UV were designed at the same level for good operational performance of the combination.

The aim of the first phase was to establish the operational parameters (among other flow rates, intensity of UV lamps, frequencies and power to the US transducer, possibly health and safety aspects) to the tests in the second phase (University of Newcastle, UK). In the first testing phase the test water was tap water added with salt, *Artemia salina* and algae.

The objective of the both testing phases was to determine the operational requirements for UV and US devises, compare the systems with the other systems/technologies that will be evaluated in the joint laboratory trial and provide data for definition of full scale test trials.

6 Ozone method

The technology for water disinfection with ozone in potable water, waste water treatment and food industry has been well established. The testing device consists of air treatment system, adsorber drier, ozone generator, ozone generator electronic controller, electronic control of the power supply for the ozone generator, mixing system and required safety equipment.

The test device manufactured by the Prominent Finland had the maximum ozone dosage of 5 g/h and the maximum flow rateof 5 m^3/h. The water basin for the treated water was be equipped with activated carbon filter in order to avoid the access of residual ozone to the working premises. The test rig used for both the preliminary and joint test phases is shown in Figure 3.

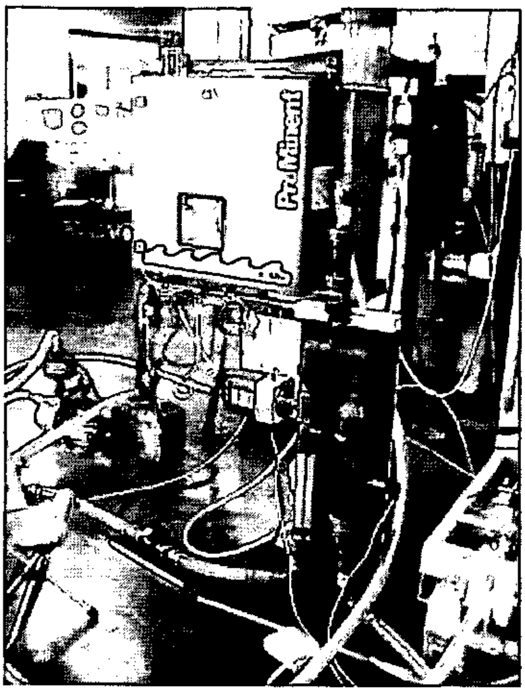

Figure 3. The ozone test device.

The aim of the first test phase was to establish the operational parameters (among other flow rates, required O_3 dosage, possibly health and safety aspects) to the tests in the second phase (University of Newcastle, UK). In the first testing phase the test water will be tap water added with salt, *Artemia salina* and algae. The responsible research organisation to test the ozone treatment system was the Finnish VTT Industrial Systems (Sassi, et al, 2002).

7 Oxicide method (electrochemical treatment)

A small electrochemical reactor was build and operated by the Dutch TNO. The effects of the treatment on various, relatively insensitive organisms were assessed, because currently little is known about the effects on marine organisms. The reactor and process conditions were adjusted during the experiments (oxygen pressure, form of electrode, anolyte use). Results from the laboratory work will be evaluated based on the biocidal efficiency, electrical efficiency, pressure drop, capacity and economics. It has to be decided whether treatment of a side stream is possible or the best approach.

Organisms are destroyed when exposed to a highly oxidative environment, and this treatment is frequently used when water streams or surfaces need to be disinfected. Well known oxidants are hypochlorite and chlorine. However, these compounds produce disinfection by-products (chlorine-containing compounds, e.g. trihalomethanes) and may be unacceptable for onboard treatment of ballast water because of safety concerns and adverse environmental effects. Figure 4 gives a view over the TNO's laboratory test system at University of Newcastle.

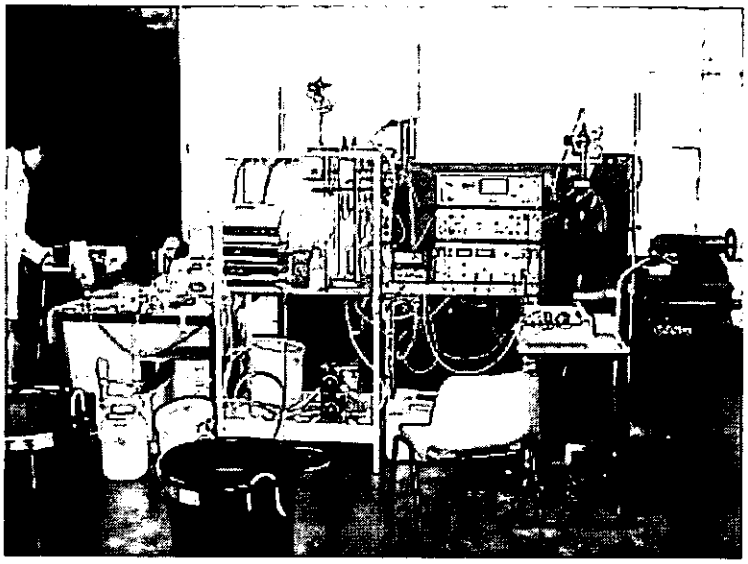

Figure 4. TNO's test system for oxicide method.

8 Hurdle technologies

The term hurdle technology is used in food industry for a strategy to prevent microbial decay of products. In hurdle technology, a combination of two (or more) chemical or physical methods is used to reduce the number of viable cells and/or reduce the likelihood of growth. This increases the probability of sufficient shelf life of food. An important example is the use of thermal treatment and preservatives.

Combining technologies can eliminate the limitations of individual techniques as well as taking advantage of the synergy between them. Without doubt, the same will be valid for ballast water treatment. For instance, large organisms may proof to be relatively insensible to a certain treatment method (e.g. chemical treatment), but can be removed by other means (e.g. filtration); this approach avoids excessive treatment with the first method.

To test the synergetic effect of combinations of techniques as described in before: mechanical separation with UV+US, UV with oxicide (e.g. H_2O_2) and thermal treatment and de-oxygenation. Specific process conditions were selected in tests in Newcastle. The objective was to determine the operational requirements for combinations of techniques. The combinations can be compared with the other systems/technologies that will be evaluated in the laboratory test phase and provide data for definition of full-scale test trials. This test phase was run by the Dutch Berson in co-operation of other task members.

9 Oxidation method

The Swedish BenRad equipment tested during the laboratory trials is based on an Advanced Oxidation Technology (AOT) consisting of a combination of ozone (O_3), two UV systems with different wavelength spectra and two different catalysts. Thus Ozonolytic / Photolytic / Photocatalytic Redox Processes are operating simultaneously within a reactor. The unique combination is designed to generate large amounts of radicals, mainly hydroxyl radicals, within the reactor. It is these radicals that destruct / eliminate the microorganisms and make the process hundred or even thousand times more effective than conventional technologies. The maximum flow for the testing device is 1,8 m^3/h.

This water purifier has successfully been used in land-based applications such as purifying of swimming pool water, drinking water, water used for irrigation in green houses and water used in fish breedings. The test device is shown in Figure 5.

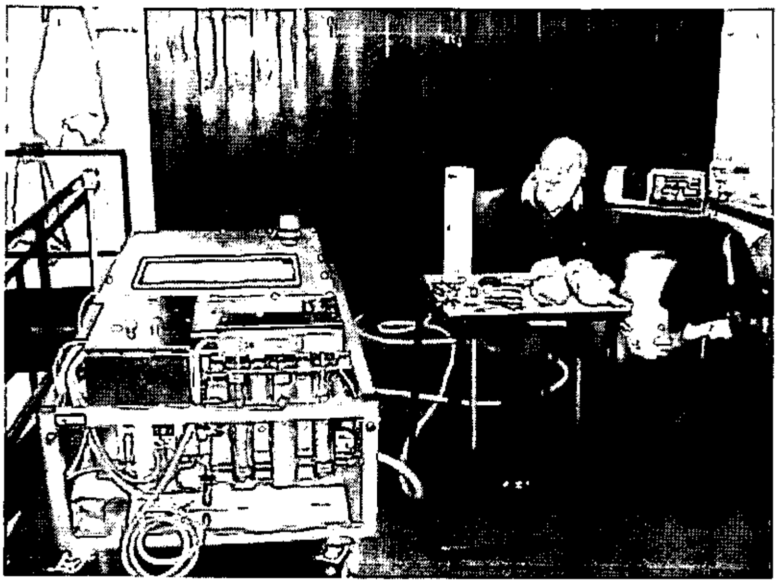

Figure 5. The Benrad's test rig.

10.. Conclusions

The laboratory test phase conducted at the University of Newcastle in June 2002 gave a valuable information on the development of the onboard ballast water treatment options. The joint test procedure ensured the reliable comparison of the test systems.

The systems tested, however, represent rather small treatment capacities, thus larger tests in realistic environmental conditons are needed to ensure the main findings and observations conducted during the laboratory test phase.

The tests described here have been used as a basic research material when designing the next research efforts of the MARTOB research project. The next step will be the full scale testing phase where the selected devices will be tested onboard a ship or installed onshore with a real seawater and the natural organisms. The full-scale tests have been scheduled to be carried out in 2003, and the updated results of the treatment options should be ready for reporting in the beginning of 2004.

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Design and Effectiveness of a high temperature thermal treatment for ballast water

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SYNOPSIS

The use of ballast water as a vector for translocation of marine species has led to the need for an onboard treatment system, which can kill these organisms cheaply and with the least impact on the environment. The objective of this paper is to present the state of the art high temperature thermal treatment system, to compare it to the existing low temperature thermal treatment systems and to present the steps undertaken in the design process of the high temperature system. The effects of temperature on zooplankton and phytoplankton are presented, followed by the laboratory scale design and testing and the full size design. The paper finishes with a look at corrosion problems and operational considerations.

INTRODUCTION

Although non-indigenous species have been introduced to foreign environments ever since ships have travelled the seas, it has only come to attention as a problem recently. This is mainly due to some high profile cases where the imported species have caused a great deal of damage to the local ecosystem and the local economies. The slipper limpet and the oyster drill, introduced from the US have had an adverse on UK oyster fisheries. *Caulerpa Taxifolia* seaweed introduced to the Mediterranean in the mid 80's has taken over from native weeds, and has reduced the habitat of larval fish and invertebrates. The recent increase in the number of imported foreign organisms is mainly caused by the very large amounts of ballast water being shipped (in the order of 10,000 million tonnes a year) and the change in shipping practices, with ships under ballast for the return trip. This means that after discharging their cargo at their destination, they load up with ballast water (and local organisms) for stability and efficiency reasons, and sail back home, discharging the ballast (and organisms) when they pick up the new cargo. The only current method used and recommended by the IMO to combat this problem is deep-water ballast exchange, where the vessel discharges its ballast when in deep water and re-ballasts. This works on the principle that coastal water is rich in nutrients and thus has a higher density of organisms than mid-ocean deep-water. Thus discharging the coastal organisms in deep-water should kill them and a smaller number of organisms should be picked up when re-ballasting, which would probably not survive the coastal conditions ofthe home waters.

The major drawback of deballasting is the fact that it is time consuming and that the vessel will be spend some time in an un-ballasted (or not optimally ballasted) state. This may have adverse effects on the stability and could possibly cause some stresses due to the uneven loads (localised sagging or hogging) and means this technique can only be used in good weather conditions, which severely limits it.
Methods that have been assessed on board vessels or on shore (large scale)[a)] and methods in the first stages of development [b)]. The following were the methods studied:
a)
Ballast water exchange
Filtration
Hydrocyclone/Cyclonic separation

b)
Biocides
Natural
Chemical
Gas super saturation
Natural air injection
Electro-ionisation
Use of fresh or treated water
Shore based treatment (probably a combination of methods)

Author's Biography

Mr. A. Vourdachas is currently a Research Associate working on the MARTOB project in the School of Marine Science and Technology of the University of Newcastle Upon Tyne, following 18 months work in a dockyard and a Master of Research in Marine Technology. Dr E. Mesbahi is a Senior Lecturer in Marine Engineering working on the MARTOB project in the School of Marine Science and Technology of the University of Newcastle Upon Tyne.

The following methods are the ones being promoted by MARTOB.
Thermal Treatment (UNEW)
De-oxygenation Treatment (SINTEF)
Ultrasonic Treatment (VTT)
Ultraviolet Treatment (EPE)
Ozonation Treatment (VTT)
Oxicide Treatment (TNO)
Hurdle Technology (BERSON)

BIOLOGICAL EFFECT OF TEMPERATURE

The following opinion is by Dionysios Raitsos-Exarchopoulos (department of Biology and Coastal Management) and Chris G. Geordiadis (Department of Agricultural and Environmental Sciences)

"All marine organisms consist of cells incorporating water in the larger extent as well as a plethora of biological macromolecules. The problems concerning this study mainly concentrate on marine organisms such as *Volox* spp., *Hydra* spp., Bell animalcules, Bryozoans, *Noctiluca* spp., Desmids, starfish larvae, *Spirogyra* spp., Diatoms and *Stentor* spp. The fact is that from the biological macromolecules the vast majority is of proteinic nature. The target temperature of 65°C for a duration of a few seconds is most certainly going to denature the proteins thus destroying the microorganisms (and all other lifeforms!). Denaturation of protein often is shown in everyday examples such as an egg boiling. Denaturation of protein is defined and described in terms of the changes, which occur in the 3 dimensional structure of the molecule. Each change in a measurable property of protein reflects a change in protein structure and is considered as denaturation (Kauzmann, 1959). Putnam (1953) indicated that solubility determination is an important quantitative method for evaluation of protein denaturation and the associative kinetics of the process. Changes in water-holding capacity and pH indicate alteration in the type and nature of intra and intermo lecular bonding in a protein system."

Although the authors above claim that all lifeforms will be destroyed by 65 C for a few seconds, this is not correct. Bacterial endospores, some fungal spores, some vegetative bacteria and some viruses will survive this treatment. However, from a practical point of view the killing efficiency is considered satisfactory.

THERMAL TREATMENT FOR BALLAST WATER

Target temperatures of anywhere from 35°C to 70°C (95°F to 158°F) have been proposed for heat treatment. But there is no consensus on how hot is hot enough. For the purpose of this presentation, low temperature treatment is defined as the treatment of ballast water at less than 45°C while high temperature treatment is above 50°C.

Low temperature thermal treatment

There have been three different low temperature thermal treatment methods tested in recent years, the Australian Quarantine and Inspection Service (AQUIS) with "M. V. Iron Whyalla", and two Cawthron Institute trials: "Union Rotoma" and "Iver Stream".
All three trials where conducted in transit around Australia and New Zealand, with treatment lasting between 30 and 80 hours.

"M. V. Iron Whyalla": During this full scale trial, heated salt water from the main engine cooling circuit (normally discharged back into the ocean) was re-routed into the test ballast water tank and allowed to overflow on to the deck via the breather pipe. The trial was able to achieve an average temperature of 38°C for the voyage during the heating trial.

"Union Rotoma": Onboard treatment of ballast was conducted by heating one of two matching after peak tanks (100m^3) connected to a circuit in which ballast water was pumped through a heat exchanger and returned to the tank. The exchanger was heated with available steam, generated from a boiler heated primarily by the ship's exhaust and backed up by an oil-fired auxiliary boiler. The trial was able to achieve a temperature of 42°C (maximum temperature attained) for 15 hour of heating.

"Iver Stream": Two trials on a chemical carrier were conducted using wing ballast tanks that had been originally designed for cargo (1500m^3) and (had?) integral stainless steel heating tubes fitted to their bases. In trial 1, heat was applied by the passage of steam through tank coils at 2.5 bar and in trial 2 at 4 bar. In trial 1, the temperature reached 34.5°C after 80 hours while trial 2 only reached 31°C after 80 hours due to a change in seawater temperature.

All three systems have got the same advantages, namely:

- Heat, which is a waste by-product of the ship's engines (heated salt water from main engine cooling circuit), is re-routed for heating ballast water, thereby saving operational costs in maintaining an effective ballast water treatment system,

- Minimal collateral damage to the environment when ballast water is discharged as no biocides or chemicals is used,

- At a designed specification, it has been proven to provide a very broad-spectrum kill of marine organisms in ballast water (>90% of original plankton killed through the flushing action of hot water),

- Heated ballast water retains a large portion of heat for an extended period after the flushing is stopped, thereby continuing the harmful effects of high temperature on any remaining organism,

- Safe operation of the ship with no unnecessary shear force and bending moments as rejected hot water (normally discharged to sea) is flushed through the tanks and remains full all the time.

They also have most of the same disadvantages and limitations:

- Unable to achieve 100% kill effectiveness of all organism/bacteria and viruses in the ballast water,

- Additional costs are incurred by the installation of the extra system,

- Appropriate pipework, heat exchangers (where present) and overflow arrangements have to be designed, approved by classification authorities, and installed in such a way that the safe operation could be ensured,

- Rate of ballast tank heating is governed by flow rate and temperature of hot water available from engine cooling circuit. These parameters would vary for different ships and hence the specific system design would vary from ship to ship,

- Different ballast tanks have different heating times due to different capacities, therefore different timings (heating duration) are required for different tanks (able to achieve a temperature of 38°C for 30 hours),

- The duration required to achieve a kill temperature of 38°C is based an initial ballast water temperature of 25°C. Longer duration of heating would be required if the initial ballast water temperature is lower.

- The treatment method is voyage dependent (not appropriate for trips involving short voyage time),

- While the temperature achieved is able to kill unwanted ballast water organisms such as *Asterias, Undaria, Dreissena* and toxic dinoflagellates, pathogenic bacteria and viruses in the ballast water are not affected by the low temperature treatment.

For low temperature thermal treatment and its requirement for long exposure times, treatment conducted in-transit makes intuitive sense, as the treatment can be conducted over the entire duration of a voyage, and would not interfere with normal ballasting and deballasting practices. Any technology for in-transit treatment must, however, be capable of producing some type of residual that will diffuse into the water relatively evenly throughout the ship. It is impossible to re-circulate all the water through a treatment plant, due to mixing and inevitable dead spots in the ballast tanks, particularly in double bottom tanks.

High Temperature thermal treatment

As elaborated earlier, high temperature thermal treatment is defined as the treatment of ballast water at above 50°C for the purpose of this presentation. High temperature thermal treatment is necessary if a short heating duration is required for the effective elimination of unwanted marine organisms, such as with short coastal trips, or with treatment at entry or exit.

Intake treatment during ballasting has considerable potential, with the advantage of treatment at source and the capacity to remove or inactivate organisms' in-line as ballast tanks are filled. Appropriate design should ensure no interference with normal ballasting operations, as ships can ballast as required during departure from port and de-ballast as required during approach to ports.
The ballast water intakes are usually situated on the bottom of the vessel or alternatively low down on the vessel's side plates. The intake consists of a large coarse grid to exclude large objects such as timber and wires. This is followed by a second screen with openings of about 10 mm, which can be removed for cleaning. This is generally done irregularly and the conditions of these screens may deteriorate significantly between inspections. This allows sediments and unwanted marine organisms to be pumped into the ballast tanks.

The other possible method for high temperature treatment is treatment at exit. This method allows us to treat the water when deballasting, before discharging it overboard. It is one of the most effective methods, as it doesn't require the water to be pumped from one tank to the other for treatment, or additional tanks to be installed, both of which can cause problems. Pumping ballast from one tank to the other can have disastrous consequences on the vessel stability and could endanger the structure by applying uneven loads. Adding additional tanks or converting cargo tanks into ballast tanks will reduce the amount of cargo that can be carried and will therefore reduce profits.
There is also no risk of cross-contamination of the treated ballast water, once treated it is discharged. A possible problem for this system is that the equipment reliability is critical as the water is not stored and there is therefore no backup, any failure and the discharged water will be full of foreign organisms.

The high temperature treatment option would be required to circumvent the voyage duration limitation, encountered by the low temperature option. In theory, exposure to high temperature treatment for a few seconds would be sufficient to cause the denaturation of all organisms in ballast water. Furthermore, it has the added advantage of either intake or in-transit or exit treatment. However, a pre-requisite for high temperature treatment option would be requirement of steam to conduct the treatment.

LABORATORY-SCALE TESTING

As there is very little data on the temperatures needed to disable plankton, it was decided to run some laboratory tests to obtain kill rate information and therefore decide on the right temperature range for the full-scale treatment system.
To ensure that the tests would represent the real world conditions experienced by the ballast water system, deionised water was mixed with the required salts in the right proportions to form "pure" seawater. Three different types of zooplankton and two types of phytoplankton were added to the water in the concentrations shown in the table below. The species were chosen as they were considered to be some of the most resilient species available and the most widely encountered in ballast water.

Table I. Standard Sea water soup

Type	*Maximum Field Densities (individuals/m^3)*	*Standard Mix Composition (individuals/m^3)*	*Standard Mix Composition for 60 l test sample*
Benthic Larvae *Nereis virens*	740	200	60
Harpacticoid copepod *Tisbe sp*	807	500	60
Calanoid copepod *Acartia sp*	159659	2500	150
Diatoms *Thallasiosira sp*	3×10^9	50×10^7	30×10^6
Dinoflagellage *Alexandrium sp*	75×10^6	4×10^7	24×10^5

The laboratory scale treatment system evolved from a simple single heater, single cooler system, following preliminary testing, when it was found that the system would not give us enough control of the temperature and that high temperatures would not be possible.
The system, which was used in the experiments, contained a pre-heater as well as the heater and cooler. The heat exchangers used glass coils immersed in insulated baths. The pre heater used an 11-spire coil and the heater a 22-spire coil, with ports to allow the use of thermocouples for temperature measurement. The insulated baths where heated using re-circulating heaters, 2 for the pre-heater and 1 for the heater. The soup was circulated through the system by gravity (using a header tank) to avoid the use of a pump, which would have a detrimental effect on the plankton and would interfere with the test, and was adjusted using a needle-valve flowmeter.
The system was then run for two weeks using tap water to obtain some initial results that could be analysed to obtain the optimum running settings for the real testing. The initial results were obtained by running the system with the pre-heater set to 10°C more than the heater, heater temperatures between 50 and 70°C and flow rates between 0.5 and 1.8 litres per minute. The plots of the results are given in appendix 3.
These tests showed the limitations of using glass coils in the heat exchangers as the thermal conductivity of glass is quite low, and the flow rates would have to be kept low to obtain the required temperatures for the proper testing, which would lengthen the tests substantially. It was then decided to investigate the performance of a copper pre-heater, with the same values as used previously, and compare it to the glass pre-heater. The plots of the results are given in appendix 3.
The final system that was used, shown in the following diagram (Fig 1.), did not use the copper coil as the pre-heater, even though it offered superior performance, as we were told that the copper would possibly poison the zooplankton.

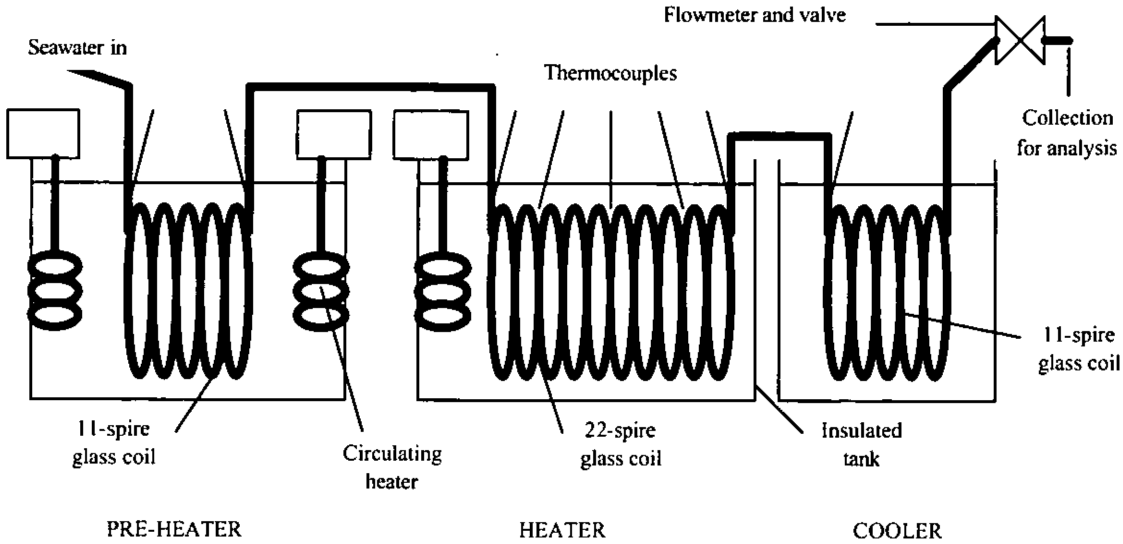

Fig 1. Laboratory scale treatment system

The tests were run over two weeks in conjunction with the other MARTOB partners to enable a fair comparison of all the methods present. Three repetitions of the same test were used to eliminate any errors and the soup was treated at temperatures going from 35 to 65°C.

The zooplankton was then filtered out and stained with a special dye, which only reacts to ATP, live plankton would therefore be stained red, and the proportions of live and dead animals could be determined. The kill-rate for each temperature was then obtained and is shown in the following graph.

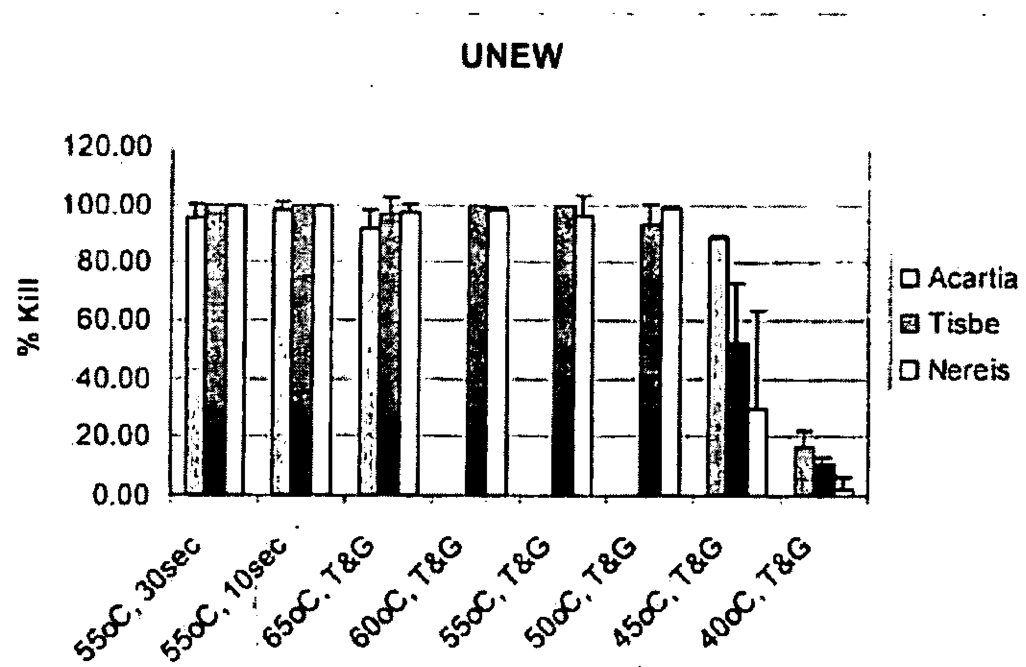

Fig 2. Heat Treatment effectiveness for 3 types of Zooplankton

As the phytoplankton was much smaller than the filter used, a 10-litre sample was collected post-filtering, for the Chlorophyll and Phaeophytin values to be determined. The values after treatment were then compared to pre-treatment values to obtain a kill-rate for each temperature, which is shown in the following graphs.

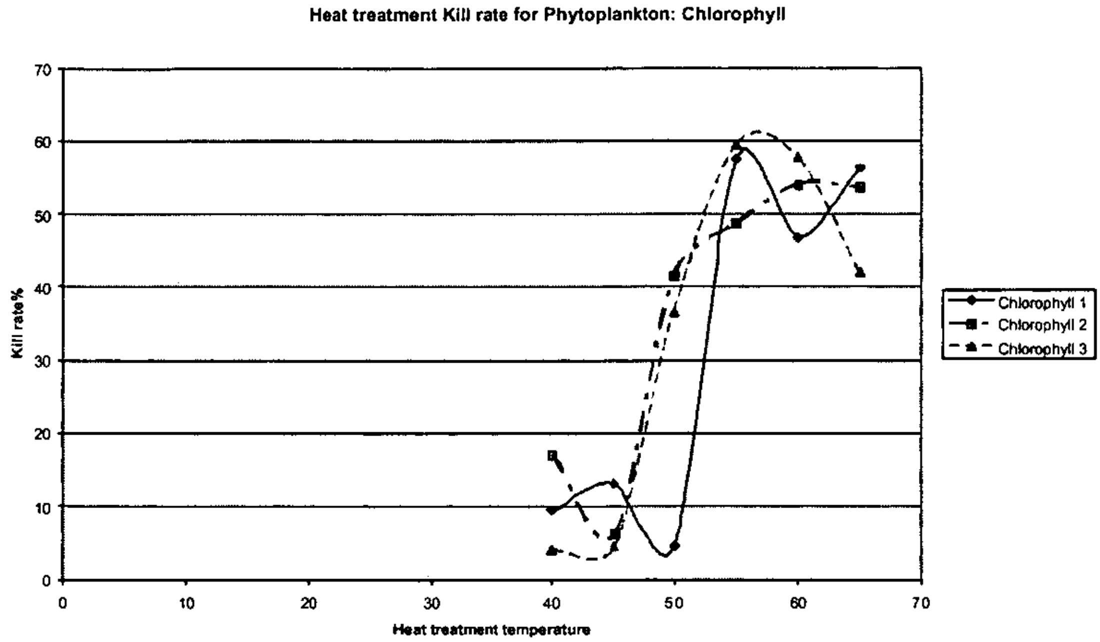

Fig 3. Heat Treatment effectiveness for Phytoplankton using Chlorophyll levels.

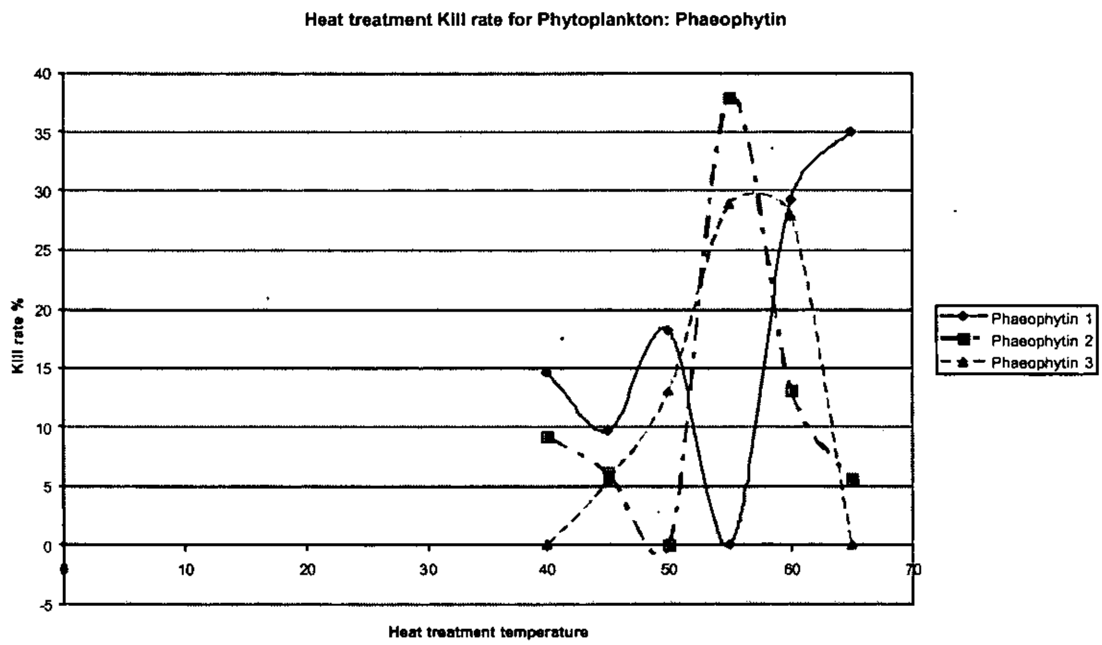

Fig 4. Heat Treatment effectiveness for Phytoplankton using Phaeophytin levels.

As can be seen from the above graphs, there is a large increase in the kill-rate around 45-50°C for all the zooplankton giving a 100% kill-rate for 50°C. Unfortunately the information obtained from the phytoplankton is not as easy to interpret with the treatment actually increasing the levels of Chlorophyll and Phaeophytin in some cases. If we combine the results by averaging them, we can place less emphasis on the erroneous results, and obtain a better result for the biological effectiveness of the heat treatment. This is represented by the following graph.

Heat treatment Kill rate for Phytoplankton

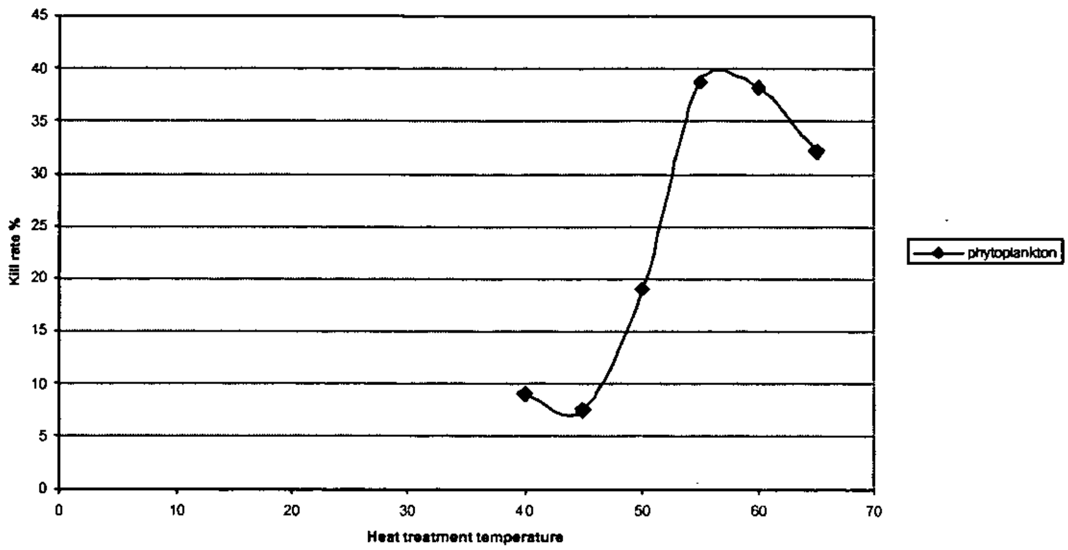

Fig 5. Heat Treatment effectiveness for Phytoplankton.

Combining this final graph to the zooplankton graph, we can now conclude that the optimum ballast water treatment temperature is 55°C.

FULL-SCALE DESIGN

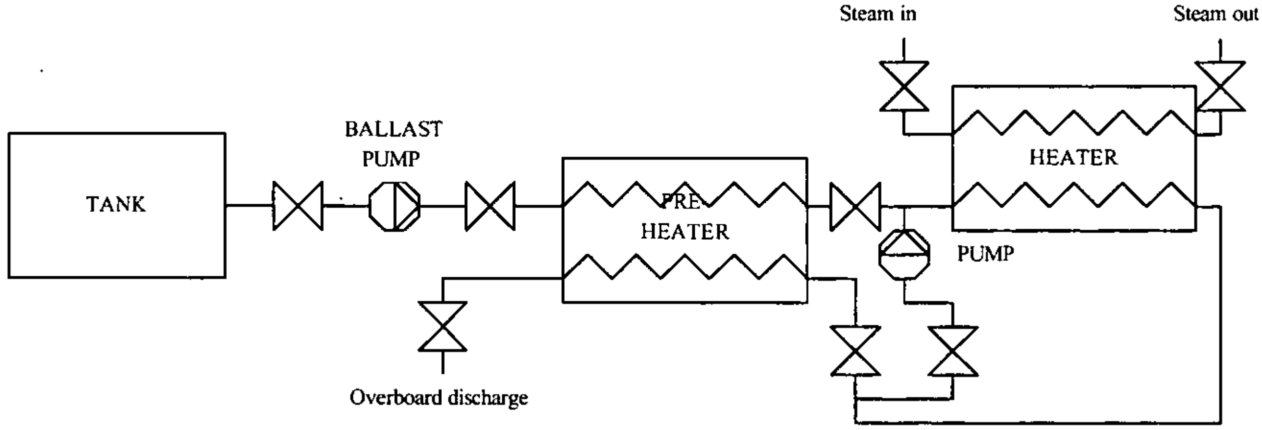

Fig 6. Schematic diagram of ballast water treatment system.

The purpose of the ballast water treatment system is to purify the ballast water and limit the translocation of non-indigenous species. This is achieved by heating the ballast water to about 55-65° C.
The average ballast capacity for a ship is 40000m³, with the ballast water at a temperature of between 15 and 20° C. To treat this water properly, its temperature has to be raised by between 45 and 50° C by a steam heat exchanger, which will require the following amount of energy:

$$energy = (mass \times c_p) \times T_{increase} = (40 \times 10^6\, kg \times 4.186) \times 50 = 8372 \times 10^6\, kJ = 8.372 \times 10^6\, MJ$$

- There are two disadvantages ofusing a single heat exchanger:
- The water after treatment is too hot to discharge.
- A single heat exchanger requires too much energy.

These problems can be remedied by using a pre-heater. This is a heat exchanger, which uses the water coming out of the steam heat exchanger (up to 65°C) to pre-heat the ballast water. This will reduce the post-treatment water temperature to a more acceptable level and allow it to be discharged overboard, but more importantly heat the water up to 40- 50°C. The water temperature will only need to be raised 15-25°C using steam, reducing the energy consumption:

$$energy = (mass \times c_p) \times T_{increase} = (40 \times 10^6\, kg \times 4.174) \times 25 = 4174 \times 10^6\, kJ = 4.174 \times 10^6\, MJ$$

Modelling & Simulation

To help design the right system, it has been proposed to define a mathematical model of the system and therefore model the heat exchangers. Following the full-scale trials, it will be possible to come back to the model and determine its accuracy.

The Pre-Heater

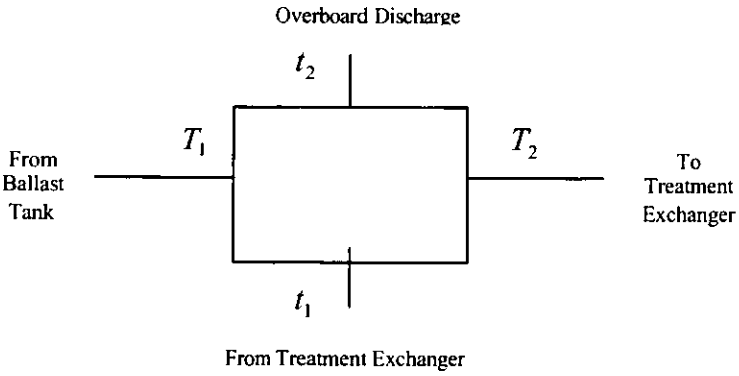

Fig 7. Simplified diagram of the pre-heater.

The effectiveness-NTU method, which was used to obtain the necessary formulae, is recommended when the inlet or outlet temperatures are to be found for a given heat exchanger (see J.P. Holman, *Heat Transfer*, 6th Ed., Mc Graw Hill). The heat exchanger effectiveness is given by the following:

$$Effectiveness = \varepsilon = \text{(actual heat transfer)/(maximum possible heat transfer)}$$

The actual heat transfer can be found from either the energy lost by the hot fluid or the energy gained by the cold fluid. Whereas the maximum possible heat transfer is obtained if a fluid was to undergo a temperature change equal to the maximum temperature difference in the heat exchanger (the difference in inlet temperatures between the cold and hot fluids). The fluid that undergoes this maximum temperature difference is the fluid with the lowest value of $\dot{m}c$.

In a general way the effectiveness is also given by the following:

$$\varepsilon = [\Delta T_{min} \text{ /Maximum temperature difference in heat exchanger]}$$

We also know that for a counterflow heat exchanger, the effectiveness is given by:

$$\varepsilon = \frac{1-\exp[-N(1-C)]}{1-C\exp[-N(1-C)]}$$

With $N = NTU = \dfrac{UA}{C_{min}}$ and $C = \dfrac{C_{min}}{C_{max}}$.

Finally $C_{min} = (\dot{m}c)_{min}$ and similarly for C_{max}

Should we already know all the temperatures, and therefore the effectiveness, the value of NTU, for a counterflow heat exchanger, can be found using the following:

$$N = \frac{1}{C-1} \times \ln\left(\frac{\varepsilon - 1}{C\varepsilon - 1}\right)$$

All these formulae are used in the mathematical model and simulation of the pre-heater.
As the specific heat of water is given in a look-up table, we also need a function to relate the tabulated results (see appendix 1).
The function obtained is as follows:

$$c = 4\times10^{-14}T^6 - 3\times10^{-11}T^5 + 1\times10^{-8}T^4 - 1\times10^{-6}T^3 + 0.0001T^2 - 0.004T + 4.2252$$

Using all the above it is now possible to elaborate a mathematical model of the pre-heater, which can be used to simulate the behaviour of a real heat exchanger. There are actually two different models; one when the characteristics of the heat exchanger (such as the area) are known and the exit temperature is the unknown. The other is used when all the temperatures are known and the area of the heat exchanger needs to be found.

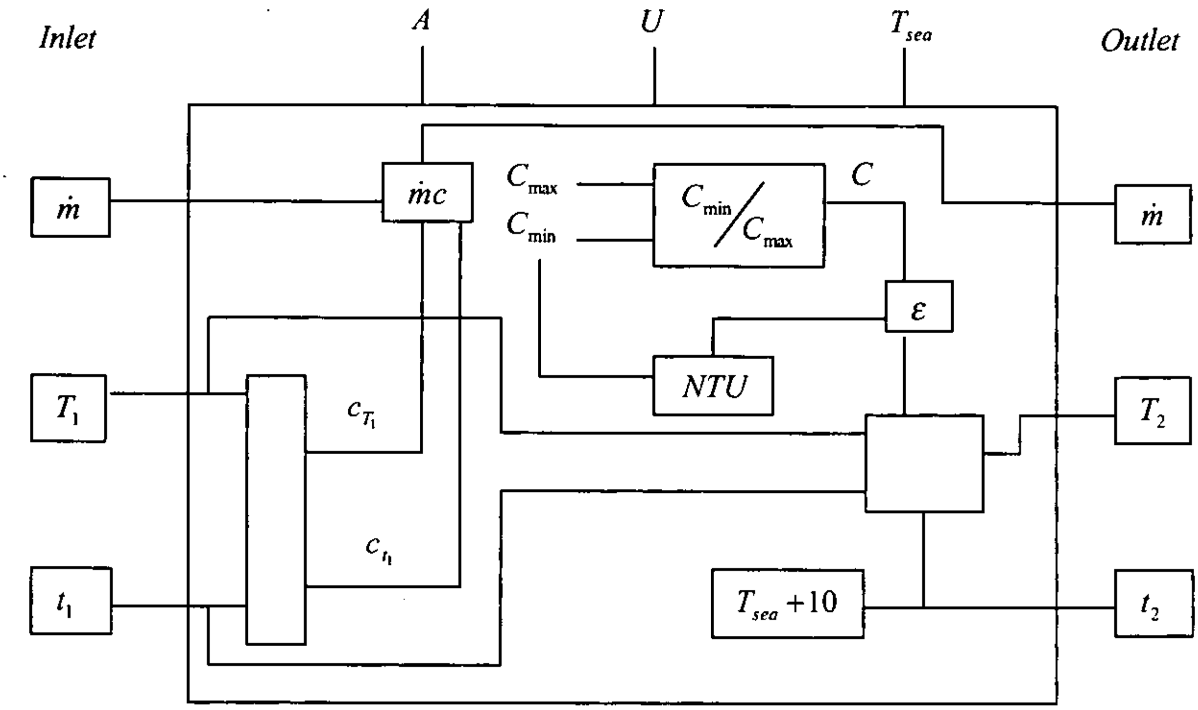

Fig 8. Block diagram of the pre-heater simulation with heat exchanger area 'A' known.

The block diagram shown above (Fig 8.) is used to obtain the exit temperature, but the area of the heat exchanger is needed. There could be a case when the exit temperature is known, such as when the amount of steam available for the treatment heater is limited and its characteristics are known. The requirement would then be to work out the optimum size of pre-heater. The following block diagram represents the model were all the temperatures are known and the area of the heat exchanger must be found.

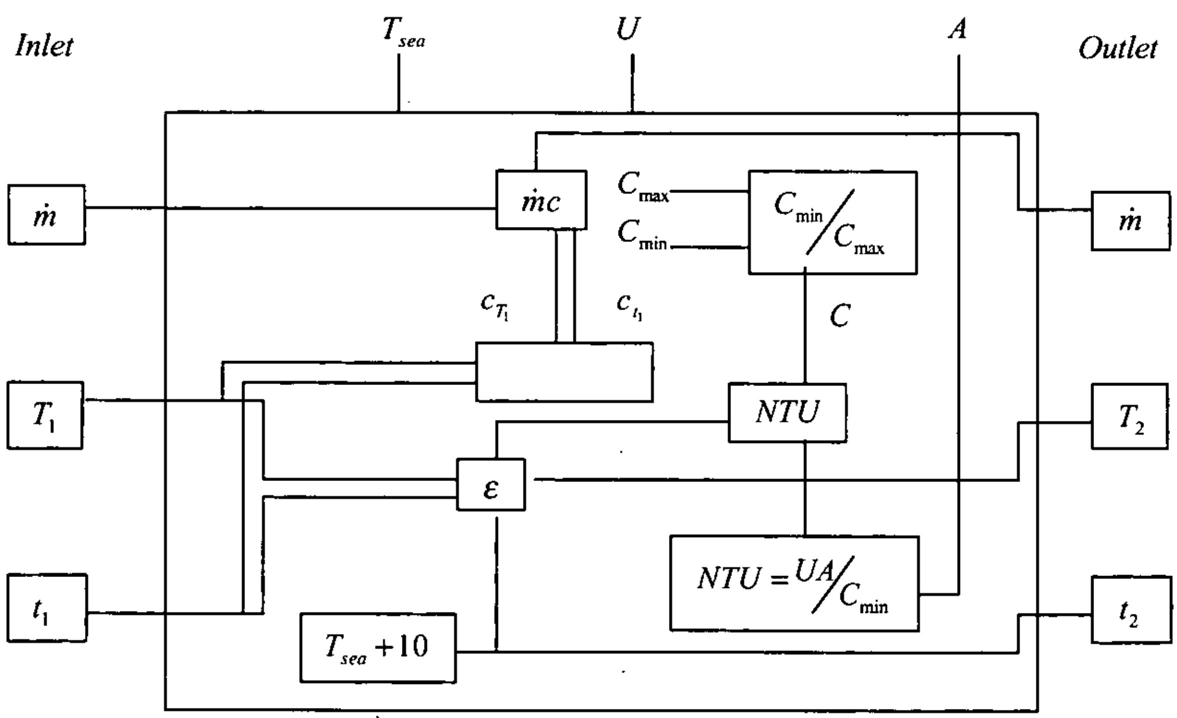

Fig 9. Block diagram of the pre-heater simulation with temperatures known and area 'A' unknown.

Treatment Exchanger (or Heater)

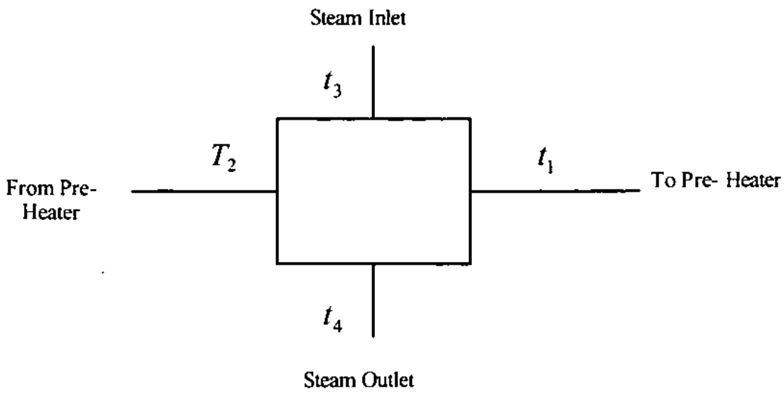

Fig 10. Simplified Schematic of the heater.

Due to the heater's position, following the pre-heater, the water inlet temperature (T_2) is known. The water outlet temperature (t_1) is equal to the treatment temperature and is therefore known as well.

The steam inlet temperature is known as well, but the outlet temperature isn't. A good way to increase efficiency and find the temperature of the steam outlet would be to use the heat exchanger as a condenser. In this case, as the steam enters the inlet as condensed steam and exits as water, the temperatures remain the same. The process for calculating the area is different and is illustrated in appendix 2.

If the steam is provided at the correct mass flow rate, the heater behaves like a condenser and the formulae from appendix 2 are used. This leads to the following block diagram:

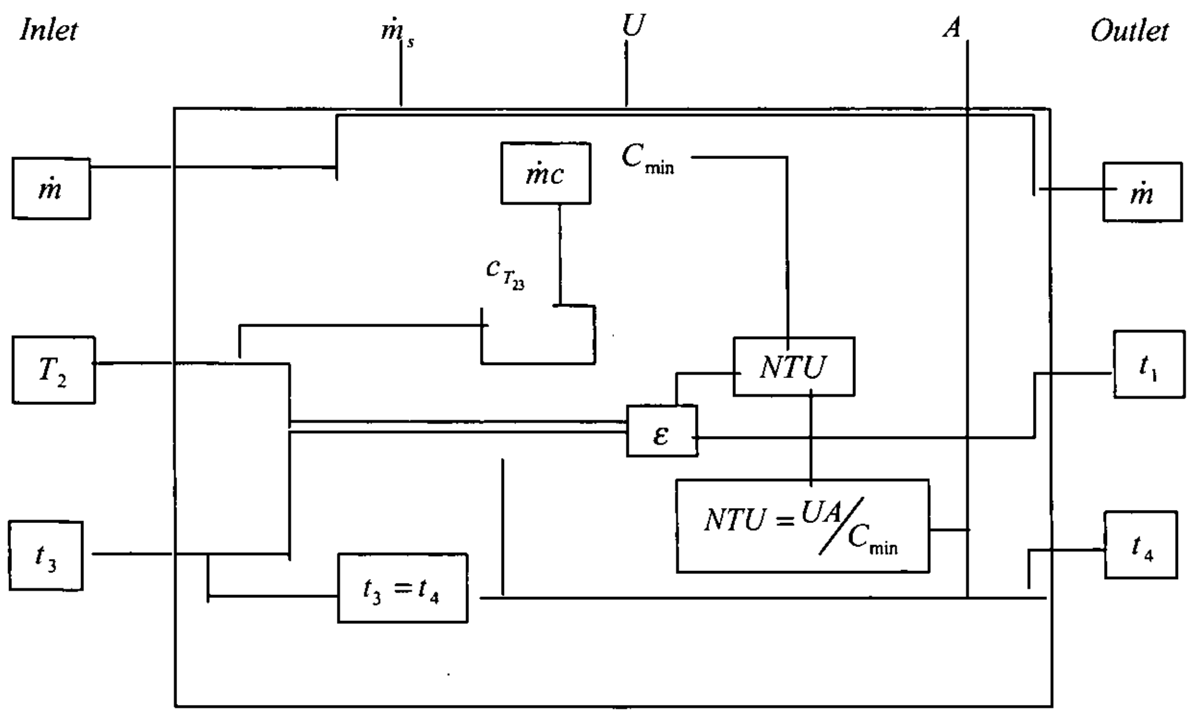

Fig 11. Block diagram of the heater simulation assuming the heater behaves like a condenser and 'A' unknown.

Full scale system

Although the design for the full-scale ballast water is not yet finalised, it will follow the following general lines:

- System with heater and pre-heater to increase efficiency.
- Plate-type Titanium treatment exchanger.
- Auxiliary boiler (165°C, 7 bar) steam used to heat the water.
- Alfa Laval filter used to keep exchangers blockage free.
- Re-circulating circuit to allow system to reach steady-state and therefore optimum treatment, before the ballast water is discharged.

There will be two onboard trials, one small scale and one full scale. The small scale trial will take place aboard a medium sized bulk-carrier with part of the ballast water branched-off to be treated. This will allow for a more manageable flow rate in the branch and therefore a smaller heat exchanger.

The full-scale test will take place on a small tanker, with the pre-heater and heater plumbed into the ballast water system. This will allow for a proper evaluation of the system and its biological effectiveness with a broad range of organisms and sea temperatures.

SOME FURTHER CONSIDERATIONS

Corrosion

The ballast water treatment system to be designed by UNEW, the heat treatment system, may have an effect on the physical and chemical properties of the ballast water. As such the effect of this treatment on the corrosivity of the ballast water must be assessed during the design.

Seawater contains around 3.5% salt and has got a pH of 8. It is a good electrolyte and can cause galvanic corrosion and crevice corrosion. Oxygen content, temperature, velocity and marine organisms affect the corrosion rate in seawater. The salt content in seawater can also have an effect on corrosion. "The 3.5% salt content of seawater produces the most corrosive chloride salt solution that can be obtained." (NACE, 1984). This due to the fact that oxygen solubility is at it's maximum with this concentration and actually diminishes with higher concentrations of salt. This is combined with high conductivity, which enhances the electro-chemical reactions in corrosion.

Following the acquisition of a cathometer, some corrosion testing was undertaken in July 2002.
The system used for these tests was based on the system used in June 2002 to test the effects of temperature on the zoo/phytoplankton, with the heating section taken almost directly from those tests (see Fig 12.). We used deionised water with three different concentrations of salt to obtain seawater with salinities of 2%NaCl, 3.5%NaCl (standard seawater) and 5%NaCl. The seawater was heated from 25°C to 55°C (and in one case 60°C) and its corrosivity measured with the cathometer in the corrosion measurement section (see Fig 13.).

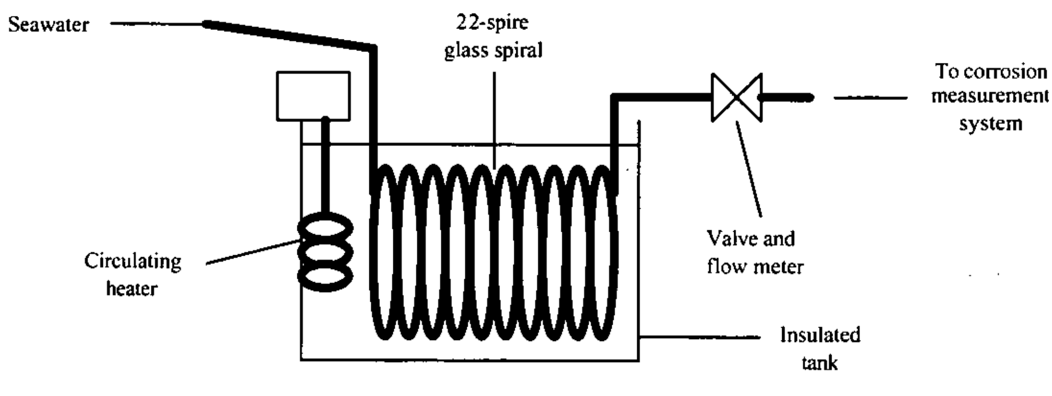

Fig 12. Corrosion testing system: Heating section.

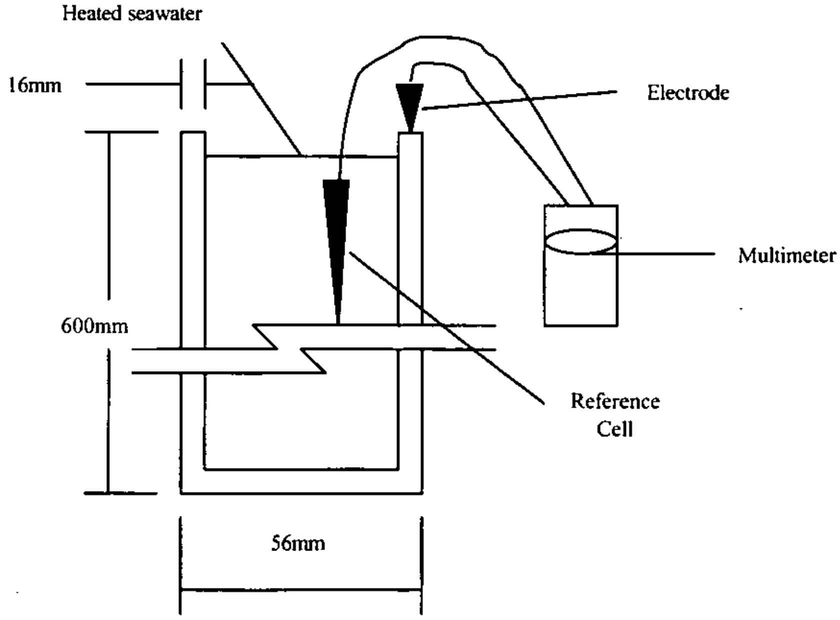

Fig 13. Corrosion testing system: Measurement section.

In order to check the corrosion level, it is necessary to measure the potential of the steelwork by attaching a standard reference cell electrically to the steelwork with a high resistance millivolt-meter in the circuit. The results in millivolts show the corrosion levels, with the higher the level, the higher the corrosion rate.
The test results are presented below, with the millivolt potential given for each temperature/concentration level:

Table II. Corrosion test results

Concentration	2% NaCl		3.5% NaCl		5% NaCl	
	Measurement		Measurement		Measurement	
Temperature	1	2	1	2	1	2
20			0.353	0.36		
25	0.433	0.448	0.455	0.454	0.427	0.444
30	0.472	0.471	0.472	0.469	0.455	0.477
35	0.483	0.489	0.48	0.487	0.481	0.49
40	0.494	0.495	0.484	0.492	0.497	0.498
45	0.502	0.509	0.497	0.5	0.5	0.506
50	0.507	0.52	0.511	0.518	0.513	0.512
55	0.521	0.524	0.521	0.525	0.513	0.513
60					0.531	0.531

As we can see from the graph, the corrosion potential increases with increasing temperature for all three concentrations.
If not looked at early enough in the design phase of a system, corrosion can cause problems during operation. These problems can range from mild discoloration, to complete catastrophic failure, with the associated monetary losses. The ballast water treatment system to be designed by UNEW is a thermal system, which may affect the corrosivity of the seawater. But the treatment is said to be "treatment at exit", meaning the treatment takes place during deballasting and will not affect the ballast tanks. The water is pumped from the ballast tank through a pre-heater, into a treatment heater then back through the pre-heater before being discharged. As the discharge temperature will only be around 5°C hotter than the temperature of the water in the tanks, the piping system after the heat exchangers should not be under any increased risk from corrosion.
Similarly, the ballast tanks and the pipe work to the heat exchangers will not be carrying any heated water and should not suffer any increased corrosion.

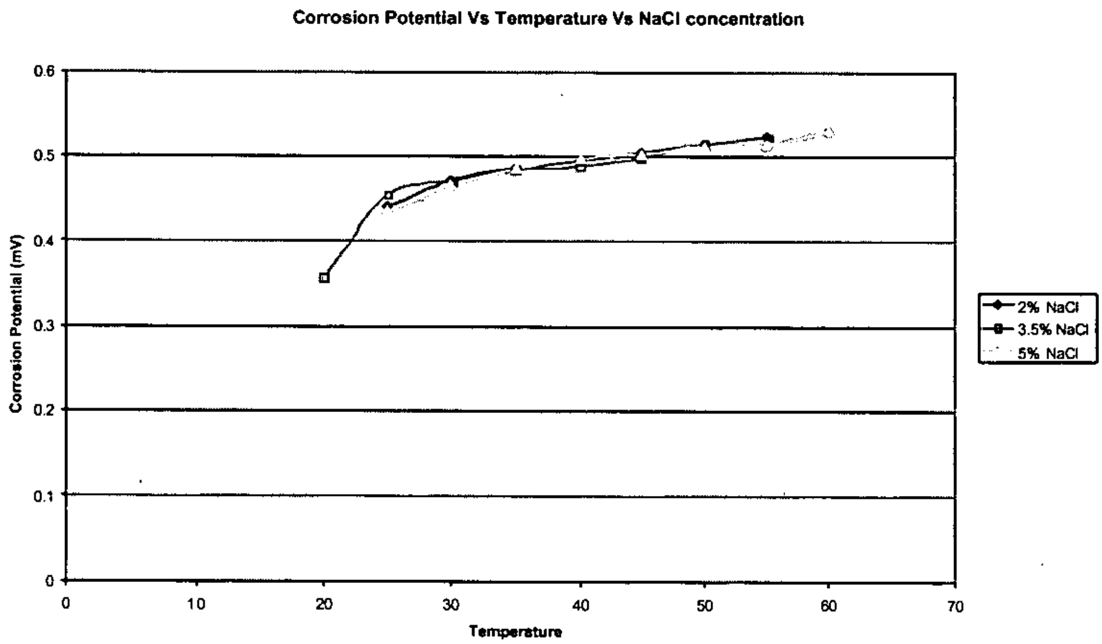

Fig 14. Corrosion Potential plotted against temperature for 3 different salt concentrations.

Any pipe work between the pre and treatment exchangers and any additional piping required to loop the water while it reaches a suitable treatment temperature, will have to deal with temperatures reaching 60°C.
As the piping is a closed system the oxygen content will not decrease and the corrosion rate may double for each 10°C increase in temperature, but the salt water will have a tendency to form a scale layer which will decrease the corrosion so a doubling of the corrosion rate for every 30°C increase in temperature seems to be more realistic. As the water velocity in

the pipe is quite high, erosion-corrosion could be a problem and crevice corrosion due to the erosion of scale layer in some parts, this will have to be monitored and/ or an erosion resistant coating will have to be used.

Finally the heat exchanger surface should not suffer from any corrosion problems as they will be made from titanium and as stated in the previous chapter, Titanium is just about impervious to corrosion in seawater. The pitting problem shouldn't manifest itself if the exchanger is well designed to minimise places where water can be oxygen starved. By using good quality control to ensure there are no defects on the metal and a good filter to stop blockages, which can cause stress on the plates, stress corrosion cracking should be kept to a minimum. Finally as Titanium is so noble, care must be taken not to set up a galvanic couple between Titanium and any other metals, which could lead to rapid deterioration.

Operational Considerations

As the treatment takes place during deballasting, quality control is paramount as any untreated water will potentially be releasing invasive species into the marine environment. There is therefore a requirement to monitor the temperature in the treatment exchanger to ensure the water is being heated to a sufficient temperature. If the treatment temperature is not being reached, the water must be re-circulated through the treatment exchanger to further treat it and help the system reach a steady-state. When this steady-state is reached, the water can then be discharged in the normal way.

A control system is therefore needed which can be linked to thermocouples in the heat exchanger module and can be used to control the valves which control the flow of water in and out of the re-circulating circuit and out of the ship. When the command to de-ballast is given, the final outlet valve (which expels the water from the hull) will be kept closed by the control system and the ballast water will be looped through the re-circulating pipe work until the preset treatment temperature is reached. When the temperature is reached and the system is in a steady state, the valves to the re-circulating pipe run will be closed and the outlet valve opened to discharge the treated ballast water. Should the temperature in the treatment exchanger drop at any point, the outlet valve would be closed and the water looped until the right temperature was reached again.

CONCLUSION

With the problem of non-indigenous species being transported by ballast water gaining more attention and the problems associated to mid-ocean ballast water exchange, different ballast water treatment systems have been investigated by various parties. Thermal treatment has been a very promising solution, with the onboard trials of the low temperature treatment systems giving good results, but being limited by the long duration required achieve the temperature and the incapacitation of the organisms. This is a problem for short voyages and for partial de-ballasting and re-ballasting when the nutrient rich treated water is mixed with new seawater.

To combat these problems, high temperature treatment at exit must be used. By using high temperatures, the organisms are killed with a much shorter duration, which allows for shorter voyages and treatment at exit. Treatment at exit allows us to treat only the water which is being discharged, which eliminates cross contamination and any increased corrosion problems in the ballast tanks.

The effects of temperature on phytoplankton and zooplankton have successfully been tested under laboratory conditions. This has allowed us to obtain a correlation between kill-rate and temperature for *Acartia*, *Nereis*, *Tisbe*, *Alexandrium* and *Thallasiosira*, five of the plankton species most commonly found in ballast water. From these tests we have been able to deduce a treatment temperature for the high temperature thermal treatment system of 55°C.

Finally from the design program presented in this paper, the heat exchangers required by the system will be sized and chosen. This will be done once the particulars of the ships and their routes on are obtained. With the proper design practices, there should be no extra corrosion problems, and the only remaining task would be to decide whether a fully automated control system would be used or if manual control is adequate.

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APPENDICES

1. Specific heat of water as a function

Before I could proceed with the mathematical model I had to transform a look up table for the specific heat of water into a function. This had to be done to allow the simulation to run smoothly without having to look up values of specific heat every time a parameter is changed. Using excel, I plotted the values of specific heat against temperature (in °C). I then found a sixth-order polynomial gave a perfect fit.

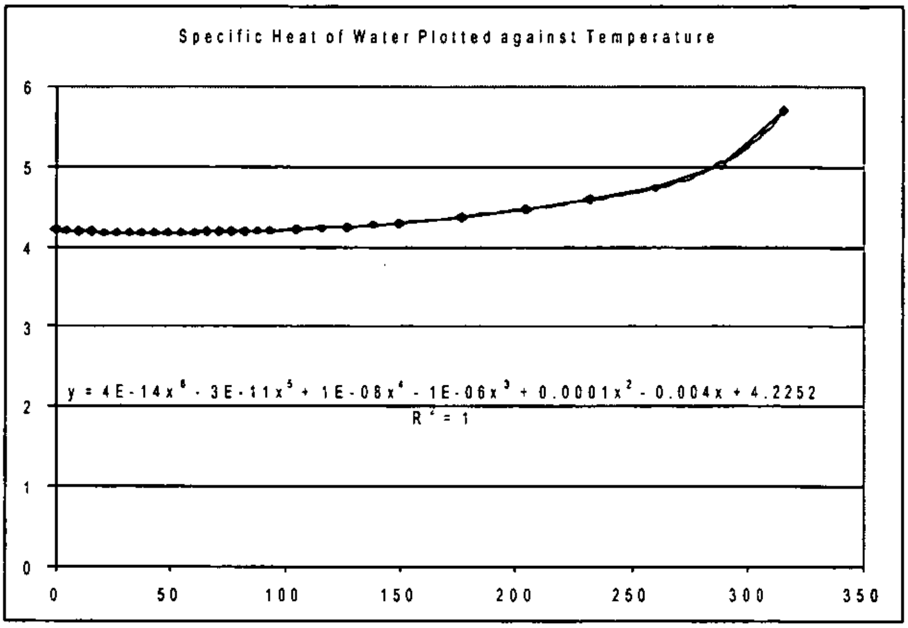


Fig 15. Specific Heat of Water plotted against Water Temperature with trend line

2. Calculating NTU for treatment heater.

Water is the minimum fluid as the specific heat of the steam is infinite due to the condensing process.

$$\varepsilon = \frac{\Delta T_w}{t_3 - T_2} = \frac{t_1 - T_2}{t_3 - T_2} = \alpha$$

For a condenser $\varepsilon = 1 - e^{-N}$

$$1 - e^{-N} = \alpha$$
$$\Leftrightarrow -e^{-N} = \alpha - 1$$
$$\Leftrightarrow -N = \ln(\alpha - 1)$$
$$\Leftrightarrow -\frac{UA}{C_{\min}} = \ln(\alpha - 1)$$
$$\Leftrightarrow A = -\frac{\ln(\alpha - 1)C_{\min}}{U} = \frac{\ln(\alpha - 1)c_w \dot{m}_w}{U}$$

For this to be true, the energy released by the steam when turning into water should be equal to the energy required by the water to be heater from T_2 to t_1.

The energy required to heat the water from T_2 to t_1 is given by the following:

$$Q_{T_2 t_1} = \dot{m}_w \Delta T_w$$

And the energy liberated by the steam during its state change is given by the following:

$$Q_{t_3 t_4} = h_{fg} \dot{m}_s$$

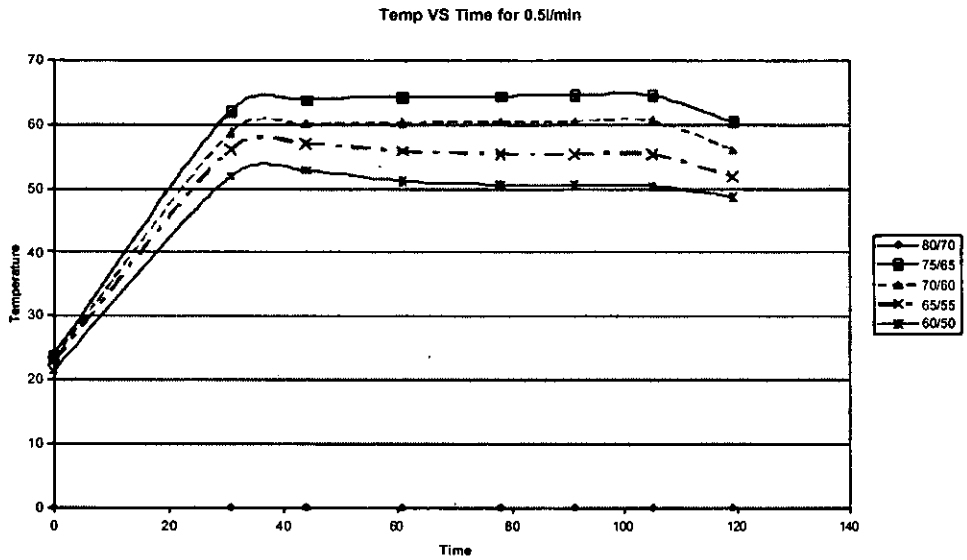
Using the energy balance, we obtain the following:

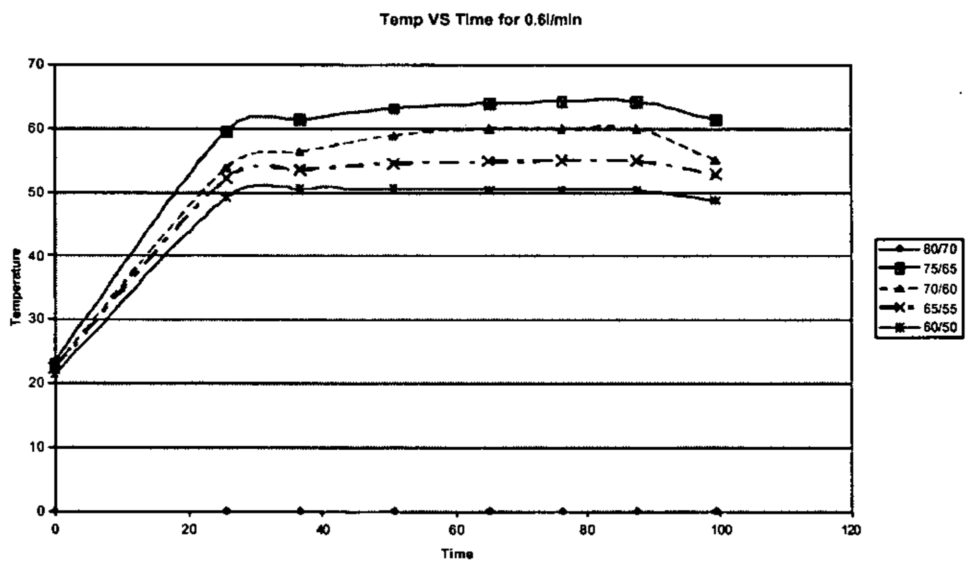
$$Q_{T_2 t_1} = Q_{t_3 t_4}$$
$$\therefore \dot{m}_w \Delta T_w = h_{fg} \dot{m}_s$$
$$\Leftrightarrow \dot{m}_s = \frac{\dot{m}_w \Delta T_w}{h_{fg}}$$

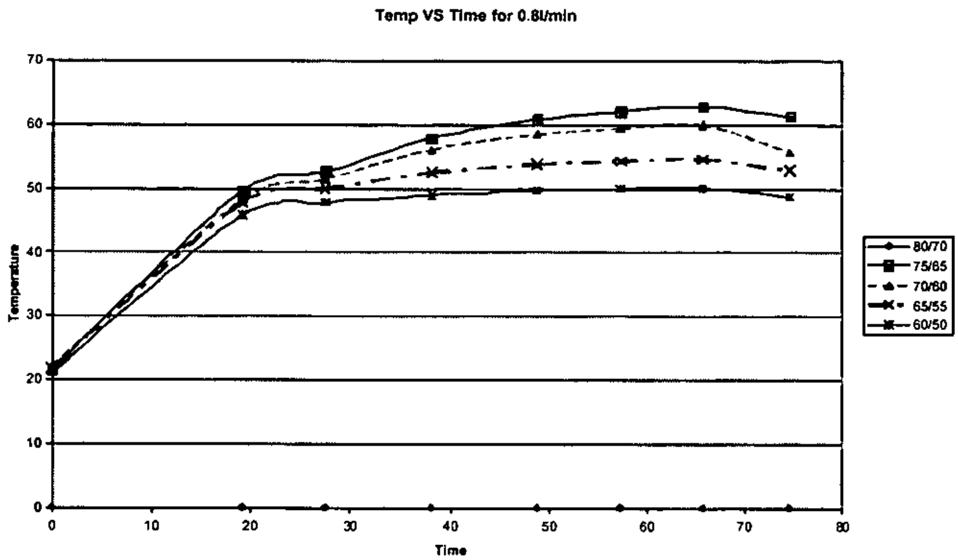
3. Time vs. Temperature plots for lab-scale heat exchanger system.

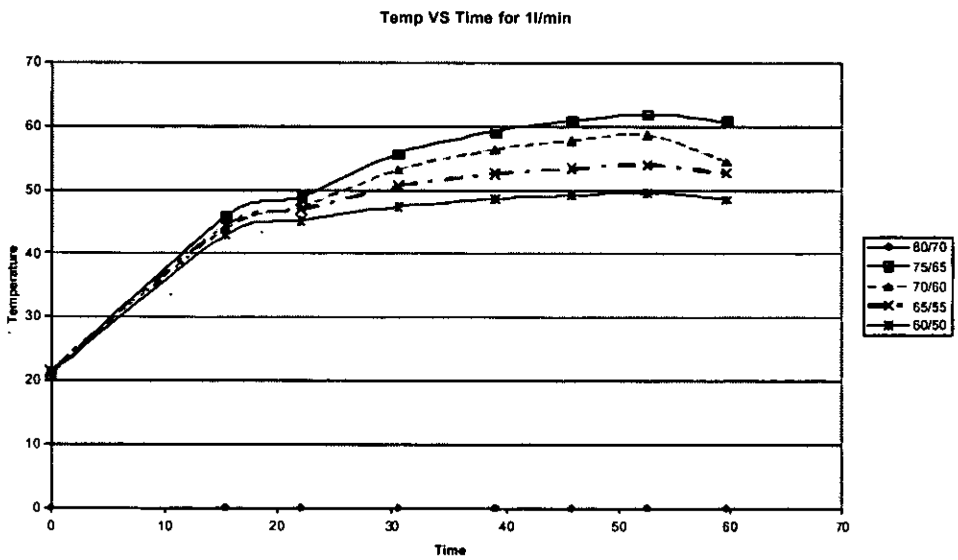
The pre-heater and heater baths are heated to Tp and Th (with Tp-Th=10°C) and fresh water is flowed through the coils and its temperature is monitored in 8 points by thermocouples. There are two thermocouples on the pre-heater, one on the inlet and one on the outlet; five on the heater, inlet, outlet and three intermediate and one thermocouple on the cooler inlet. The tests were run with five values of Tp (and therefore Th) and seven values of flow rate.
Two series of experiments were run, one with an 11-spire glass coil as a pre-heater and one with an 11-spire copper coil as a pre-heater.
The results of these experiments are summarised in the plots below.

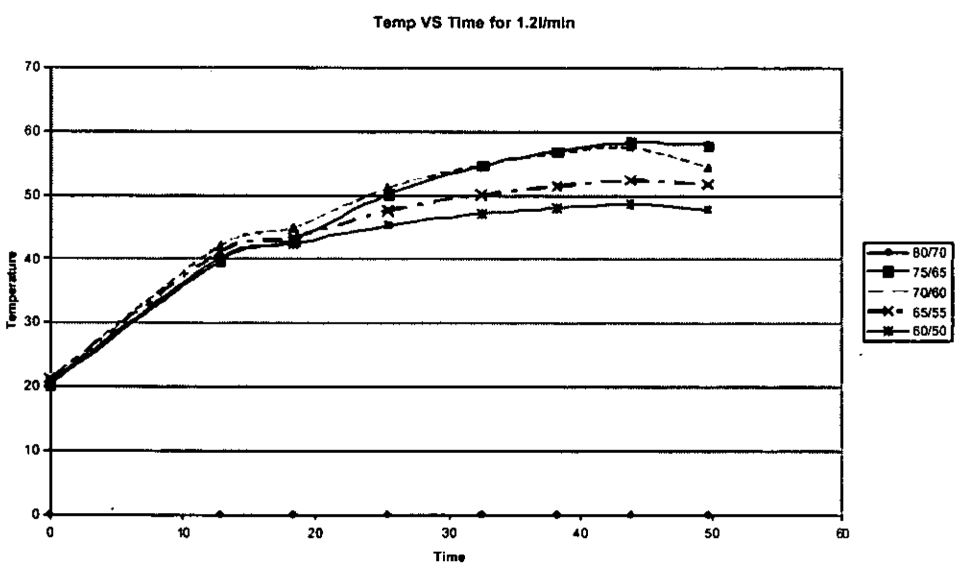
Glass Coil Heat exchanger



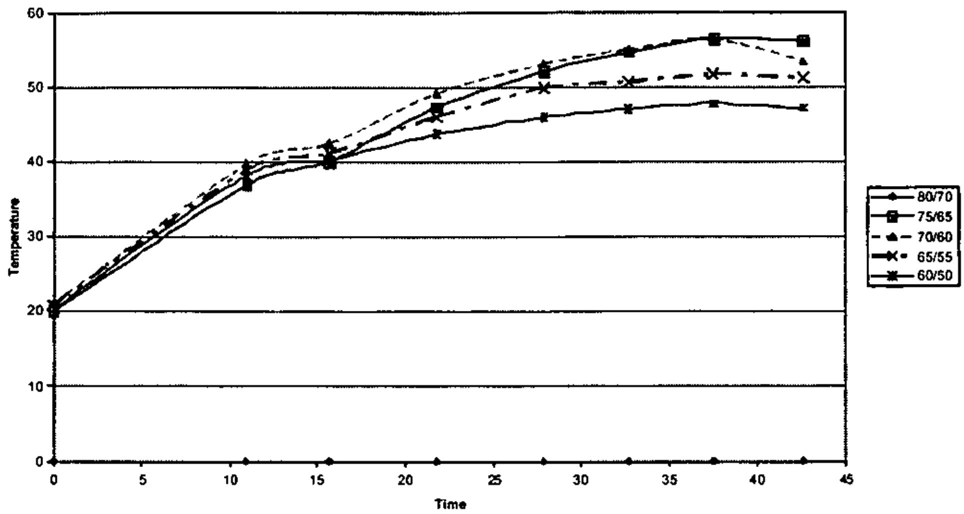



Temp VS Time for 0.8l/min
Temperature
Time
80/70
75/65
70/60
65/55
60/50

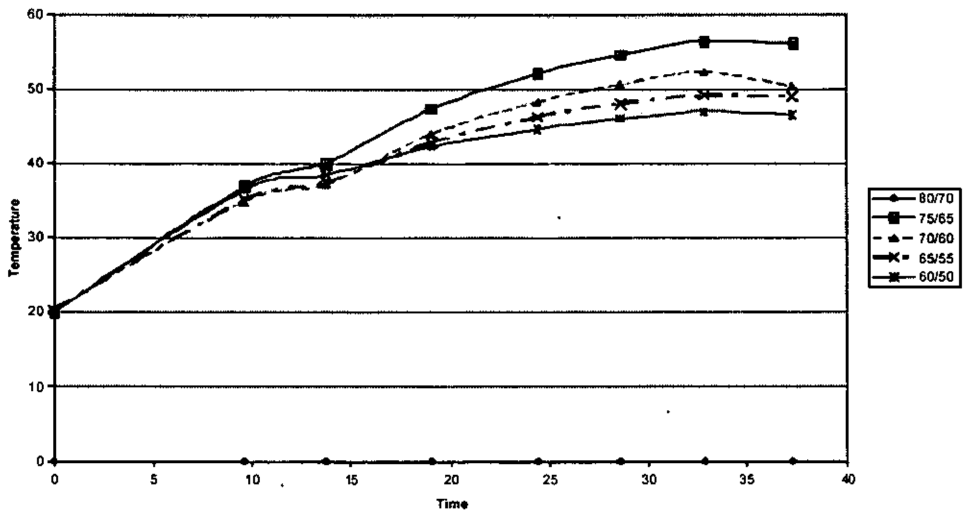

Temp VS Time for 1l/min
Temperature
Time
80/70
75/65
70/60
65/55
60/50


Temp VS Time for 1.2l/min
Temperature
Time
80/70
75/65
70/60
65/55
60/50

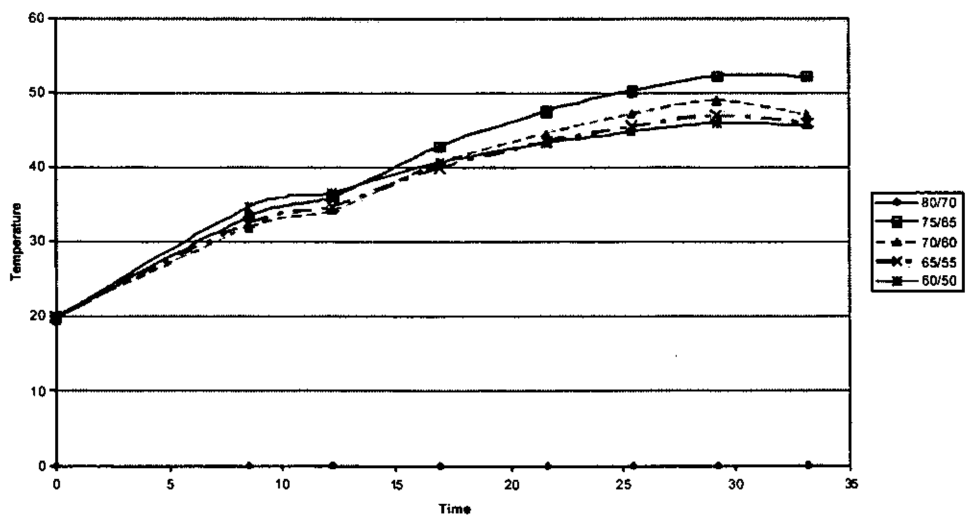
Temp VS Time for 1.4l/min



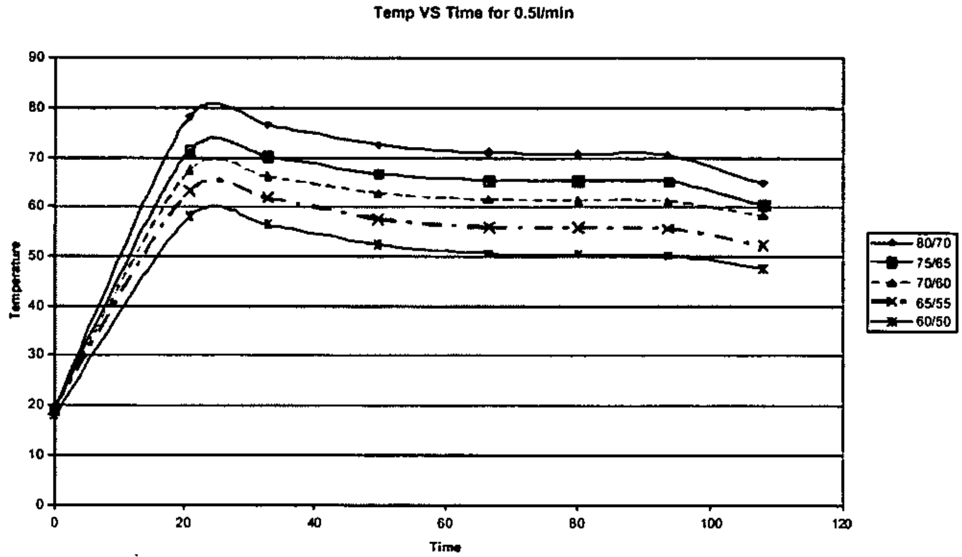
Temp VS Time for 1.6l/min

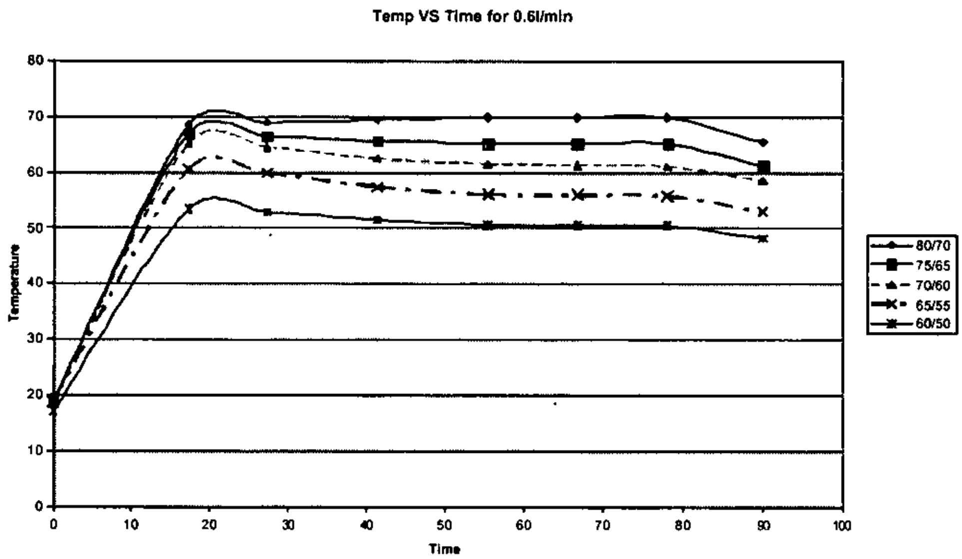


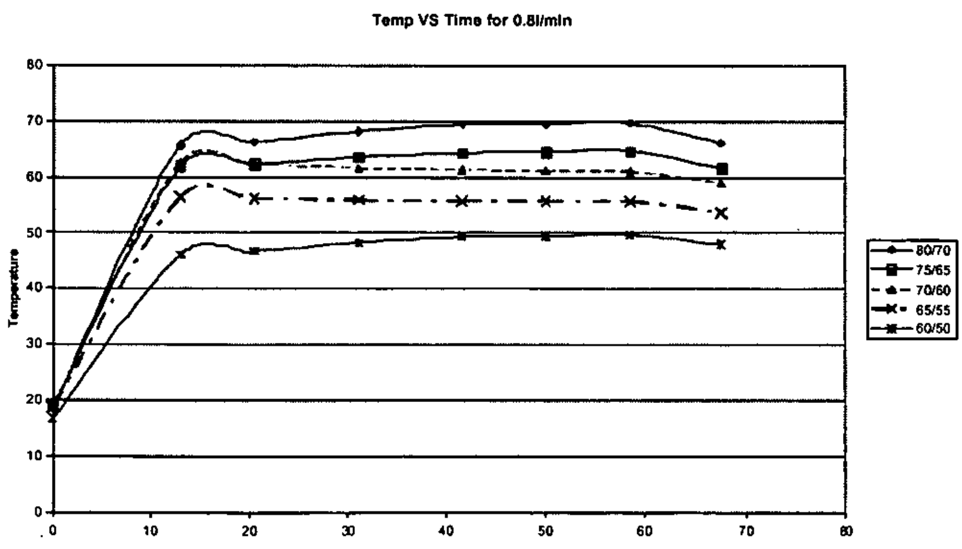
Temp VS Time for 1.8l/min



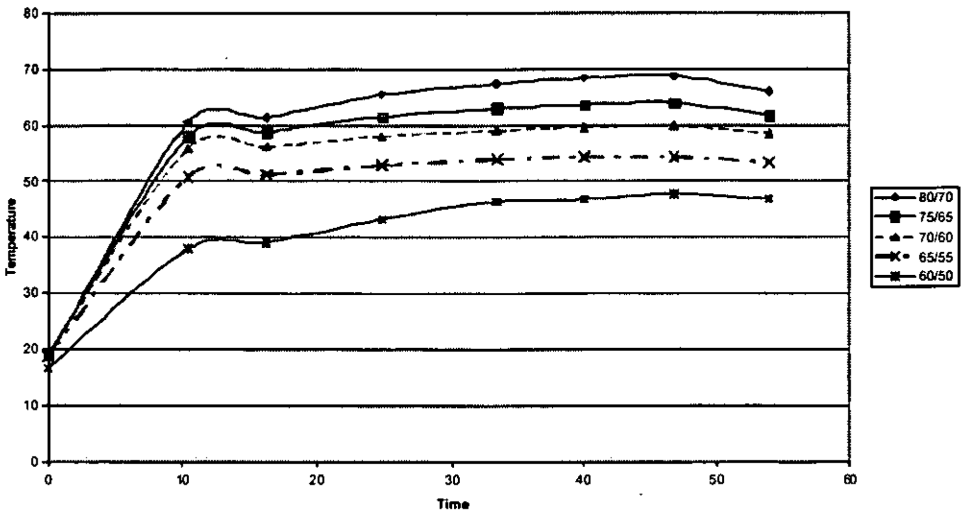
Copper Coil Heat exchanger



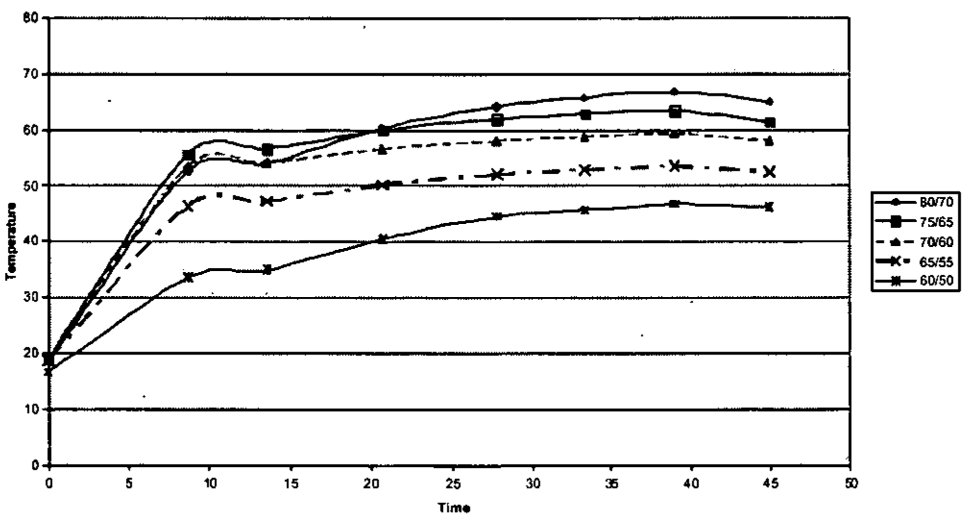




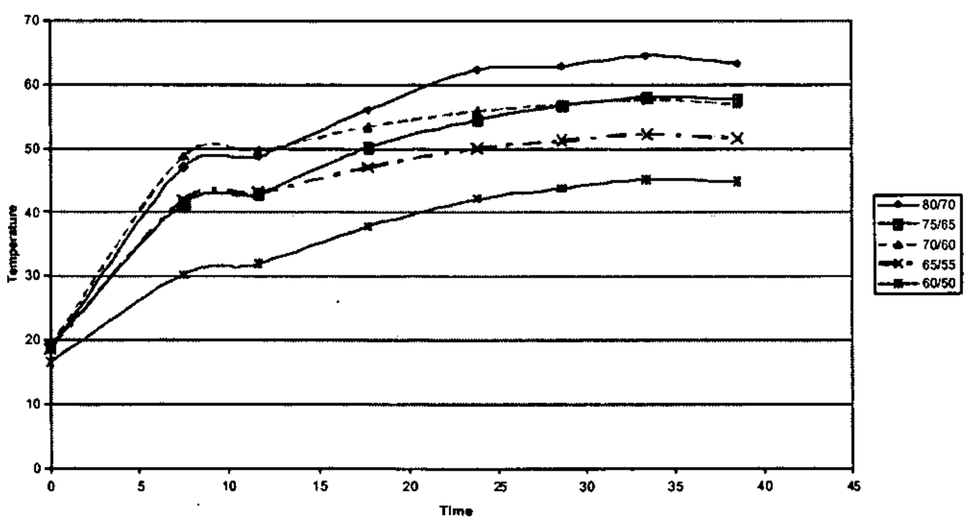
Temp VS Time for 1l/min

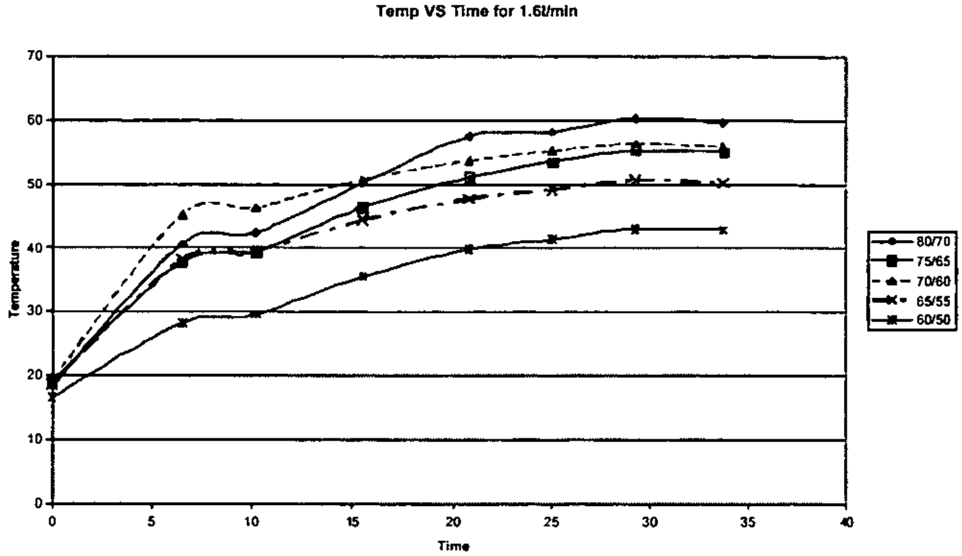


Temp VS Time for 1.2l/min



Temp VS Time for 1.4l/min




Temp VS Time for 1.6l/min
Temperature
Time
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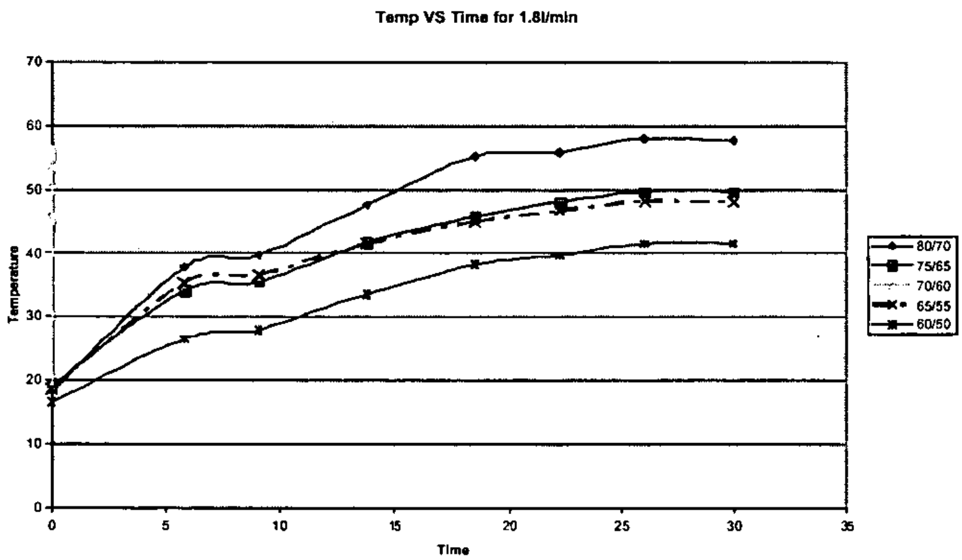
Temp VS Time for 1.8l/min
Temperature
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The development and testing of ultrasonic and ozone devices for ballast water treatment

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Synopsis
This paper describes the laboratory tests of the ultrasonic and ozone treatment devices conducted in the MARTOB research project in June 2002. A research project MARTOB (On Board Treatment of Ballast Water (Technologies Development and Applications) and Application of Low-sulphur Marine Fuels), partly funded by EU, was established in 2001 to find out solutions on the development of onboard ballast water treatment. The research program consists of various sub-projects and working packages among them the laboratory scale testing of the different treatment systems has been one of the most interesting tasks. The main aims of this study have been to investigate the various possible methods for controlling the transfer of non-indigenous organisms and bacteria through the ballast water.

The aim of this paper is to discuss on the general design principles of the ozone and ultrasonic based treatment devices, both designed and manufactured by Finnish enterprises. The ozone device, designed by Prominent Finland LTD and the Ultrasonic device designed and manufactured by Acomarin Engineering LTD were first pretested at VTT laboratories in Espoo, Finland. The general functions of the devices were tested using certain test organisms. The ultraviolet treatment system manufactured by the Dutch Berson Milieutechniek B.V. was added to the ultrasonic treatment rig, thus it was possible also to run different combined treatment methods. Finally these devices were transported to UK where a wider laboratory test set up was arranged together with a group of other ballast water treatment methods.

1 Introduction

The main objectives of the MARTOB project are to investigate methodologies and technologies for preventing the introduction of non-indigenous species through ships' ballast water, to develop design tools and treatment equipment to be used in the further development of ballast water treatment techniques, to assess the effectiveness, safety, and environmental and economic aspects of current and newly developed methods, to develop cost-effective (capital and operating), safe, environmentally friendly onboard ballast water treatment methods which have a minimum impact on ship operations and to produce guidelines for crew training and criteria for selecting an appropriate ballast water management method.

In addition to the Ballast Water treatment issues also the low sulphur fuels are studied in terms of assessment of the financial, technical and operational effects of a sulphur cap on marine bunker fuel in European waters, and proposal of a verification scheme ensuring compliance with a sulphur cap from all players in the market and help to facilitate the introduction of an important sulphur emission abatement measure without unintentional distortion of competition in the shipping market.

Author's biography
Mr. Jukka Sassi is working as a research engineer at VTT Industrial Systems in Espoo, Finland. His special research area at VTT is environmental engineering, including testing and measurements. He has also worked at VTT's low-velocity wind tunnel, thus having an experience on the industrial aerodynamics. He is a project manager of Work Package 3 of the Martob project.

The test trials of the proposed ballast water treatments included in the project were held at Newcastle University in early June, 2002, including the following technologies: high temperature heat treatment (University of Newcastle as the task leader), oxicide treatment (TNO), ultraviolet, ultrasound and ozone methods (VTT), de-oxygenation (SINTEF), Advanced Oxidation Method (BenRad) and combinations of the above technologies as the hurdle technology (BERSON). Before the Newcastle trials, various partners carried out preliminary test trials.

This paper describes the test arrangements and preliminary results based on the test trials carried out by VTT Industrial Systems with ultrasound and ozone devices. VTT was also responsible on the ultraviolet treatment studies together with the Dutch Berson milieutechniek BV including also a set of combined treatment methods, called hurdle technologies. These treatment options, however, have not discussed in this paper, but will be presented later within the MARTOB project.

2 Brief description of the ozone and ultrasonic treatment principles

2.1 Ozone technology

Ozone (O_3) is the triatomic form of oxygen which is a gas at room temperature. It has been used for the disinfection of water supplies since 1886. Marine applications of ozone include depuration of shellfish, oxidation of colour producing organics and toxins, improvement of filtration, control of microbiological contamination in aquaria and aquaculture, and control of biofouling in cooling water systems. Ozone has been used in aquaria since the early 1970's, in marine power plant cooling systems since 1970's and for the depuration of shellfish since 1920's. (Oemcke and van Leeuwen, 1998).

Ozone is a fairly powerful but unstable, oxidising agent which rapidly destroys viruses and bacteria, including spores, when used as a disinfectant in conventional water treatment. Ozone is more effective biocide than chlorine and is being used increasingly in the place of chlorine in the treatment of domestic and industrial water supplies. Salt-water ozone reactors are currently used for salt-water aquariums and fish hatcheries. Ozone quickly decomposes to oxygen, with a half life in water at 20°C of less than 30 minutes. The process is dependent on the production of ozone on-site, by passing high tension, high frequency electrical discharges through dry air. Effects of ozone are rapid, with contact times 5 to 10 minutes at a dosage of 1-2 mg/l. When water was of poor quality much larger concentrations have to be applied.

Ozone gas is highly toxic and has an odour detection threshold of about 0.01 ppm. A high level of safety measures, including monitoring of carbon scrubbed vented gas, therefore has to be adopted with its use. Although ozone leaves no residuals in the water, it may cause precipitation of manganese and iron and is not suitable for water with high turbidity. In addition to the associated high costs of this treatment it is possible that ozone may be a potentially corrosive agent in ballast systems. In addition, for ozone treatment to be effective, ballast water may require pre-treatment to remove sediment (IWACO, 2001).

In the ozone device used in MARTOB test trials ozone is produced by the reaction of an oxygen molecule and an oxygen atom with the principle of silent electrical discharge. The system produces ozone from a gas containing oxygen, usually ambient air, like in these test trials, or pure oxygen. The gas is passed through an electronic field produced between two electrodes. The air is treated to ensure it is dry and fee from dust particles. Part of the oxygen in the air is converted into ozone in the electrical field. The air stream, which now contains ozone, is then fed to the contact tank for dissolving in water requiring disinfection.

2.2 Ultrasound technology

Ultrasonic liquid treatment uses high frequency energy to cause vibration in liquids to produce physical or chemical effects. Ultrasound, part of the sonic spectrum that ranges from 20 kHz to 10 MHz, is generated by a transducer that converts mechanical or electrical energy into high frequency acoustical (sound) energy. The sound energy is then fed to a horn that transmits the energy as high frequency vibrations to the liquid being processed. A typical ultrasonic processing chamber is shown in Figure 1.

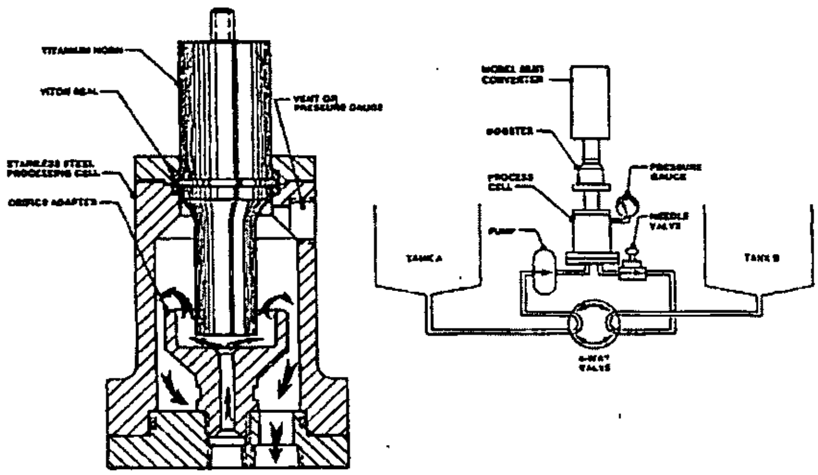

Figure1. Schematic of Ultrasonic Treatment System (Buchholz et al, 1998).

The energy that exists within the cavity and in the immediate vicinity of the gas bubbles just before collapse causes both physical and chemical effects in the liquid. Physical effects result when cavitation is intense enough to rupture cell membranes, free particulates from solid surfaces, and destroy particles and organisms through particulate collisions or by forcing them apart. Chemical effects result because the conditions immediately proceeding collapse of a cavitation bubble are similar in magnitude to ultra-high energy combustion conditions. Within the cavitation bubble and the immediate surrounding area, temperatures range from 2000 to 5000 C, and pressure reaches 1800 atmospheres. These extreme temperatures and pressures, which last only microseconds, do not exist long enough to heat the liquids being processed. However, the localized temperature and pressure increases are sufficient to increase chemical reactivity, polymer degradation, and chemical free-radical production (Buchholz et al, 1998).

Ultrasonic treatment is relatively new technology in ballast water treatment. Two types of ultrasound exists, low intensity, which is not used to disinfection, and power ultrasound. Ultrasound is generated by transducer which convert the mechanical or electrical energy into high frequency vibration. The effect of ultrasound is based on physical and chemical changes, destruction of organisms and rupture of cell membranes, resulted from cavitation. The cavitation is influenced by frequency, power density, exposure time and properties of the treated water.

The ultrasound device used in this research study was designed and constructed by Acomarin Engineering Ltd, Naantali, Finland, see figure 2. The device is equipped with dr. Hielscher UIP 2000 Ultrasonic Processor, including generator, transducer and sonotrode, which is made of titanium. The processor is exclusively designed for the purposes of disintegration (e.g. cell disruption, emulsifying, homogenising), thermoplastic molding, coating-lacquer removal, intensive surface cleaning, wire cleaning, cutting, drilling, lapping and compressing, used by industry or sonochemistry laboratories. The amplitude is adjustable and equipped with automatic frequency scanning system. Generator and transducer are housed separately and processor is dry running protected.

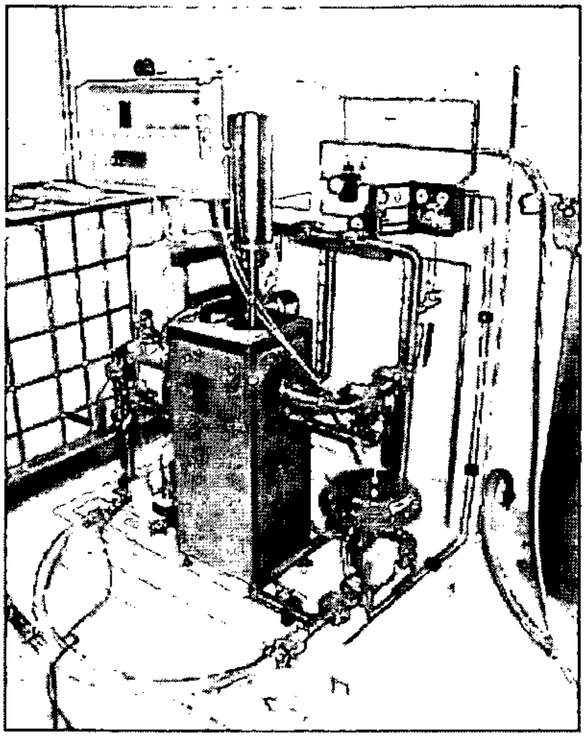

Figure 2. The ultraviolet light and ultrasonic devices mounted in the same aggregate. US transducer is mounted inside the stainless steel box.

3 Test arrangements

VTT's responsibilities in the MARTOB's testing programme were to carry out the tests with ultraviolet light (UV), ultrasound (US) and ozone (O_3) and also, as the Work Package Leader, to prepare the summary report of the laboratory test phase in co-operation with all the Task Leaders and project co-ordinator, and attend to the general schedule of the laboratory test phase

The test platform was designed in the way that it was possible to test all three devices without any major re-modification of the test system. US and ultraviolet light devices were installed in the same aggregate in order to enable the test trials of the combination of US and UV as part of the hurdle technologies (see Figure 3). The flow meter (converter type Danfoss MAG 6000 equipped with MAG 1100 DN 10 sensor, maximum flow rate 2827 l/h) and pressure meter (pressure transmitter Danfoss MBS 3000, pressure range 0-6 bar) were utilised to monitor and record the flow rates and pressure levels during the treatment process. Required sampling taps before and after the treatment were included in the test platform.

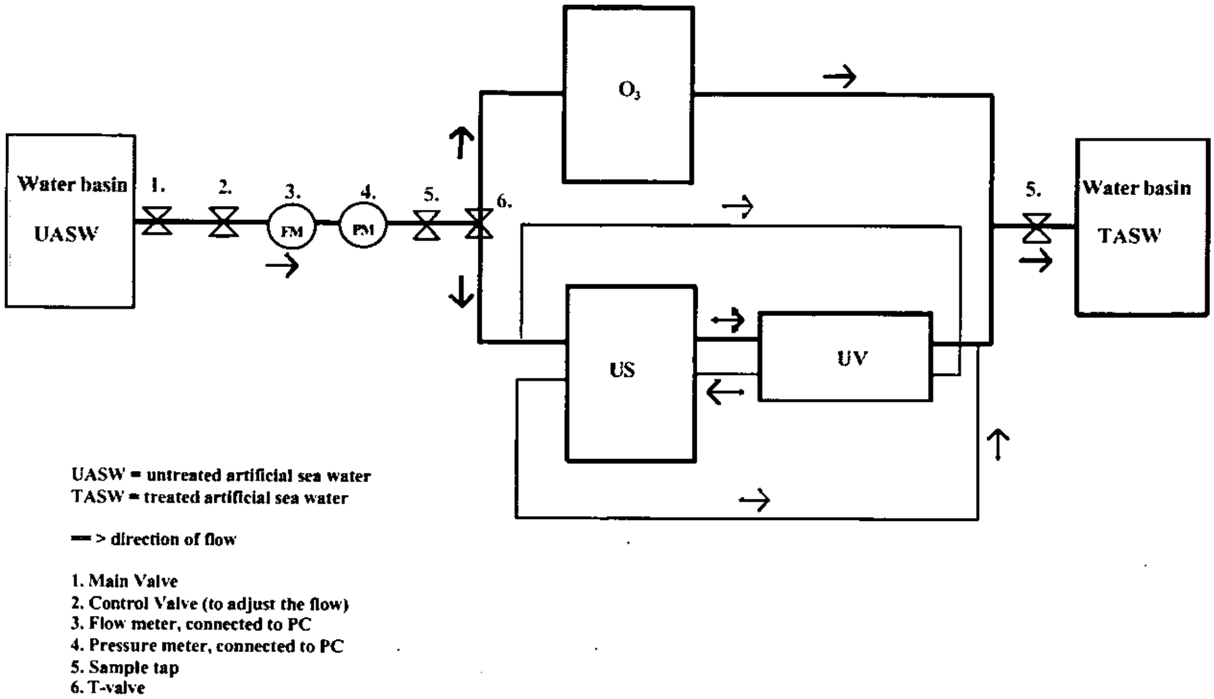

Figure 3. The lay-out of the test platform.

The preliminary test trials were carried out in Otaniemi, Espoo, from 24th April to 22nd May 2002, as part of the MARTOB project. Two different target organisms were used, *Artemia salina* (Crustacea) and algae. The impact of three different treatments, i.e. ozonization (O_3), ultrasound (US) and ultraviolet (UV), to *Artemia salina* was tested. Also the test trials with two combinations of US and UV were conducted in order to see if the response of *Artemia* depends on the treatment order.

Each treatment was accomplished with several settlements with different operational parameters including O_3 -doses, ultrasound transducer amplitudes and flow rates.

Later, the wider laboratory-scale trials were carried out from the 6th to the 14th June 2002. For reasons of logistics and consistency, all the devices were tested in the same location, in the facilities provided by the University of Newcastle. The treatments tested included de-oxigenation, high temperature thermal treatment, oxicide, oxidation method, ozone, ultrasounds, ultraviolet light, as well as a hurdle technology, i.e. different combinations of the methods mentioned. The standard test protocol created in the Martob project was applied in order to have a comparative and reliable assessment of the biological effectiveness of the different treatments

The trials involved setting up tanks with 70 litres of standard sea water, i.e. Martob Soup, made up of artificial sea water and containing five species representative of those found in ballast water, i.e. *Nereis virens, Acartia tonsa, Tisbe battagliai, Alexandrium tamarense, Thalassiosira pseudonana*. Samples of two litres of this water were taken from a tank before and after treatment to assess how effective each treatment was at removing or killing the organisms. From the sampled water, three sub-samples were taken for the determination of chlorophyll a and phaeophytin values. In addition to the treated tanks, control tanks were set up and sampled at intervals over the period of the trials. Over the entire experimental period the standard sea water, was made up from three different cultures of the representative species which varied in species density. Sampling and analysis were carried out by University of Newcastle and Fisheries Research Services.

In addition to the biological assessment also corrosion measurements were carried out by TNO during the test trials in Newcastle.

4 Preliminary results

4.1 Preliminary tests in Finland

Regarding the ozone treatment the operational and treatment efficiency parameters has been listed in Table 1. The mortality and activity rates using *Artemia* has been indicated in Figures 4 and 5.

Table 1. Ozone (O_3) treatment, operational and treatment efficiency parameters. Activity = A_1 / A_0, where A_0 = actively swimming individuals / total individuals counted in before treatment sample. A_1 = actively swimming individuals / total individuals counted in after treatment samples.

Flow rate [l/h]	Ozone dosage [g/h]	Mortality [%]	Activity [%]	Density before treatment [ind. l^{-1}]	Reduction in density during treatment [%]	Total count before treatment [ind. l^{-1}]	Total count after treatment [ind. l^{-1}]
500	0,5	2	94	888	41	444	515
500	2,5	0	91	932	4	233	524
500	3,75	0	61	1020	48	102	244
500	5,0	0	33	1488	55	372	505
200	2,5	7	74	1600	43	160	275
200	3,75	16	46	1850	55	185	345
200	5,0	4	32	1680	51	168	249
150	2,5	0	51	1990	60	199	239
150	3,75	46	20	1330	50	133	199
150	5,0	68	8	1340	39	134	247

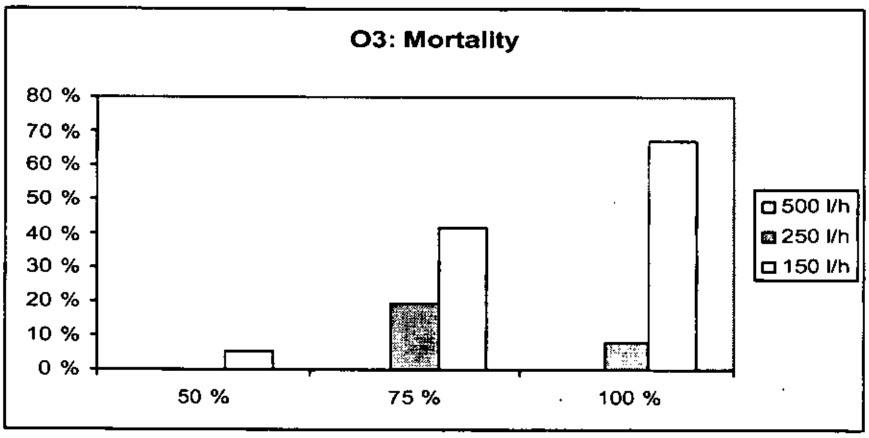

Figure 4. Ozone treatment, mortality rates on different parameter combinations.

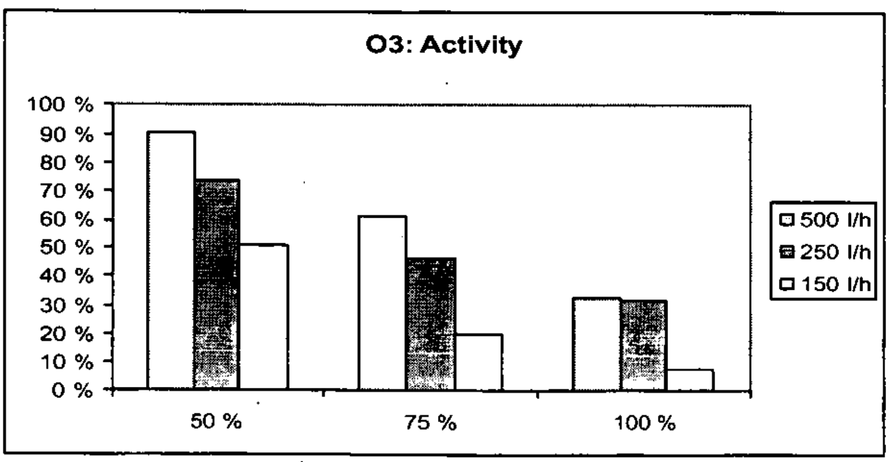

Figure 5. Ozone treatment, activity rates on different parameter combinations.

Ozone treatment had obviously some effect only on the slowest flow rate and on the maximum ozone dosage (150 l/h, ozone dosage 5 g/h). In ozone treatment the contact times were short enough to effect only on activity rates but not on mortality rates of *Artemia*. Mortality rates increased rapidly, however, with increased contact time (decreasing flow rate).

Regarding the ultrasound treatment the operational and treatment efficiency parameters has been listed in Table 2 and mortality rates has been indicated in Figure 6.

Table 2. The operational and treatment efficiency parameters of ultrasound treatment.

Flow rate [l/h]	Transducer amplitude [%]	Mortality [%]	Activity [%]	Density before treatment [ind. l^{-1}]	Reduction in density during treatment [%]	Total count before treatment [ind. l^{-1}]	Total count after treatment [ind. l^{-1}]
600	50	77	16	330	83	66	83
600	100	89	12	610	97	183	32
400	50	70	24	180	88	36	33
400	100	88	14	575	98	115	22
200	50	100	0	275	100	82	2

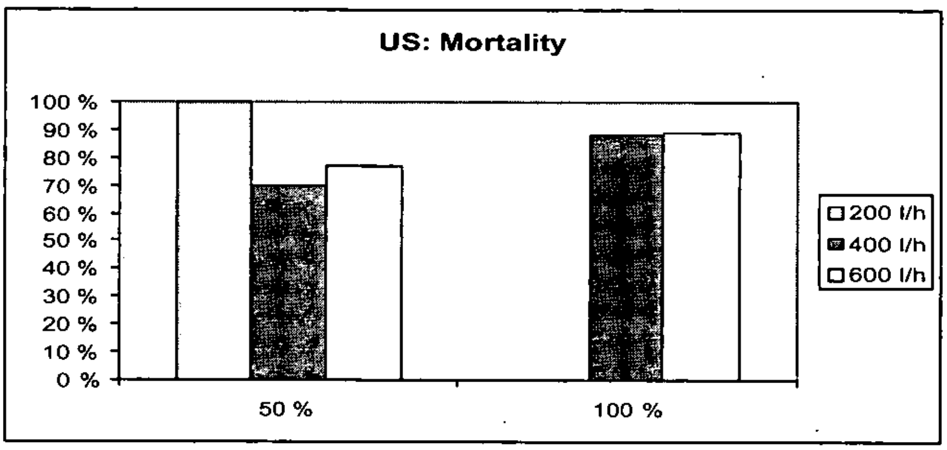

Figure 6. The mortality rates of ultrasound treatment.

4.2 Test trials in University of Newcastle, UK

During the first three and a half days VTT used a centrifugal pump as a means to introduce the water into the treatment system. After realising that the pump itself was eliminating all the zooplankton, a gravity system to supply the water was used.

The mortality attained by ultrasound system was always below 40% for all the tests, whileas the highest value for the ozone treatment was 88.89 %, eliminating *Nereis*.There were no apparent differences among the ultrasound tests. Similarly patterns occurred with the ultraviolet light treatment, where even applying to various flow rates, no differences were appreciated

None of the treatments reached a removal of 95% of zooplankton. However from the methodologies tested, ozone appeared to achieve the best results. The results obtained by Cooper *et al.* (2001) showed that they achieved 99% removal of bacteria after 4 to 6 hours ozonating the tanks from the *Tonsina* vessel (maximum system capacity of 1800g O_3/h, leading to an O_3 loading rate of 0.6 mg/l/h in each tank). Unfortunately their performance with respect to higher organisms at the field scale is as yet untested. Figures 7 and 8 show the preliminary test results with phytoplankton (*Chlorophyll a)* both for ozone and ultrasound treatments.

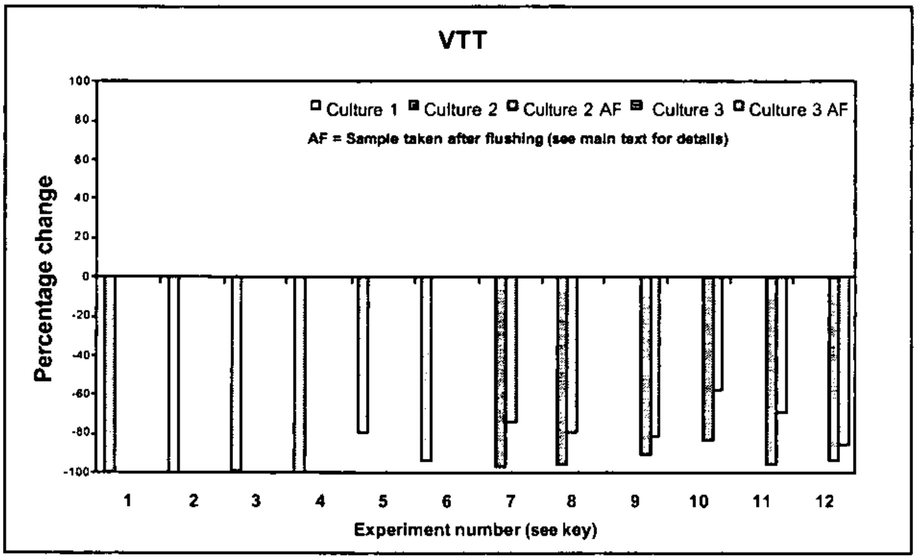

Figure 7.Percentage changes in chlorophyll a levels after ozone treatment.

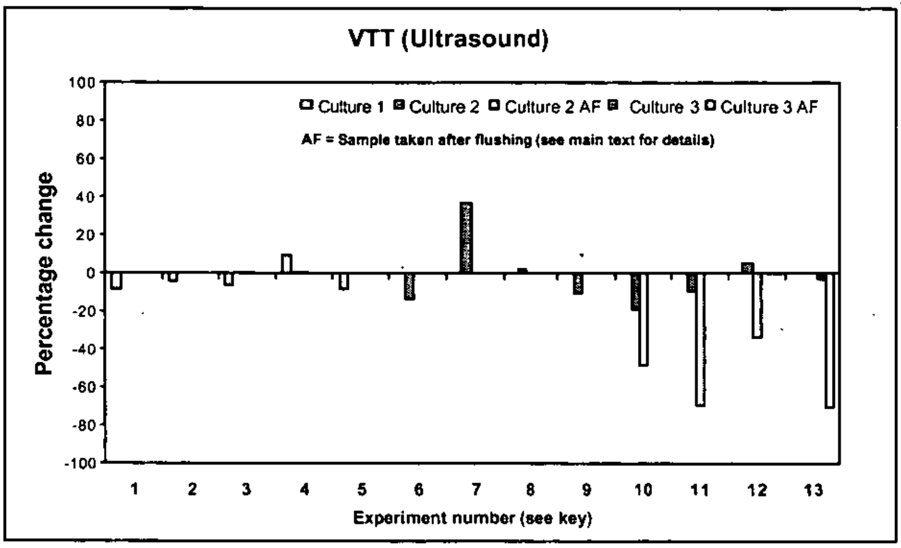

Figure 8. Percentage changes in chlorophyll a levels after ultrasound treatment.

4.3 Corrosion effects

In terms of ultrasound method no risk of corrosion increase or risk with respect to coating and gaskets has been identified. Ozone method caused a significant increase of the Redox potential (short term effect) with possible consequences on metal corrosion, coatings and gaskets. In conclusion, all risk increases are acceptable with respect with today knowledge and can be managed for new ship design with existing techniques and methods.

5 Discussion and recommendations

Of all the treatments tested during the Newcastle trials the experiments carried out with the ozone treatment were the most effective at reducing chlorophyll *a* levels. However, there has to be some caution when examining these results as the initial six ozone experiments were carried out with a pump to transfer the water into the treatment system and this was shown to have the effect of killing all the zooplankton. It is unlikely that the phytoplankton would have been affected as much as the zooplankton by the pump and the following six experiments, which bypassed the pump all together, also show a reduction in chlorophyll *a*.

Previous studies on ozone have concluded that it may have some potential for ballast water treatment but that pre-treatment such as filtering would be required and that it is likely to be ineffective against difficult taxa such as dinoflagellate cysts (Oemcke, 1998). Difficult to kill taxa are likely to require greater doses of ozone for longer periods of time, which raises issues of corrosion and depletion of sacrificial anodes within the ballast tank (Oemcke, 1998). A ship board study concentrated on bacteria initially but had no data with respect to phytoplankton (Cooper et al., 2001). It is therefore difficult to compare the results of these experiments as they have been run under very different circumstances. The results from the Newcastle tests are promising but it will be necessary to test the equipment further in order to investigate how it copes with heavy sediment loads and a greater range of organisms.

Strategy for large scale test trials will be based on the experience gained from laboratory scale test trials. The future large scale test phase will be carried out utilising the Baltic Sea marine environment. Duration of test runs must be long enough in order to minimise the technical sources of errors, i.e. piping, fittings, valves and small amount of water. The utilisation of real sea water enables the access to unlimited amount of water and thus the error caused by small amount of water can be reduced. Also the link to the actual marine environment is evident. Ultrasound treatment should also be tested with a turbulent flow, since turbulence increases the efficiency of ultrasound treatment.

Regarding the ozone treatment, instead of the flow-through arrangement the contact time will be extended by introducing ozone to a contact tank in order to monitor ozone dosage per amount of water versus contact time. Various ozone dosages and contact times will be studied, possibly also long term test runs might be carried out. Sampling will be conducted before and after the treatment to monitor the organisms concentrations and species and the alterations induced by the treatment.

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Assessing cost, environmental aspects, effectiveness, and safety of ballast water treatment methods - information collection and preliminary method development for the MARTOB project

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SYNOPSIS

Ballast water management methods need to be effective at preventing the spread of non-indigenous species and should also be safe, cost-effective, and environmentally friendly. These properties of ballast water management systems were reviewed to establish a reference point for the further development of on-board ballast water treatment systems within the MARTOB project. This paper summarises material from the review and describes how the information was assessed to provide recommendations for suitable measurements (quantitative or qualitative) for the laboratory and large scale testing phases of the MARTOB project.

INTRODUCTION

MARTOB is a three-year project funded under the European Union Framework Programme and is directed towards reducing the environmental effects of shipping activities related to ballast water management and the use of high sulphur marine fuels. This paper discusses only the ballast water component of the project, which has a major aim of developing methods for treating ballast water on board ships. The introduction of non-indigenous species though vectors such as ballast water has resulted in problems in many of the world's oceans and water bodies and new introductions are being discovered regularly. Some of these introductions have caused serious economic and ecological damage. Public health problems can also result from introductions of viruses or toxic algae. Ballast water is thought to be one of the major vectors for introductions of non-indigenous species because billions of tonnes of water are transported and released each year and many surveys have detected viable organisms within ballast water.

The only readily available method of ballast water management today is deep ocean ballast water exchange. This method is described in "Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Aquatic Organisms and Pathogens" [1], which were developed by member countries of the International Maritime Organization (IMO) and first issued in 1993. The IMO guidelines are voluntary but some jurisdictions have made ballast water exchange mandatory. The method is not, however, considered to be completely effective at removing organisms from the ballast water, because there may be organisms remaining in sediments in ballast water tanks, and it is often not possible to completely flush out the water that was taken on at port. Voluntary ballast water exchange is considered to be an interim measure and the IMO is currently working on an international ballast water convention, with the aim for this to be introduced in 2003, subject to agreement of member countries. Although the convention is still under development, it is expected to include ballast water treatment standards that can be applied to equipment for treating ballast water.

Authors' Biography

J. Ellis is an environmental engineer and project manager at SSPA Sweden. K. Maas, an environmental economist, is project manager at TME. T. McCollin is a plankton biologist and carries out research on ballast water issues.

A goal of the MARTOB project is to develop recommendations for ballast water management methods that involve treating the water on board the ship. The main work components to be carried out as part of the ballast water portion of the project are as follows:

- Collection and assessment of data and information on ballast water management methods and existing relevant legislation, and a review and update of alien species introductions in European waters
- Development of selected methods for on-board treatment of ballast water through lab-scale testing and in-depth analysis
- Large and full-scale testing of selected ballast water treatment methods.

This paper describes review work carried out during the first phase of the project to collect and assess information on the treatment efficiency, safety, cost, and environmental effects for on-board operation of ballast water management methods. This information was assessed with a view to identifying gaps and defining information needs and collection methods for the treatment systems to be tested during subsequent phases of the MARTOB project. In addition, the information review helped establish a reference point with respect to performance of ballast water treatment systems tested previously.

OBJECTIVES AND SCOPE

The primary objective of the review of information on ballast water management systems was to determine the types of information that had previously been collected, the methods that had been used for data collection, and the characteristics of systems that were considered important with respect to effectiveness, environmental impacts, costs, safety, and application on board ships. Currently there are no standards for ballast water treatment, so as a result different methods have been used for collecting and reporting information on ballast water treatment effectiveness. In addition, other system characteristics such as safety, costs, and potential environmental impact of the methods have not been assessed in a consistent manner. Although the IMO is discussing treatment standards to be included in the ballast water convention planned for 2003, at this time the details of these standards have not been agreed upon. It was important as part of the MARTOB project to define data collection requirements for the laboratory scale and full scale testing phase of the project carried out in 2002 and 2003 respectively. Important considerations for the MARTOB project included available budget, applicability to the treatment methods being tested, and project schedule.

Information was reviewed for ballast water management systems that are currently in use, have been tested at a reasonable scale, or are in an ongoing testing and development phase. More focus was placed on those methods that are currently in use or have been tested at large scale. Table I lists the on-board ballast water management methods that were reviewed and summarises their current status with respect to use and testing. In addition, shore based treatment was briefly reviewed. Note that not all categories of information, i.e. effectiveness, cost, safety, and environmental effects, were included for methods that have only undergone limited testing and for which there was limited information available.

Table 1 On-board ballast water management methods and current stage of development, as reviewed for the MARTOB project

Ballast Water Management Method	*Current Use / Stage of Development*
- Ballast water exchange (Re-ballasting, continuous flushing, dilution)	Practiced on a regular basis
- Thermal Treatment	Shipboard trials of low temperature treatment have been carried out [2]
- Filtration	Tested on board one ship; also tested on a barge and at shore based facilities [3], [4], [5]
- Hydrocyclone separation	Tested on board a cruise ship and a stationary barge [6]
- Ultraviolet Irradiation	Tested with hydrocyclone as primary treatment method on board a cruise ship and a stationary barge [6]
Methods with limited testing: - Biocides (chemical and natural) - Oxygen removal - Gas supersaturation - Ultrasound - Natural Air Injection - Electro-ionisation	Testing has been at a limited scale for ballast water treatment application

A description of the technologies can be found in the references noted in the table, or in comprehensive reports on ballast water treatment such as in [2], [7], and [8].

The methods undergoing testing in the MARTOB project are a subset or combination of the methods listed in Table I and are as follows:

- Thermal treatment
- Biological de-oxygenation (oxygen removal)
- Ultraviolet irradiation and ultra-sound
- Ozone (chemical biocide)
- Oxicide method (chemical biocide)
- Oxidation / UV + Ozone + Catalysts (combination chemical biocide and UV)
- Hurdle technologies (combinations of the above methods)

For a ballast water treatment technology to be accepted and adopted for use, it will need to demonstrate good performance in the following categories of criteria:

- Biological effectiveness
- Environmental impacts
- Safety
- Costs
- Practicality and applicability for shipboard operation

These categories of criteria will be used throughout the MARTOB project to assess the technologies as they are being tested. The goal of the work described here was to attempt to provide a guide for defining the type and form of information to be collected for each of the first four criteria. Practicality and applicability for shipboard operation will be assessed by others in the MARTOB project, through evaluation of the full-scale designs and shipboard trials in a later project phase.

INFORMATION SOURCES/APPROACH

Information on the ballast water treatment methods reviewed was collected through review of existing literature, contacting other researchers directly, and discussions with the technology development partners within the MARTOB project. Published literature, 'grey' literature, and communications by telephone and e-mail were used to collect information. Where there was limited information on new technologies to be used aboard ships, available information for land-based applications was collected and assessed when applicable.

BIOLOGICAL EFFECTIVENESS

Part of the information collected for the review of ballast water treatment methods dealt with the assessment of the biological effectiveness of these methods. As the aim of ballast water treatment is to reduce the risk of introducing non native species it is important to establish how effective each method is at achieving this aim. It is also important to be able to compare the results of different experiments in order that comparisons can be made between the biological efficiency of different treatment technologies e.g. one treatment may be extremely effective against a particular taxa but not as effective against others.

A review of the literature highlighted that assessing biological effectiveness is not an easy task. In the past, the methods used to assess biological effectiveness varied depending on the equipment being tested and also on the interest and expertise of the researchers carrying out the experiments. A summary of the many criteria that have been used to assess biological effectiveness for ballast water treatment or management methods is shown in Table II. These are generally assessment methods that have been used during experiments on board vessels or at large scale shore based test facilities and therefore the list does not list all possible criteria as many other methods may have been used at a laboratory scale.

Table II. A summary of some of the criteria used to assess biological efficiency of ballast water treatment methods.

Criteria used to assess biological efficiency	*Study*
Indicator taxa such as copepods, spionid polychaetes, freshwater zooplankton, dinoflagellates or diatoms were used to assess whether a particular treatment or management method reduced the number of these taxa. Sometimes used in association with salinity differences before and after ballast water exchange.	[9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20]
Diversity and abundance of phytoplankton before and after ballast water exchange	[21], [15], [22], [23]
Salinity, chemical characteristics and nutrient levels.	[24], [13], [14]
Tracers such as dye, fluorescent microspheres and *Artemia salina*	[25], [26], [23], [16], [17]
Chlorophyll *a* analysis	[19]

Removal of specific harmful phytoplankton species	[27]
Removal of organisms above a certain size (particularly used when testing filtration techniques)	[19]

As can be seen from Table II there is much variation between test criteria, and within these criteria there are also differences between studies. As an example, the taxa used as indicator organisms are different in the majority of studies. There are many different reasons for choosing certain taxa. For example, for mid ocean exchange, taxa representative of coastal areas could be chosen in order to assess how effectively the exchange process removes these taxa. However, for testing a shore based treatment, easily identifiable species that can be used to "spike" the test water may be used so that a known concentration is added and samples taken before and after treatment can be easily compared. Other researchers have used natural populations by siting experiments on harbours for easy access to port waters.

However, this variation makes it almost impossible to compare the results of the experiments and there have been suggestions that in order to obtain comparable results on an international scale it is necessary to use specified indicator organisms. In recent years there have been several suggestions put forward as to which organisms could be used as representative taxa. As a component of the MARTOB project was to compare the biological efficiency of several treatment methods, it was necessary to choose an approach that could be used to obtain comparable results. It was therefore decided to use known quantities of representative taxa in a "standard sea water". Although there are currently no official defined sets of test organisms the work within the MARTOB project involved a literature search that collated the available information. This was then used as a basis for developing a test protocol that could be used for undertaking the shore based tests of the treatment methods under consideration in the MARTOB project [28].

ENVIRONMENTAL IMPACTS

The environmental impacts of ballast water treatment vary by method and can result in both direct impacts to receiving water and indirect impacts resulting from emissions to air and materials use. Direct impacts on receiving water quality can result from discharges from the ballast water systems including:

- Discharge of ballast water with altered quality: physical parameters (temperature, suspended solids, pH), chemical treatment residuals, metals (if corrosion is increased), nutrients, organics (dead organisms)
- Discharge of solids from physical separation methods: concentrated organisms and sediments
- Discharge of living organisms surviving treatment (and possible increased numbers if treatment is done during ballasting).

Indirect environmental effects of ballast water management could include energy consumption and associated emissions, materials used, and waste generated during operation or through disposal of worn out components and equipment. Energy may be required to operate the treatment system or may be needed for pumping. Ballasting and de-ballasting is normally done using gravity feed as much as possible, but some treatment methods would require all ballast water to be pumped through the treatment system. Materials consumed during operation could include consumables such as chemicals or nutrients, as well as parts that would have to be replaced throughout the life of the equipment. There is also the potential for an impact through spills of materials stored on board for ballast water treatment. Although chemical biocides such as ozone or hydrogen peroxide could be generated on board, nutrients required for biological oxygen removal or chemicals such as sodium hypochlorite would need to be stored on board and would have an impact if spilled.

A summary of environmental impacts using examples from the ballast water treatment methodologies included in the review is provided in Table III. Suggestions of possible criteria for assessing each impact category are also provided.

The information review showed that most of the available information on environmental impacts from treatment methods has been estimated by qualitative assessments of effects and probable consequences. Some studies have provided estimates of energy use ([29], [2]), which can be useful both for estimating costs and for estimating environmental impacts related to fossil fuel consumption. Most of the technologies are still in the development stage so equipment size, materials required for construction, and materials use can only be estimated until the technologies are ready for full-scale use. This information could be used for assessing impacts using a life cycle assessment (LCA) or inventory approach. This method looks at the environmental impacts of a process or product "from cradle to grave" from impacts of materials used for production through to disposal of the product at the end of its useful life. It is recognized that materials used for a treatment system would be extremely small compared to the material in a ship. LCA has not been used much in marine transport to date, but its use is increasing and if LCA is done on the whole transport chain assessments for treatment technologies would be beneficial.

Table III Summary of environmental impacts from ballast water management methods and possible criteria for assessing

Environmental Effect Category	*Treatment system types and specific effects*	*Possible criteria for assessment*
Direct Impact through Discharge to Receiving Water		
Impact from surviving non-indigenous organisms; increased discharge of some organism types	Most of the treatment methods tested to date are not 100% effective against all organism types, examples: Ballast Water Exchange: flushing rates or organisms vary Filtration, Hydrocyclone: Bacteria and organisms smaller than the filter size or too light to be separated by the hydrocyclone remain. Thermal treatment: survival of organism types could occur, will vary depending on temperature and exposure time Oxygen Removal: not effective against all life stages and species Treatments that occur during ballasting or while the vessel is en-route can result in re-growth within tanks unless there is a residual or time is short. When treatment occurs during discharge re-growth in the tank is not an issue.	Testing of biological effectiveness as described previously can give an indication of survival rates for representative species. For specific situations a risk assessment of species from donor port and conditions in the receiving port can be carried out.
Discharge of water with altered quality. Parameter groups: - physical (temperature, TSS, pH) - nutrients (N, P) - dissolved oxygen/oxygen demand (BOD, COD) - chemical (biocide residuals) - metals (for methods that may increase corrosion) - organic matter (dead organisms from treatment process)	Physical: Thermal treatment results in increased temperature Nutrients: Biological de-oxygenation requires the addition of nutrients and carbon sources to stimulate growth of bacteria to remove oxygen Dissolved oxygen/oxygen demand: All oxygen removal methods (biological, bubbling nitrogen gas, etc.) will result in discharge of ballast water with low dissolved oxygen. Biological methods could also result in increased BOD. Chemical: Residuals from methods such as ozone and hydrogen peroxide would quickly break down. Methods using chlorine based disinfectants such as sodium hypochlorite may have toxic by-products or residuals. Metals: Methods that involve treating within the tanks or return of treated water (with residual) to tanks may increase corrosion. Oxygen removal and chemical biocides could increase corrosivity. Could lead to higher levels of iron, zinc, or aluminium. Organic Matter: All methods except physical separation method would result in the discharge of dead organisms with the ballast water.	Measurement or estimation changes in water quality parameters resulting from ballast water treatment processes (compared to the 'no treatment' option or estimate as a % change over background). Estimation of mixing zones. Could rank water quality changes based on their persistence in the environment and potential impact (although potential impact is dependent on the sensitivity of the receiving environment).
Discharge of solids (organisms and sediments)	Physical separation methods such as filtration and hydrocyclone separation result in a mixture of separated organisms and sediments.	Qualitative assessment is probably best because quantities of solids would be dependent on concentrations in the intake water.
Other Environmental Impacts Including Waste Materials, Discharges to Air, and Materials Use		
Energy Consumption and Associated Emissions to Air	Most methods require energy either to operate the treatment system or to pump the ballast water through the system. Exceptions would include chemicals or nutrients that could be added directly to a ballast water tank.	Estimation of energy requirements to treat a given volume of ballast water.
Materials Use	Methods such as filtration, hydrocyclones, high temperature thermal treatment, ozone, UV, and ultrasound require treatment equipment.	Estimation or inventory of materials type and quantities required could be averaged over a treatment volume and/or service life.
Accidental releases or spills of biocides / nutrients / chemicals required for treatment processes	For biocides where the chemical is stored on board there is a potential for a spill. Biological oxygen removal or use of a biocide such as sodium hypochlorite would require on board storage.	Estimation of maxiumum amount of a harmful substance required to be stored on board; assessment of spill risk.

Environmental Impact Assessment for MARTOB Technologies

Potential impacts from the technologies to be tested in the MARTOB project fall into all categories included in Table III. Information on the environmental impacts of the technologies will be collected during the lab scale and full (or large) scale testing. Possible criteria for assessing the impacts are listed in Table III; some of these criteria will be simplified to fit within the scope and budget of the project. It is expected that the following information will be collected and calculated for treating a given volume of ballast water for a sample ship:

- Data on change in water quality parameters that are expected to be altered by the specific treatment, and comparison to the 'no treatment' option, as well as to relevant water quality standards; qualitative assessment of the potential impact
- Energy use (both for the technology and expected extra pumping requirements)
- Materials required for equipment and maintenance
- Waste materials generated through replacement components and operations
- Potential volumes and impacts of spills of environmentally harmful products.

For impacts from organisms surviving the treatment, information collected during the assessment of biological effectiveness could provide an indication. For water quality impacts, only those parameters that are expected to be changed by the treatment technology will be measured. Environmental impact categories for the life cycle assessment of transport will be used to assess energy and materials use.

SAFETY AND HAZARDS

Information on the primary safety issues and hazard types associated with ballast water management methods was collected as part of the review. Safety of the ship and crew is a primary concern and it is desirable that any hazards associated with ballast water management be kept to a minimum. Ballast water management methods were discussed from the following safety perspectives:

- Safety of vessel (ship survivability): stability, structural strength, visibility
- Safety of crew (ship operations):
  - Operational: physical equipment hazards: chemical, electrical, or biological hazards
  - Chemical storage
  - Safety/contamination of living spaces

Ballast water exchange methods have undergone the most scrutiny from a safety perspective because exchange is the method most often used and specified by guidelines. The sequential ballast water exchange method seems to generate the most safety issues, including concerns about longitudinal strength and increased susceptibility to slamming and pounding. Other issues include bridge visibility, intact stability, excessive trim, and propeller emergence [30]. Flow-through exchange has safety concerns related to potential over or under-pressurisation of tanks and water and ice on decks. Individual ballast water management plans are developed for specific vessels to help mitigate the risks, and new vessels can be designed to minimise risks associated with ballast water exchange.

Methods that involve treating ballast water on board, including those investigated in the MARTOB project, generally have safety concerns of a different type than the physical and structural hazards associated with ballast water exchange. Additional categories of hazards include chemical, electrical, and biological. Chemical hazards are present during the use and/or storage of chemical biocides that are classified as dangerous goods. Electrical hazards can exist for treatment technologies such as ultraviolet irradiation, which requires high voltage electricity. Biological hazards could exist when handling sediments or solids from hydrocyclones or filters, if the ballast water has been taken from polluted harbours. Thermal treatment can create additional hot water hazards on board the ship. If water of an elevated temperature is returned to the ballast water tanks there can be metal fatigue and stress. Human error is a factor in many accidents and with all ballast water treatment or management methods stress and fatigue resulting from additional workload may contribute to unsafe conditions.

In addition to safety concerns related to the operation of ballast water treatment systems, e.g. concerns about handling chemicals and about electrical or mechanical hazards of equipment, there can be concerns about the release or leakage of treated ballast water of altered quality. Chemical residuals in the ballast water may be a concern if tank contents leak to other tanks, or if there are vapours in the void spaces that can be a concern during crew or survey visits. Some vapours could also be hazardous with respect to explosion. Piping systems containing ballast water with residuals may also generate vapours that are harmful for the crew or the surrounding equipment.

Safety aspects to be considered during evaluation of the MARTOB methods will include the following:

- Operational issues:
  - Use of hazardous chemicals (on-site generation and storage)
  - Equipment hazards (relating to heating equipment, UV, electrical, separators, pumps and overflow mechanisms)

- Storage and handling of chemicals and residuals: potential spills, vapour release,
- Potential for unintentional release of treated ballast water containing residuals: from ballast tanks or piping systems.

ECONOMIC CONSIDERATIONS

Installation of an on-board ballast water treatment method will lead to changes in ship capital costs, changes in annual operating costs, and possibly will lead to extra training and management costs and economic benefits or disadvantages. Generally, cost calculations are highly dependent on some *basic data* associated with shipping trade and ballast water treatment. These may include type and characteristics of the vessel, sailing and trading pattern, including aspects like route, distances, speed, sailing and harbour time, and number of voyages per year, volume of ballast water, number of ballast pumps and their capacities, type of fuel used, type of treatment, and treatment capacity. Before making any cost calculation, some basic data, as mentioned above, should be described.

Various researchers and research organizations worldwide have carried out some economic analysis on ballast water treatment methods. The most comprehensive study available today is the recent study by Rigby and Taylor (2001). This study provides some basic information on capital and operational costs for specific ballast water treatment methods, but includes little or no information on crew time, management costs, economic advantages or disadvantages. Besides the lack of standard data for different treatment options, the interest rate and economic life span used in cost calculations are often different. Due to the lack of a common ground for cost calculations, cost data found in literature for treatment alternatives is hardly ever comparable.

Assessment of economic viability

To assess economic viability of the ballast water treatment options to be tested within the MARTOB project, two main cost components are relevant - capital costs and operational costs. In addition to these cost components, cost related to extra training and management and the potential economic benefits or disadvantages will be assessed during evaluation. The type of cost data needed to be able to evaluate the economic viability of the different treatment systems is described in the following paragraphs.

Capital costs

Capital costs reflect the one-time costs incurred to implement a treatment alternative. This may include, the total costs of purchasing the treatment system, and installation and testing cost. Normally investment costs are annualised to be able to sum them with the annual operational costs to yield total costs per year of the ballast water treatment method. In the literature, ballast water treatment options are depreciated and compared based on a time horizon ranging from 5-15 years. Interest rates used for depreciation also vary, ranging from 6% to 10%. It is noted that based on literature sources and information provided by ship owners and associations, there is no single best selection of time horizon possible. As the main purpose of the cost calculations in the MARTOB project is to be able to evaluate economic viability and to compare different ballast water treatment options it has been decided to use a fixed time horizon and depreciation rate of 10 years and 8%.

Operational costs

Operational costs reflect the on-going costs that will be incurred on a yearly basis throughout the economic life span of the treatment equipment. Operational costs can be specified into personnel costs, material costs and maintenance costs.

Personnel costs include costs of personnel involvement to run the treatment system. It should be specified how many personnel hours are involved during ballast water treatment and what the status of the personnel is. To be able to establish a level playing field for cost comparison, personnel costs should be based on a fixed rate per hour for a specific personnel status.

Material costs include costs of all materials needed in the course of system operation; this could involve energy costs and costs of consumables. The treatment system may require energy to operate. Energy use should be specified, for example as kW or GJ per hour. Based on the energy requirement of treatment systems, energy content of fuel and energy conversion factors, the amount of fuel consumed by the ballast water treatment system can be calculated. As in the case of personnel costs, fuel cost should also be based on a fixed fuel price. Consumables could, for example, include chemical additives used for treatment, additional oil use or lubricants. The quantity and required frequency of consumable use should be specified. Based on those figures and a fixed product price, the costs of consumables used can be calculated.

Maintenance costs can be divided into material costs and personnel costs. Treatment systems may require TAM (Turn Around Maintenance), refurbishment, or total overhaul, which may involve the use of spare parts, after some time. It will be necessary to know at what time interval regular maintenance is needed and what wear and tear maintenance is expected. In addition to the material cost involved during maintenance, personnel cost will also be involved. It should be specified if shore based experts will handle maintenance or if engineers on-board can handle it. The time involved for maintenance could also be important. This will especially be the case if the treatment system will be out of order for a certain time and cannot be used for treatment.

Training and management costs
The installation of a ballast water treatment system may lead to extra training for personnel on-board. Training needs can range from a one-hour explanation of the system to a full day instruction of how to operate the system, health and safety precautions and how to register data. *Training costs* should be specified as total costs, hours and personnel involved. *Management costs* could include costs for obtaining certification, costs related to the development of a specific management system or costs from preparation of a safety manual. These costs can be one-time costs or cost that will recur every few years. As a minimum the interval and the amount of the cost should be specified.

Economic benefits or disadvantages
Economic benefits and economic disadvantages of treatment options will have an influence on the total costs of the treatment options. Some treatment techniques may be economically beneficial in the sense that it may reduce the requirement for tank cleaning or it may reduce tank corrosion and hence costs of anti-corrosion treatments. Other techniques might lead to economic disadvantages such as increased ballast water tank cleaning costs, increased corrosion, accelerated deterioration of seals or piping system equipment, delay in the harbour, or cargo space reduction.

CONCLUSIONS

The review showed that there are currently no standard methods available for assessing the biological effectiveness, environmental effects, cost, and safety of ballast water management methods. A review of the literature on biological effectiveness has shown that assessment methods vary and the choice of method can depend on the type of equipment and the interests/expertise of the researcher. For the MARTOB project the approach of using representative taxa of organisms was considered appropriate for the shore based tests. This should allow comparison of the different ballast water treatment methods being developed within the project. The review of environmental effects of treatment methods showed considerable variation among methods, but major categories of impacts were identified. Altered quality of ballast water, energy use, materials use for equipment and maintenance, and potential impacts of spills on receiving water quality will be considered within the MARTOB project. Safety aspects to be considered include hazards during operations related to chemicals and equipment, storage and handling of chemicals and residuals, and hazards related to unintentional release or leaks of ballast water containing residuals on board the ship. The literature review showed that available cost data for treatment alternatives is not usually comparable due to differences in the types of costs included as well as variations in interest rates and economic life span. Within the MARTOB project both capital costs and operational costs will be included - the latter will include estimates for personnel costs, material costs, maintenance costs, and training and management costs. Potential economic benefits or disadvantages will also be considered. A fixed time horizon and depreciation rate will be used for capital costs. The use of standard evaluation criteria within the MARTOB project should allow assessment and comparison of the various treatment methods tested within the project.

ACKNOWLEDGEMENTS

The MARTOB project is partially funded by the Competitive and Sustainable Growth (GROWTH) Programme of the European Commission.

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A filtration and UV based ballast water treatment technology: Including a review of initial testing and lessons learned aboard three cruise ships and two floating test platforms

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SYNOPSIS

The paper reviews the ongoing development of a system for the treatment of ballast water using a solids separation primary treatment and UV light secondary treatment system. The installation and testing of systems aboard three cruise ships is reviewed. Lessons learned from the shipboard and other testing are discussed. A separate test report for medium pressure cross-flow UV treatment on a full-scale shipboard ballast system is included. This ultraviolet light system was capable of inactivating phytoplankton and removing >95% of the total number of zooplankton organisms present.

INTRODUCTION

Full-scale Ballast Water Treatment Systems were installed aboard three cruise ships, one Panamax container ship and one parcel tanker during 2000 and 2001. These systems ranged in capacity from 200 to 350m3/hr ballast water flow rate. They included cyclonic separation of solids as a pretreatment during ballasting and low pressure UV light disinfection, at target dosage rates of 100 to 125 mWsec/cm2, during both ballasting and deballasting. Operation and testing of the systems installed on the three cruise ships has shown that onboard UV treatment, during both ballasting and deballasting, can be effective in removing organisms from ballast water. The level of removal is, however, dependent on the UV dose delivered to the ballast water and the effectiveness of the primary treatment solids removal system during ballasting. Testing both on board ship and separately aboard a test barge in Lake Superior indicated that cyclonic separation is not an effective means of removing larger organisms from the ballast water[1].

The same tests in Lake Superior also indicated that mechanical screen and disk filtration to 100 microns or less was very effective in removing organisms above the rated size of the filter[1]. A new system has been developed employing disk filtration at 50 or 100 microns with automatic back flush as a pretreatment during ballasting and medium pressure UV light disinfection with a target dosage of >200 mJ/cm2 during both ballasting and deballasting. This system has been offered to several ship operators with ballast flow rates between 200 and 300 m3/hr.

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ONBOARD BALLAST WATER TREATMENT

Many existing and proposed onboard ballast water treatment techniques consist of primary and secondary treatment methods. Primary treatment is normally considered to be the removal of larger organisms and suspended solids from ballast water in order to enhance secondary treatment. Secondary treatment is intended to inactivate the remaining organisms, disinfect the ballast water, and render it suitable for discharge.

Performance of shipboard BWT systems is generally based on their biological effectiveness as well as their adaptability to the ballast pumping and piping systems on ships. This paper discusses the ongoing development of a ballast water treatment system intended for ships with ballast water flow rates up to approximately 1000 m3/hr. larger flow rates are possible, but the system would consume a very large amount of electrical power and could be subject to space limitations.

Primary treatment must be accomplished when the ship is ballasting. Sediments and larger organisms that are removed can normally be returned to the ballasting port. When used for onboard ballast water treatment, filters must have automatic back-flush capability to meet the requirement of unattended automatic operation. The Great Lakes Ballast Technology Demonstration Project (GLBTDP) concluded that filtration with automatic back-flush screen and disk filters was feasible with existing technology down to about 50 microns[1]. Based on the information available, it is the authors' judgment that disk filtration to 50 to 100 microns should be sufficient primary treatment to allow for effective secondary treatment with medium pressure ultraviolet light or other technologies.

UV irradiation has been the subject of laboratory and pilot plant testing on a range of marine organisms with relatively positive results. UV works by damaging parts of the organisms' DNA. The biological effect depends on the dose, which is normally expressed as mWsec/cm2 and is dependent on power, exposure surface, flow rate and distance from the UV source. With the correct dose of UV, viruses, bacteria, and most types of zooplankton and phytoplankton can be killed or rendered nonviable.

INITIAL TESTING OF SOLIDS SEPARATION AND UV SYSTEMS

A Ballast Treatment System, using cyclonic separation and low pressure UV, was installed aboard the cruise ship *Regal Princess* in early April of 2000 and was sized to treat the full ballast pump flow of 200 m3/hr. It underwent its initial performance testing in the spring and summer of 2000. Similar systems were installed on two other cruise ships in 2001 treating ballast flows of 220 and 255 m3/hr. Onboard testing was conducted on the *Sea Princess* in the fall of 2002.

The GLBTDP 2000 barge test program also tested a cyclonic separator with low pressure UV light. The barge test system used the same components as those on the *Regal Princess* and *Sea Princess*, but scaled up to the barge flow rate of 1500 USGPM (approx. 350 m3/hr). Preliminary findings of *Regal Princess* and GLBTDP testing programs are discussed in a paper presented at the Marine Environmental Technology Symposium (MEETS) in 2001[2].

The results of the 2000 shipboard and barge testing were positive and indicated significant removal of microorganisms. The results, however, do not appear to meet the recently suggested IMO MEPC standard of 95% removal of all organisms. Later barge testing in 2001 also indicated that filtration using a disk or screen filter is much more effective as a UV pretreatment than cyclonic separation[1].

In the summer of 2001, scientists from the Univ. of Maryland conducted testing on several ballast water treatment technologies including medium pressure UV light. The testing was conducted aboard the *Cape May*, a Ready Reserve Fleet (RRF) ship operated by the US Maritime Administration (MARAD). The results of the UV irradiation testing without pretreatment are presented in the Appendix. These results indicate that medium pressure UV at the 200mWsec/cm2 dosage rates tested and with the addition of effective pretreatment to remove the larger more UV resistant organisms should result in removal of organisms very close to the 95% level suggested by IMO. The *Cape May* testing also did not include a second UV treatment of the ballast water as it was being discharged from the tanks. This second treatment should further reduce live zooplankton and phytoplankton populations and eliminate in excess of 95% of any bacteria that may have resulted from the initial kill of other organisms or from regrowth in the ballast tanks.

LESSONS LEARNED

Several important and helpful lessons were learned from the installation, operation and testing aboard the *Regal Princess* and other cruise ships and from the related GLBTDP barge testing and the UV testing aboard the *Cape May*. These lessons have led to the development of a new and more effective BWT system using 50 or 100-micron auto backflush disk filtration and medium pressure UV. The result will be more effective reduction of non-indigenous species, bacteria and pathogens and a more suitable and acceptable system for trouble free shipboard installation and operation.

1. A treatment system based on separation of solids and UV irradiation will perform reliably aboard an operating commercial ship. The three cruise ship installations were completed without major problems and without interfering with the normal operation of the ship.

2. The system works equally well during ballasting and deballasting. UV treatment should be carried out during deballasting as well as ballasting. The onboard tests indicated that there is significant regrowth of bacteria in the ballast water while it is resident in the ballast tanks[3]. UV irradiation during deballasting also increased zooplankton mortality[3]. The *Cape May* tests indicated that some bacteria might be released as a result of the initial UV treatment (results not shown here). Therefore, a second UV treatment of the ballast water as it is pumped off the ship is desirable.

3. Cangelosi et al. (2001) reported that the UV transmittance of source water, especially resulting from dissolved compounds, which cannot be removed with physical separation devices, strongly influences system performance[3]. This is an exceptionally important lesson for equipment designers. Future systems must be rated on the basis of the minimum expected UV transmittance.

The medium pressure cross-flow design Aquionics UV, used in the *Cape May* tests and included in the new ballast water treatment system discussed here, should perform much more effectively for the treatment of ballast water where UV transmissions can vary widely. The water is always much closer to the UV light source and receives a higher dosage, although for a shorter time, than in axial flow UV chambers.

Another factor affecting performance of low pressure UV light is the water temperature. The optimum water temperature is 70°F. Ballast water temperatures above or below 70°F, which is often the case for seawater, will result in a drop in the UV output for low pressure UV lamps. Medium pressure lamp UV output is not affected by water temperature.

4. The UV dosages available during the *Regal Princess* and barge testing were not 100% effective against the microorganisms encountered, based on the test results[3]. Since specific standards are not yet available to establish the required system effectiveness against various types of biological life, it is difficult to choose an appropriate UV dosage rate. One suggested IMO standard would require reductions of 95% of all organisms. The performance of the medium pressure cross-flow system on the *Cape May* indicates that removal of greater than 95% of organisms should be achievable with medium pressure UV light with an effective pretreatment and irradiation during both ballasting and deballasting.

5. Feedback from Princess Cruises and from other owners and operators, considering the installation of ballast water treatment systems, has confirmed that simplicity and minimum operator attention are primary considerations. Fully automatic hands off operation and reliability will be important parts of ballast water treatment system specifications. Cleaning the quartz tubes containing the UV lamps was a significant maintenance requirement on the initial shipboard installations. The Aquionics cross flow design incorporates an automatic tube wiping device and an inspection hatch to minimize the need for cleaning.

6. Problems were encountered on several ships due to vibrations, corrosion, and electrical interference. Any system developed for shipboard installation must be robust, properly installed and designed to handle the shipboard physical and electrical environment. The components on the new system are robust and proven in many similar applications.

7. Testing conducted on the GLBTDP barge using automatic back flushing filtration alone and followed by UV established that filtration followed by UV combines the effectiveness of filtration against zooplankton and some phytoplankton, with the biocidal effects of UV on microbes and smaller phytoplankton[3]. This, together with the results of the *Cape May* tests, has led to the development of the new ballast water treatment system described above and shown in Fig. A.

CONCLUSIONS

Filtration followed by medium pressure UV light irradiation appears to be the most practical non-biocide treatment alternative at the present time. Simplicity, reliability and fully automatic operation are essential for shipboard treatment systems.

Testing aboard the *Regal Princess, Sea Princess* and the GLBTDP test barge and the test program with medium pressure UV light described in the Appendix have provided valuable efficacy information for the filtration and UV irradiation treatment method. They also provided essential feedback for further development and a solid basis and model for future full-scale installation and testing projects.

Standards for onboard testing must be finalized and agreed as soon as possible. Treatment technologies must undergo continuing development and improvement to ensure the most effective solution.

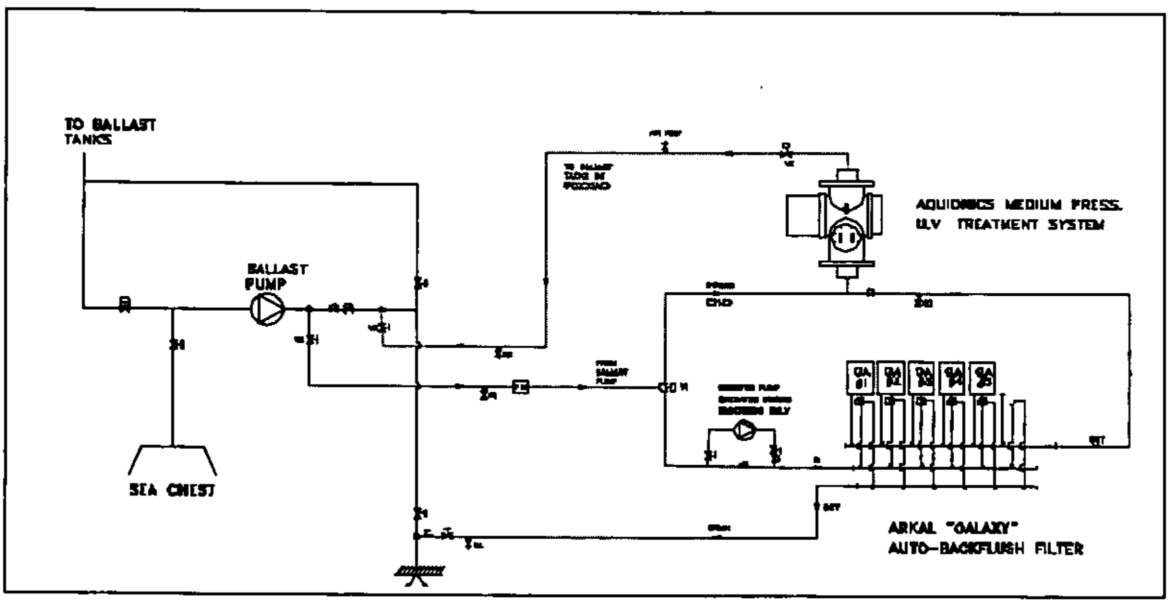

Fig. A Typical shipboard ballast water treatment system with auto-backflush filter and medium pressure UV light

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APPENDIX

Results of Experiments Conducted Aboard the MARAD Vessel *Cape May* in Baltimore Harbor, 2001.

Brief Synopsis of Experiment

Experiments were conducted during September 2001 using an Aquionics 32 kW ultraviolet irradiation system mounted in line (upstream) from the ship's ballast pump operating at 1450 gallons per minute. The system contained sixteen 2 kW medium pressure mercury lamps. Water samples were collected from twin ballast tanks (8P & 8S), which received, respectively, treated and untreated water. Treated and untreated water was also directed to 200L plastic mesocosms mounted in the machinery space and filled concomitantly with the ballast tanks. Samples were taken from both ballast tanks and mesocosms 24 and 48h following ballasting.
Live/dead counts were made of zooplankton using microscópic examination of 20μm filtered samples within one hour of collection. Growth potential of ambient phytoplankton assemblages in treated and untreated samples was measured by chlorophyll a analysis of water before and after exposure to fluorescent lights. Culturable bacteria were determined by standard plate counting techniques using appropriate sterile procedures. Colony counts were made on treated and untreated samples following up to 72 hours incubation on Petri Pads impregnated with marine broth. A more detailed account of the methodologies employed in the determination of biological end-points is given by Wright and Dawson[4] (2002). Data from bacterial studies will be reported elsewhere.

Ultraviolet Irradiation

Zooplankton

Two experiments were completed at nominal dose rate of 200mW sec cm^2 at flow rates through the system of 1450 gpm. At this dose total zooplankton mortalities in mesocosms at 24h and 48h post-exposure were 94.4 % and 98 % respectively (figure 1). Corresponding zooplankton mortalities in ballast tanks were 92.8% and 95% respectively (figure 2). Overall control mortalities in mesocosms were 6.0% after 24h and 9.4% after 48h (figure 3). Control mortalities in the ballast tank were 12.2% after 24h and 30.8% after 48h (figure 4).

Phytoplankton

UV irradiation at 200mW sec cm^2 resulted in greatly reduced phytoplankton growth relative to unexposed control water. Results from water samples taken immediately following treatment and from samples taken after a 24-hour latency period will be presented elsewhere.

Fig. 1 Mesocosms. UV exposure

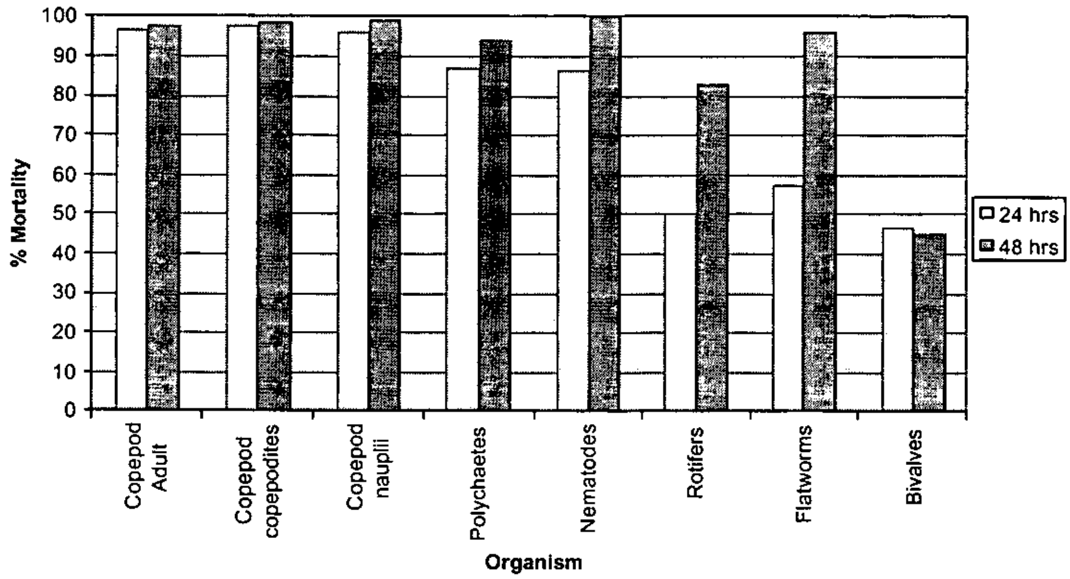


Fig 2. Ballast Water Tank- UV Exposed Populations

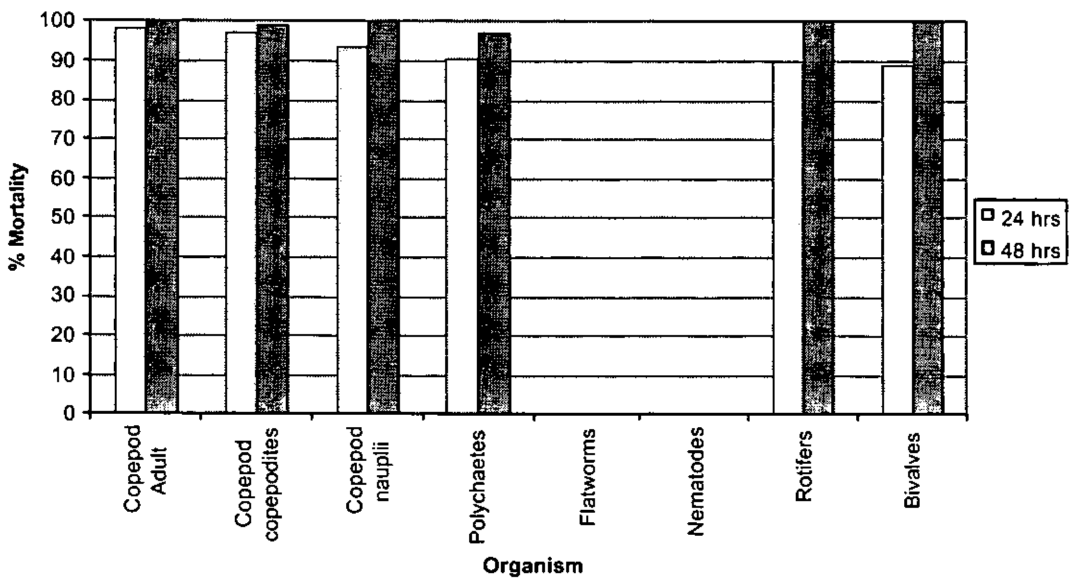


Fig 3. Mesocosm UV Exposure Control

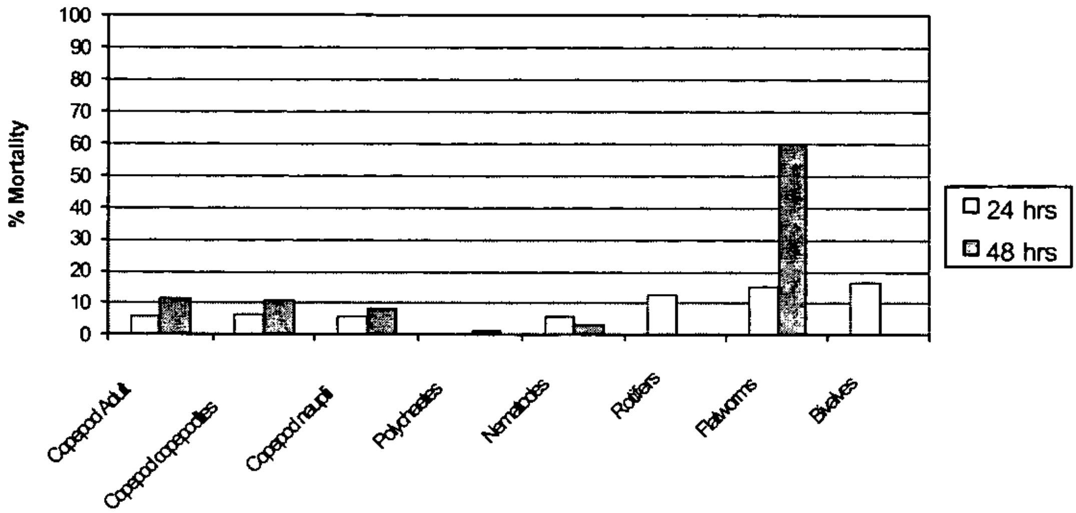
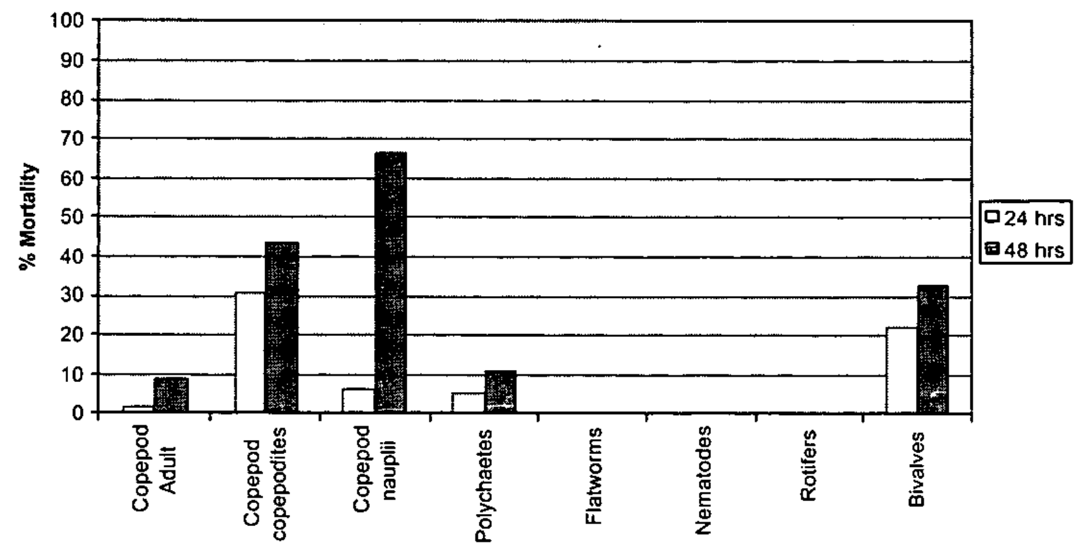


Fig 4. Ballast Tank Control



Biological de-oxygenation of ballast water

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SYNOPSIS

Ballast water has been recognised as a major vector for the transplant of aquatic species across bio-geographical boundaries. In order to minimize the risk of transfer, it will be necessary to treat the ballast water so that most of the organisms in the water are killed or removed. The solubility of oxygen in water is low, but due to the low metabolic activity in the water, ballast water will not normally become anoxic even after a long time (weeks) in the ballast tank. By adding nutrients to the ballast water, the growth of the indigenous bacteria in the water can be stimulated, and the ballast water will become anoxic. Most higher aquatic organisms require a steady supply of oxygen, and only a few species will survive without oxygen for extended periods (more than 3-4 days). Biological de-oxygenation may thus be used to kill higher organisms in ballast water. Advantages include small requirements for retrofitting onboard the ship and low treatment costs. However, the method will generally not kill bacteria or different resting bodies (spores, cysts, etc.), and the efficiency against vegetative cells of microalgae is unknown. The applicability and efficiency of the method is currently being evaluated in the MARTOB project.

INTRODUCTION

There is a growing concern about the damage to aquatic ecosystems caused by immigration of non-indigenous species. It is estimated that more than 10 000 million tonnes of ballast water is transported by shipping activities annually, and ballast water has been recognised as a major vector for the transplant of marine species across bio-geographical boundaries. Most transported species do not survive in the new environment, but those that do, quickly adapt and often thrive at rates beyond natural control of competitors and predators. This has caused great damage to local ecosystems and can lead to enormous economic losses. In order to minimize the risk of transfer, it will be necessary to treat the ballast water so that most of the organisms in the water are killed. In the MARTOB project several different treatment methods for ballast water are examined, including biological de-oxygenation.

DISSOLVED OXYGEN IN WATER AND BALLAST WATER

Biological de-oxygenation is based on the fact that the solubility of oxygen in water is low. In distilled water at 10 °C, the saturation level is 11.3 mg/L. The solubility decreases both with increasing temperature and with increasing salt concentration. In seawater (35 S) at 25 °C the saturation level is 6.8 mg/L. Hypoxic water is often defined as water containing less than 2.9 mg/L, while anoxic water contains no oxygen.

Despite the low solubility, ballast water does not usually become anoxic during transport. Immediately after the water has been pumped into the ballast tanks, the oxygen concentration will reflect the water it was pumped from. In surface seawater the dissolved oxygen level is close to the expected saturation level for the temperature and salinity of the water, but usually about 3 % supersaturated due to bubble injection and photosynthesis[1]. During transport, respiring organisms in the ballast water will consume oxygen, while oxygen in the headspace above the ballast water will diffuse into the water to replenish the consumed oxygen. The amount of oxygen in the headspace will depend upon the degree of filling of the ballast tank, but can be considerably higher than the amount dissolved in the water. If the ballast tank is 90 % filled, and the headspace contains air, the headspace has 3-4 times more oxygen than what is dissolved in the ballast water. However, the rate of transfer of oxygen from the air in the headspace and into the ballast water will be low. Therefore, if the rate of oxygen consumption in the water is high, the bulk of the water may become anoxic long before all the oxygen in the headspace is consumed.

In a study of ballast water arriving at the Sture oil terminal on the west coast of Norway from April 1996 to September 1997, the ballast water from 30 vessels from all major geographic areas were examined[2]. The age of the ballast water was from 2 to 18 days, and the oxygen content ranged from 6.8 – 14.0 mg/L, *i.e.* well above the hypoxic limit of 2.9 mg/L. The

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temperature and salinity ranged from 5.5 – 23.4 °C and 1 – 37 S, respectively. No significant correlation between the age of the ballast water and the oxygen content was observed. Most of the examined ballast waters were supersaturated when the temperature and salinity of the waters were taken into account, with an average saturation level of 110 ± 16 %.

BIOLOGICAL DE-OXYGENATION

All natural waters contain bacteria. Biological de-oxygenation is based on addition of a nutrient solution to the ballast water to stimulate the growth of the indigenous bacteria in the water. As a result, the water will become depleted in oxygen and organisms that require a steady supply of oxygen will die. The process has been demonstrated in laboratory scale with seawater from the Trondheim Fjord (Fig. 1). In these experiments the viable count of bacteria increased from $0.3\text{-}8 \cdot 10^4$ cfu/ml to $2\text{-}8 \cdot 10^6$ cfu/ml in the tanks with added nutrients, while it remained unchanged in the control tanks. In some experiments the brine shrimp *Artemia salinas* or the rotifer *Brachionus plicatis* were added to the tanks. Both species apparently died (visual observation only) when the water in the treated tanks became anoxic, while they were still alive 24 to 72 hours later in the control tanks.

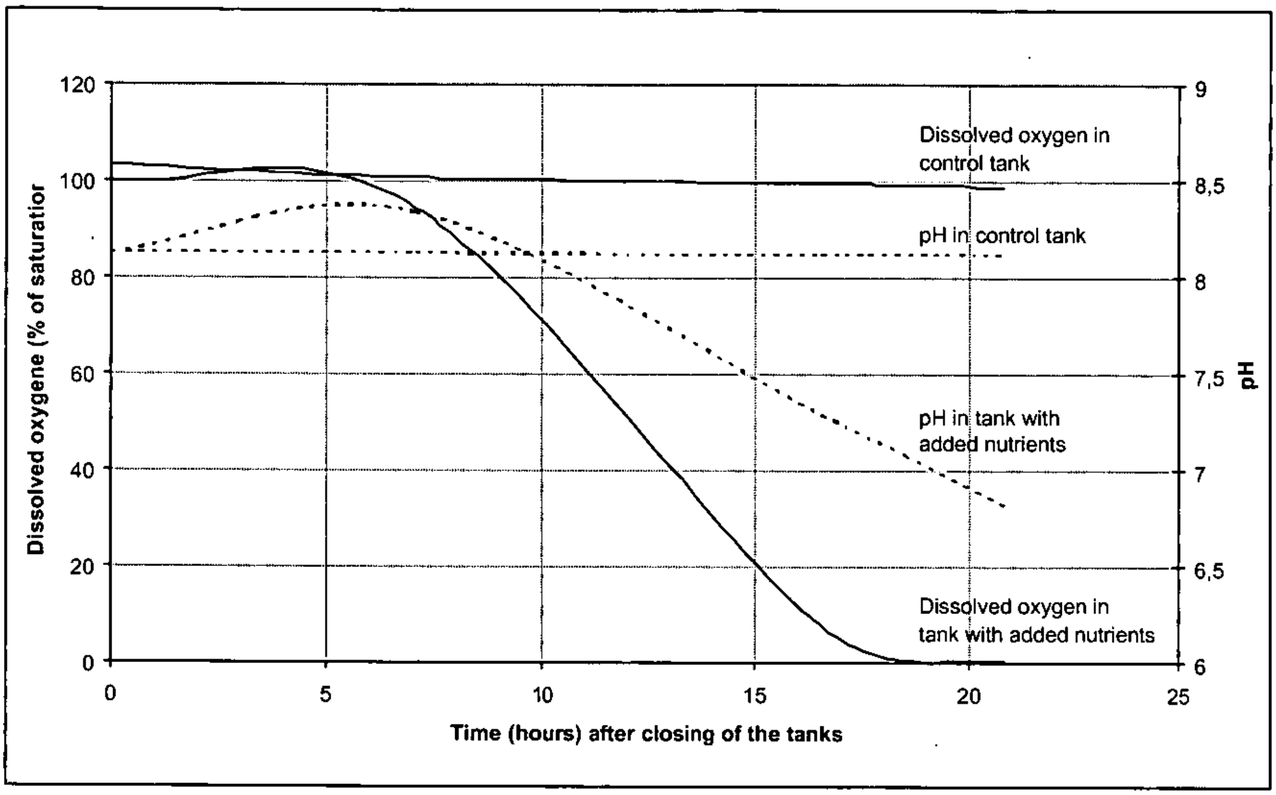

Fig. 1 Dissolved oxygen and pH as a function of time in seawater with and without added nutrients and enclosed in a 3 liter jar-fermentor

Because biological de-oxygenation is based on the growth of the indigenous bacteria in the water, the rate of the process will depend upon the temperature of the water. In the above laboratory experiments it took about 1 day at 15-20 °C to obtain anoxic conditions. Assuming $Q_{10} = 3$, it then should take about 3 days at 5 °C.

The practical application of the method should be simple. The ship will be equipped with a tank containing a concentrated nutrient solution. From the tank a given amount of concentrate, defined by the amount of ballast water, is pumped into the ballast tank. A preliminary estimate indicate that one liter concentrate should be enough to treat 10-15 m^3 ballast water, and the cost of the treatment should be less than 0.1 EUR/m^3 ballast water.

The efficiency of the process will depend upon the sensitivity of the different organisms to anoxic conditions (discussed below). Once oxygen has been depleted, sulphate-reducing bacteria (SRB) in the seawater may start to produce H_2S. This is an extremely toxic gas and may pose a threat to the crew as well as to other organis ms when the ballast water is discharged. The activity of the SRB may also lead to increased corrosion. However, by adding nitrate to the ballast water it should be possible to control and minimise the activity of SRB. The removal of oxygen should in itself lead to less corrosion[3]. The main environmental concern with the method is the release of ballast water with an increased content of nitrogen and phosphorus.

The aim of the studies of biological de-oxygenation in the MARTOB project is to assess the applicability and the efficiency of the method. This include both laboratory and onboard studies, as well as theoretical assessment of efficiency, environmental impact and ship and crew safety.

ANOXIC TOLERANCE OF AQUATIC ORGANISMS

The anoxic tolerance of aquatic organisms varies from organisms that will die if oxygen is present to organisms that will die if they are deprived of oxygen for more than a few minutes. The tolerance of the marine macrofauna (fishes, crustaceans, molluscs, etc) towards low oxygen levels have recently been extensively reviewed[3-5]. In a comprehensive, but rather old treatiseon marine ecology from 1972, the anoxic tolerance of microorganisms and the meiofauna is also discussed[6].

Fishes

Most fish species will die if deprived of oxygen for more than a few minutes or hours. Generally the threshold for asphyxia seems to be in the range of 0.8-1.4 mg/L, but many will also die if exposed to levels of 1.5-3 mg/L for extended periods (hours to days). The most tolerant species, such as some flatfishes, seem to require an exposure time to anoxia of around 24 hours for 50 % mortality (LT_{50}). The sensitivity of fish eggs and fish larvae to low oxygen levels does not seem to be very different from the sensitivity of adult fishes.

Invertebrates

The invertebrates include a large number of different phyla such as Annelida (worms), Porifera (sponges), Mollusca (bivalves, gastropods, etc.), Cnidaria (sea-firs, sea anemones, jellyfishes, corals), Ctenophora (comb jellies), Platyhelminthes (flatworms), Echinodermata (starfishes, brittle stars, sea urchins, etc.) and Arthropoda (crustaceans, insects, spiders). They are often divided into macrofauna and meiofauna. The latter is defined as animals that pass through a sieve with a mesh diameter of 0.5 mm.

The ability to survive anoxia varies considerably within the invertebrate macrofauna. Particularly molluscs can often tolerate anoxia for very long periods (LT_{50} = 4-85 days), due to their special hibernation response. Next to the outstanding ability of molluscs (and some specialists of other taxa) to resist anoxia, come some annelids (worms) (LT_{50} = <55-120 hours) and echinoderms (LT_{50} = 35-90 hours), while crustaceans are most sensitive (LT_{50} = 1-91 hours). However, based on ecological studies, Diaz & Rosenberg[4] conclude that polychaetes (bristle worms) are the most tolerant taxa towards hypoxia, followed by bivalves, and then crustaceans. This indicates that one should separate between the ability to tolerate hypoxia and the ability to survive anoxia.

While many adult molluscs can survive very long periods of anoxic conditions, the veligers (larvae), which are much more relevant with respect to transport in ballast water, are much more sensitive with LT_{50} in the range of 10-50 hours depending on the development stage and body size.

Some invertebrates produce cysts or other resting bodies that may be very tolerant of anoxia. The cysts of the brine shrimp *Artemia franciscana* can survive more than 6 years of anoxia[7]. The gemmules, asexual survival and dispersion bodies, of the freshwater sponge *Ephydatia muelleri* can survive anoxia for more than 112 days[8].

Little is known about the tolerance of the invertebrate meiofauna to anoxic conditions. Studies of the meiofauna and macrofauna in the same area (reviewed in ref. 4) show that the meiofauna is more tolerant to hypoxic conditions than the macrofauna. The most tolerant group in the meiofauna seems to be the nematodes, while harpacticoids are much more sensitive to hypoxia, indicating that the tolerance is to some extent related to taxonomic group and not size only.

Seaweeds

Seaweeds are macroscopic algae, and an important part of the flora of intertidal and subtidal zones of the seashore in many regions. Little seems to be known about the ability of seaweeds to survive in a dark, anoxic environment. Cawthron Institute reported that sparging seawater with nitrogen was effective in killing zoospores of the seaweed *Undaria pinnatifida*[9].

Microorganisms

Microorganisms are microscopic organisms consisting of a single cell or cell cluster. The main groups are bacteria, archea, protozoa, fungi, slime moulds, microalgae and viruses. In connection with ballast water, it is particularly the transfer of micro algae such as dinoflagellates that can cause toxic blooms that have been focused. Microalgae are primarily phototrophic, but many species are capable of heterotrophic growth in darkness. However, this growth usually requires oxygen, and the algae will not grow under dark, anoxic conditions. How bng they survive is another question. According to Vidaver[10] most marine algae succumb rapidly in the dark if given insufficient amounts of oxygen. A few are, however, able to ferment sugars anaerobically in the dark and may thus withstand extended periods of exposure to oxygen free media. Many species of microalgae also form sexual and/or asexual resting spores or cysts. These are not likely to be affected by the presence or absence of oxygen.

Biological de-oxygenation is based on the stimulation of the growth of the indigenous bacteria in the water, and de-oxygenated ballast water will have an increased concentration of bacteria. However, the increase will most likely be due to the growth of "harmless" opportunistic bacteria, not pathogens that usually require more specific growth conditions.

DISCUSSION AND CONCLUSIONS

Biological de-oxygenation is based on addition of nutrients to the ballast water to stimulate the growth of the indigenous bacteria in the water. This should make the ballast water anoxic after 1-3 days depending on the temperature, and organisms that require a steady supply of oxygen will then start to die. However, in order to kill a substantial part of the sensitive species, anoxic conditions should be maintained for at least 2-3 days. Thus, the method is best suited for ballast water that is transported over long distances and/or kept in the tanks for a longer period (4-6 days or more). On the other hand, biological de-oxygenation is a low cost solution that requires a minimum of retrofitting aboard the ship, can be used for all types and volumes of ballast tanks, and requires very little crew training and crew time. Because of the low requirement for retrofitting, the method may be particularly suited for existing ships where it may be difficult to find room for more space demanding treatment systems.

De-oxygenation will most likely be very efficient towards most fishes and crustaceans provided anoxia is maintained for a few days. Crustaceans are among the most abundant higher organisms in ballast water. Echinoderms and annelids may require a somewhat longer anoxic period (1-2 weeks) to be killed, while many adult molluscs can tolerate long periods of anoxia and will most likely survive de-oxygenation of ballast water. However, the larvae, which are much more relevant with respect to transport in ballast water, are much more vulnerable to de-oxygenation.

De-oxygenation will not kill all organisms in ballast water. Bacteria, fungi and viruses, as well as different resting bodies (spores, cysts, etc.) are not likely to be affected. The effect on seaweeds and vegetative cells of microalgae is not known.

In order to avoid excessive H_2S production once the water becomes anoxic, careful composition of the nutrient solution is required. The main environmental concern with the method is the release of ballast water with an increased content of nitrogen and phosphorus.

ACKNOWLEDGEMENTS
The MARTOB project is partially funded by the European Commission (under the Competitive and Sustainable Growth (GROWTH) Programme). The biological de-oxygenation part of the project is also partially funded by Norsk Hydro ASA.

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An advanced oxidation technology for decontamination of ballast water

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SYNOPSIS

An advanced oxidation technology (AOT) is a combination of two or more oxidation / reduction systems. BenRad's AOT is a combination of ozone, UV and catalysts and involves the in–situ generation of hydroxyl radicals (OH). This is a new and patented technology. Low pressure mercury UV lamps with two different wavelength spectra, 185 and 254 nm, are used. At 185 nm ozone is produced in the water by utilising the oxygen dissolved in the water. Catalysts are coated on the inside of the unit and thus exposed to UV radiation. The water purification units are made of titanium.

Hydroxyl radicals are generated in three ways:

- UV-light hits the catalyst surface and electrons are exited leading to radical formation
- Ozone in water generates hydrogen peroxide which UV breaks down to radicals
- UV-light hits ozone in water and ozone breaks down to singlet oxygen and oxygen; singlet oxygen can form radicals in the water.

Hydroxyl radicals are very aggressive and short-lived (nanoseconds). When a molecule is attacked a chain reaction starts which does not stop until the microorganisms are decomposed into carbon dioxide and water. No OH radicals, ozone or other chemicals or by-products are present in the treated water leaving the purification unit.

The BenRad AOT destroys microorganisms including virus, protozoa, fungi, algae. For treatment of ballast water the BenRad AOT units should be used on board for decontamination of the water during ballasting and again during deballasting.

INTRODUCTION

The broad objective for the treatment of ballast water is to eliminate or destroy organisms which are harmful to humans and animals or interfere with ecosystems in the regions where deballasting will take place. When selecting a method of treatment, the target organisms and the quality of the water have to be taken into account. Other parameters are the time elapsed between ballasting and deballasting, water temperature, pH, turbidity, and flow rates required. The generation of toxic by-products, chemical safety, cost and ease of handling also have to be considered.

There is probably not yet a single decontamination technology that satisfies the needs entirely for all types of marine vessels. Thus, regardless of decontamination procedure preferred in the particular ballast water treatment situation, it has to be a combination of two or more purification systems in order to reach the degree of purity that is required. The design parameters for the treatment stage will be specific to the installation concerned.

Direct transfer of experience and data from one marine application to another is not always possible. The various water parameters and the physical and technical aspects may differ from one marine vessel to the other.

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Consequently, there is a dear need for a basic look at several components of the design of the ballast water treatment units with respect to the objectives to be reached.

Meshes and strainers are available in many sizes. They can be custom-made to fit as a pre-filter to any other purification system. Filters, of at least one type or configuration, are almost always used upstream any additional decontamination method.

While there is a growing interest in disinfection by means of Advanced Oxidation Technologies (AOT), chlorination remains the overwhelming choice for water treatment in general. Sodium- or potassium hypochlorite are used. The amount needed for desired disinfection is strongly pH dependent A comprehensive recording system has to be used when using chlorides. The advantages of using chlorine dioxide over other Cl-compunds as a disinfectant are: it is in general more effective, it does not react with bromide compounds to form bromine or bromate, it is effective in reducing Zebra mussels [1]. Chlorine dioxide is unstable and therefore has to be generated at the point of use. In some regions, *e.g.* The Netherlands, Germany, Italy, Denmark, the use of chlorides have been restricted and dramatically reduced, due to the toxicity of chlorides and the by-products formed. Further restrictions of the use of chlorides are to be expected.

Reactions in which atoms undergo changes in oxidation number are known as redox[2]. Ozone (O_3) is a strong oxidant and the sterilisation speed is much faster than that of chlorides. O_3 is rapidly decomposed leaving no residuals. A problem is to take care of the ozone that is not solved in the water. Ozone reacts with many of the compounds in water either through molecular ozone or by hydroxyl radicals (•OH) formed during ozone decomposition [3,4,5].

UV disinfection has gained widespread use in the water treatment field throughout the world due in part to concerns over the toxicity from chemical disinfectant residuals and over transport, storage and dosing of chemicals. UV radiation of wavelength between 240 and 290 nm penetrates the cell and cell nucleus, and causes the death of the organism [6].

UV light is generated in a UV reactor and acts within a relatively small irradiated water volume. Two factors play a decisive role with UV disinfection: irradiation time and intensity. Each organism when passing through the irradiation chamber shall be exposed to at least 40 mJ/cm^2 to guarantee an inactivation of more than 4 decimals [6].

Recently there has been great interest in the use of the combinations H_2O_2/UV and O_3/UV processes, referred to as advanced oxidation technology (AOT) . Also H_2O_2/O_3/UV has been used with excellent results due to the effective formation of OH radicals. A radical is any species – atom or molecule – capable of independent existence and containing one or more unpaired electrons. An unpaired electron is one that occupies an atomic or molecular orbital by itself. Such an electron will as soon as possible – often within nanoseconds – gain an electron from somewhere in order to be paired. New radicals are formed by the loss or by the gain of a single electron from a non-radical and a new radical may be formed, a chain reaction has started[4,7,8,9,10].

THE ADVANCED OXIDATION TECHNOLOGY USED BY BENRAD MARINE TECHNOLOGY

Advanced Oxidation Technologies have emerged as an important class of technologies for accelerating the oxidation and thus the destruction of a wide range of organic contaminants in polluted water.

The AOT used by the company BenRad Marine Technology consists of a combination of O_3/UV/catalysts. The ozone is generated directly in the water by means of UV radiation. Conventional low pressure Hg UV lamps generate the maximum energy level at 254 nm wavelength. Lower wavelength UV emissions are lost as a result of absorbance by impurities in the quartz envelope of the lamp and the quartz sleeve around the lamp. Specially developed lamps with very pure quartz material are able to maximise the 185 nm emission, giving the lamp significant energy output at 185 and 254 nm wavelengths. The 185 nm emission forms O_3 in water provided there is enough oxygen dissolved in the water [11]. O_3 is instantly decomposed by the 254 nm, and OH radicals are formed [8]. These hydroxyl radicals have a high oxidising potential and are short-lived (nanoseconds). The oxidising effect is performed in the same moment as the radical is formed. The $O_3/UV/TiO_2$ combination, often named as a photocatalytic reaction, has been found to be most effective, due to the fact that large amounts of OH radicals are formed within a titanium reactor. This AOT arrangement is covered by BenRad's patent, Swedish patent no 504 204/1997.

Of the catalysts used in the BenRad system the semiconductor titanium dioxide (TiO_2) plays a major role. TiO_2 absorbs UV light of a special wavelength, this leads to the formation of an electron-hole pair (e^-, h^+) and ensuing reduction (e^-) and oxidation (h^+) [4].

The decontamination of water by AOT processes of the organic contaminants is affected by some practical considerations limiting the purification process. Such limiting factors are: a wide range of pollutants present in different concentrations, flow rate of the water (exposure time), temperature of the water and the quality of the pre-treatment (filtration) systems used upstream the AOT purification unit.

The action of radicals on contaminants is a complicated chemical and physical field and is only partly understood. When a number of various contaminants are present in the water the outcome of the purification process is difficult to predict. Laboratory experiments and pilot plant studies have often to be done using the polluted water in question before any full-scale plant can be considered. Nevertheless, a number of plants and installations are presently in successful operation. Decontamination results are achieved that may satisfy a number of situations.

DOCUMENTATION

A summary of tests performed on the BenRad AOT water purifiers is given in this section. The tests have been made on small water purification units called M 28 and M 74. Most of these tests have been performed by official institutions, their full reports can be sent on request.

BenRad's products are CE labelled (Communauté Européenné) and fulfil Lloyd's Register Approval.

Radical yield measurement

At the Royal Institute of Technology in Stockholm a chemiluminescence method was used for detection of hydroxyl radicals. Gamma irradiation was used to quantify the radicals. A linear increase of OH radicals was obtained with time, indicating a continuous generation of radicals in the reactor chamber. It was therefore confirmed that the BenRad water purifiers generate radicals.

Corrosion measurements

In order to study the degree of corrosion on steel that can be caused by the BenRad AOT some tests were performed. At Volvo Company in Skövde the rate of corrosion was tested in a cooling tower after the installation of a BenRad water purifier; the Linear Polarization Resistance was measured. The corrosion rate was found to be 0.014 – 0.015 mm per year, which means 0,14 mm during a period of 10 years. That is considered to be a low corrosion rate.

Oxidation

The removal of dyes from the water is an indirect method indicating the degree of oxidation. Alizarin red, Phenol red, Toludine blue, Eosin yellow, Eosin blue, Brilliard blue, Cresyl violet acetate and Methylene blue was tested. Small amounts of the various colour pigments mentioned were added to the water in a tank containing 20 l of water. The water was circulating through the BenRad water purifier. A significant reduction of the colour intensity was observed after 5 minutes, after 3 hours all the colour was removed.

The system obviously consumes oxygen in its advanced oxidation process. The dissolved oxygen in the water is the main source for ozone generation, which in turn produces radicals. The concentration of oxygen in the water is temperature dependant. In the temperature range between 5 to 40° C the concentration of oxygen varies from 15 ppm to 5 ppm. An obvious risk appears in a closed circulating system where the dissolved oxygen gradually is reduced to a point where the low oxygen concentration undermines the generation of ozone. It is, however, not the only radical generation process in the BenRad AOT for water purification as has been described above. It is of course easy to add oxygen to the water.

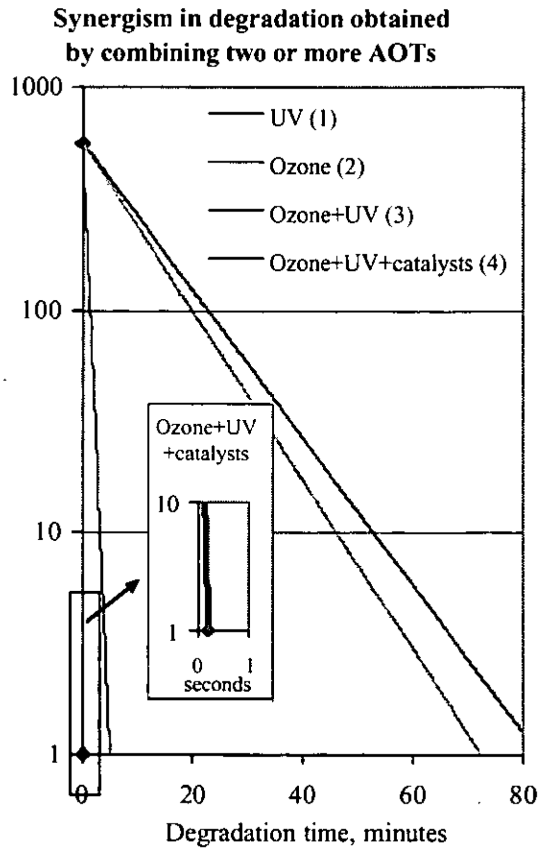

Fig. 1 The diagram shows the decomposition time of an organic compound by means of UV oxidation (1), ozone oxidation (2) and the synergism obtained when UV and O_3 oxidations are used simultaneously (3), and when the BenRad combination of UV, O_3 and catalytic oxidations is used simultaneously (4).

Microorganisms

The bacteria-reducing effect of a BenRad water purifier was tested by the Department of Clinical Bacteriology at Göteborg University. The following bacteria were tested: *Eschericia coli, Streptococcus (Enterococcus) faecalis, Salmonella enteritidis, Campylobacter jejuni and Legionella pneumophila.* The conclusion of the report is: "The BenRad water purifier has a very marked bacteria-reducing effect on the bacteria being tested in water".

Similar tests were carried out at the SIK Foundation in Göteborg. The bacteria tested were *Staphilococcus aureus, Listeria innocua, Aeromonas hydrophila, Yersinia enterocolitica and Baccilus cereus.* The following fungi was also tested: *Aspergillus niger* and *Saecharonyces cereviciae.* The report concludes that "the concentration of the bacteria and fungi used in the tests decreased very fast".

At the Laboratory of Parasitology, Statens Serum Institute in Copenhagen, the reduction of *Cryptosporidium parvum* was tested in water circulating through a BenRad water purifier. The report concludes: "The BenRad device effectively destroys *Cryptosporidium parvum* ocysts with a reduction of *Cryptosporidium parvum* oocysts of 99.98% after 3.5 hours exposure".

The destruction of poliovirus was tested at the Department of Virology, Statens Serum Institute in Copenhagen. The report concludes: "The capacity of BenRad water purifier to inactive poliovirus has been tested in one type of experiment which was repeated twice. In three out of four samples tested no virus could be detected, but in one sample a small amount of virus was traced. However, in all four samples the reduction of live poliovirus was more than 4.60 Log_{10} $^{-10}$".

The Agriculture University of Norway in Oslo tested the destruction of *Tobacco Mosaic Virus*, *Tobacco Necrosis Virus* and *Tomato Bushy Stunt Virus*. For *Tobacco Mosaic Virus* there was a reduction of 2 log after 20 minutes; for the other two types of virus tested the reduction was 5 log after 10 minutes. Spores *Phytophthora palmivora*, *Phytophthora cactorum* and *Fysarium avenaceum* were also "eliminated very fast".

The tests on various plankton species, which have been made at MARTOB in Newcastle in the Summer 2002, will be published elsewhere.

BenRad water purifiers are installed in a number places. Such installations are at tanks for drinking water, cooling towers, jacuzzis, swimming pools, gardens, fish industries, chicken farms etc. The efficiency is monitored continuously or at regular intervals in all installations.

THE BALLAST WATER PURIFICATION UNIT *AD MODUM* BENRAD MARINE TECHNOLOGY

A prototype has been constructed to be tested at MARTOB onboard a vehicle transport vessel. This prototype is made for a flow rate of 200 – 400 $m^3 h^{-1}$. The unit can be enlarged, and several units can also be combined, to meet the flow rates required. The decontamination of the ballast water shall be done at the ballasting and deballasting procedure.

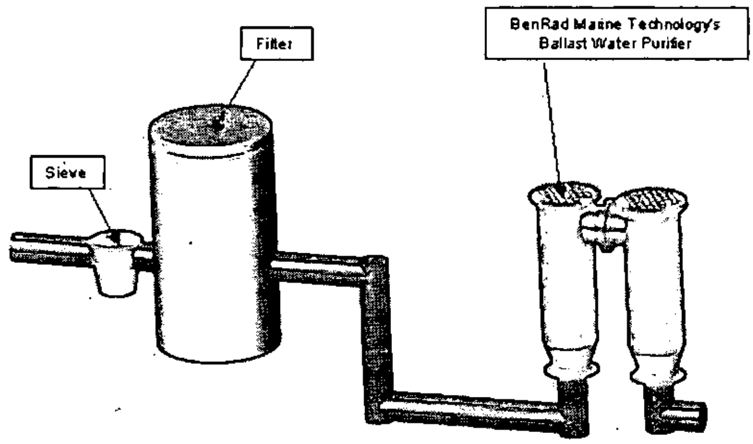

Fig. 2 Schematic drawing of the installation system using a ballast water purification unit made by BenRad Marine Technology. Upstream the unit there is a pre-filtration system.

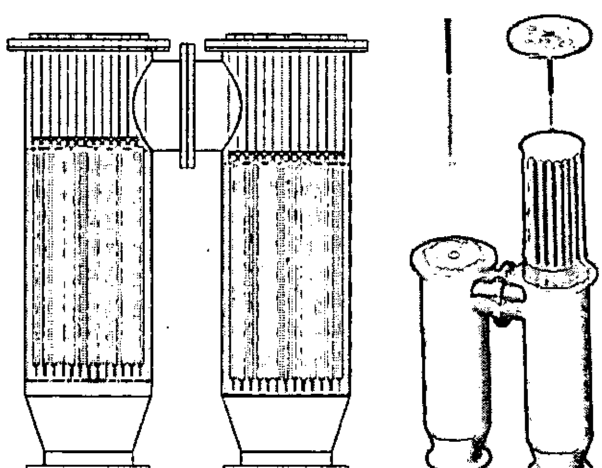

Fig. 3 The prototype of the ballast water purification unit shown in Fig.2. In the first titanium reactor cylinder there are a number of UV 185 nm lamps, in the other reactor there are UV 254 nm lamps. The lamps are inserted in individual titanium pipes containing the catalysts. The unit is 1.6 m high and 1.3 m broad.

CONCLUSION

It will seem as the advanced oxidation technology used by BenRad Marine Technology and presented in this paper is well suited for decontamination of ballast water on condition that pre-filtration system is in harmony with the AOT unit.

This AOT unit is cost-effective; require minimum space, maintenance and energy (8 kW). There are no chemicals involved, ozone or radicals are not to be found in the treated water and no by-products are formed.

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Membrane-magnetic separation for ballast water treatment

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SYNOPSIS

A superconductor magnet-used water purification system is developed to clean ballast water in oil tankers and water included in pumped oil at offshore oil fields. The key part of the system consists of HTC bulk magnets, a cryocooler to keep them at a cryogenic temperature, and a magnetizer to excite the magnets. The system is capable of treating 100 cubic meters of contaminated water a day in such process sequence as mixing contaminated water with magnet powder and a flocculant, stirring the mixture to form magnetic flocs, filtering the flocs, transferring them to a rotary magnetic shell and dumping them in a sludge tank. We made an experiment on two types of contaminated sample water, one includes kaolin particles and the other does crude oil. The experiment proved that more than 93% of kaolin particles are removed and 90% of oil is removed from the sample waters. The concentration of TOC (Total Organic Carbon) in recovered sludge is 23,000mg/L, which means the oil in the sample water is 960 times more concentrated. All these processes are finished within 5 minutes. The performance and compactness make the system applicable to the purification of ballast water or water included in pumped oil at oceanic oil well stations.

INTRODUCTION

Ballast water is necessary for tankers to cruise safely in the ocean, but the water includes aquabiotics or pathogenic organisms. When all the water is discharged at destination, such biotics and organisms are migrated there, which may disrupt the ecosystem and bring a considerable damage and loss on water resources there, further the oil residue on hull walls are released into ballast water, and it also affects the environment when discharge to the ocean, too. To prevent non-native microorganisms are an important issue which is discussed in IMO (International Marine Organization) to provide regulations on the discharge of ballast water. What to be removed are zooplanktons, phytoplankton and micro-particles like the oil remaining unwashed. To get rid of such microorganisms, ultra-violet rays or ultrasonic waves have been used, but it is not an easy job to perish them more than 90%.

Another way is attempted to replace ballast water with deep sea water during voyage. Deep sea water indeed contains less microorganisms but even the replacement can not control the concentration less than 10% in ballast water. Therefore, a high performance and compact water purification system is long demanded for to be operated even in a limited space in a tanker.

On the platform on ocean floor oil fields, crude oil is pumped up with pressured sea water being injected into oil stratum, but some sea water is included in up-lifted oil in a form of emulsion[1,2]. Such emulsified water can not be discharged into the ocean as it is. Some means are thought of to separate water and oil, such as liquid cyclone, gravity separation on a gradient board, or steam-used oil removal equipment, but all the equipment can not make the water clean enough to meet a dischargeable water quality standard. In the same sense as the ballast water, a high performance and space-saving water purification system is needed.

To develop a high speed water purification technology to be applied to ballast water in tankers and emulsified oily water at ocean oil wells, the editor made a prototype of a water purification system ("membrane-magnetic separator") aiming at a space-saving system capable of processing 100 cubic meters of water a day using small but powerful superconductor bulk magnets. This paper reports the structure of the prototype and its performance to remove two types of contaminants such as kaolin and crude oil each of which is previously mixed in tap water.

Author's Biography
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PROTOTYPE MEMBRANE-MAGNETIC SEPARATION SYSTEM

Structure of Membrane and Magnetic Separator

The structure of the new membrane-magnetic separation system[3] combines membrane separation and magnetic separation. As shown in Figure 1, it divides purification into a series of three components: a preapplication treatment unit that gathers the targeted contaminants in the wastewater into magnetic flocs; a membrane separator that filters the magnetic flocs thus formed with a membrane in order to obtain purified water; and a magnetic separator that magnetically collects the magnetic flocs deposited on the surface of the membrane, washes the surface of the membrane for reuse, and recovers the magnetic flocs as highly concentrated sludge.

In the preapplication-treatment component, first, ferromagnetic magnetic particles (Fe_3O_4), a flocculant ($Fe_2(SO_4)_3$-nH_2O), and a polymer are introduced into the wastewater taken in. They are then stirred and mixed in to the wastewater to generate magnetic flocs (containing contaminant particulates and ferromagnetic particles) in order to magnetize nonmagnetic contaminants, such as fine organic matter. Three to four minutes is an adequate time for stirring and mixing.

Since most of the particulates in the generated magnetic flocs have a diameter of several hundred microns, we considered a single membrane that would trap and filter the magnetic flocs sufficient if it had a micropore diameter of several tens of microns. The membrane unit with a frame and a wire net is shown in Figure 2. A stainless-steel wire net with a pore diameter of 43 μ m is used as a membrane, and the width of an aperture inside of frame is 200 mm. Twelve membrane units forming the rotating micropore membrane, are located on the outer circumference of a rotating shell with an outer diameter of 400 mm.

To provide continuous purification, the configuration adopted is that of a rotating membrane fitted to the outermost

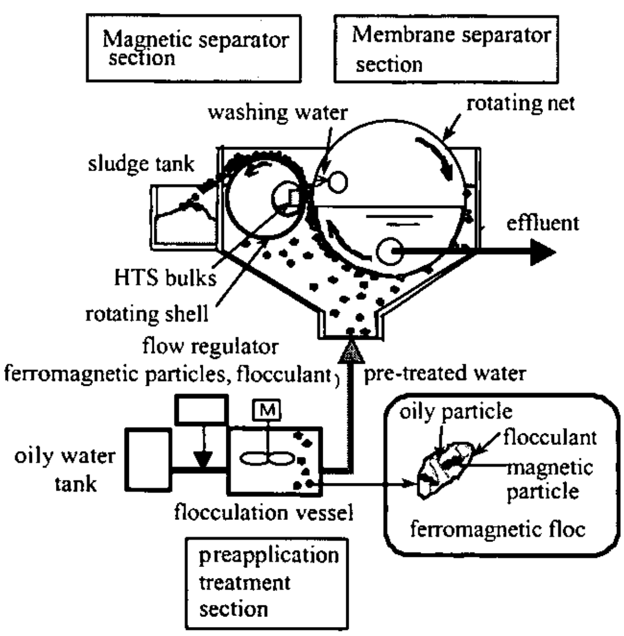

Fig. 1 Structure of high-Tc bulk superconductor-based membrane-magnetic separator for water purification The preapplication treatment wastewater including magnetic flocs is passed to the membrane-magnetic separation section for purification and the concentrated sludge on the rotating recovery shell is recovered in the magnetic separation section.

circumference of a rotating drum, and the pre-treated water is passed from the outside to the inside of the membrane. The magnetic flocs are trapped and accumulated on the surface of the rotating membrane, the wastewater is purified and flows to the inside of the drum, and the purified water is released to the outside of the system. The magnetic flocs thus accumulated on the membrane in the water migrate from the rotating membrane towards the HTS bulk magnet positioned near the surface of the pre-treated water. The magnetic flocs are separated from the membrane by the high magnetic field and the shower-like flow of wash water from inside the membrane near the surface, so the membrane goes through continuous purification and is continuously readied for reuse.

In the magnetic separator, the HTS bulk magnet, magnetized in advance and cooled by a cooler inside a vacuum adiabatic chamber, is fixed inside a nonmagnetic rotating cylinder. The separated magnetic flocs adrift in the magnetic field near the surface migrate swiftly to the magnet, drawn by the strong attraction of the HTS bulk magnet. The migrating magnetic flocs adhere to the surface of the cylinder and are then transferred to the atmosphere above the surface of the water by the rotation of the cylinder. At this point, the surplus water in the magnetic flocs falls downwards due to gravitation, and the concentration of the magnetic flocs rises, resulting in highly concentrated sludge. The sludge is continuously stripped from the surface of the cylinder by a claw and drops of its own weight into a sludge reservoir. The surface of the cylinder is continuously readied for reuse by the claw. Through this series of operations the wastewater is continuously purified, and the byproduct is highly concentrated sludge.

Since magnetic flocs may be magnetically drawn to the surface of the cylinder at high speed by the strong magnetism of the HTS bulk magnet, a large volume of magnetic floc can be separated per time unit. Therefore, if the number of revolutions is increased, the new purification system can purify large volumes of pre-treated water even with a small rotating membrane; therefore, a small purification system could purify large volumes of water.

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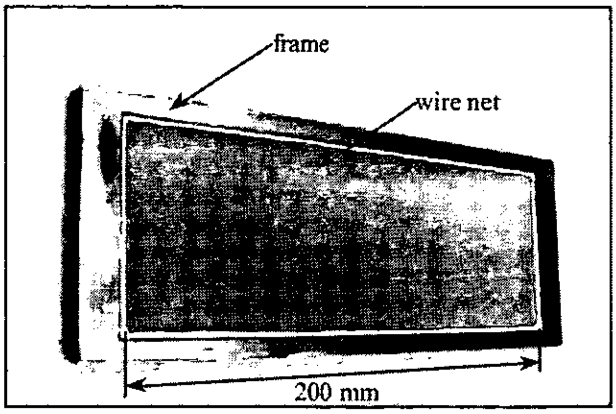

Fig. 2 One membrane unit with a frame and a wire net. A stainless steel wire net with a pore diameter of 43 μ m is used as the membrane, and the width of the aperture inside of the stainless steel frame is 200 mm.

field near the surface migrate swiftly to the magnet, drawn by the strong attraction of the HTS bulk magnet. The migrating magnetic flocs adhere to the surface of the cylinder and are then transferred to the atmosphere above the surface of the water by the rotation of the cylinder. At this point, the surplus water in the magnetic flocs falls downwards due to gravitation, and the concentration of the magnetic flocs rises, resulting in highly concentrated sludge. The sludge is continuously stripped from the surface of the cylinder by a claw and drops of its own weight into a sludge reservoir. The surface of the cylinder is continuously readied for reuse by the claw. Through this series of operations the wastewater is continuously purified, and the byproduct is highly concentrated sludge.

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Configuration of the HTS Bulk Magnet System

Figure 3 is a sketch of the 33-mm-square, 20-mm-thick $YBa_2Cu_3O_7$ impregnated high-temperature superconducting bulk superconductor by epoxy resins[4] used in the system. We used eleven such bulks to build a 387-mm-long trial HTS bulk magnet system. Figure 4 shows the configuration of the magnet system and its magnetization method. A small, single-stage Gifford-McMahon helium cryocooler cools the inside of the adiabatic vacuum chamber of the HTS bulk to a temperature of approximately 35 K. For connection to the magnetizing unit, the HTS bulks are embedded in the tip of a copper, thermal-conductive bar. The other end of the thermal-conductive bar is joined to the cold station of the cooler by a flange via an indium sheet. The low-temperature unit is wrapped many times with laminated heat-insulating material to prevent the penetration of radiation heat.

Split solenoid superconducting magnets are used to magnetize the HTS bulks. The magnetic field in the tunnel between the split magnets is 70 mm in diameter and approximately 100 mm long with a maximum field of 5.0 T. As the configuration of the magnetizing system in Figure 3 shows, the HTS bulk section of the HTS bulk magnet system is inserted into the tunnel between the split superconducting magnets before excitation. After cooling the bulks to a temperature of approximately 100 K, just above its critical temperature Tc, the split superconducting magnets are excited so they emit a prescribed magnetic field. Since the bulk does not reach a state of superconduction, the magnetic field penetrates the bulk unassisted. When the bulk is then cooled further, the temperature falls below its Tc and the internal magnetic flux gradually begins to be trapped. The split superconducting magnets are demagnetized at a few degrees above the lowest temperature, and the temperature of the bulk then dropped to the lowest temperature. These operations complete the zero-field-cooling magnetization process. Finally, the HTS bulk magnet system is extracted from the solenoid magnets (with the cooler still running) and mounted it in the sludge- cylinder of the prototype membrane-magnetic separator.

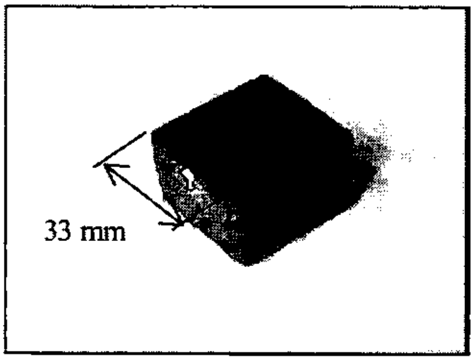


Fig. 3 $YBa_2Cu_3O_7$ bulk superconductor impregnated with epoxy resin (20 mm thick). Eleven such bulk magnets are used to build a 387-mm-long trial HTS bulk magnet.

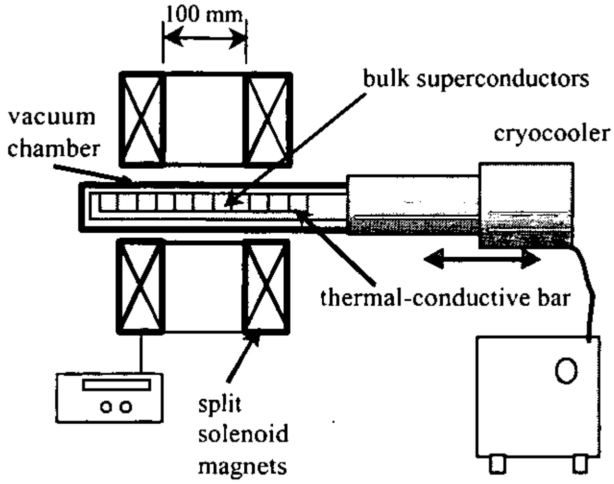


Fig. 4 Magnetization system of bulk superconductors. The magnetic field in the tunnel between the split magnets is 70 mm in diameter and approximately 100 mm long.

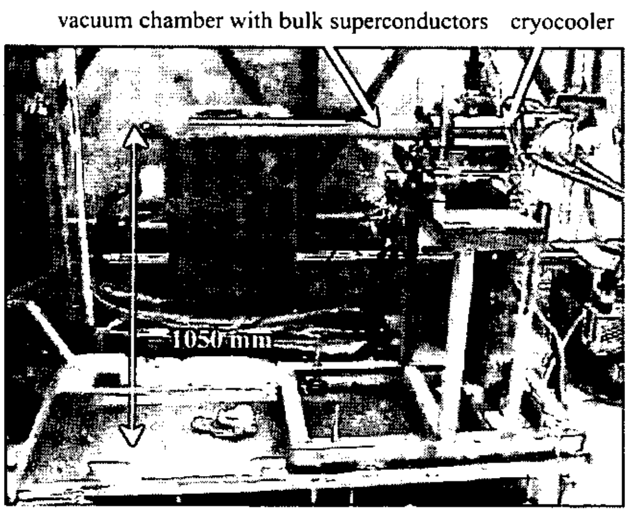


Fig. 5 Superconducting magnet system with bulk superconductors. Under steady-state conditions, the temperature of the bulk magnets is 34 K and all superconductors are cooled uniformly by the GM cryocooler.

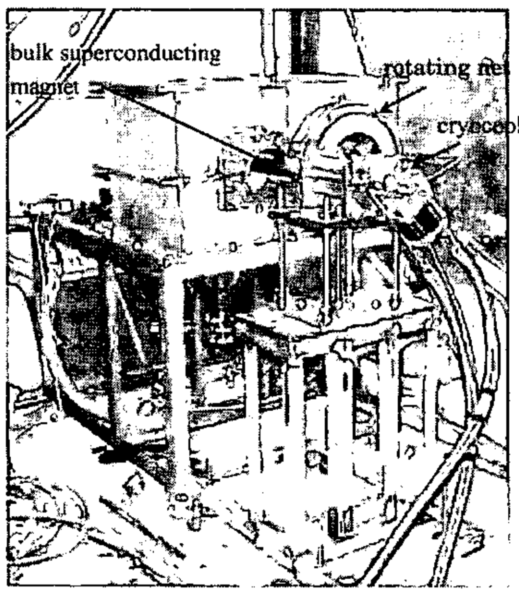


Fig. 6 Photograph of magnetic separator with a treatment flow rate of 100 m^3/day.

The magnetized superconductors retains their strong magnetism forever as far as they are appropriately kept cold by a cryocooler. The experimental superconductor bulk magnet system is shown in Fig. 5, and a photo picture of the magnetic separator is shown in Fig. 6. The system measures 1,380mm high, the dodecagonal rotary net cage is 200mm wide and 400mm in diameter where 12 filters are installed on each plane.

Table I. Performance of bulk-superconductor cooling system

bulks temperature	34 K
cool-down time	4 hours
electric power consumption	2.8 kW

EXPERIMENTAL RESULTS AND DISCUSSIONS

Magnetization of HTS Bulk Magnets

A magnetization characteristic of the superconductor bulk magnets under the 5.0T magnetic field is shown in Fig. 7 (b) and (c). In the coordinates system, the upper wall of the vacuum adiabatic chamber is assumed as x-y plane. As seen in Fig. 7 (a), there are 11 bulk magnets arranged straight in row, and the center of the sixth one from either end of the row meets the zero point of x-y coordinates. Bz stands for the distribution of magnet field intensity along z-axis (vertical). The intensity is 3.2T at said center on the surface of the chamber which is the maximum in the distribution, and a nearly uniform intensity distribution was observed in the range from -50mm to +50mm along x-axis, that is, the magnet at the center and two magnets beside showed the nearly same magnet field intensity. When going further from the range, the intensity was lowered in proportion to the distribution of magnetism of the magnetizer. We obtained the magnetic field 1.6T to 3.2T in the range of 200mm (+100 to -100mm). At this time, the cooling temperature for the bulk magnets was about 35K, and the power consumption of cryocooler was 2.8kw. (See Table I). The graph (c) in Fig. 2 views maximum intensities along z-axis, and it is inversely proportional to the distance from the chamber's wall surface, further it goes, lower the intensity becomes. At 6mm away from the surface at x=0mm and y=0mm, the intensity is 1.0T, this means the bulk magnet is generating a stronger magnet field than an ordinary rare-earth metal permanent magnet.

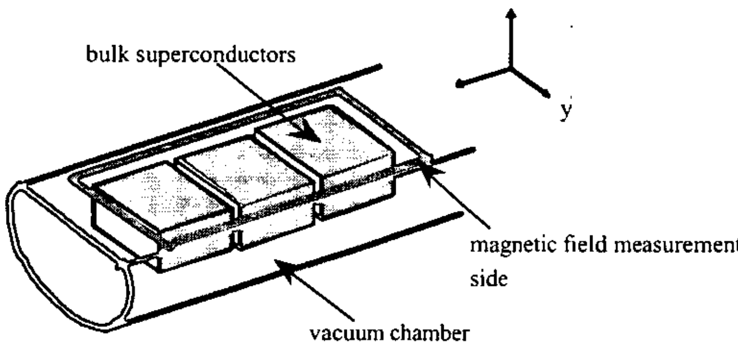
Purification of kaolin-contaminated water

We made a contaminated sample water for the experiment by adding kaolin particles to tap water on purpose. The grain size of kaolin particles is 0.5 micron meters and the concentration in tap water is 92 mg/L. We processed 100m^3 of sample water per day. The water is mixed with magnetic powder and a flocculant and stirred to form flocs. The flocs are trapped on the rotary filter and transferred to the magnet separator where they are accumulated to be sludge on the rotary shell. The sludge is scraped off the shell's surface and dumped into the sludge tank after water is dripped and drained.

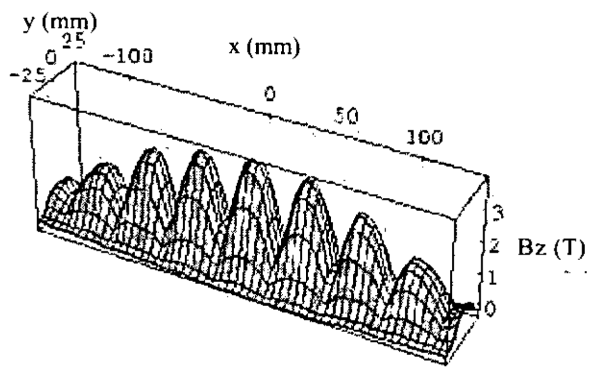
The Table II shows a result of the experiment. The system removed 93% of suspended particles ("suspended solids") which convinced us of its applicability to purification of plankton-contaminated water, because the size of plankton is similar to that of the kaolin particles or it is even larger. The concentration of sludge immediately after the magnet separation was 90,000mg/L and it is further concentrated by dripping and draining water in the atmosphere. However, this concentration would be lower in the application to plankton-contaminated water because the concentration of planktons in the original water becomes a little lower than that of kaolin in this experiment. It would be several tens-thousand mg/L. This is a continuous system but the time duration when a particle in the sample water is input to the line to when it is dumped in the sludge tank is about 5 minutes.

The Fig. 8 shows a photo picture of the waters before and after the process. The processed water is more transparent which is proving our purification technology is effective and significant. The Fig. 9 shows a photo picture viewing down on the rotary filter and magnet separator in operation, in which we can recognize how the suspended solids are captured on the cage, transferred to the rotary shell under magnetism, scraped off and dumped in the sludge tank. The position to scrape is about 100mm away from the magnetic separation and the magnetic field intensity there is about 0.05T, which means the magnetic force hardly works on the sludge and the scraping is easily carried out

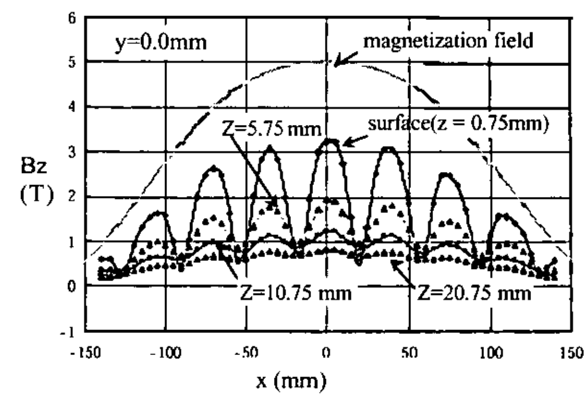
In the past, the editor and his associates attempted an experiment on a batch type system using superconductor coil magnets to remove planktons from red tide[5], and the Table III show some outcomes of the experiment. The object to have been removed was phytoplankotons such as *Chattonella antiqua*、 *Heterosigma akashio* and *Heterocapsa circularisquama*. We made magnetic flocs of the planktons in the same manner as this experiment. The flocs were captured on the metal net under magnetism. The removal rate in that experiment was 92% or better. It is a satisfactory rate for the application to water purification. It differs in the methodology of separation of magnetic flocs, but we are confident that the membrane-magnet separation may prove a comparable performance with this.



(a) 3D axis for magnetic field measurement



(b) Magnetic field distribution at 34 K



(c) Magnetic field distribution at each distance

Fig. 7 Measured magnetic field distribution of bulk superconductors on the surface of the vacuum chamber by zero-field cooling. The split solenoid superconducting magnets can generate 5.0 T and was used for magnetization and the trapped maximum magnetic field was 3.2 T.

Table II Treatment test results for China clay pollution water at flow rate of $100m^3$/day.

item	influent	effluent	removal efficiency (%)
suspended solids (mg / L)	92	6.8	93
concentration of solids in recovered sludge (mg/L)	-	90,000	-

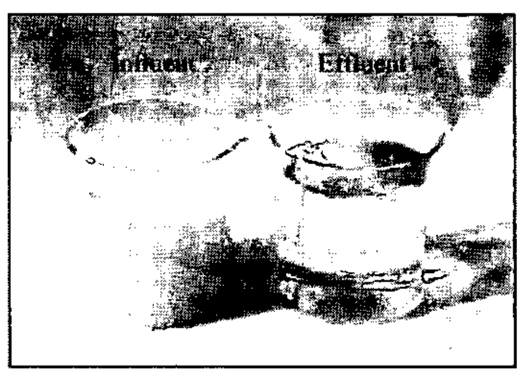


Fig. 8 Views of the model influent containing kaolin particles and of the effluent

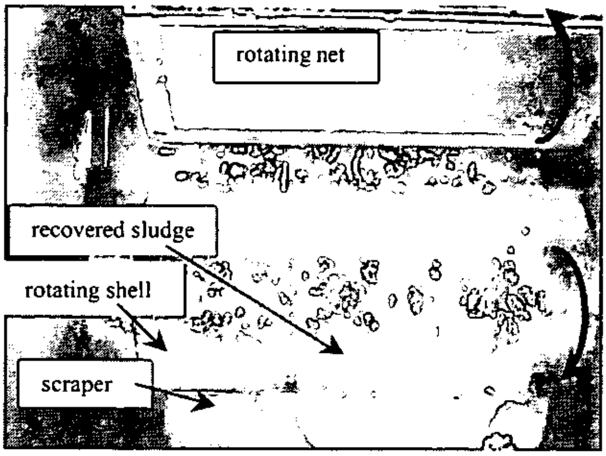


Fig. 9 Recovering sludge by magnetic separation.

Table Ⅲ Treatment test results for three kinds of phytoplanktons of red[5)]

	Chlorophyll-a (μg/L)	Marine Bacteria (cells/mL)
Chattonella antiqua		
influent	169	-
effluent	6.3	-
%removal	96	-
Heterosigma akashio		
influent	112.7	137,500
effluent	15	1,500
%removal	87	99
Heterocapsa circularisquama		
influent	169	5,670
effluent	6.3	440
%removal	96	92

Purification of oil-emulsified water

We made a contaminated sample water for the experiment by adding oil to tap water and agitating to emulsify it. As seen in the microscopic picture of Fig. 10(a), the size of a emulsified particle is ranging from 1 to 10 micron meters and they are suspended in the water. They are mixed with magnet powder, a flocculant and a high molecule polymer. When they are stirred, oil particles and the power are coagulated and flocs are formed as seen in Fig. 10 (b). A result of this experiment is shown in Fig. 11. Based on TOC for evaluation, the removal rate was 90% or better. The concentration of TOC in the recovered sludge was 23,000mg/L. This is 960 times thicker than the original contaminant concentration 24mg/L. This result suggests that the water purification technology proved in this experiment is applicable to the treatment of oily water on ocean oil well stations, and it makes possible to discharge post-process water directly to the ocean.

(a) influent

(b) preapplication treatment water

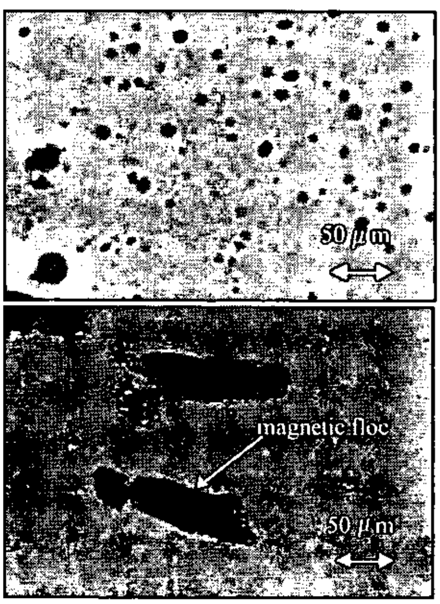


Fig. 10 (a) Microscope photograph of emulsified oil particles in influent and (b) magnetic flocs in preapplication treatment

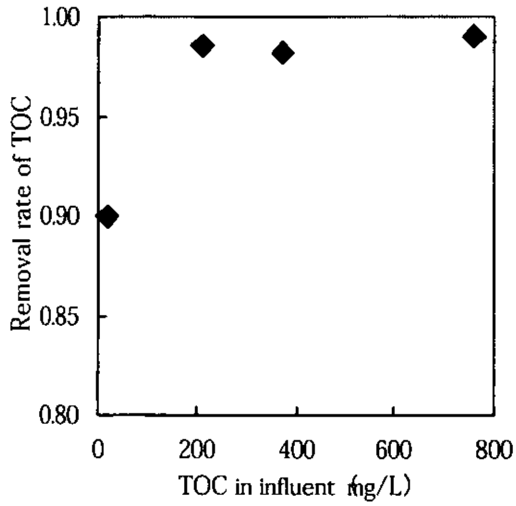


Fig. 11 Efficiency for removing oil from water.

SUMMARY

We have been experimenting on the purification of several contaminated sample waters by using the continuous water purification technology, featured with the superconductor bulk magnets which generates a high intensity of magnet field, and finally, we list up the following conclusions as the summary of this report:

Not less than 90% of particles in contaminated water is removed in 5 minutes, which is promising the development of an equipment which is capable of a high speed and continuous water purification in a limited space. Recovered sludge is also highly concentrated to be tractable for an easy disposal. We clearly recognized and confirmed that the technology and methodology are effective to the purification of ballast water and oil-emulsified water.

We developed this technology with the aid of an Industrial Technology R&D Implementation Technology Development Grant from the New Energy and Industrial Technology Development Organization (NEDO) of Japan.

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A standard means of assessing the effectiveness of ballast water treatment regimes: any one for soup?

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SYNOPSIS

The development and acceptance by regulators of on board treatment facilities for ballast water is hampered by the current lack of a standard test regime. To gain international and regulator acceptance any test regime should be (i) simple to use (ii) applicable over a large geographic area (iii) be based upon ecologically appropriate organisms and (iv) be cost-effective. The MARTOB programme is developing a series of on-board treatment regimes and in order to provide a benchmark for comparisons a standard test protocol was developed. To create a representative biological sample to be used in the tests, the following organisms were chosen: a estuarine/marine benthic larvae (nectochate larvae of the polychaete *Nereis virens*), a benthic harpacticoid copepod known to be invasive (*Tisbe battagliai*), a planktonic calanoid copepod also known to be invasive (*Acartia tonsa*), the diatom *Thalassiosira pseudonana* and the dinoflagellate *Alexandrium tamarense*. This 'soup' was then subjected to treatment by the regimes under test: de-oxigenation, high temperature thermal treatment, oxicide (electrochemical) method, advanced oxidation, ozone, ultrasound, ultra-violet light, and a hurdle methodology (different combinations of the above). The effectiveness of each method was characterised by the overall percentage mortality and the percentage mortality of each of the test organisms.

INTRODUCTION

One of the most important issues currently under discussion at the International Maritime Organisation's (IMO) Marine Environment Protection Committee (MEPC) is the development of a ballast water standard for testing ballast water treatment methods. A standard is currently in the process of being drafted, which will ensure all potential ballast water treatment methods meet common criteria. This standard will also allow the performance of different types of treatment methods to be compared.

Within the MARTOB project it was necessary to compare the performance of various ballast water treatment techniques and a standard testing protocol was therefore required.[1] However, the standards under discussion at IMO were unlikely to be finalised in time to be utilised by the MARTOB project and it was therefore necessary to develop a test protocol specifically for this project. The protocol that was developed was based to some extent on the draft standards but as these are currently under development other suggested protocols were also be taken into account.

Within the ICES/IOC/IMO Study Group on Ballast Water and Other Ship Vectors (SGBOSV), there is a general concern about the need for the development of a standard test regime. Such a regime requires some generally accepted criteria: (1) water quality standards (2) which species are going to be used for laboratory tests, (3) how are they going to be combined in order to create a ballast water sample representative of the natural situation and (4) what metric to use as the measure of the biological effectiveness of the different treatments. Once the acceptance of the standard is achieved, all the treatment methods, or combination of methods (chemical, biological, mechanical, physical or others) can be tested and compared to a common baseline.

This paper sets out to address these four issues in the context of the MARTOB project and to demonstrate its application to some treatment experiments.

Author's Biography
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(1) WATER QUALITY STANDARDS

Salinity

The principle concerns relate to ballasting and deballasting of vessels in similar environments. For example estuarine/estuarine or FW/FW transfer. Organisms moving form the inner Baltic to the Mediterranean or *vice versa* would suffer an osmotic shock and not survive. In order to provide a standardised protocol a standard test condition must be employed. We have selected a salinity of 33 for the test regime as this represents a typical inshore - lower estuary salinity for large areas of the temperate regions of both hemispheres. However, we use (see below) organisms in the tests which have high tolerance for low and variable salinity such that this test regime mimics estuarine-coastal situations. A protocol focusing on freshwater or very low (<20) salinities will require additional suites of test organisms to be produced and therefore complicated the testing.

Turbidity

Turbidity can range from 1mg/l in estuaries with a low tidal range up to 1-10g/l in extremely turbid estuaries with high tidal ranges like the Severn, UK. Typical grain sizes of suspended sediment are generally less than 10μm. Turbidity may be caused by either organic or inorganic particles and we therefore suggested that in order to mimic natural conditions in a relatively highly turbid estuary 1g/l of either kaolin or flour should be added to the water to create a turbid sample.

pH

Normal seawater has a pH of ~8.3. The buffering capacity of seawater is great so this was not thought to be a problem

Temperature

The natural temperature range for the organisms to be used in the test soup is 5.5-20°C.[2-6] Therefore in order to keep the organisms alive before testing maintenance of the cultures and tests had to be carried out in cool temperatures. We recommended 10-15°C, middle of range preferred.

Production of stock water

The stock test mixture was made up in artificial sea water (ASW). We wanted water with known composition, therefore instead of using filtered natural seawater, which could have contained organisms such as bacteria or resting cysts, deionised water was added to commercially produced aquarium salt (35g/l) was utilised. Hence we ensured a supply of water that was always of known and consistent composition as the basis of the comparisons.

Details about the preparation of the ASW (salinity, pH, temperature and turbidity) are given in **Appendix I.**

(2) SPECIES SELECTION

Based on the findings reported from several ballast water studies, the taxa most likely to survive long voyages are: Copepods (mainly harpacticoids, calanoids and cyclopoids, in various developmental stages), polychaete larvae (mainly spionids), bivalve veligers, barnacle (nauplii and cyprids), gastropod larvae, decapods (adults and larvae), diatoms and dinoflagellates. [7-14] However resistance varies greatly between taxa even within the same group.

The most resistant ones, hence the most likely potential invaders, include larvae of benthic organisms including oyster (e.g. *Saccostrea cucullata* (Born)) and mussel (e.g. *Mytilopsis sallei* (Recluz)), as well as some spionid polychaetes (e.g. *Boccardia*). When sampled from ballast water tanks, these have all managed to settle in laboratory culture tanks.[9]

Some calanoid (e.g. *Pseudodiaptomus marinus*) and harpacticoid (e.g. *Tisbe* sp.) copepod species, due to their biological features have the capacity of surviving long journeys in ballast tanks. Many species of *Pseudodiaptomus* are neritic but euryhaline and hardy;[15] and *Tisbe* contains a number of hardy species with cosmopolitan distribution, opportunistic feeding behaviour (most of them are omnivorous, feeding on a large variety of food such as algae, bacteria, detritus and artificial fish feed and even scavenging on dead animals), fast growth and high reproduction.[16,17] Furthermore Miliou noted that the mortality rate in *T. holothuriae* was lowest in complete darkness and the sex ratio (female/male 0.65) was biased towards females. These observations would favour rapid population growth in the conditions in ballast water tanks.[18]

With regards to phytoplankton, diatoms and dinoflagellates appear to be the taxa that survive in high numbers in ballast water. In a comparison of 7 shipping studies carried out in Europe, the most commonly found diatoms included small centric diatoms such as *Skeletonema* spp., *Chaetoceros* spp and *Thalassiosira* spp. Other diatoms such as *Ditylum brightwellii*, *Thalassionema* *nitzschoides* and *Navicula* spp. were also commonly found.[19] It is not so clear which dinoflagellates most commonly survive within ballast tanks as they can be difficult to identify and not all studies have identified dinoflagellates to the same taxonomic level. However, in two studies carried out in the UK unidentified thecate and naked dinoflagellates, *Prorocentrum* spp., *Gymnodinium* spp., *Ceratium* spp., *Scrippsiella* spp., *Gyrodinium* spp. and *Protoperidinium* spp were among the most commonly found taxa.[20,21] Dinoflagellates are capable of forming a protective cyst resting stage and can survive for up to several years in sediments waiting for conditions to improve before excysting. This protective cyst stage makes them very difficult to kill as the cyst is highly resistant. Toxic species such as *Gymnodinium catenatum* and *Alexandrium tamarense* have been introduced to Australian waters via ballast water and it is species such as these that ballast water treatment should aim to remove.

Once we knew which organisms were the most likely to survive in ballast water tanks, we had to decide which species were going to be chosen, always taking into account that they had to meet the criteria that would make our test regime accepted internationally: (i) simple to use (ii) applicable over a large geographic area (iii) be based upon ecologically appropriate organisms and (iv) be cost-effective. Therefore we chose species that would be commercially available all year round. In this manner, the mixture would be simple to get at any time of the year (instead of sampling and sorting the organisms from the sea), permitting its use for conducting experiments independently from the season, relatively cost-effective, and we would always have the certainty of the genetic compostion and prior exposure history of the stock (contrary to what could happen getting the organisms from nature). The organisms selected had to be also cosmopolitan, in order to have a test mixture representative of different habitats and thus applicable over a large geographic area.

(3) COMPOSITION OF A TEST MIXTURE

The ICES/IOC/IMO Study Group on Ballast and Other Ship Vectors (SGBOSV) recommends the use of certain representative biological groups in order to assess the efficiency of the different proposed ballast water treatment methodologies.[22] A representative group has to meet a range of criteria, such as being robust, the most resistant species and life stages have to be highly represented, they should be non-pathogenic or toxic, and preferably with a fairly global distribution. The purpose of each selected organism group is to serve as a model for one group of organisms reflecting how that group resists ballast water treatment.

The possible groups and examples of some suitable test species would be:[22]

- Phytoplankton (Dinoflagellates and Diatoms (*Skeletonema costatum, Phaeodactylum tricornutum*)),
- Crustaceans (Crabs, Shrimp (*Artemia salina*), Copepods (*Acartia tonsa*), Amphipods (*Coriophium volultator*)),
- Rotifers (*Brachionus plicatilis*),
- Polychaetes,
- Molluscs (Mussels, Gastropods),
- Fish (Turbot (*Scophthalmus maximus*)),
- Echinoderms,
- Ctenophores,
- Coelenterates,
- Bacteria (*Vibrio fisheri*) and Viruses.

However one of the two options developed by the Marine Environment Protection Committee (MEPC) is to use representative species from five taxonomic groups in the development of a ballast water treatment standard.[23] Moreover a test mixture composed of all the above seems unnecessarily complex For many of the groups there is no surety of availability and mortality of the most resistant groups implies mortality of the less resistant taxa. We therefore proposed that the test mixture, referred to colloquially as the soup, should be composed of:

1. Benthic larvae: Larvae of the rag-worm (Polychaete: *Nereis virens*) are available all year round and can be supplied alive or cryogenically preserved for revival at need. Moreover they are known to be an introduced species to the Pacific coast of North America.[24]
2. Harpacticoid copepod: *Tisbe battagliai*, for its resistance in long journeys in ballast tanks, as well as its fast growth and high reproduction rate.
3. Calanoid copepod: *Acartia tonsa*, as it is readily cultured and has transferred from the US to European estuaries
4. Diatoms: *Thalassiosira pseudonana* are centric diatoms, which are commonly grown in culture and are easier to count than chain forming diatoms such as *Skeletonema costatum*.
5. Dinoflagellates: *Alexandrium tamarense* as this would represent one of the most difficult species to remove from ballast water owing to the fact it can form cysts, which can resist many forms of ballast water treatment.

These 5 elements were combined to make the standard test mix.

The proposed mix does not include any fish eggs or larvae. In many countries, including the UK experiments involving vertebrates require special licences. For this reason we excluded them from the standard test mix and proposed that separate trials of a mix containing fish eggs and larvae (probably salmon or turbot) be conducted, under licence for the most promising techniques identified in the trials with the standard mix.

The reason for not including bacteria is to avoid complications to the test mixture since including them in the standard test mixture would imply applying a different methodology. Rotifers were also excluded, as they are classified as worms, therefore very similar to polychaetes. Molluscs and echinoderms have planktonic stages which are transported by ballast water, but they are more vulnerable, therefore there is no need to include them into the representative group as other more robust and resistant organisms are present. Ctenophores and coelenterates are soft even in the adult form, therefore the same criterion is applied to them.

Mixture composition

The premise here is that densities should reflect the top end of the natural range for each taxa, but it is also necessary to have enough numbers to allow statistical treatment of the results.

Table I. Plankton species used in soup, their field densities to compose the test mixture and the amount of water added with each species.

Plankton species	*Maximum field densities (indivs m^{-3})*	*Standard mix composition (indivs m^{-3})*	*Standard mix composition of a 70l test solution*
1. Benthic larvae: *Nereis virens* nectochaete larvae	740	1100	80
2. Harpacticoid copepod: *Tisbe battagliai*	807*	1100*	80
3. Calanoid copepod: *Acartia tonsa*.	159,659	2,500	200
4. Diatoms: *Thalassiosira pseudonana*.	$3x10^9$	$50x10^7$	$30x10^6$
5. Dinoflagellates: *Alexandrium tamrense*.	$75x10^6$	$4x10^7$	$24x10^5$

*Original numbers: indivis/m^{-2}, and transformed for 10m depth in the water column.

From the literature, maximum abundances of *Nereis virens* nectochaete larvae (in the St. Lawrence River estuary, Quebec, Canada) are between 2,112 and 3,400 individuals per m^2, thus 211 to 340 per m^3 (assuming a depth of 10m in the water column).[25,26] However the highest field densities from other nectochaete larvae (along the sandy beach of Porto-Novo, Tamil Nadu, India) are found to be 740 individuals per m^{-3}, [27] while the mean abundance number of polychaete larvae (off Northumberland) is 74 individuals per m^3.[28] Therefore a density of around 1,100 individuals per m^3 was used for the test mixture.

Tisbe sp. density can range between 156 and 807 individuals per m^3 in west Seattle.[29] While maximum abundances in One Tree Lagoon, in the Great Barrier Reef, are 49.6 individuals per m^3.[30] Hence a density of 1,100 individuals per m^3 was the approximate quantity used for the test mixture.

Between 1975 and 1992, maximum *Acartia* sp. abundance was found to be as high as 87,318 in the Venice Lagoon though that had never previously been observed.[31] Moreover even higher numbers (159,659 indiv/m^3) were found at Phosphorescent Bay in Puerto Rico for *A. tonsa*.[32] On the Uruguayan coast near Montevideo, a maximum abundance of 12,564 individuals/m^3 of *A. tonsa* was observed, and similar numbers (14,800 indiv/m^3) have been registered from the Damariscotta River esturay in Main,[33] from the Navesink and Shrewsbury rivers and Snady Hook system in New Jersey (17,114 indiv/m^3),[34] or from Nueces Estuary in Texas (13,351 indiv/m^3)[35]. While in San Francisco Bay/Estuary from 1972 to 1993,[36] *Acartia* sp. abundance ranged from minimum abundances of <100 (in 1983 and 1993) to almost 2,400 (in 1977); in the Calcasieu estuary, maximum abundance values are about 3,716 indiv/m^3 (Vecchione, 1989[35]).[37] Maximum mean abundances of *Acartia* sp. off Northumberland (between January 1990 and December 1993) are around 1449.6 individuals/m^3.[28] For the aforementioned, it was therefore used 2,500 individuals/m^3 in the test mixture.

With regards phytoplankton, cell concentrations (of the species causing the bloom) during a bloom are usually over 10^6 cells l^{-1} and can be up to 10^9 cells l^{-1} for smaller cells such as *Aureococcus anophagefferens*.[38]

However, it is very difficult to generalize and state an average density of diatoms and dinoflagellates for coastal waters. FRS carries out phytoplankton monitoring at a sampling station about five miles offshore and as a very general guide the following cell numbers are the average: Around 200,000 cells l^{-1} is a general average density for total diatoms at the Stonehaven sampling station. For dinoflagellates the average count is about 10,000 cells l^{-1}. However, a density of approximately 75,000 cells l^{-1} was the highest cell number recorded for dinoflagellates and 3,000,000 cells l^{-1} for diatoms (*Chaetoceros socialis*).

Elsewhere in Scotland densities of 9-10 million cells l^{-1} have been recorded during a dinoflagellate bloom of *Gymnodinium* spp.

A study of the Thames estuary and similar areas by Belcher and Swale found that the phytoplankton assemblage was dominated by small centric diatoms, the majority of them species of *Thalassiosira*. The population generally fluctuated between 100,000 and 1,000,000 cells l^{-1}.[39]

(4) ASSESSING BIOLOGICAL EFFECTIVENESS

In the past, studies assessing ballast water treatment technologies have worked out the biological effectiveness anlyzing the organisms survivorship immediately after taking the samples through direct observations. However, this implied either testing the mechanisms in port and sending the non-preserved samples straight to the laboratory or assessing them on board during the journey. In both cases difficulties can arise such as problems in the transport to the laboratory or bad weather conditions (when the analysis are done on-board). Another way of assessing the effectiveness of the treatments could be working it out as the toxicity (temperature, dosage, amplitude, intensity, flow rate or number of days in anoxia, depending on the treatment tested) at which 50% of the organisms are killed (L_{50}), using mathematical models to assume this values. However we wanted to develop a simple protocol, based on observed kills, and independent from weather conditions or laboratory distances. We therefore calculated the biological effectiveness as the percentage of mortality after treatment and we used a vital staining (a product that stains organisms while they are alive without affecting their survival) in order to avoid the latter problems.

In order to assess the biological effectiveness of each ballast water treatment method, the number of organisms living after treatment had to be determined. This required that the specimens had to be fixed and stained in a manner that allowed living and recently dead material to be easily distinguished. However, in order to differentiate the mortality caused by the fixation from the treatment, a vital stain was used prior to their fixation. This allowed the efficiency, expressed as % kill, of each technique for each group of organisms to be reported.

Zooplankton Fixation and Staining

Discrepancy about the best fixation and its percentage (ethanol at 70, 75 or 90%, or formalin at 4 or 10%) is found among different studies.[9-11,40,41] However after having carried out a literature review we adopted buffered formalin in a 4% solution.[42-44]

A stain, which differentiates live from dead organisms at the time of sampling was needed. We used neutral red as a vital staining since it provides a rapid method of sorting dead copepods from live as well as other marine species.[45] We followed the ICDC staining technique (based on neutral red) as according to Omori & Ikeda[44] this technique modified by Crippen and Perrier[46] is the best to distinguish live and dead specimens by colour.

See **Appendix I** for further details about the protocol followed.

INITIAL TRIALS OF THE PROTOCOL

During the MARTOB laboratory-scale trials (from the 6th to the 14th June 2002), different ballast water treatment methodologies were tested in the facilities of Newcastle University. The treatments tested included: de-oxygenation, high temperature thermal treatment, oxicide, advanced oxidation (combination of ozone, ultraviolet light (UV) and catalysts), ozone, ultrasound, UV, as well as a hurdle methodology (different combinations of the above). The standard test protocol was applied in order to have a comparative and reliable assessment of the biological effectiveness of the different treatments.

Control

To be able to have a measure of comparison between the survival of the treated and untreated (control) organisms, a control tank containing one sample of the standard mixture was set up and left for 24 hours at room temperature. Sub-samples were taken at intervals to monitor background mortality (**Table II**). Three replicates were performed during three consecutive days (12-14th June) and the results are shown in **Fig. 1**.

Table II Time after set -up and sample volumes used for control soup sampling.

Time of sampling	Volume of sample (l)
0 min	10
30 min	3
1h	3
2h	3
3h	3
4h	3
5h	3
6h	3
24h	Remainder (39)

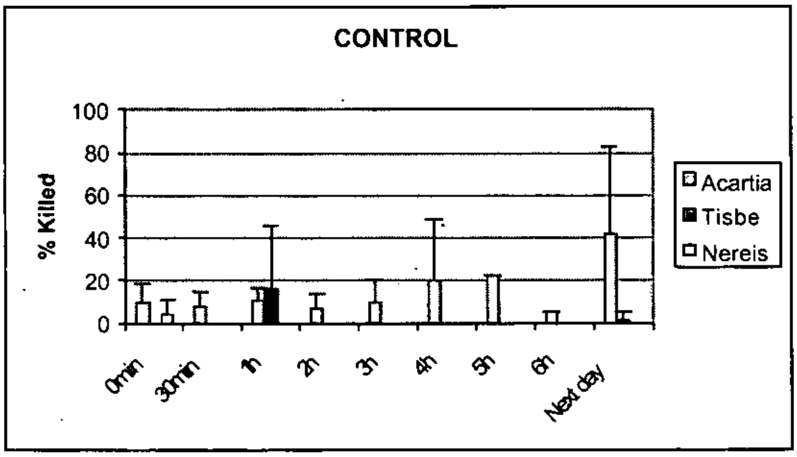

Fig. 1. Results from the Control samples.

A Kruskal-Wallis analysis indicated ($p>0.05$) that there were no significant differences in the mortality of the organisms in relation to the time when the sample was taken for any of the three species. Hence no statistically significant increase in the number of dead organisms from the moment the organisms were poured into the tank and after 24hours was found.

The highest mortality recorded in any one hour was less than 17% and the mean was less than 6%. We can therefore conclude that the mortality of the organisms in the soup prior to applying them into the different treatments (always within the first hour) was of the order of 5.44%.

However, when the percentage of organisms dying in the before treatment was higher than 5%, its additional mortality was accounted for in the data analysis and calculation of the efficiency of the treatment.

The Marine Technology Department, School of Marine Science and Technology, from Newcastle University (UNEW) performed high temperature thermal treatment, and their results are presented as a case study of the assessment protocol.

UNEW Case Study: High Temperature Thermal Treatment

For this treatment different temperatures were tested: 40, 45, 50, 55, 60 and 65 °C. All of them were assessed as instant exposures ('Touch & Go'). Longer exposures were also examined at 55°C (temperature maintained for 10 and 55 seconds). Three replicates were carried out for each of the conditions (see Mesbahi *et al.* for details [1]).

The total mortality achieved by each treatment is shown in **Fig. 2a**. Mortality higher than 95% was achieved at temperature above 50°C. At 65°C the elimination of the organisms decreased to 86.9%, however this decrease was not significant, therefore we could not consider it a real decrease.

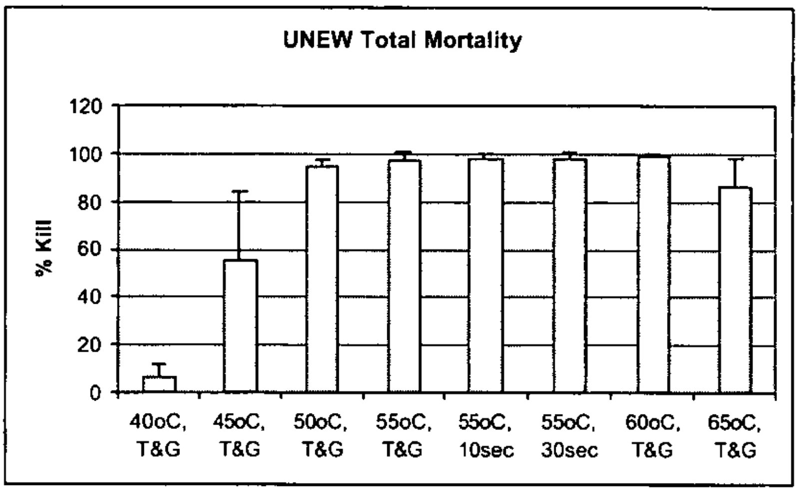

Fig. 2a Total % kill for each UNEW treatment
Note: T&G' means instant exposure or 'Touch and Go'.

Significant differences were found between 'Touch & Go' (T&G) temperatures for the different species (**Fig. 2b**). With regard to *Acartia* its mortality at 40°C was significantly lower than with the other temperatures (one-way ANOVA, $p<0.01$). For *Tisbe* and *Nereis* both 40 and 45°C were significantly lower than the rest. (Kruskal-Wallis test, $p<0.05$)

In general, a high mortality (above 95%) for all taxa was achieved at 55°C Touch and Go.

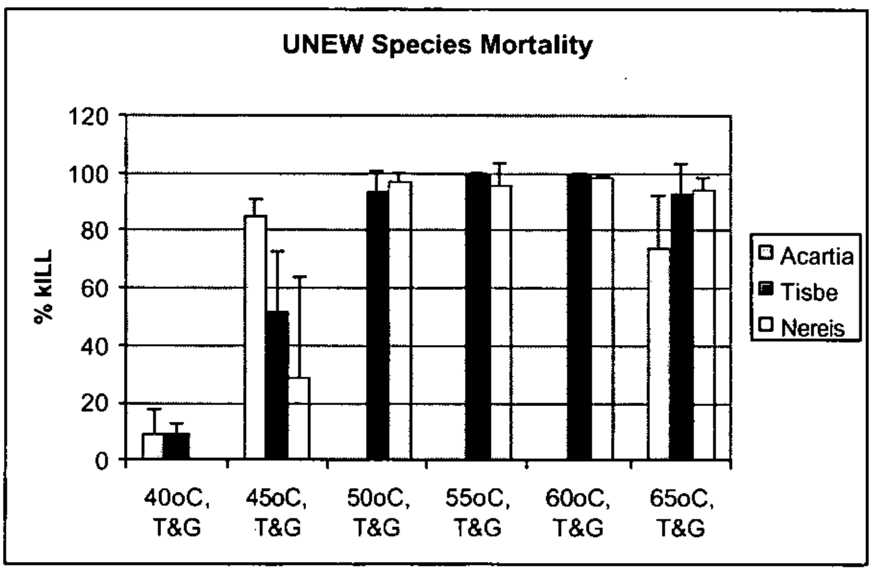

Fig. 2b. Species % kill for different temperatures at instant, 'Touch and Go' (T&G), exposure.
Note: T&G' means instant exposure or 'Touch and Go'.

No differences were found between the three treatments at 55°C (T&G, 10 and 30 seconds), which means that at this particular temperature the increase in the time of exposure did not improve the effectiveness of the treatment (**Fig. 3**).

After having carried out a regression analysis for the Touch and Go treatments (from 40 to 65°C), we can state that in the case of both *Tisbe* (r^2=64.6%) and *Nereis* (r^2=63.9%), the variation in their mortality was significantly related to the temperature (F-test, p<0.001 for both species). This relation was not apparent for *Acartia*, although no *Acartia* was available for three of the six temperatures tested.

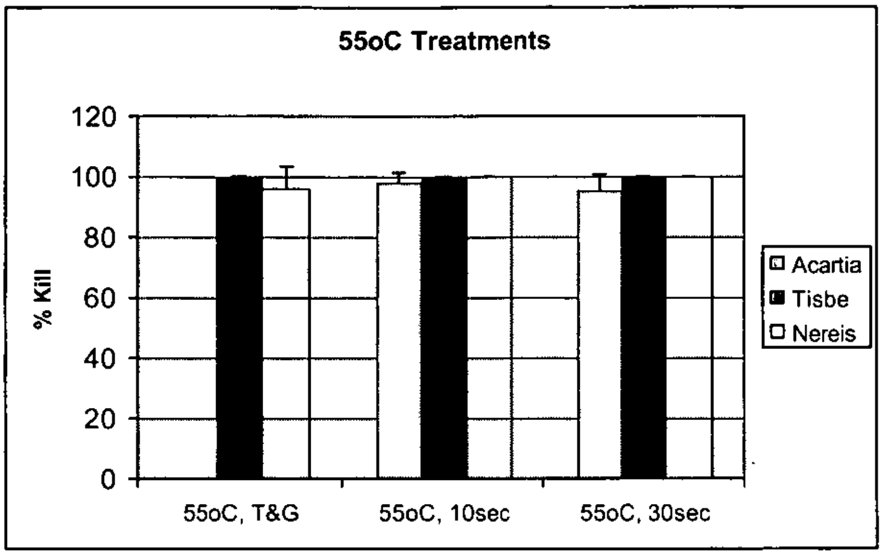

Fig. 3. % of Mortality for different exposure times (instant or Touch and Go (T&G), 10 seconds and 30 seconds) at 55°C.

DISCUSSION AND CONCLUSIONS

After running the MARTOB laboratory-scale trials, we can state that the protocol developed and the soup designed were simple to use, highly reliable and effective. We proved that the soup survived successfully for 24 hours. The mortality of the organisms in the soup prior to applying them into the different treatments (always within the first hour) was of the order of 5.44% (**Fig. 1**). Hence it can be used as a meaningful and reliable means to assess and compare different ballast water treatment methodologies. A range of species representative of a real world situation which have all been transferred in the past, are resistant species, non-pathogenic and cosmopolitan, hence applicable over a large geographic area can be supplied, maintained, dispensed and delivered in good condition for tests all year round, all of it being relatively cost-effective. The water quality standards provided were ensured by making up the test mixture in artificial sea water while the staining methods allowed the determination as to whether organisms had been killed by the treatment.

The principle difficulties that arose concerned attempts at having turbid samples. A standard turbidity of 1g/l was chosen and was made up of 50/50 organic and inorganic material. The turbidity caused problems for filtration and for counting. The particles of kaolin (used for inorganic turbidity) tend to aggregate, therefore clogging the filter and impeding the observation of any organism in the turbid samples. This aspect needs some thought before further tests are carried out.

We restricted the mixture to a salinity of 33, therefore if different salinities are required to represent other situations, such as fresh water ecosystems, or tropical seas, changes in the protocol will have to be applied.

Fish eggs and larvae were excluded because in many countries, including the UK, experiments involving vertebrates require special licences. A set of experiments will soon be carried out under licence for the most promising techniques identified in the trials with the standard mix.

Regarding UNEW tests, all the treaments above 55°C were very effective. These results are in accordance with the experiments carried out on the ship *Iron Whyalla*, where 90-100% of the phyto and zooplankton did not survive after using waste engine heat (35-38°C).[47] Other options with additional heat exchangers at higher temperatures tested on the *Sandra Marie* and the *Union Rotoma* ships, found a 80-90% plankton mortality and a total destruction of the *Crassostrea calamaria* larvae, respectively.[48,49]

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APPENDIX I

PROTOCOLS FOR LABORATORY TESTING

1. Standard artificial seawater was prepared for all tests 24 hours before use. Deionised water (supplier) was added to Tropic Marine salt (35g/l) in 4 mesocosms of 250 or 450l. Following the addition of water, the mixture was agitated continuously for 24h using compressed air to ensure that all the salt had dissolved. Salinity (around 33) and pH (around 8.3) were checked using a refractometer and pH-meter, respectively.

2 If a turbid sample was required 1g solid per litre of water was added. For 70l sample 70g kaolin for inorganic matter, 70g flour for organic mater or 45 and 45g of each if mixed turbidity was required, was added. This produced a turbid suspension, representative of a relatively highly turbid estuary

3 Cultures were supplied in bulk, zooplankton every 2 days and phytoplankton every 5 days. They were stored in CT rooms at 10 and 15°C respectively. Samples were measured out directly from the cultures, each species being stored in separate bottles until the mixture was required and assembled just before use. The organisms were mixed with 70l of seawater that had been pumped into a tank, to create a sample of organisms. A test mixture of 70l include the following number of each organism:

Nereis virens larvae	80
Acartia tonsa	200
Tisbe battagliai	80
Thalassiosira pseudonana	30×10^6
Alexandrium tamarense	24×10^5

After pouring the species samples the bottles used to carry them were rinsed twice in the same water and added to the mixture.

4 Prior to pumping the soup into test rigs the mixture was gently agitated to ensure a homogeneous mixture. Following pumping to the test rigs the tank was rinsed with clean seawater to ensure removal of any residual organisms.

5 Before initiating the treatments, a 10l initial sample was collected from each test rig for laboratory analysis as control samples (see below). Treatments were carried out and on completion a 50l sample was taken for posterior analysis.

6 All samples were filtered through a 63µm sieve. The zooplankton was rinsed from the sieve with clean seawater into labelled pots.

7 Zooplankton samples were stained, fixed, count and preserved as follows:

Stock solutions:

- A stock solution of stain was prepared by dissolving 1.0g of Neutral red powder in 1l of deioniased water.
- 1N NaAc (Sodium Acetate) stock solution was prepared by dissolving 63g of NaAc in 1l of deionized water.
- A stock solution of buffered fixative was prepared by diluting commercially available 10% formalin in a 4:10 ratio to obtain 4% fomalin, and then adding 25g borax to 1l of 4% formalin to make it buffered.

Staining and fixing:

Zooplankton samples were stained with 0.1% Neutral Red solution in the ratio of 3ml stain/100ml sample.
After staining for 60 min, 4 ml of 1N NaAc solution was added per 100ml of sample.
The specimens were then fixed with 4% formalin in a volume equal to that of the sample (50/50).
Thereafter all samples were stored overnight at 5°C prior to counting.

Counting and preserving:

Following the overnight storage and before examination of the samples, Glacial Acetic Acid was added dropwise to each sample, until the colour of the solution changed to magenta. The sample was filtered through a 48µm sieve and washed with tap water. During the counting procedure the samples were kept in water and examined microscopically in Petri dishes. After counting, organisms were preserved in 4% buffered formalin.

Live copepods stained immediately prior to fixation turned a deep magenta after acidification, whereas dead specimens were light pink to white. *Nereis* had to be more carefully observed, as dark staining did not guarantee viability. Some treatments affected the staining in such way that 'live' organisms varied in colour from magenta to orange. Therefore the assessment of individuals also included a morphological examination.

For the counting procedure whole organisms as well as bits were taken into account. The quantity of organisms delivered by the suppliers was a range between two densities therefore we dealt with volumes and not with an exact number of organisms to make the soup samples.

7 Biological effectiveness of each trial was characterised by the percentage kill of each test organism type as well as the overall kill rate. The percentage of mortality was calculated as the number of dead animals divided by the sum of dead and alive animals found in the after treatment samples. When no material or no whole animals were found a 100% in mortality was recorded.

Implications of Open Ocean Ballast Water Exchange

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G. Gravir, MSc, and E. Bitner-Gregersen, PhD
Det Norske Veritas

SYNOPSIS

Open ocean ballast water exchange is currently recommended as the main ballast water management measure in the IMO guidelines. It is expected that IMO member countries will adopt a convention regulating ballast water issues in the Spring of 2004. It is important to recognise that open ocean exchange is only partly effective and is not always possible to perform due to safety and operational issues involved. This paper estimates the percentage of ballast water that will not be possible to sequential exchange in the North Atlantic, by considering wind and wave statistics, global ship traffic patterns and bottom topography data. We have assumed that the safety critical significant wave height is between 3 to 6 meters, and applied a statistical approach to compute the probability for mid-ocean ballast water exchange during different voyage scenarios in the North Atlantic. The modelling results indicate that the likely amount of untreated ballast water in the North Atlantic will be in the range of 25-100 million tonnes. These findings, based on several assumptions, clearly indicate that a significant portion of the ballast water transported annually in the North Atlantic will have to be treated by other methods, or discharged as untreated ballast water.

INTRODUCTION

Vessels in ocean trade carry species in their ballast water that may impact the marine ecosystems when discharged. The undesirable spreading of such organisms during the discharge of ballast water around the world's ports is of major concern for the shipping industry. It is expected that the IMO (International Maritime Organisation) member countries will adopt a convention[1] regulating ballast water issues in the Spring of 2004. Open ocean ballast water exchange is currently recommended as the main ballast water management measure in the existing IMO guidelines[2]. Open ocean exchange of ballast water involves replacing coastal water with open ocean water during a voyage, either by emptying and refilling ballast tanks (sequential exchange) or by flow-through dilution. It is important to recognise that open ocean exchange is only partly effective and is not always possible to perform due to the safety issues involved. A vessel executing sequential exchange while exposed to wave loads may experience excessive bending moments and shear stresses representing a threat to structural integrity. Slamming and tank sloshing may also increase the risk of causing structural damage to the vessel. Recent studies have pointed out that many medium size and small vessels typically operating in shallow waters close to shore will have difficulties to complying with the IMO guidelines. These operational considerations and safety aspects illustrates that a portion of the approximately 2.7 billion tonnes[28] of ballast water transported annually will have to be treated by other methods, or discharged as untreated ballast water. This paper estimates the percentage of ballast water that will not be possible to sequential exchange in the North Atlantic, by considering wind and wave statistics, global ship traffic patterns and bottom topography data.

SAFETY FACTORS

The hazards associated with the sequential method are presented in a study performed by the International Association of Classification Societies[31] (IACS). One hazard is that permissible bending moments and the shear forces on the ship's hull may be exceeded[3,6,7]. Other studies have concluded that ocean exchange is safe in terms of bending moments and shear stresses[4,5,8]. A diagonal sequential method could be an effective method for reducing the still water bending moment and shear force to within permissible levels[3]. Other criteria most frequently found difficult to maintain during all stages of the exchange sequence are bridge visibility, propeller immersion and minimum forward draft[3,4,5].

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These assessments are based on the still water condition. Wave loading on vessels could significantly increase bending moments and shear stresses, and the possibility for damage due to slamming and sloshing in partially filled tanks. Some sea-keeping analyses have been conducted in order to obtain a better picture of the problem. Sloshing in partly filled tanks seems to be a problem, especially for single skinned bulk and tank vessels[3]. Ref. 8 found that exchange could be made safely at sea as long as significant wave heights are below a maximum value between 3 and 6 m, considering wave-induced bending moments and shear forces.

A Japanese's study[4] reported that 20 of 21 vessels analysed do not satisfy the forward draft requirements. The minimum bow draft requirement aims to avoid slamming, which could cause local structure damage in the forward region. In order to consider the implications of the reductions in forward draft, they performed analysis to identify the significant wave height of the sea condition at which slamming could occur, with a certain probability. The significant wave height at which slamming may cause safety concerns depend on design criteria. The Japanese study[4] applied a criterion of one slamming event during the exchange period. The calculations were made for different ship types and ballast conditions. The significant wave height at which slamming occurs once per exchange period was calculated to be in the range 2.4 to 7.5 m for a 2 hour exchange period. The significant wave height for one slamming event during a 2 day exchange period was calculated to be in the range 2 to 6.2 m. This study indicates that slamming may occur at significant wave heights less than the draft, depending on vessel type, size and ballast conditions.

American Bureau of Shipping[5] (ABS) applied a criterion of 3 slamming events per 100 waves. For such a slack criteria, all vessels were found to comply with this criterion at sea states of significant wave heights below 8 meters.

Thus it is apparent that a vessel carry out sequential exchange while exposed to wave loads might experience excessive bending moments and shear stresses representing a threat to structural integrity. Slamming and tank sloshing increase the risk of causing structural damage to the vessel. Based on the above discussion, we have assumed that the safety critical significant wave height is between 3 to 6 meters, and that this applies to all vessels. This is clearly a simplification. The critical limits will depend on actual sea-state (direction, periods, spectrum etc.) and ship specifics (arrangements, design, ballast condition etc.). Reporting from ships that arrive to U.S. ports from overseas indicate that sequential exchange seems to be the most likely option for most of the vessels[29]. For example, this option covers about 75% of the reports from vessels treating ballast water coming into California and Texas ports[29]. Some variations are observed between vessels types. In this study, we assume that sequential exchange is used on 75% of the ballast water treated annually.

FEASIBILITY FOR SEQUENTIAL EXCHANGE IN THE NORTH ATLANTIC

A Geographical Information System (GIS) is used to estimate open ocean exchange feasibility for the North Atlantic, by considering waves statistics, global ship traffic patterns and bottom topography data. A study submitted by Spain to MEPC[10] pointed out problems with executing mid ocean exchange according to the IMO Guidelines at several main sea routes operated by medium sized and small vessels. Such routes were between the North Sea and other European countries, in the Mediterranean Sea and between Caribbean Sea and North/South of America. These and other shallow and near coastline sea routes represents a large portion of the traffic, as illustrated by the global traffic data from AMVER[11] and bottom topography data in Figure 1.

The AMVER (Automated Mutual-assistance Vessel Rescue system) data is based on records from more than 100,000 voyages annually[12], representing more than 10% of the large ocean-going cargo fleet. According to this data, the North Atlantic traffic accounts for about 35% of the international traffic[13]. From the AMVER data we find that about 60% of the traffic in the North Atlantic operates within 200 nautical miles (nm) from shore at any given time. These findings correspond with Ref. 14, reporting that nearly 70% of ship emissions occur within 400 km of land, and Ref. 15, reporting 74-83% of the ships to be within 200 nm of land at all times (based on: Refs. 16 and 17).

The AMVER data does not include short sea shipping (typically national and local trades) with voyages of less than 24 hours, and includes mainly vessels larger than 2,000 Dwt. The Norwegian Ordinary Register (NOR) includes ships mainly in domestic trade. 89% of the NOR registered fleet is less than 1,000 gross tons[18]. This indicates that the short sea shipping fleet is typically less than 2,000 Dwt. Based on this assumption, we find that this category constitutes 43% of the world merchant fleet by number and 2% of the fleet by tonnage size[19] (see Table 1). These trades represent moderate risk with respect to the introduction of alien species through ballast water exchange, but may play an important role as a potential secondary catalyst for further regional spread of already introduced species.

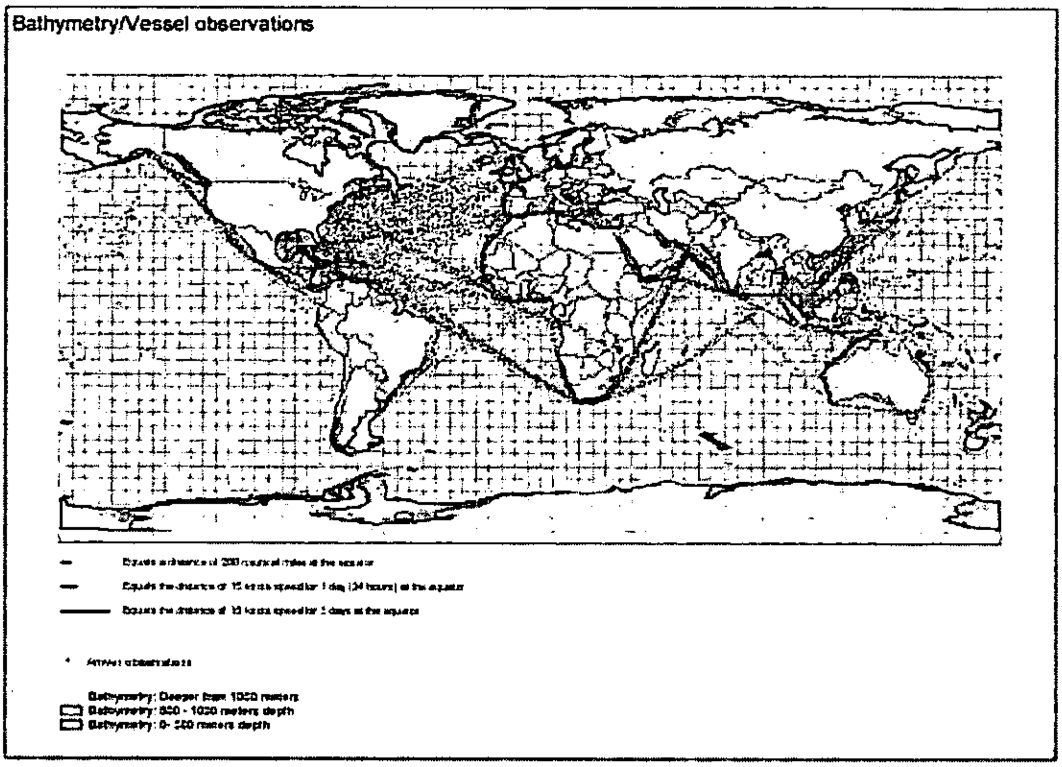

Figure 1 Traffic density and bottom topography[11,25]

The AMVER data mainly consists of regional (between neighbouring nations and within continents) and inter-continental traffic. A fraction of the vessels reporting within the 200 nm zones are in inter-continental traffic. We may assume that ships in inter-continental traffic spend 1 day within the 200 nm zone at each side of the continent and that the voyages on average take 7 days. The AMVER data then indicate that 56% of the ships above 2,000 Dwt are in inter-continental trade and that the remaining 44% are in regional traffic.

Further, we may assume that 44% of the smallest vessels above 2,000 Dwt of the world merchant fleet represent ships in regional traffic. This corresponds to all ships between 2,000 and 10,000 Dwt. They constitute 27% of the merchant fleet by number and 7% by tonnage size (see Table 1). These ships represent moderate risk with respect to the introduction of alien species through ballast water exchange, as origin and discharge of ballast water is mainly within the same region/continent.

The above assumptions result in an estimate for the fleet in inter-continental trade amounting to 30% by number. These ships are above 10,000 Dwt and constitute 90% of the fleet by tonnage (see Table 1). Statistics from Fearnleys[20] indicate that most of the oil products and dry bulk (coal, iron ore and grains) cargos are mainly transported with large vessels (> 50,000 Dwt) within a fairly well defined system of international sea routes. These principal cargoes combined, account for about 60% of the total international seaborne cargo. Thus, the large oil tankers and bulk carriers account for the majority of international ballast water movement.

The lowest possibility for exchange according to global wave statistics seems to be for the routes north of the 25-degree latitude during the winter[21]. Large seasonal and geographical variations in wave height are observed[22] (Figure 2). Figure 3 illustrates that significant wave heights above 3 m and above 6 m, occur less than 50% and 10% of the time, respectively[23,24].

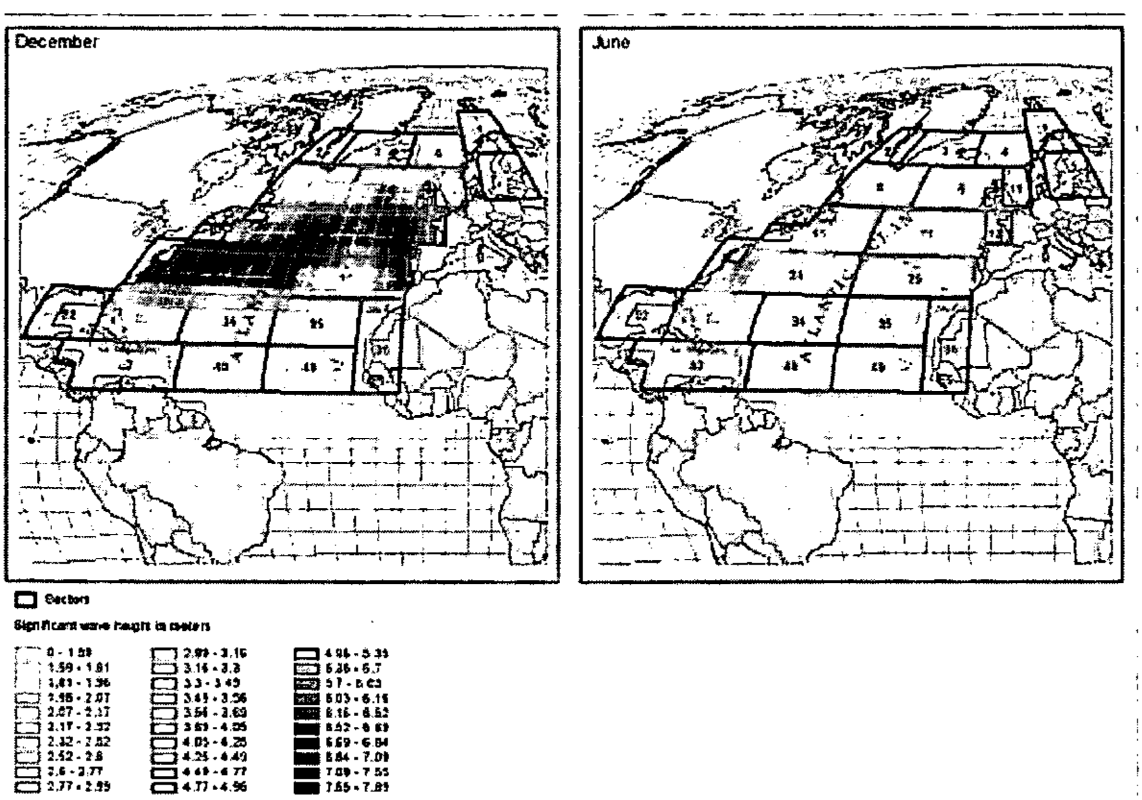

Figure 2 Average max wave conditions in December and June for the North Atlantic[22] (from the period 1964 to 1993, based on Gulev & Hasse data, monthly mean wind sea height of 0.14% percentile exceedance, 30-years monthly average has been calculated), including illustrations of wave sectors used by British Maritime Technology[23] (BMT)

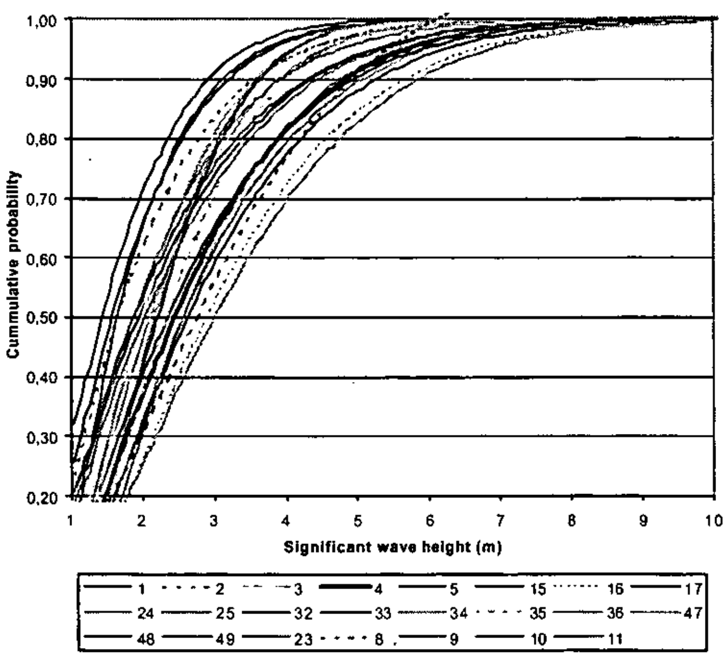

Figure 3 The distribution of significant wave height for different sectors in the Northern Atlantic[23, 24] (see Figure 2)

By combining wave statistics (Figures 3) with the ship traffic distribution (Figure 1), we can calculate the fraction of vessels that will experience a significant wave height above defined levels at any given time (Figure 4). The calculations show that about 26% of the traffic in the Northern Atlantic will experience significant wave heights higher than 3 meters. However, this number is only valid at any given time during a year, and does not represent the exchange probability for required sea states of up to 2 days, as discussed below.

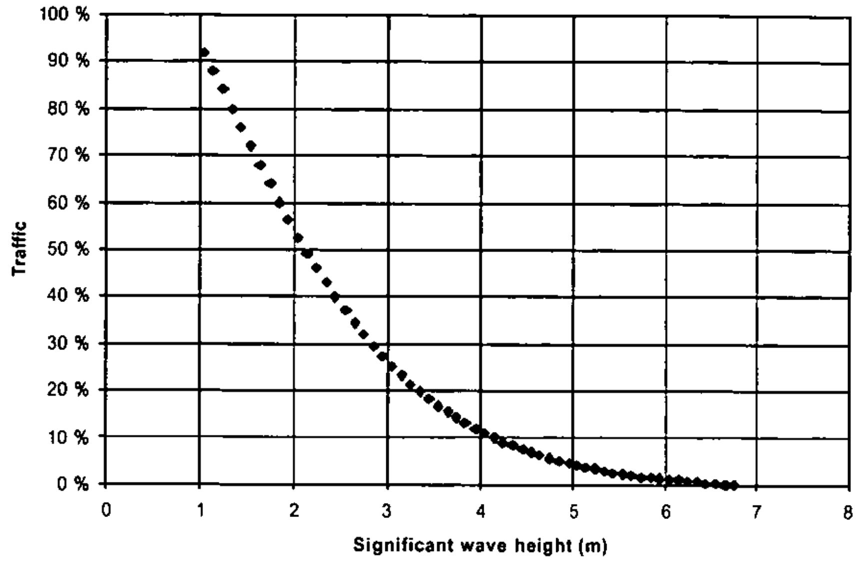

Figure 4 Expected fraction of traffic experience to significant wave height at any given time in the Northern Atlantic

MODELLING OF BALLAST WATER EXCHANGE

Ships on inter-continental voyages will have to exchange ballast water mid-ocean. We may assume that the voyage on average takes 7 days and that 2 days are spent within the 200 nm zones. This leaves 5 days for open ocean exchange. We may further assume that safety critical problems occur when the significant wave height is above 3m. Note that the necessary ballast water exchange period varies, but larger ships may use up to 2 days[4] for ballast water exchange.

We have applied a statistical approach to compute the probability for exchange during 5 day voyage, assuming that exchange is only performed if wind speed is lower than 12 m/s for 1 and 2 days. This wind speed represents about 3m significant wave height, using a relationship between wind speed and significant wave height reported by Ref. 26. A 17 m/s wind scenario is also considered, reflecting significant wave heights of typically 6m. For the defined scenarios, the model computes statistics based on Monte Carlo simulations, using hindcast wind data[27] from the period 1955-1999. The wind data refers to a position outside mid Norway and inside BMT sector 4 in the Norwegian Sea (67.020° North and 6.930° East). It is assumed that wind and wave data from this position is representative for the North Atlantic wind and wave climate (See BMT sector 4, Figure 3), where sector 4 seems to represent an average metocean conditions.

The probability for being unable to carry out ballast water exchange during a voyage of 5 days, requiring 1 day for exchange is 0.07. That is, 7% of the ships will not be able to carry out open ocean exchange during a trade. Or in other words, 7 out of 100 inter-continental ballast voyages will not be able to exchange ballast water mid-ocean. When the required exchange time is increased to 2 days, 30% of the vessels will not be capable of performing exchange. If we assume that the operation is safety critical for significant waves above 6m, 1 out of 600 ballast voyages will not be capable of performing exchange. This latter result is valid for an exchange period of 1 day.

Ships in regional traffic will typically have average voyage duration of 3 days. We may assume that 2 days are spent within the 200 nm zones, leaving 1 day for open ocean exchange. If the exchange operation is critical at significant wave height above 3m, 43% of the ships will experience problems conducting the open ocean exchange (Table 1). For critical significant waves above 6m, some 13% of ballast voyages will not be capable of performing exchange (Table 1). Seasonal variation in traffic and weather conditions may influence the results.

Table 1 Probability for sequential mid-ocean exchange in the North Atlantic

Main traffic categories	*Bio Risk*	*Voyage duration (days)*	*Depth >500 m*	*Vessel sizes (Dwt)*	*Fraction by number*	*Fraction by tonnage*	*Probability for not exchange $hs^{(3)}_{(critical)} = 3m$*	*Probability for not exchange $hs^{(3)}_{(critical)} = 6m$*
National	Medium	<1	No	<2,000	43.1%	2.2%	-	-
Regional[(1)]	Medium	2-3	Partly	2,000-10,000	26.5%	7.4%	43%	13%
International[(2)]	High	> 8	Mainly	>10,000	30.4%	90.4%	7%	0.2%

[(1)] Voyage duration in open ocean is assumed to be 1 day, and required exchange time equal 1 day
[(2)] Voyage duration in open ocean is assumed to be 5 days, and required exchange time equal 1 day
[(3)] $hs_{(critical)}$ - assumed critical significant waves heights

RESULTS & CONCLUSION

The total amount of ballast water discharged annually amounts to 2.7 billion tonnes[28]. The ship traffic in the North Atlantic represents 35% of the world traffic. The annual ballast water discharge in the North Atlantic may then be estimated to some 0.9 billion tonnes (35% of total).

The results from the feasibility assessment presented above are summarised in Table 1. At large, it shows that the ships in inter-continental traffic will experience problems with open ocean ballast water exchange in 7% of the voyages, while ships in regional traffic will experience problems in 43% of the voyages (assuming one day is sufficient for exchange). The former category represents some 90% of the fleet by tonnage while the latter category represents 7%. Ships in regional traffic will carry out 3-4 times as many voyages as ships in inter-continental traffic. A rough estimate may then be that about 20% of the ballast water discharged is related to ships in regional traffic, and that the remaining 80% is discharged by ships in international trade. National traffic has not been considered here, as these ships do normally not sail in open ocean areas.

A rough estimate may then be that 43% of the ballast water transported by regional traffic will be discharged (9% of total) without open ocean exchange and that 7% of the ballast water transported by ships in inter-continental traffic (6% of total) will be discharged without exchange. This implies that the ballast water discharged without treatment in the North Atlantic will be from both ships in regional and inter-continental traffic, and that this annually amounts to some 135 million tonnes. Taking into account that about 75% of the ballast water[29] is treated with the sequential exchange method reduces this estimate to 100 million tonnes. Alternative methods for ballast water treatment are available[9], but the costs are much higher compared to executing open ocean exchange[30]. The main assumption made to derive the above estimates, is that safety critical conditions will take place for the vessels when the significant wave height exceeds 3m. If we assume that the operation is safety critical for significant waves above 6m, some 0.2% of the inter-continental ballast voyages and 13% of regional ballast voyages will not be capable for performing exchange, representing about 25 million tonnes. This estimate indicates that the untreated amounts of the ballast water in the North Atlantic, likely will be in the range of 25-100 million tonnes. However, the exchange period may be longer and close to two days for some vessels[4]. This will mainly be the case for larger ships, and could increase the estimated amount of untreated ballast water for ships in inter-continental trade.

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An economic solution of ballast water treatment for oil tankers

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Abstract

World wide shipping activities transfer 12,000 million tonnes of ballast water annually [1, 2, 3]. Ship ballast water carried marine organisms. It is estimated more than 5,000 marine species are being transferred daily around the world. As a consequence, every 9 weeks, a new species is settled in a new environment. Ballast water management has been a major challenge in modern shipping. The current deep-sea ballast water exchange practice has been considered an insufficient measure in tackling the problem due to ship's safety, stability concerns and the low effectiveness of the method itself. A number of onboard treatment methods are being under investigation and development across the world, including physical, chemical, mechanical and biological methods.

The paper presents a study and detailed design of a rapid heating system using waste heat from the steam discharged from oil cargo pumps on an oil tanker. The treatment can be performed continuously with a high treatment rate. Its operational cost is virtually zero and this is seen a break through in ballast water treatment. The paper includes detailed system layout, cost analysis and conclusions and recommendations for further development of such the system.

Key words: ballast water, thermal treatment, oil tanker, marine ecosystem

Introduction

The aim of this study is to design a system to perform ballast water treatment by raising the water temperature to about 65°C [4, 5]. The treated water is used to pre-heat the inlet water and leaves the system (to ballast tanks or to sea) with only 5-10°C above the inlet seawater. Thus, the heat amount required is minimised and there is no thermal stress to ship's hull. There are several heat sources which can be used for this heating purpose, like, waste heat from engine exhaust gases, engine cooling systems and steam condensers on oil tankers. If the waste heat is not sufficient to satisfy the proposed heating process, additional heat can be supplied from auxiliary boilers.

The option of using waste heat from engine limits the process to taking place only during voyage when engine are in operation. In practice, ballast and deballast of a ship often take place while the ship is in ports or near ports in conjunction with cargo loading and unloading. This study concentrates on using waste heat released in the steam condensers of cargo pumps on an oil tanker. The study and design demonstrated that the amount available from the condensers is sufficient to heat the ballast water to the required treatment temperature at a flow rate near to the ballast water flow rate of normal ship operation.

For normal operation of oil tankers, ballast is taken in when cargo oil is unloaded. During the unloading process, large amount of steam is required to drive the cargo pumps. The steam enters to condensers after leaving the pumps where a large quantity of heat is released to the cooling water (seawater). If this amount is used for treating ballast water and it is sufficient, the treatment process can be performed without any additional operational cost, even no additional cost for running the ballast water pumps since ballast water pumps need to be in operation during cargo oil unloading process even without ballast water treatment.

The system and design

Vessel Description

The oil tanker used in this study is an "Aframax" owned by Neptune Orient Lines (NOL) Ltd. Table 1 illustrates the main technical data of the vessel [6].

Table 1: Main technical data of the vessel

Built By: Imabari Shipbuilding Co Ltd (Koyo Dockyard)			
Classification	NKK	No. of Cargo Tanks	14 + 2 SLP
Year Built	1999 (approx.)	Cargo Oil Capacity	122,814.26 m^3
DWT	107,000 tonnes	Cargo Pump Capacity	3 X 2500 m^3/h
GRT	57,950 tonnes	Stripping Pump	1 X 200 m^3/h
LOA	246.8 m	No. of Ballast Tanks	13 + 2 emergency
Beam	42.0 m	Ballast Tanks Capacity	41,261.78 m^3
Depth	21.3 m	Ballast Pumps	2 X 1800 m^3/h (3 Bar)
Draft	14.0 m	Aux. Boiler	2 x 25,000 kg/h
Speed	14.6 knots	Crude Oil Washing, Inert Gas system and Segregated Ballast Tanks	

Ballast treatment concept

The vessel in this study uses steam-driven cargo pumps. The cargo oil pump turbine (COPT) condenser condensing 43,000 kg/h (Table 2) of steam during cargo offloading operation. This is a large amount of "waste" heat that can be used to heat treat ballast water.

The concept of the treatment system as shown in Figure 1 is that ballast enters through the sea chest and is routed to pre-heaters that raise the temperature of the seawater to an initial temperature of 55°C. It then passes through the steam turbine vacuum condenser (which is originally cooled by seawater) where it reaches the target temperature of 65°C. On exit, it passes through the same set of pre-heaters, as mentioned above, where it transfers its heat to the incoming ballast water, before entering the ballast tanks.

Table 2. COPT condenser data

Fluid	Exh. steam	Seawater (cooling)	Seawater (heating)
Working pressure	500 mmHg V	2 bar	-
Design pressure	1 bar	3.5 bar	-
Inlet temperature	72.5 °C	30 °C	55 °C
Outlet temperature	72.5 °C	51.4 °C	65 °C
Flow rate	43,000 kg/h	1100 m^3/h	2165 m^3/h
Velocity	-	1.79 m/s	2.55 m/s

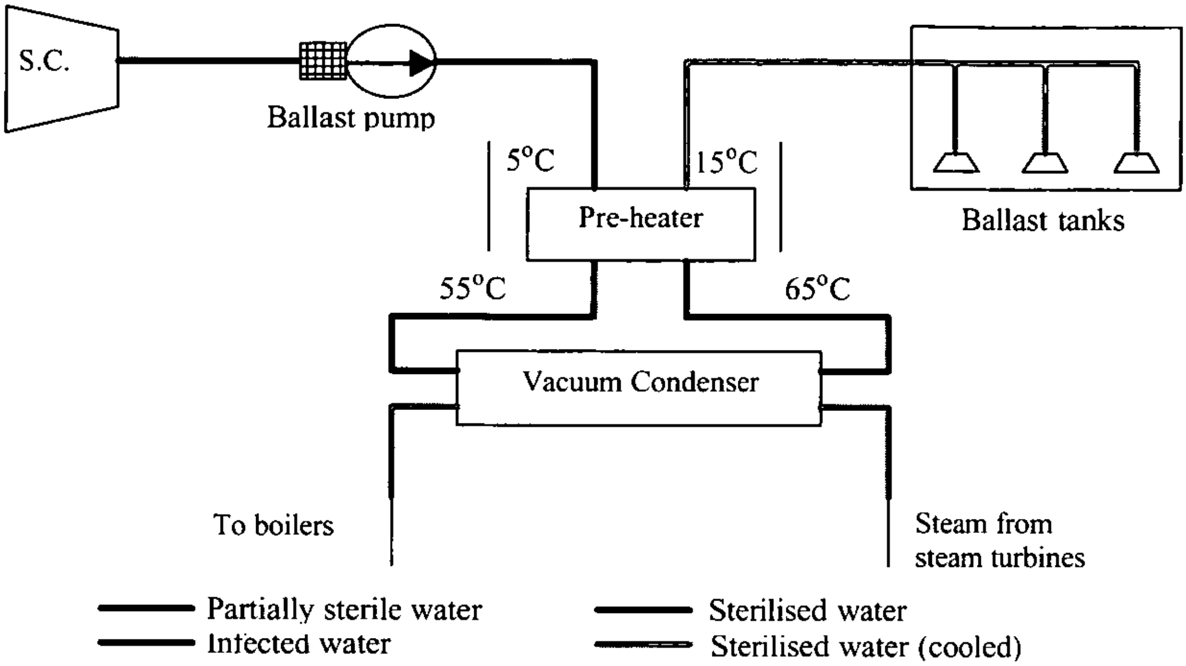

Figure 1: Proposed Thermal Treatment System

Design criteria

Target temperature

Temperature selection for this rapid heating ballast water treatment is a function of organism lethal temperature and exposure time. The thermal lethal temperature is the point at which an organism is instantly killed due to either denaturing of cellular proteins or increasing the organism's metabolism beyond sustainable levels. Temperatures close to an organism's thermal lethal temperature can be tolerated for short periods with little non-reversible damage. This implies that for a lower temperature, a proportionate increase in exposure time is required to destroy the organisms. At the chosen treatment temperature of 65°C, a few seconds is sufficient to destroy micro-organisms and all other life forms.

Seawater ambient temperature

The selection of a design seawater ambient temperature determines the capacity of heat exchangers required for thermal treatment. To avoid the danger of "under-designing", ballast water temperature at winter level of 5°C is selected as the design ambient seawater temperature.

Treatment flow rate

To achieve low operational costs, the ideal treatment time should be in consistence with that of the cargo discharge operation as this will fully utilise the waste heat available. The cargo discharge operation duration is approximately 16.4 hours, which defines the flow rate of ballast water at 2516 m^3/h (2580 t/h).

It is not practical to set this as the target flow rate at this stage as other factors need to be considered such as, heat availability from the COPT condenser and fluid velocities in the pipes. Thus the treatment flow rate needs to be determined from calculations.

Heat availability

The COPT condenser is a shell-and-tube heat exchanger; single-pass, cross-flow type. Steam from the COPT enters the condenser and is cooled by the seawater. By taking an efficiency of 85%, the heat available was found to be 21,786 kW.

Fluid flow velocities

Erosion of metal may be resulted from high water velocity which subsequently aids in corrosion by removing the oxide film and cavitations. The limit of this velocity is dependent upon the material. Table 3 shows the velocities for various materials [7, 8].

Table 3: Fluid velocity range based on material

Material	Velocity range (m/s)
Copper	0.9-1.2
Admiralty brass	0.9-1.8
Aluminium brass	1.2-3.0
70/30 Cupro-nickel	1.8-4.5

To minimise the cost of system installation, the study proposes to use the existing COPT condenser which's tubes are made of aluminium brass. This allows a maximum theoretical treatment flow rate of 1891 t/h based on a limiting velocity of 3.0 m/s in the cooling tubes.

However, a lower flow velocity of 2.55 m/s was selected which yielded a treatment flow rate of 1607t/h. Based on this flow rate, the temperature range that can be treated by the COPT condenser is 12.5°C.

Applying the design criteria and its impact

Taking into account the required flow rate of 2580 t/h to meet the cargo discharge operation duration, and the selected treatment flow rate of 1607t/h, it is evident that:

- Another source of energy must be found to supplement the energy from the COPT after cargo discharge operation.
- There will be an increase in the duration required for ballasting the vessel.

Use of auxiliary boiler

The auxiliary boiler is required to provide an alternate source of energy for the thermal treatment system after the cargo discharge operation, or at any other time when the COPT is not in operation. An example of this would be in bad weather.

Availability of steam from auxiliary boiler

On the vessel, there is an existing steam line from the auxiliary boiler to the COPT condenser. Calculations show that 25,280 kW is available from the COPT condenser utilising steam from the auxiliary boiler.

Cost of running the auxiliary boiler

The auxiliary boiler uses "C" heavy fuel oil with a fuel consumption of 1941 kg/h, costing USD 267 per hours at fuel cost of USD 137 per tonne. The costs of utilising steam from the auxiliary boiler for the thermal treatment of ballast water immediately after the cargo discharge operation should also be considered.

Based on the increased treatment flow rate of 1865 t/h, it would take an additional 8.56 hours to treat the remaining amount of ballast water required for normal ballast condition. This will cost USD 2285 per ballast operation.

Over-staying at oil terminal for ballasting

It is concluded that there are no additional charges with regards to over-staying at the oil terminal as berthing/mooring are a one time charge and not dependent upon duration. Also, the tanker can ballast while under anchor or during transit from the terminal out to sea.

Some terminals and port authorities require vessels to have full immersion of the propeller in the event of emergencies. This should not be issue as the vessel will be at >62% of its normal ballast condition.

Taking into account the documentation period, the new minimum duration spent by the tanker at an oil terminal from time of cargo discharge would be 16.4 hrs + 2 hrs = 18.4 hrs. This will result an additional 6.56 hours stay in port. Thus, there is potential for the vessel schedule to be affected and this translates into loss of charter or generation of income. However, it is questionable how drastically 6.5 hours will affect the schedule of the vessel. The speed of the vessel might be very slow depending on the route taken out from the oil terminal, especially if it passes by the anchorage. The vessel can continue ballasting while in transit. Without knowing the region in which the vessel operates in and the operation schedules, this factor shall not be considered further

System onboard installation

Pre-heater and steam heater

Based on the design parameters, two plate type heat exchangers (PHE), MX-25BFM [9, 10], were selected to conduct the preheating. The dimensions of the model are 3370 x 920 x 2890 mm (L x W x H) with a connection pipe of 250 mm diameter. The existing condenser is used as the high temperature steam heater of shell-tube type.

Availability of space

It is found that sufficient space is available for the pre-heaters' installation in the pump room where pre-heaters can be ideally installed close to the COPT condenser. As shown in Figure 2, a platform needs to be extended at the 3[rd] deck in the pump room to accommodate the pre-heaters. The engine room and pump room needs to be kept segregated thus a bulkhead penetration piece will be installed for pipe connection.

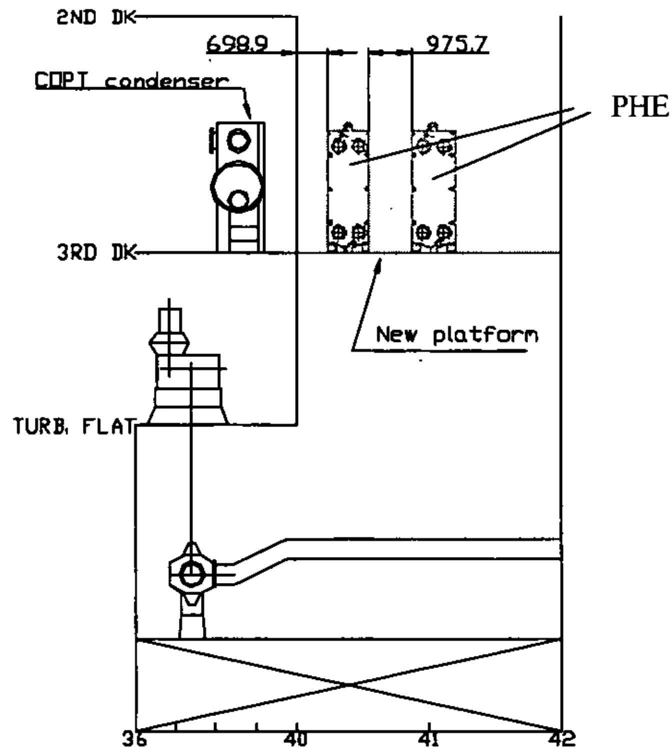

Figure 2: Location of new platform and PHE

System integration

Figure 3 illustrates an overview of the thermal treatment system integrating pre-heater, condenser, ballast pipework and ballast tanks. The total wet weight of the system is about 35 tonne. Its effect on ship's cargo capacity can be ignored.

Cost estimate

A cost estimate is developed for this study. Quotations and estimates were obtained form various sources from the industry. The estimated capital cost of this thermal treatment system is USD 338,563. Details of the cost are given in Table 4.

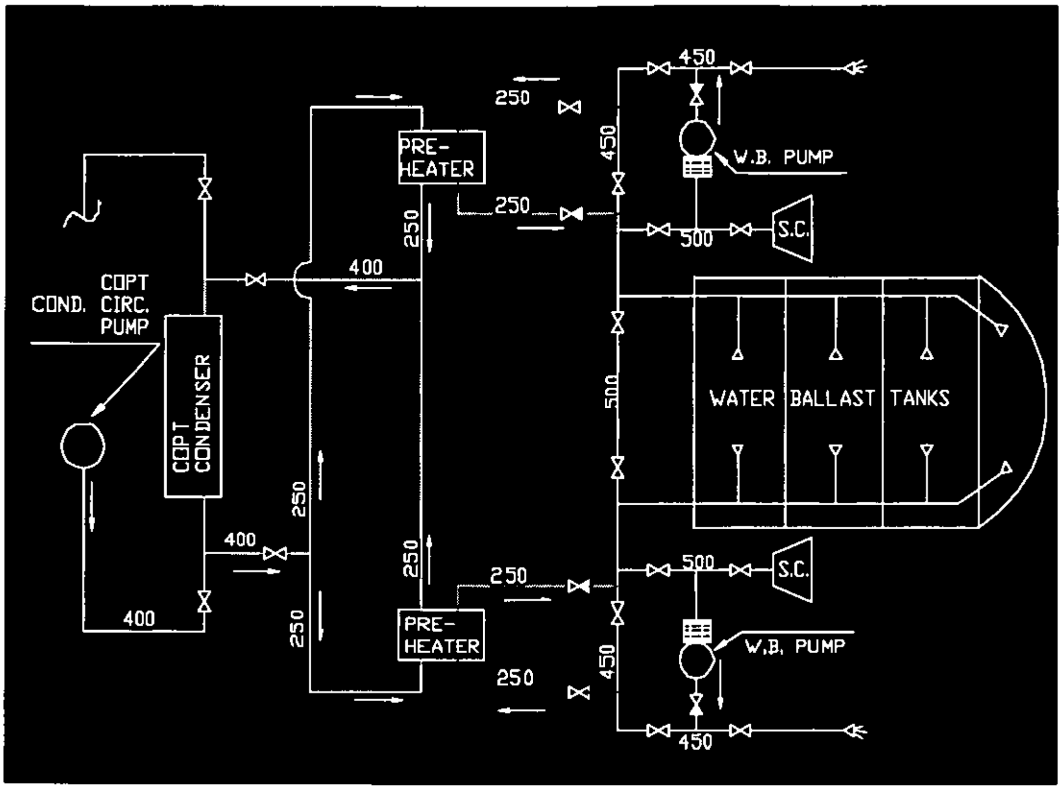

Figure 3. Ballast water thermal treatment system

Table 4: Break down costs for system installation and materials

Item	Cost per unit / per metre (US$)	Quantity / length (m)	Price (US$)
Platform	12,963.60	1	12,963.60
PHE	131,679.00	2	263,358.00
Installation of PHE	2,105.20	2	4,210.40
Bulkhead penetration	2,632.60	2	5,265.20
250 mm pipe	304.70	61.13	18,626.31
250 mm valve	1,540.12	4	6,160.48
250 mm elbow	182.82	25	4,570.50
400 mm pipe	481.98	8.43	4,063.09
400 mm valve	4,171.62	4	16,686.48
400 mm elbow	398.88	3	1,196.64
Reducer	731.28	2	1,462.56
		Total	**338,563.26**

Conclusions and recommendations

The study has clearly demonstrated the principles and design of the treatment system. It has reached the conclusion that the proposed high temperature treatment is a very cost-effective treatment method for oil tankers with steam driven cargo pumps. The performance of the steam condenser / heater, in terms of corrosion, erosion and pressure take-up, needs to be further examined during the operation of the systems.

Acknowledgement

The authors of the paper would like to thank Neptune Orient Lines Ltd, who provided the technical data of the vessel for this study, and Alfa Laval Marine for their assistance in providing technical data for heat exchangers.

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The environment: a joint responsibility

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SYNPOSIS

It is argued that the environment belongs to all of us and that local communities should therefore be involved in its stewardship. However, three measures must be taken to empower lay people to participate in environmental management issues. First, there is a need to improve environmental knowledge in the general public. This should be achieved, not solely through the formal education system, but educational initiatives that involve all sections of society and operate outside the system. Second, public debate should be conducted in an atmosphere of collaboration between groups in society, not confrontation. Third, means must be found whereby members of society can develop their views on issues and then participate in management processes. The involvement of community groups in scientific research is one way of doing this. Public consultation exercises, such as techniques used in forming focus groups, stakeholders' dialogues and citizens' juries, are other means.

INTRODUCTION

Stewardship of the environment is seen by most people in society as a distant responsibility of politicians, scientists, industrialists, planners and 'green environmentalists'[1]. In fact, the environment belongs, not to particular sections of society, but to all of us. It follows that we should share the responsibility for managing it at sustainable levels for the benefit of future generations. This position is increasingly recognised in both scientific and government circles. For example, the Department for Environment, Food and Rural Affairs' publication *Safeguarding Our Seas: A Strategy for the Conservation and Sustainable Development of our Marine Environment*[2] develops a new, shared vision for the integrated management of coastal areas. It entrusts 'people with a responsibility to care for the community to which they belong'. The report of House of Commons Select Committee on Public Administration[3] on *Innovations in Citizen Participation in Government* also points out the benefits of involving the lay public in environmental stewardship. They are likely to be of two kinds. First, public involvement will improve the quality of decision-making processes. This is because society possesses a wealth of non-scientific knowledge, wisdom, skills and perceptions, both cultural and social, which may be highly beneficial in determining wise policy on environmental issues. As Christie & White[4] have argued, local knowledge, coupled with specialist knowledge of the scientist, is more potent than either kind of knowledge on its own. Valuable information may be encompassed either in 'traditional' knowledge or in the specialist knowledge of groups, such as fishermen[5] or farmers[6,7],whose livelihoods bring them into close contact with the environment. Second, lay people may provide an additional dimension to debates on environmental issues because they approach them from non-political perspectives[8].

The idea that members of local communities can play their part in environmental stewardship is not a new concept at all. Indeed, it was probably 'normal' in communities that operated (or still operate) at subsistence level. The traditional management of coastal fisheries has, for example, been community-based in many parts of the world. These communities had real or perceived ownership of the area in which they fished, and controlled access to it[9]. Such systems have tended to collapse in modern times, due predominantly to western influences[10] but they are still practiced in remote regions, such as parts of western Africa[11] and the Maluku Province in Indonesia[12]. It has been suggested[13] that there is much to be learned from them, and that it would be of great benefit if the best of modern management practices could be blended with the best of their traditional counterparts in developing cost-effective management strategies for coastal fisheries. The proposal is supported by evidence that community-based

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management can work in the modern world. There have been significant improvements in reef quality, and fish diversity and abundance, on Apo, Negros, Pamilacan and Balicasag islands in the Philippines, following the introduction of a community-based system of management[14, 15] The importance of the community approach to fisheries management, in the sense of involving fishermen in the decision-making processes, has also been recognised in other parts of the Philippines[16] (Pomeroy & Pido 1994), Denmark[17](Nielsen 1994), Japan[18] (Lim *et al.* 1995) and the UK[19, 20, 21].

So what needs to be done in order to empower local and regional communities to participate in stewardship of the marine environment? It is argued here that three problems must be addressed before this can become a realistic objective. They are addressed separately in the sections that follow:

1. Environmental knowledge.

Knowledge of the environment was (or in some cases still is) well-developed where systems of community-based management (or still operate)[22]. Regrettably, while there is still good environmental knowledge in specialist groups in society[23] and in some cultures, such as those of Vanuatu (in the Pacific), in which people depend on the immediate environment for their food and other resources[24], it is generally poor. It is ironic that, at a time when there is an explosion of environmental knowledge[25], the general public appears to woefully ignorant of environmental issues. It is especially alarming that most people have little knowledge of common organisms that occur in their localities[23]. How can we expect people to develop a conservation ethic when they are unaware of, and therefore do not value, their local flora and fauna?

The formal education system is an obvious way in which knowledge and awareness, of science can be achieved, and there has been substantially more emphasis on some of its aspects, such as man's impact on the environment, during the past two or three decades. Many schemes have highly laudable objectives. Key Stage 4 of the National School's Curriculum in England and Wales aims to produce pupils who 'form balanced judgements about some of the major environmental issues facing society'. Adult (life-long) learning is a relatively unexploited opportunity, and Thomas[26] cites an example of the way in which participants at an adult education course used newly-acquired knowledge to persuade a farmer to conserve an area of ancient woodland. Unfortunately, such examples are uncommon and it is difficult to escape the conclusion that the impact of formal environmental education has been poor. There is little evidence of change since Holdren & Ehrlich's[27] reference to the 'monumental failure of biological education' in influencing the opinions of politicians and industrialists on environmental issues.

However, the formal education systems should not be the sole focus of environmental education. There is an obvious need for new educational initiatives which operate outside the system. Educational campaigns and projects of the kind operated by the Marine Conservation Society offer one possibility. They have, for example, highlighted problems of plastic litter pollution in the marine environment and water quality on leisure beaches in Britain[28, 29, 30]. Beach clean-up events can have long-term effects on people's behaviour towards the environment[31]. Other possibilities, include the involvement of the general public in surveys, such as surveys of waders and wildfowl in British coastal waters[32] and the national surveys of garden birds [33]. There are special benefits if the participants in such projects are of a range of ages and backgrounds. They offer novel learning opportunities because people can learn from one another's skills and experience, sometimes in unexpected ways. Adults can, for example, benefit from working with children. Evans *et al.*[34] found that knowledge of recycling waste materials, which was gained by children at school, was transferred to their parents, and influenced their attitudes towards recycling, and Birchenough[23] that parents' knowledge of common garden birds improved when they joined in surveys of them with their children.

2. Working together: collaboration, not confrontation.

It is hardly surprising that the public has difficulty in comprehending environmental issues when the information it receives comes from a range of different sources, may be poorly expressed, is unclear, has a 'political spin' or is simply wrong. Blame can be apportioned in different ways to several of the key players. Scientists are probably regarded as objective observers but they are notoriously bad communicators, are indecisive and are often portrayed unsympathetically by the media[35]. A compounding problem is that science has difficulty in reacting quickly to new issues because the publication of research is a slow process, due to dependence on the peer review system to maintain quality. Furthermore, there is a disturbing tendency for members of the scientific community to talk solely to one another, since the journals in which they publish are unlikely to be read by the public and their conferences are normally closed events. At least in ENSUS 2002, we have attempted to open our doors to a wider audience. Industrialists have even greater problems than scientists because they are viewed more cynically by the public. Despite increasing evidence of an enlightened approach, in which industry and other groups in society engage in open debate within a climate of mutual trust[36], their image is still poor. The public perception of industry is still one of exploiters (sometimes ruthless ones) of the environment. In the absence of clear or trust-worthy information, the Environmental Non-Governmental Organisations (ENGOs) have enormous power to influence public opinion on major issues. It is one that, in many respects, they use responsibly, drawing the public's attention to matters of concern. For example, World Wide Fund for Nature (WWF) has been highly successfully in emphasising pollution problems in specific geographical areas, such as Antarctica[37], the Arctic[38] and the Baltic Sea[39] , in identifying habitats which are endangered, such as Spanish wetlands[40]. However, ENGOs provide a disservice when they over-simplify issues and use of selected data to support their arguments. For instance, it is reported that the Greenpeace 1996 campaign against Danish fishermen who were trawling for sandeels was based on the simple message: industrial fishing is harmful to the environment and unnecessary, and should be banned. Whether this conclusion is right or wrong, the regulators had to consider the problem from other perspectives. Some influential scientific opinion did not agree with Greenpeace that the fishery was having such a severe impact on the environment, and it also became evident that natural climatic factors may have been responsible, at least in part, for declines in populations of sandeels. There were social, economic and political considerations because, not only was the fishery of economic importance to Denmark, but Danish access to sandeel stocks had been permitted as a trade-off for the cod and haddock quotas given to other EU member states[41].

The confrontational approach is unlikely to produce effective long-term solutions to environmental problems. There is no doubt that, given the opportunity, all sections of society are capable of working together in partnership. ENGOs worked impressively with Government at the Earth Summit in Rio in 1992[42]. Four ENGOs, Friends of the Earth, Campaign for the Protection of Rural England, Royal Society for the Protection of Birds (RSPB) and WWF, became actively involved in the UK Government's roundtable on sustainable development. Furthermore, RSPB, WWF and the Wildlife Trust are members of its biodiversity working groups. There are also many examples in which these, and other ENGOs, have worked with local government in producing local biodiversity action plans. There have also been impressive partnerships between ENGOs and industry. WWF, together with other ENGOs and representatives from the timber and retail industries, founded the Forestry Stewardship Council in 1993[42]. The proposal was to eco-label timber products from those sections of the industry which were prepared to manage their forests at sustainable levels, thereby giving them a competitive advantage. By 1996, 25% of forest products sold in Britain conformed to the eco-labelling criteria. At this time, WWF also founded the Marine Stewardship Council in conjunction with Unilever to ensure that marketed fish were from sustainable fisheries. Even more recently, WWF has been working with paint and chemical manufacturers in an evaluation of new biocide-free antifouling paints. Such tests must by their nature take time because TBT-based coatings can provide effective antifouling cover for five or more years. Nevertheless, the discovery of alternative tin-free paint systems, which are shown on full environmental and economic analyses, to be less harmful to the environment than TBT-based paints, is one of the bases on which regulatory decisions should be made.

Unfortunately however, collaboration has not yet replaced confrontation. The position of at least some ENGOs is ambivalent. Greenpeace worked successfully with industry in producing and marketing an 'ozone-friendly' refrigerator *Greenfreeze*[43] but is prepared to take direct action against other sections of industry. Gray[44] expresses doubt that, despite claims to the contrary, there has been increased collaboration between the ENGOs and industry during the past decade. So why does confrontation occur? It is a sad reflection if, as Eyerman & Jamison[45] have suggested, direct actions by ENGOs are necessary to maintain their membership bases.

3. Involving the public in environmental stewardship.

However, even when the ethos of collaboration has been accepted and the lay public is scientifically-literate, there is still a need to develop public viewpoints on issues and to introduce them into the political arena. One approach is to involve communities in scientific research so that they actually collect and analyse data, and have the opportunity develop their ideas on specific issues. The School of Marine Sciences and Technology, Newcastle University (UK) operates a scheme of this kind *'The North Sea: Our Joint Responsibility'* from its Dove Marine Laboratory. Members of the community take part in scientific exercises under the guidance of experts from industry or the University. Projects have included: assessments of the pollution caused by toxins used in antifouling paints, over-collection of bait, such as lugworm and shore-crabs, by sea-anglers; the distribution and abundance of flora and fauna on rocky shores; the bycatch in the local scampi fishery; and monitoring numbers of shorebirds. Participants are encouraged to develop action plans related to their projects. It is evident that, not only adults, but young members of society can develop valuable ideas. For example, local schoolchildren, mostly 11 and 12 year olds, surveyed birds in the sand dunes south of Blyth as part of a general survey of birds in the area. They recorded the Skylark and the Song Thrush, both of which have declined nationally in recent years. The children recognised the value of the habitat, commented on its degradation (e.g. through unrestricted access and litter pollution) and made a number of recommendations for its future management[46]. Community-based research can also generate valuable scientific information. Indeed, the community offers a potentially huge and inexpensive workforce for projects that are labour intensive but technically straight-forward. Many scientists are sceptical and still need to be convinced that volunteers have a part to play. However, the evidence is becoming overwhelming. They is an ever-increasing number OF published studies that would never have been completed without volunteer assistance[47, 48, 49, 50, 51].

Not everyone had the time or inclination to become involved in scientific research. Fortunately, there are a range of other means by which the public can develop and express its views on issues[3]. Each presents members of society, in some cases specialist groups in it, the chance to develop and voice their opinions. They are used relatively infrequently at present but are undoubtedly generating interest. They include the following:

Focus groups. This method is used in market research and increasingly in academic sociological research. A representative group, perhaps of about 10 people, discusses and then reports on, an issue of concern.

Deliberative polling. This is used mainly in market research. A large representative group of perhaps several hundred people conducts a debate on an issue. They are polled on the issue before and after the event.

Stakeholder dialogues. This consultation is restricted to those who have, or who express, an interest in the subject matter.

Internet dialogues. Discussions open to anyone who has access to the internet.

Citizens' juries. They are a way of involving the public in the decisions of public authorities. So far, they have been set-up to consider mostly health issues in the United States and they can be adapted appropriately for environmental and other issues[52]. Juries consist of ordinary members of the public, acting in their capacities as citizens concerned with the public good rather than consumers concerned with private interest. The proceedings are held in public, and include presentations by parties with vested interests and expert witnesses. These people are 'cross-examined' by jury members and public attending the proceedings. The jury evaluates the information it has received and is then expected reach an independent, public decision. The verdict carries authority because it represents the objective view of society.

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Volunteer mammal monitors: Measuring the professionalism of amateurs

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SYNOPSIS

Despite the international success of the UK's volunteer-based monitoring of bird populations, much of the remainder of terrestrial biodiversity has hitherto been very poorly monitored and this is generally true for mammals. A succession of government reports have highlighted the dangers of this lack of mammal monitoring, and what could and should be done to remedy the situation. In the absence of a properly funded national scheme, much hope rests on the mobilisation of volunteers. However, there has been rather little measurement of the efficacy of volunteers in this capacity, and how this might be affected by their background and training. In this paper we consider the uses of volunteers in the context of mammal monitoring in terms of British mammals, before going on to present results on their effectiveness and limitations as revealed by samples of people who have participated in mammal monitoring programmes at Wytham Woods in Oxfordshire.

INTRODUCTION

Robust information about the distribution and abundance of species is the foundation to the design and implementation of any unifying population management strategy. Amateur naturalists have long been involved in collecting this vital information in the UK. Many environmental charities and NGOs rely heavily on the help of, and data collected by, these volunteers (e.g. British Trust for Ornithology, The Mammal Society, The Bat Conservation Trust, The National Federation of Badger Groups, The Wildlife Trusts). However, although many scientific publications base analyses on volunteer data, this is seldom detailed in the 'methods' section (exceptions are e.g. Reading *et al.*[1,2]) and specific studies analysing the quality of data collected by volunteers are rare.

There are many national and international statutory obligations to provide biological monitoring data (e.g. under the Biodiversity Convention), and the UK government has recently commissioned two major reports (Macdonald *et al.*[3]; Toms *et al.*[4]) to investigate the feasibility to collect scientific and statistically robust data on regional and national trends in species distribution and abundance. Both these reports emphasise the need and importance to involve amateur volunteers in data collection and field surveys. However, if the results of local surveys are to be comparable within a national initiative, it is essential to ensure that all data are collected using similar methods as well as standardising for inter-observer variability. This is especially important in the case of monitoring mammalian species. Whereas most other surveys are carried out by observing and identifying species directly (e.g. botanical surveys: identification of plants; ornithological surveys: observation of birds), mammal surveys usually rely on the correct identification of field signs left by that species. Thus, surveying for mammal field signs generally requires more skill and training, and is also more easily prone to mis-identification errors.

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In the UK many large-scale mammal surveys have been carried out with considerable volunteer involvement. Most commonly, volunteer-based surveys concentrate on surveying for only one species and involve a large number of volunteers from many different backgrounds (e.g. badgers: Wilson, Harris & McLaren[5]; dormice: Bright, Morris & Mitchell-Jones[6], deer: Langbein[7], Johnson[8]; hares: Hutchins & Harris[9]; Langbein *et al.*[10]). Others focus on one specific family (e.g. bats: Walsh *et al.*[11]) or class of mammals (e.g. predators: Tapper[12]), or aim to establish a database for many different species (e.g. The Winter and Sign Transect Survey, funded by DEFRA and jointly run by the British Trust for Ornithology and the Mammal Society; Mammals on Roads Survey, funded by the JNCC, PTES and the Royal Holloway, University of London).

Most of these surveys require some form of basic training or written instruction and aim to standardise the way in which data are collected. In this context, it is important to identify methods that are both useful for mammal monitoring and suitable for use by volunteers. To enhance the credibility of volunteer-based field studies in the wider scientific community, the abilities of volunteers compared to professional biologists need to be evaluated quantitatively, and the factors affecting their competence have to be investigated.

To tackle these issues, by developing calibrated methods for volunteer mammal monitoring data collection and by validating volunteer data, we instituted a project to monitor mammal populations, at Wytham Woods, Oxfordshire, in April 2000. Wytham is the site of a suite of ongoing long-term studies of resident mammal populations (e.g. badgers: Macdonald & Newman[13]; small mammals: Richards[14]; deer: Morecroft *et al.*[15]), against which to validate data collected by volunteers.

We report here on a series of validation studies from Wytham, describing the deployment of volunteers to monitor badgers, small mammals and deer, and comparing data collected by volunteers with data collected by professional research biologists. We then briefly assess the effectiveness of the volunteers, as perceived by the scientists running the monitoring programme, and how this was affected by characteristics such as their age, fitness and gender.

METHODS

Site

Wytham Woods are located 5km north-west of Oxford (OS Ref: SP 462, 080). The woods are positioned on two eastern outlying hills of the Cotswold escarpment, between 60 and 165m altitude. The woodland and associated copses constitute 424ha of mainly mixed-species semi-natural, deciduous woodland, surrounded by permanent pasture and mixed arable farmland (Macdonald & Newman[13]).

The volunteers

Volunteers were recruited by the Earthwatch Institute Europe (www.earthwatch.org). All age classes were represented and there was a slight female bias (Fig. 1).

Fig 1 Age and gender profiles of volunteer sub-sets used in qualitative assessment

Our sample is representative of that section of the public from Britain (n= 149) and abroad (n= 6) attracted to the particular form of voluntary conservation work (at a cost of £150 per 5 days, including meals, but excluding accommodation) arranged by the Earthwatch Institute. Sponsored placements accounted for one quarter of our volunteers (36 out of 155). Volunteers came from various social and educational backgrounds: students, professionals, retired, probation services and drugs rehabilitation programmes. Some had considerable background knowledge in biology (e.g. amateur naturalists, veterinarians, biology students and teachers), while others were embarking upon a new interest in wildlife conservation.

Here we report on data from 155 volunteers: 96 volunteers in 2000 (split between 8 teams from April to December), and 59 volunteers in 2001 (split between 7 teams from April to December – during this period restrictions due to FMD affected recruitment). Each team spent 5 days assisting in the field.

Surveying badgers
Badger activity was monitored through bait-marking surveys (Delahay *et al.*[16]), sett surveys (Clements *et al.*[17]) and direct counts of badgers at setts.

Volunteers were required to find and plot latrine sites (bait-marking survey) or setts (sett surveys) using map and compass to survey the study area (scale 1:3000). Two training regimes were tested in the latrine survey: (i) written material only about the characteristics and positioning of badger latrines; (ii) 1h practical field-training session. Latrine and sett locations were verified by an experienced researcher and compared to our bi-annual bait-marking surveys (Johnson *et al.*[18]).

During badger counts, groups of three volunteers were positioned at different badger setts, and were asked to count the maximum number of badgers seen simultaneously at the sett per evening. Frequently, a professional scientist was present to verify the volunteers' counts. Data were then compared to results from our long-term capture-mark-recapture studies (Macdonald & Newman[13]).

Small mammal trapping
Small mammals (wood mice *Apodemus sylvaticus*, bank voles *Clethrionomys glaerolus*, and field voles *Microtus agrestis*) were censused repeatedly at three different woodland sites by standard capture-mark-recapture methods using Longworth live-trap grids (Gurnell & Flowerdew[19]). We measured the time needed by the volunteer teams to lay-out the field grids and assemble and position all 100 traps and compared these times with the time needed by one professional researcher. Practical explanation and training were given until volunteers were demonstratively proficient at the task (i.e. correct setting of traps, correct animal-welfare-friendly handling, accurate data collection and recording). Though the time this took varied, it was essential to ensure animal welfare standards. Three different trapping grid results were then compared and evaluated against our long-term data set derived from trapping grids in comparable habitats/ locations (Flowerdew & Ellwood[20]).

Surveying deer
Deer numbers (fallow *Dama dama*, roe *Capreolus capreolus*, muntjac *Muntiacus reevsi*) were estimated from standing crop faecal counts in 10m x 10m quadrats (Mayle *et al.*[21]). Volunteers were responsible for laying out and surveying the quadrat areas for droppings. They were asked to identify the species producing the droppings, but in this case their identification was always verified by an experienced researcher (for detailed analysis of identifying skills of volunteers see below). Per plot we measured the time it took for volunteer teams to stake out and survey the quadrat for droppings and compared these times to the time needed by one professional researcher. Data were also compared to population estimates from (semi-) professional and certified deer-stalkers from the British Deer Society, derived from visual counts, and to dropping count data collected by researchers working full-time on deer at Wytham.

Additionally, we performed an experiment to test the survey method itself. We asked what proportion of droppings present in a quadrat is likely to be found? 10m x 10m quadrats were cleared of droppings by the teams and then naturalistic piles of droppings, representing a range of deer and lagomorph species, were re-introduced to the plot by the researchers, unseen by the volunteers. Volunteers (with no experience) and experienced researchers then searched the plots for the known number of introduced droppings. The experimental survey was then repeated twice (each with a different distribution of droppings) using the same volunteers after they had had acquired a) 3h and b) two 3h sessions of surveying experience. Deer dropping-identification skills of volunteers were analysed on day 2 (3h field training) and day 3 (2x 3h field training) of this experiment.

Multi-species winter transects
Mammalian species diversity was assessed using winter (December) transects, and results were compared to the established Wytham Woods species list (Macdonald & Stafford[22]). Volunteers received 3h training on the identification of mammal field signs during a guided walk. In the afternoon on the second day after the training,

volunteers were split into three sub-teams of four and were asked to walk along one of three different 1.5km long transects, marked on a detailed map (scale 1:3000). All field signs of mammals were marked and species identified using standard field guides. Each transect was surveyed twice by two different teams.

Evaluation of volunteers

In 2001, we also assessed volunteers at the individual level on a 0-5 subjective scale of their ability (assuming a professional biologist would score 5/5) for each of the different tasks listed above (assembly/ setting/ checking of Longworth traps; handling of small mammals; experimental deer dropping survey/ identification; badger censusing at setts, badger fieldsign survey; winter transect surveys). Volunteers were assessed by one male and one female supervising scientist (CN & CDB) and the resulting scores were then averaged for each task. Assessment scores also included ability to understand the principles of the task, to execute the task correctly and efficiently, and ability to work reliably without supervision. Additionally, a subjective score was given for attention to information, fitness (scored from 0= lacking the physical stamina to carry out five days of light fieldwork, to 5= comfortably able to complete five days of light fieldwork), and mental aptitude (defined as their enthusiasm for the work). Though all volunteers were informed beforehand of the general principles of the assessment study, they were not told any details of the assessment that was being made until the conclusion of the team visit, and were not aware of the scoring criteria. Therefore, they were not likely to alter their behaviour in any systematic way. Additional quantitative measures were incorporated into the scoring where possible, such as their ability to survey for deer droppings in the artificially stocked 10m x 10m quadrats described above.

All "per task" assessment scores were then combined to create overall mean scores, which indicated the researchers' perception of the volunteers' usefulness. A second similar measure, defined as volunteer capacity, was made to include the assessment scores of each volunteer's physical and mental aptitude.

We employed a preliminary analysis of co-variance (*ANCOVA*) to explore which factors affected volunteer performance for each task, including the predictive variables *gender* (male/ female), *age* (dichotomised to under/ over 40 years of age), *previous experience* of conservation work before coming to Wytham (yes/ no), a measure of observed *physical aptitude* (i.e. fitness) for the tasks (on a scale from 0-5), and *mental aptitude* (on a scale from 0-5). To analyse indicative results in more detail, Mann-Whitney-U tests and Kruskal-Wallis tests were used where applicable. All statistical analyses were performed using Minitab (Release 11.21)[23].

RESULTS

Badger surveys

After basic practical instruction in standard surveying techniques, volunteer teams took on average three times longer to survey an area for badger setts and outliers compared to an experienced researcher (*ANOVA*: $F_{1,25} = 102.57$, $P < 0.001$) based on three days of surveying. By surveying an area systematically (i.e. walking 20 transects across 100m x 100m quadrats), the teams found 90% of main badger setts (Fig. 2). However, they found only 67% of smaller outliers (Fig. 2).

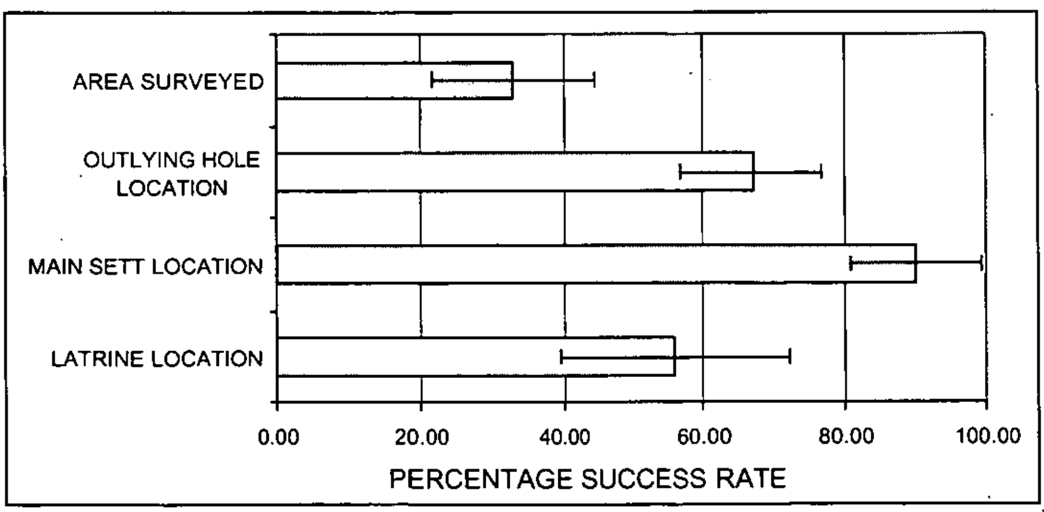

Fig 2 Effectiveness of volunteers compared with professional researchers at finding badger field signs (based on 25 hours surveying)

Volunteers who were given only written instructions proved significantly less successful than those given instructions in the field (*ANOVA*: $F_{1,7}$= 16.33 $P < 0.01$), so much so that the experiment had to be terminated prematurely after the first day, because lack of success was proving frustrating to these teams (after which the same field training was given as in the other group). Thus, based on volunteers receiving practical field-training, teams found only 56% of the latrines located by research scientists.

Over 63 observation evenings between May and September in both years at 10 different setts, direct counts by volunteers consistently returned 64.2% (s.d.=14.16) of the number of badgers known to be resident at these setts from long-term trapping records (Macdonald & Newman[13]) ($mean_{Adult}$ = 62.6%, s.d.= 13.2; $mean_{Cub}$ = 64.7%, s.d.= 15.39). In the cases where professional scientists were in attendance at the setts (n= 28) their counts and the volunteer counts did not differ significantly (*Wilcoxon matched pairs test*, p>0.05).

Small mammal trapping

After basic training (i.e. verbal explanation and 10 minutes of practical demonstration/ supervision) volunteers were able to operate Longworth traps effectively. Assembling the traps correctly was most problematic for volunteers: 50% were able to set the traps correctly after one demonstration, 81% after two demonstrations, 98% after three demonstration, whereas three volunteers needed up to seven repeated demonstrations.

Due to the deployment of a *team* (8-12) of volunteers time-savings were substantial. Whereas one experienced researcher would need ca. 2.5 hours to set up one small mammal trapping grid ($mean_{researcher}$= 150min, s.d. 65min; n=3), volunteer teams finished within 1hour ($mean_{volunteer\ team}$= 50min, s.d. 14min, n=3) (*ANOVA*, $F_{17} = 14.58$; $P <$ 0.01). To check 100 traps in the field, one experienced researcher needed approx. 1.5hours ($mean_{researcher}$= 93min, s.d. 42min, n=3), whereas volunteer teams finished within 45 minutes ($mean_{volunteer\ team}$= 42min, s.d. 8min, n=3) (*ANOVA*, $F_{1,7} = 9.71$; $P < 0.05$). However, inexperienced volunteers took individually substantially longer to handle (weigh, sex and clip-mark) captured animals than experienced researchers ($mean_{researcher}$= 65s, s.d. 17s; 2 researchers, 20 animals); ($mean_{volunteer}$= 222s, s.d. 76s; 50 volunteers; 120 animals) (*ANOVA*, $F_{1,7} = 11.79$; $P <$ 0.01). While volunteers were closely supervised, this was only with regard to ensuring animal welfare standards, but in no way sought to enhance their success.

The volunteers' results were comparable with small rodent numbers obtained by our long-term capture-mark-recapture study (Flowerdew & Ellwood[20]), i.e over 10 sample grids the volunteer average was 13.2 (s.d.=6.14) while the average obtained by professionals was 14.15 (s.d.= 7.86) in similar habitats in the same year/ time period. After the initial training period all volunteers were able to reliably recognise bank voles, field voles and wood mice (after two animals of each species: 8 out of 10 right, n= 120), sex (after 2 examples of males and females: 7 out of 10 right, n=120) and weight (after one demonstration of weighing: 10 out of 10 right, n= 120).

Surveying deer

From April to December 2000, 124 quadrats were surveyed. The time needed to survey one quadrat decreased in proportion to the number of people involved. Whereas one experienced researcher needed on average 10.3min, s.d. 2.4min (n=20), a team of 5 volunteers finished on average within 2.1min, s.d. 0.3min (n=79). Confidence in the volunteer team's ability to correctly identify deer droppings to species was derived from specific testing of their ability, see below.

In 2000, the population estimates produced by volunteers (129 fallow, 65 roe, 7 muntjac) compared well to visual estimates of deer abundance estimated by (semi-) professional stalkers from the British Deer Society (100 fallow, 40 roe, muntjac unknown). Similarly, between April and December 2001, 177 quadrats were surveyed. The estimates produced were 73 fallow, 31 roe and 6 muntjac. These numbers are consistent with the British Deer Society estimates for 2001 (75 fallow, 35 roe, muntjac unknown). For fallow deer the difference between the numbers estimated from volunteer dropping counts in 2000 and 2001 reflects accurately the absolute numbers of deer shot during the interceding winter (70 fallow).

Volunteers found on average 71% (s.d.= 22%) of the droppings piles in the artificially stocked plots, while professional scientists found 74% (s.d. = 12%). Volunteer performance declined with time from 75% on day 1 (no experience) to 67% by day 3 (by which time they had two 3h surveying sessions of experience).

Volunteer ability to identify deer droppings according to species correctly increased with field training. Whereas after 3h of field experience volunteers mis-identified 19.17% (s.d. 29.63, n= 72) of the droppings, this number dropped to 6.94% (s.d. 16.53, n=72) after two 3h field-training sessions.

Multi-species winter transects

Winter transects could have detected fifteen mammal species known to be present in the wood. Volunteers using this method found a maximum of 11 species (n=8; mean = 9.12; s.d.=0.52) while under similar conditions professionals found a maximum of 12 species (n=8; mean=10.5; s.d.=0.93). Thus, professionals found significantly more species (mean), from field-signs and sightings, than did volunteers (*ANOVA*: $F_{1,15}$=5.07; $P < 0.05$). Some species, such as the badger, were detected on all of the six transects performed, while other species (e.g. stoats: *Mustela ermina*, weasels: *Mustela nivalis*) were never detected. While animal burrows (e.g. badgers, foxes *Vulpes vulpes*), feeding remains (grey squirrels *Sciurus carolinensis*, small rodents) and mole-hills *Talpa europa* also provided evidence for some species, most species were inferred from droppings and/ or footprints. The only species for which direct visual observations were made were fallow deer, grey squirrel and brown hare *Lepus europaeus*.

Assessment of Volunteers

The preliminary *ANCOVA* standardising for inter-dependence of the measured individual-specific parameters, revealed that gender, previous experience, and fitness had significant effects on volunteer suitability for several different tasks, whereas age and mental aptitude had no influence on volunteer performance (see Table 1).

Task	Factor	P-value
Setting Longworth traps	Experience	0.503
	Gender	0.098
	Age	0.548
	Fitness	0.160
Handling small rodents	Experience	0.045*
	Gender	0.176
	Age	0.479
	Fitness	0.085
Census badgers	Experience	0.875
	Gender	0.628
	Age	0.438
	Fitness	0.585
Attention to information	Experience	0.039*
	Gender	0.006*
	Age	0.935
	Fitness	0.068
Exp. deer dropping survey	Experience	<0.001*
	Gender	<0.001*
	Age	0.194
	Fitness	<0.001*
Average ability	Experience	0.151
	Gender	0.052*
	Age	0.690
	Fitness	0.140
Average suitability	Experience	0.251
	Gender	0.091
	Age	0.662
	Fitness	0.085

Table 1 *ANCOVA* results for factors influencing volunteer performance for different tasks.

Gender had a strong effect on volunteer ability to find deer droppings in the experimental quadrats (*Mann-Whitney-U test*: n1=17, n2=27, P<0.001) and attention to information (*Mann-Whitney-U test*: n1=26, n2=31, P<0.001) with men performing significantly better than women. Thus, the overall mean ability scores for men were marginally greater than those of women (*Mann-Whitney-U test*: n1=26, n2=31, P<0.05). The variance in mean scores ($mean_{men}$ = 3.16 ± 0.68, $mean_{women}$= 2.75 ± 0.77) was consistently higher in women than it was in men (*ANOVA*: $F_{1,14}$=3.70, P< 0.05), indeed our highest and our lowest scoring volunteers were both female.

Previous experience of 3h field training (i.e. handling 2-4 mice) significantly increased volunteer ability to handle small mammals (*Mann-Whitney-U test*: n1=20, n2=24, P< 0.01). By contrast, volunteers with previous experience demonstrated a significantly lower success rate at finding deer droppings in the experimental quadrats than did novices (*Mann-Whitney-U test*: n1=20, n2=24, P< 0.05). However, experienced volunteers took significantly less time to carry out the survey (*Chi-Square test*: χ^2_2=9.64, n1=20, n2=24, P< 0.01). Experienced volunteers also paid significantly more attention to background information than novices (Mann-*Whitney-U test*: n1=20, n2=24, P< 0.05).

Overall, fitness had a significant influence on mean perceived usefulness (*Kruskal-Wallis test*: $H_{4,56}$:11.82, P< 0.05) and capability (*Kruskal-Wallis test*: $H_{4,56}$:14.20, P< 0.01) of volunteers, with fitter people being perceived by the researchers to be better suited to the tasks than less fit people.

DISCUSSION

In the UK, most species monitoring programs on local, regional and national level depend heavily on the involvement of amateurs. Yet, many scientists doubt the accuracy and reliability of results based on field data collected by volunteers. In the US an amendment was made in 1993 to prohibit the US National Biological Survey from accepting the services of volunteers, as the House of Representatives asserted that volunteers were incompetent and biased. Although the British Trust for Ornithology and other UK-based environmental charities rejected this view and concluded "Trust the Volunteers" (Greenwood[24]), detailed scientific studies investigating the accuracy and variability of volunteer data are still rare. This present study aimed to address this disparity and evaluate the potential for using volunteers in scientific studies by testing the veracity of the data they collected against data collected by professionals and to evaluate the most effective deployment of a volunteer labour force.

We used volunteers to monitor three very different types of mammal: badgers, small rodents and deer. In these particular circumstances and with the particular variety of volunteers we tested, our analyses showed an average ability score for volunteers of 2.94 out of 5.0, s.d = 0.75), amounting to an efficiency of 59.6% compared to a professional researcher. In addition, the wide variability in volunteer-performance (min. = 23.2%, max. = 84%, average = 58.8%) was significantly moderated by gender, fitness and previous experience.

Influence of training

As most volunteer-based studies utilize the assistance of people from a variety of social and educational backgrounds and with varying physical ability, it is important to understand what effects these factors have on volunteer performance, both from the standpoint of data accuracy and effective volunteer training and deployment. The necessity for basic field-training is recognised by many volunteer-based monitoring programmes and environmental charities often offer species specific training days to their members (e.g. Mammal Training Workshops of the Mammal Society, Training Days of the Wildlife Trusts). Macdonald *et al.*[3] presented a case study analysing how recruitment and training affected volunteer performance while surveying for water voles. Eighty percent of volunteers who received field training returned their survey forms and found all the known water vole colonies. By contrast, of the volunteers who received no practical field training, only thirty percent returned their survey forms and this group found only thirty percent of the water vole colonies known to be present in the study area. In this present study, practical field-training and demonstrations proved to be essential for all the monitoring techniques used. For example, volunteers provided with only written instructions were unable to find /identify badger latrines. Generally, we found that after basic training (e.g. half a day per focal species, including background theory, practical demonstration and initial close supervision) volunteers produced results which were within the range recorded by people using the same methods professionally. For example, a 3 hour training session generally gave volunteers the confidence and competence to operate Longworth-trapping grids and handle, sex and weigh small rodents.

Although volunteers were supervised carefully, this was often only a precautionary measure to ensure animal welfare (e.g. in the case of small mammal trapping) and volunteer safety during field-work. Supervision was not designed to enhance volunteer performance (e.g. trapping success, deer dropping counts) in a way that might distort our evaluation of their performance.

Influence of volunteer-characteristics

Team training and management was found not only to influence data quality, but also to have a significant effect on volunteer motivation. Importantly, we also found that the varying attitudes of volunteers towards different tasks appeared to be a crucial factor influencing their performance. In this particular sample of volunteers, women were often more hesitant than men, and sometimes had to be 'persuaded' to perform certain tasks, such as handling mice or touching deer droppings; thus, overall, men appeared to make slightly better volunteers. Generally, these gender biases in perceived aptitude could be traced to a significantly broader range and greater individual variation in women's scores. However, with encouragement and additional tuition this hesitancy was often overcome. By contrast, people from less privileged backgrounds, as exemplified in our sample by those from a drug rehabilitation programme, showed far less hesitation to undertake tasks; indeed, they were generally amongst our highest scoring volunteers.

Our volunteers varied widely in their physical abilities. On the whole, people at the limit of their physical fitness did not perform as well as those volunteers who found the work physically easy. Once controlled for fitness, age had no significant influence on volunteer performance.

Previous experience, i.e., having been involved with practical conservation work prior to assisting with this project was also an important factor, but not always a positive advantage. While experienced volunteers proved more able to trap and handle small mammals (both in terms of *per capita* efficiency and handling ability), they demonstrated a lower success rate at finding deer droppings in the experimental quadrats, not least due to being significantly quicker. Thus we hypothesise that their experience resulted in over-confidence as well as a lower threshold of boredom, with the result that more droppings were missed. A background knowledge of the natural history did, however, appear to give the more experienced volunteers a keener interest in instructive and explanatory sessions.

Calibration and validation of volunteer data

One of the constraints of using volunteers in the collection of scientific data is that it can often limit the choice of appropriate investigative methods. Many tasks are too technical, arduous or prolonged to be suitable for the involvement of non-professional volunteers (e.g. procedures licensed under the Animals (Scientific Procedures) Act, 1986). Thus, a trade-off between data accuracy (i.e. detail of information included) and data veracity (i.e. minimum variability) is often necessary (e.g. Langbein *et al.*[10]).

Thus, two principal questions have to be addressed in evaluating volunteer data: are the methods that can be used by/ taught to volunteers themselves reliable (calibration); and given that the methods perform satisfactorily, how do novices compare with professionals (validation).

In the case of the methods used for counting deer droppings, censusing badgers at setts and surveying for badger setts, it appears that the methods themselves are the limiting factors. Our results show that with increasing experience a degree of nonchalance can develop, for example with deer dropping surveys, consequently survey times, along with survey accuracy decreased, indicating that the task was not interesting nor involving enough to sustain surveyor enthusiasm. Supervision ensured that volunteers surveyed thoroughly and systematically and thus there appeared to be no significant differences between the ability of volunteers and professionals to find droppings; with both parties underestimating the actual numbers present using this method. Similarly, volunteers are as successful in counting badgers, by observation at setts, as professional scientists, although this methods results in an underestimate of badger numbers when compared to trapping results. Surveying for badger setts is a more difficult technique to calibrate. Although amateurs and professionals should always find all multi-hole main setts present if they survey an area systematically, our results indicated that amateurs found only 90% of the setts in Wytham. However, failing to detect all setts was generally a consequence of being unable to read maps accurately, and thus cover "*all*" of the ground in the study area. By contrast, latrines are far smaller features and can be missed much more easily, especially if the surveyors are inexperienced at finding and identifying these field-signs. It became clear during the field- training phase of this exercise that experienced researchers found latrines much more readily and faster than our sample of amateur volunteers.

Benefits of using volunteers

While it is essential to calibrate the accuracy of volunteers this does not diminish their value. On a practical level their strengths are obvious (Toms *et al.*[4]). They allow numerous sites to be surveyed simultaneously (e.g. the spring red deer census on Exmoor: Langbein[10]); they can cover a large geographical area (e.g. the national hare and badger surveys: Hutchings & Harris[9]; Wilson *et al.*[5]), and they can save time (e.g. deer dropping survey and small mammal trapping: this study). In this context our training regime (alongside the training days of other environmental charities such as the Wildlife Trusts and the Mammal Society) represents an economy of scale: While training is time-consuming, many volunteers can be trained simultaneously, representing a time-, and cost- effective method for ultimately increasing the number of people able to contribute to the collection of scientific data for wildlife conservation, especially if the trained volunteers are able to make a long-term commitment to project. For example, had our programme required, our results indicate that half a day of training would have produced two volunteer teams of 6 people competent to survey the entire woods for deer droppings with acceptable accuracy ten times faster than one experienced scientist.

A pragmatic reason for using volunteers is that they are increasingly willing to pay to be involved in environmental science, unlocking new revenue for conservation. Additionally, the involvement of volunteers from the wider public in conservation-based research also increases the public's environmental awareness and understanding of scientific issues.

CONCLUSIONS

It is important to bear in mind that, while our volunteers represented a diverse social background, they remain a sub-group and they were required to perform relatively specific biological field tasks. Consequently our results capture only a particular snapshot from the complex and varied range of tasks volunteers may be able to assist with in a scientific context. Nonetheless, in addition to obvious differences in the perceived usefulness of individuals, we found significant generalisations regarding the performance of people on our teams.

With these generalisations in mind we were to make our teams very much more effective, by balancing the composition of working groups, and adapting our management to their strengths and weaknesses. Similarly, the success of our project rested heavily on having a diversity of tasks and a sufficiency of volunteers, without this flexibility the essential balance between ensuring recreation for the volunteers and securing results for the researchers would have been unattainable with our teams. Another caveat is that, while the team managers might seek to maximise the team's performance, the fact that the volunteers are volunteering, and have their own goals (such as enjoyment) place important constraints on management. Consequently, we conclude that flexibility in the tasks, taking into account the physical abilities and mental aptitudes of volunteers is necessary to maximise the benefits from their deployment and to ensure sufficient data accuracy for scientific studies.

A final important consideration is what do volunteers get out of the experience? Are they encouraged to volunteer further? From the 155 volunteers passing through our programme, seven (=4.5 %) have actually changed career, re-training in biology (in several cases after years in a successful alternative career), while a minimum of 30% that we know of, through sustained contact, have joined conservation groups such as the National Federation of Badger Groups, the Mammal Society etc. Thus, it seems that as well as providing volunteers with the skills necessary to contribute to wildlife conservation, it is also possible to foster their enthusiasm and encourage them to put these skills to good use.

ACKNOWLEDGEMENTS

This study would not have been possible without the effort, hard work and goodwill of our volunteer teams to whom we owe a debt of thanks. A special note should be made of the novice volunteers coming from the Ley Community, who have made a tremendous contribution to this project. Thanks also to Graeme McLaren, David Slater and Stephen Ellwood for assisting with team management. The project relies heavily upon being able to use facilities at the Wytham field station, and our thanks to Mike Morecroft, Michele Taylor and Phil Smith for making this possible. We are grateful to the estates staff for their co-operation. A special note of thanks must also be made to the Earthwatch Institute, who recruited all the volunteers to date, especially to Robert Barrington, Pamela Mackney, Nat Spring, Michael Humphries, Jeremy Stokes and Valda Uden. This manuscript has benefited considerably from the comments of Fran Tattersall and Paul Johnson of WildCRU. Thanks also to Jessamy Battersby of the JNCC for her support and advice under the auspices of the Mammal Surveillance and Monitoring Network. We are very grateful for financial support from English Nature, the Ernest Cook Trust and The Mammals Trust UK.

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The role of volunteers in coral reef conservation: history, current status and future directions

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SYNOPSIS

Non-professional researchers ('volunteers') have long been recognised as an important resource for collecting field data and facilitating environmental awareness work in a range of scientific disciplines. Recently, their use has been particularly important in coral reef conservation because of the popularity of SCUBA diving, the lure of tropical locations to potential volunteers and growing interest in marine science. This interest has been channelled into a range of programmes from those that involve data collection during recreational dives to those with long-term field bases where volunteer participate for relatively extensive time periods within highly structured projects. In addition to the growing number of volunteers, these programmes are currently profiting from an increased awareness of the problems facing reefs and the growing recognition of host-countries of their benefits. Since the establishment of the first programmes explicitly for non-professionals, the literature on the use of volunteers in coral reef projects and the validity of their data has grown slowly but steadily, reducing the scepticism associated with their findings and recommendations. Many groups are now able to focus on increasingly sophisticated use of their databases and in some cases this has led to close links with the academic community. Furthermore, volunteer programmes have now been recognised as being particularly effective when significant survey effort is required and perhaps the best example of this principle is 'Reef Check', where teams of non-professionals have carried out a global assessment of the status of the world's reefs. Volunteer organisations will continue to refine their science programmes and outputs. However, it is proposed that the following areas of volunteer programmes are currently underdeveloped and warrant further attention: (a) using non-professionals for assisting and conducting 'academic' research; (b) taking more advantage of their continual field presence to study stochastic events such as coral bleaching and hurricanes, undertake research that can be conducted between dives and collect socio-economic information and (c) continuing to utilise trained and experienced volunteers after their time on a particular programme.

INTRODUCTION

Non-professional researchers are widely regarded as an efficient approach for generating data sets within a range of scientific disciplines, perhaps originating with the collation of data from amateur ornithologists (e.g. 1). More recently, numerous authors have commented on the increasing use of non-professional researchers in tropical marine science[2-6]. This trend has been largely driven by the popularity of SCUBA diving, along with ocean and coastal tourism generally[7], which provides a large number of potential 'volunteers' who can be trained to provide data within either structured programmes or as a component of their own recreational diving. For example, interest from the sport diving community and the need for data to assist management of coral reefs has led to the establishment of projects in the Caribbean, East Africa, Indo-Pacific and South Pacific by UK-based NGOs alone (summarised in 4). Such work has also led to an increasing number of coastal zone management agencies in those countries with coral reefs recognising the benefits that volunteer programmes provide, especially significant databases at little or no cost, which has generated further opportunities for new and existing organisations.

In addition to the popularity of diving, along with a rising general interest in marine issues driven by the media and aquaria, the number of volunteers joining coral conservation NGOs is also increasing because of a suite of socio-economic factors. These include the growing number of school leavers taking 'gap years' before university, the desire by many people to take 'adventurous' holidays[8] and a dynamic job market which provides people with time available between contracts. These programmes are, therefore, able to provide sufficient self-financing manpower to undertake large-scale temporal and spatial surveys and further increase public awareness through participation in conservation work. In addition to the educational benefits to actual participants, surveys undertaken by volunteers can attract more publicity than traditional scientific research and, therefore, raise general awareness of a range of environmental issues and bring indirect pressure on regulatory authorities[9].

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Non-diving programmes

The use of volunteers in marine science and conservation does not necessarily have to involve diving and a large programme of beach clean-ups (the 'International Coastal Cleanup') has been co-ordinated by US-based The Ocean Conservancy, with the groups involved submitting standard forms detailing the rubbish collected on a given beach. Furthermore, Frontier projects within the Society for Environmental Exploration have incorporated littoral work into its tropical conservation programmes, along with utilising their volunteers to collect data on catches by local fisherfolk. Intertidal work has considerable logistical advantages over those requiring diving and can be equally attractive to amateur naturalists in temperate areas as shown, for example, by work which provided vital data on the distribution of British seashore species in Northumberland[10] and the effects of TBT on dogwhelks[9]. Non-diving, along with diving, volunteers have also worked with academics in a wide range of marine projects (e.g. whale watching, investigating tropical coastal ecology and studying coral recruitment and growth) in the programme run by the Earthwatch hstitute, where non-professionals are assigned to professional researchers to assist with fieldwork requiring additional manpower.

Programmes where volunteers collect data during their own recreational diving

Perhaps the first systematic use of volunteer divers to collect data from coral reefs was the pioneering 'REEFWATCH' programme developed at the University of York and launched in 1982[4]. This initiative provided standard data sheets to divers visiting coral reefs which they could fill in and hence provide general data on the health of the area. A similar approach is now utilised by the Reef Environmental Education Foundation (REEF), based in the USA, whose 'Fish Survey Project' provides multimedia instruction of their survey technique, and encourages volunteers to take identification tests, and then collates standard recording forms from members who collect data during recreational diving trips[11]. Via their 'roving diver' technique, where members swim around a reef recording the fish species seen and assigning each a semi-quantitative abundance scale, REEF are now able to provide extensive species lists and abundance ratings to sites within the majority of Caribbean countries and more recently the tropical eastern Pacific (Gulf of California to the Galapagos Islands) and Hawaiian Islands. Such data have obvious applications such as spatio-temporal assessments and monitoring of the status of commercially important species[12].

This approach of providing a standard methodology for divers to apply while diving on reefs has also resulted in 'Reef Check', perhaps the most ambitious and successful use of volunteer divers to date. Reef Check has used teams as opposed to individuals and has also allied non-professional divers with marine scientists to maintain training and data collection standards but the emphasis is still on motivated recreational divers, along with all local stakeholders, to become involved in the collection of data on reef health. The Reef Check protocol allows teams of volunteers to collect data describing the survey site and its environmental conditions and human impacts, abundances of indicator fish and invertebrate taxa and the percentage of the seabed covered by different substrate types and organisms (including live and dead coral). Reef Check was originally conceived in 1996 as an activity for the 1997 'International Year of the Reef' and surveyed over 300 sites worldwide in order to assess the global status of reefs and these results were published in 1999[13]. Such momentum meant that Reef Check has continued, is currently in its sixth year and has recently published a five year report containing data collected by over 5,000 people on 1,500 reefs in more than half of all coral reef countries[14]. A further, volunteer-based reef benthic health assessment protocol, named the Reef Condition Monitoring Program (RECON), has recently been developed by The Ocean Conservancy and is designed to fill a complementary and less technical niche compared to Reef Check[15].

These extensive, but relatively unstructured, programmes generate key data and have the advantages of minimal field expenses incurred by the organising body, large memberships diving on a wide range of reefs generating a huge database of information and can incorporate volunteers who may only dive sporadically through to those who regularly submit data. However, organisations such as REEF and Reef Check have limited control over the distribution of survey sites (since this is effectively decided by where REEF members choose as dive destinations or where a team leader is able to assemble a Reef Check team) and, while they provide vital large-scale patterns or comparative data between areas, it is difficult for them to focus on a particular conservation initiative in a given location. Indeed, REEF now organise short (one week) cruises to enable intensive data collection from specific areas. Similarly, Reef Check now lists one of its goals as being "to stimulate local community action to protect remaining pristine reefs and rehabilitate damaged reefs worldwide using ecologically sound and economically sustainable solutions"[14] and the technique has been adopted in many locations for community-based monitoring and education programmes[16]. In an attempt to address some of the sampling issues of such projects, The Nature Conservancy's 'Sea Stewards' programme in the Florida Keys, which monitors the efficacy of no-take zones using a standardised protocol, uses teams of trained divers who are assigned a pair of sampling sites (one inside a protected area and the other outside) and data are collected systematically during both dry and wet seasons[17]. Sea Stewards are also encouraged to dive their sites as often as possible to make general observations.

Programmes where volunteers are based at long-term field sites

The desire to focus on more specific projects has generally led UK NGOs to adopt a model of establishing long-term field bases to house volunteers for relatively long periods as part of structured programmes. The origins of this model, which effectively leads to more localised projects nested within the over-arching work of initiatives such as Reef Check, owe much to the history of university expeditions within the UK and the apparent desire of primarily UK volunteers to dedicate significant financial and time commitments to conservation work. Irrespective of the social forces driving the success of tropical marine conservation NGOs in the UK, their projects have aided coral reef conservation and each has an extensive list of outputs and achievements, including key roles in the establishment of marine reserves. The UK's work with volunteers serves as an example to others wishing to establish this type of structured project.

Generally, the data collection of structured programmes with long-term field bases has focused on mapping habitats and their characteristics, using a range of quantitative and semi-quantitative techniques, since the resulting maps are a fundamental requirement in establishing coastal management plans[18]. In the context of conserving reef diversity, habitat maps provide an inventory of habitat types and their statistics[19-21], the location of environmentally sensitive areas[22], allow representative networks of habitats to be identified[23], identify hot spots of habitat diversity, permit changes in habitat cover to be detected[24] and allow boundary demarcation of multiple-use zoning schemes[25]. Furthermore, the conservation of marine habitats may serve as a practicable surrogate for conserving other scales of diversity including species and ecosystems[26]. In addition to the desire of host-country agencies to acquire such maps, the rise of volunteer based NGOs has coincided with the development of accurate, commercially available Global Positioning Systems (GPS), the increased availability and decreased costs of remotely sensed imagery and the ability to analyse this imagery on desktop computers (see 27 for an overview of the remote sensing of tropical coastal zones), all of which are essential for habitat mapping. Hence organisations such as Coral Cay Conservation have produced habitat maps for many project sites as the basis for planning and establishing marine reserves (e.g. 20). Such maps are often supplemented by additional data including Reef Check health data, quantitative fish counts and the establishment of long-term monitoring sites.

In addition to data collection, volunteer programmes with long-term field bases usually offer significant training opportunities to local counter-parts and undertake environmental awareness work with a range of local stakeholders. For example, Coral Cay Conservation's 'scholarships' in Belize provided dive training, marine taxonomy and ecology courses and surveying experience to hundreds of Belizeans during the 1990s. Indeed, some of the Frontier projects within the Society for Environmental Exploration are now solely aimed at training local personnel (D. Stanwell-Smith, pers. comm.). However, since they are often characterised by good logistical capabilities, volunteer programmes are typically tasked to work in relatively remote locations since these are often the most difficult places for host-country agencies to gather data. While programmes in such sites fulfil vital data requirements, they are by definition limited in their ability to participate in a wider coastal zone management role. For example, remote locations limit the accessibility of training opportunities to host-country nationals, generally support only low population densities that can be targeted for environmental education and regular communication between field science staff and national partner agencies is often difficult. Work in the Bay Islands of Honduras by Coral Cay Conservation has shown that volunteer programmes can also be successful when based within a town and indeed, if required, can have a much more significant influence on coastal zone management initiatives[28]. By living and working within a town location, fully integrated volunteer projects can establish a dynamic survey programme matching local concerns and altering when necessary to new threats. Furthermore, subsequent result dissemination and management recommendations can be viewed as objective while remaining sensitive to local issues. Such dissemination is also significantly aided by the continual technical expertise, counter-part training and environmental education that can be offered to stakeholders by locally based field science staff. In addition, the close relationship with the community inevitably leads to interest from other population centres.

Finally, since volunteer programmes have been shown to be highly beneficial and cost-effective, larger initiatives working in the same geographic area can rapidly gain access to vital data sets for minimal in-kind support. Volunteer programmes can also expand the scope and success of internationally funded projects via provision of capacity for training of host-country nationals, logistical support for visiting researchers, links to local stakeholders and a conduit for further funding. However, it is important to recognise that volunteer programmes are only one component of efforts to establish sustainable use of coral reef resources and have their own limitations, including limited financial resources. While volunteer projects can add significantly to coastal zone conservation initiatives, they do not replace the need for building the national capacity which is required for enforcing long-term management goals.

DATA QUALITY

Within any scientific discipline, whenever non-professional researchers are used there are inevitably questions about the quality and validity of the data (e.g. 8,9,29), perhaps forgetting that bias and imprecision can also be considerable among scientists (e.g. 30-32). While some people remain sceptical about 'volunteer data', within tropical marine science the boundaries between traditional academic research and volunteer programmes have been largely broken down by increased collaboration, the realisation of the scale of problems facing the world's reefs, the success of high profile projects such as

Reef Check and efforts to assess the accuracy and precision of information collected by non-professionals. Furthermore, it has remained clear that many areas of reef research and conservation remain the preserve of the professional academic community as, for example, work has shown that volunteers struggle to collect accurate quantitative data of many taxa, particularly those that are taxonomically complex or cryptic. Hence many academics now recognise volunteer data as a useful 'broad brush' assessment of a reefal area and the attention of those working with non-professionals is increasingly switching away from issues of data quality to more sophisticated uses and applications of the data and publishing them in peer-reviewed journals.

Despite this increasing awareness of the value of volunteer data there is a need to demonstrate empirically the quality of information generated by volunteer marine programmes. However, there are a limited number of validation studies and I am aware of only ten published papers relating to littoral or sub-littoral surveys. Four of these are in temperate areas, including two involving non-diving volunteers, and show firstly that assessments of the distributions of temperate seashore species were generally accurate, although there was evidence that they tended to over-estimate invertebrate abundances[10]. Secondly, assessments of imposex in the dogwhelk *Nucella lapillus* by volunteers and an experienced scientist were very similar[9]. When diving in temperate waters, Halusky et al.[33] showed that a research team successfully accomplished a series of tasks on artificial reefs, including site descriptions and profiles, collecting oceanographic parameters and biological assessments. It has also been suggested that novice divers show a similar level of accuracy to that of experienced scientific divers when estimating the length of plastic fish silhouettes but that these errors could be reduced significantly via use of stereo-video system[34].

In tropical systems, where all studies involved diving volunteers, a study by Mumby et al.[35] focused on the semi-quantitative assessment of Caribbean benthic reef communities at a range of taxonomic resolutions and showed that data accuracy and consistency were sufficient for habitat mapping using remotely sensed imagery. This study was subsequently followed by work that showed that the known inaccuracies of the data did not significantly affect the type of analysis being undertaken[36]. Brown[37] assessed fish data collected by volunteers in Hawai'i and reported significantly lower values for density and species richness and diversity compared to staff values. Benthic data was also collected but could not be assessed because the protocol usually involved *in situ* supervision or collaboration with a staff member[37]. Darwall and Dulvy[5] and Schmitt and Sullivan[38] showed that volunteers could provide useful data on fish communities in Tanzania and the Florida Keys respectively. Further work on fish surveys using the REEF roving diver technique has shown that non-expert datasets were similar to expert datasets, although expert data were more statistically powerful when the amount of data collected was equivalent between skill levels[29]. An assessment of Reef Check showed that although volunteers initially have obvious inaccuracies recording benthic categories and fish and invertebrate abundances, data can be improved with further training and survey experience[39]. An additional critical assessment of the Reef Check protocol will lead to a series of recommendations for improving the quality of training (J. Hill, pers. comm.). Finally, many other programmes, such as the ReefBase 'Aquanaut' scheme[40], have undertaken critical assessments and pilot studies but the results are currently unpublished. Although the number of papers may be limited, the majority of results provide considerable support for use of non-professional data by resource managers and scientists to supplement and enhance primary research and assessment and monitoring programmes.

FUTURE DIRECTIONS

Over the last 15 years, the importance of volunteer derived data, along with associated training and education opportunities, in coral reef conservation has increased considerably and these programmes will continue to expand with the increasing number of environmentally aware citizens. With the increasing recognition of the threats to reefs it also seems inevitable that opportunities to establish projects will continue to expand. Furthermore, the potential integration of volunteer programmes into over-arching national and regional initiatives, along with additional funding, seems likely to increase their scope and effectiveness. However, I also feel that certain areas of volunteer programmes are underdeveloped and their improvement could bring further benefits to reef conservation initiatives.

Firstly, the increasing links between volunteer programmes and the academic community could be strengthened and expanded. With research funding difficult to obtain the Earthwatch model of assigning volunteers to academically led projects provides highly cost-effectives field manpower and seems likely to increase in popularity. However, projects with long-term field bases also offer facilities that could be used by scientists undertaking fieldwork, often in return for lectures to the volunteers, access to the data and results or co-authorship of subsequent publications. Such research can also only benefit from the data that is inevitably available on the area from the volunteer data collection programme. Indeed, mutually beneficial involvement of volunteers in almost any type of academic research seems possible, varying from collecting specimens or monitoring equipment that is left on the reef for long periods to recording data that requires limited expertise but considerable time in the water. Work observing the behaviour of Nassau grouper (*Epinephelus striatus*) in the Bahamas using Earthwatch volunteers provides an excellent example of this latter application[41]. Collaboration with the academic community should also include making volunteer data easily available to researchers who could incorporate them into their work without necessarily visiting the site. REEF's excellent online database[1] of Caribbean fish lists and abundances provides a model of how this might be achieved.

Secondly, volunteer programmes with structured field sites could capitalise more on their continual field presence. While this situation is exploited to generate large data sets and establish frequently revisited monitoring sites, it could also be used to collect information on ecological issues that can be difficult for the academic community because of the restrictions of funding and timing fieldwork. A good example is studying the spatio-temporal patterns of coral bleaching and subsequent mortality. Mass coral bleaching has occurred in association with episodes of elevated sea temperatures over the past 20 years and involves the loss of symbiotic zooxanthellae following chronic photoinhibition (see 42 for a fuller discussion on the causes and consequences of bleaching). By definition, therefore, bleaching events are stochastic and difficult to coincide with fieldwork by researchers who spend only a limited time on reefs but, for example, of the deluge of primary literature following the 1998 bleaching event it is noticeable that little or any of it resulted from work by volunteer programmes who were in the field before, during and after bleaching. The fine-scale short and long-term effects of hurricanes are another example of where volunteer programmes could exploit their detailed databases of reefs local to field bases.

While diving surveys are inevitably the central focus of long-term volunteer projects, there are also periods between dives that could be utilised to undertake non-diving projects. For example, seagrass beds and mangrove stands are key components of tropical marine ecosystems but work to understand their ecology and conservation value is limited compared to coral reefs (e.g. 43) and can be studied using snorkelling. In addition, the links that develop between volunteer programmes and local stakeholders could be used to gather vital socio-economic data. While it is important to recognise that, like ecological data, the collection of some socio-economic information may either be culturally sensitive or only possible by professional specialists, the recent publication of a guide to methods and analysis[44] highlights opportunities to collect important data to supplement biological information and improve the efficacy of management initiatives.

Finally, there seems to be scope for further utilising trained and experienced volunteers on their return from a particular programme. After participating on a coral conservation project, a volunteer or field staff member may return with months of training and experience in coral reef surveys and these skills could be better exploited. For example, academics may need field assistants and a register of trained and interested people could be beneficial. Furthermore, within the volunteer community, a system of accreditation would enable volunteers to move between programmes with, for example, a volunteer from a UK NGO subsequently completing REEF fish data sheets during their recreational diving. Closer links between tropical and temperate organisations could also be established since trained divers returning from the tropics would be ideal candidates to join initiatives such as the 'SEASEARCH' programme mapping habitats in UK waters[45]. Academic qualifications granted during participation in a programme, as with the Business Training and Education Council (BTEC) Advanced Diploma in Tropical Habitat Conservation awarded to volunteers by Frontier projects within the Society for Environmental Exploration, may also help encourage more volunteers to join projects and then remain in marine science.

CONCLUSIONS

Involving volunteers in marine science, particularly in tropical areas, has the significant advantages of the aesthetic attractiveness of the coastal zone and the popularity of SCUBA diving. However, these factors have been well exploited by a range of programmes to assist with coral reef management and mitigate the threats to this ecologically and commercially important ecosystem. The future for volunteer projects also appears exciting with increasing opportunities for new and existing organisations, further realisation and development of the capabilities of non-professional researchers and the blurring of the boundaries between volunteer science and traditional academic research. This increasing involvement of programmes utilising non-professionals can only be beneficial to tropical marine conservation but it is obvious that foreign volunteer projects are not a long-term solution to coastal management in developing countries. Hence it is important that these excellent projects act as a catalyst for the formation of in-country NGOs, encompassing all stakeholders, and generating a sense of resource 'ownership' and subsequent community-based management by local populations (e.g. 46).

ACKNOWLEDGEMENTS

This paper is dedicated to all the staff and participants of volunteer programmes around the world who work tirelessly to help protect coral reefs. I would also like to thank Dan Afzal, Mark Andrews, Maria Beger, Jos Hill, Gregor Hodgson, Peter Mumby, Peter Raines, Jonathon Ridley, Jean-Luc Solandt and Damon Stanwell-Smith for discussions that have led to the ideas included in this paper.

[1] http://www.reef.org

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Beaches to basking sharks: conservation projects of the Marine Conservation Society

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SYNOPSIS

The Marine Conservation Society (MCS) is the UK charity dedicated to the protection of the marine environment and its wildlife. Over the last two decades MCS has campaigned, lobbied and educated on a range of marine conservation issues, from phasing out of TBT in anti-fouling paint to the protection of the basking shark in UK territorial waters. In addition to policy work, MCS has actively involved volunteers in marine conservation projects including *Beachwatch*, *Adopt-a-Beach*, *Seasearch* and *Basking Shark Watch* that have generated useful baseline data. Whilst the nature of community environmental monitoring schemes raises issues of data quality, detailed guidelines and support minimise error and consolidate the invaluable role of the public in generating meaningful conservation databases. The lack of scientific rigour of these projects must be balanced against their overall goal of generating quality-controlled baseline data on a large spatial and participative scale.

INTRODUCTION

Since established as the Underwater Conservation Society in 1979, the Marine Conservation Society (MCS) has been at the forefront of campaigning on a range of marine conservation issues including marine nature reserves, bathing water quality, coastal litter, coral reef destruction, endocrine disrupting chemicals, overfishing, offshore renewable energy, salmon farming, oil pollution and port waste disposal. Whilst lobbying for changes in government policy, MCS has also enabled the wider community to get pro-actively involved with marine conservation issues both above and below the waves. The Marine Conservation Society co-ordinates several projects enabling concerned volunteers to contribute valuable ecological and environmental quality data – *Beachwatch*, *Adopt-a-Beach*, *Seasearch* and *Basking Shark and Turtle Watch*.

BEACHWATCH

Marine and beach litter, including plastic bags, cotton-bud sticks and fishing line have a range of potentially damaging impacts. Inappropriate disposal can harm or kill wildlife, reduce the aesthetic quality of beaches, spoil fish catches and damage human health and property. *Beachwatch* is an annual UK-wide beach litter survey and clean-up, organised by MCS since 1993 to provide a snapshot of the sources and amounts of marine litter around the UK coast. Now celebrating its 10th year, *Beachwatch* has become the most extensive monitoring programme in Europe for coastal and marine litter, and thousands of volunteers join the nationwide war on litter each year.

Results from the ninth annual Beachwatch beach-clean and survey on the 15th and 16th September 2001 are presented in **Table I**. A total of 194 beaches, covering 141 km of coastline in England, Scotland, Wales, Northern Ireland and the Channel Islands were cleaned and surveyed by 1,980 volunteers. In total, 222,704 items of debris were recorded, with a wet weight of 8,321 kg (approx. 8.3 metric tonnes).

Table I Summary of results for Beachwatch 2001

Beachwatch 2001 Summary	
Volunteers	1,980
Number of beaches surveyed	194
Length (km)	141.3
Number of bags	2,127
Weight (kg)	8,321
% from Tourism/Beach Visitors	37.2
% from Fishing	12.2
% from SRD	6.7
% from Shipping*	3.0
% from Fly Tipped	0.9
% from Medical	0.1

% Non-sourced	39.8
Total number of items	222,704
Mean Items/km	**1,576**

The Marine Conservation Society acknowledges that *Beachwatch* is not rigorously scientific, however a balance must be struck between the logistical need to recruit thousands of volunteers to gain a snapshot of marine litter over a single weekend with the needs of a rigorous monitoring project. It is argued that MCS has been extremely successful in balancing these needs and raising the profile of the beach litter issue.

Strengths

The strengths of *Beachwatch* are that it is open, accessible and regularly reported. Rather than being centred on one individual survey, *Beachwatch* is based on a well-organised national programme with a globally-recognised approach geared specifically to sourcing and prevention of litter. In addition, MCS successfully co-ordinate in the order of 2,000 people every September to take part, a successful feat of awareness-raising in itself (see **Table II**).

Table II Comparison of Beachwatch surveys since project launch in 1994

Year	Number of volunteers	Length of coast surveyed (km)	Items/km	% Plastics
1994	2,062	179.0	1,045	54
1995	2,365	193.0	1,654	53
1996	3,371	196.5	1,482	52
1997	2,449	168.8	1,554	57
1998	3,344	166.7	1,936	57
1999	1,686	91.8	1,913	54
2000	1,378	104.2	1,780	56
2001	1,980	141.3	1,576	54

Weaknesses

The main weakness of the *Beachwatch* protocol is litter sourcing in that this is carried out remote from the items themselves. All items recorded by the volunteer on a form are attributed to a source – beach visitor, fishing, shipping, sewage related debris, fly-tipped medical or non-sourced – at MCS Head Office. Accurate attribution is difficult since many of these items, such as a plastic drink bottle, can come from multiple sources - beach visitors, dumped from a boat or fly-tipped. It will always be difficult to attribute containers to source without witnesses or, for example, diagnostic overseas language on the container. Furthermore, there will also be variation in volunteer effort and observation skills among the 2000 or so who volunteer for *Beachwatch* every year, however this is likely to lead only to an overall underestimation of beach and coastal litter.

Under and over-estimating the amounts of litter from shipping

Plastic pieces were previously attributed to shipping, leading to an overestimate, but this was rectified in 1998 and plastic pieces are now categorised as non-sourced. On the other hand there is a large category of non-sourced litter (often as much as 39%), much of which is potentially attributable to shipping. Overall estimates are therefore probably significant underestimates of shipping pollution, particularly on open exposed beaches next to shipping lanes, such as in Pembrokeshire, Shetland or the Firth of Forth.

The data gathered from *Beachwatch* is published by MCS[1] and used to raise awareness of the impacts of litter, through public distribution, the media, government agencies and industry, and promote measures to reduce litter at source.

ADOPT-A-BEACH

Beachwatch is the flagship autumn event of the *Adopt-a-Beach* project. By adopting their favourite stretch of beach, conducting seasonal litter surveys and extending the litter monitoring throughout the year, communities are providing even more detailed information to help MCS turn the tide on litter both locally and nationally. Both *Adopt-a-Beach* and *Beachwatch* surveys involve recording every item of litter found on a representative 100m stretch of the chosen beach or, if shorter than 100m, the entire beach. Easy-to-use tally forms are provided categorising over 90 litter items. Since the protocol is the same, *Adopt-a-Beach* has similar strengths and weaknesses to *Beachwatch*. However, since *Adopt-a-Beach* surveys are conducted in spring, summer and winter, in addition to the autumn *Beachwatch* event, they provide an insight into seasonal variation in the composition of marine and coastal litter. A project report and updated website (www.adoptabeach.org.uk) are currently in production.

SEASEARCH

History

Seasearch is a volunteer underwater habitat survey project for recreational SCUBA divers established in the mid 1980s by the Marine Conservation Society and the NCC (now the Joint Nature Conservation Committee) to involve divers in gathering baseline habitat information from near-shore areas around the British coastline. The information has contributed to the Marine Nature Conservation Review, culminating in 1998 with the production of the Coastal Directory series. A search for surveys in the MNCR MERMAID database[2] reveals 19 *Seasearch* surveys dating from 1982 to 1998, ranging geographically from Loch Broom to Sussex.

Rationale

With over 20,000km of coastline there is still much to learn about the UK's underwater scenery and wildlife. Our invaluable eyes beneath the sea, recreational divers are in the unique position of being able to record simple information underwater. By recording depth, time, latitude, longitude, species and habitats, they can make a valuable contribution to marine conservation. Since the 1980's *Seasearch* surveys have taken place in Jersey and Guernsey, Pembrokeshire, Cardigan Bay, Anglesey, Isles of Scilly, Cornwall, Devon, Dorset, Lundy, Morecambe Bay, Northumberland, Sussex and throughout Scotland, predominantly the west coast.

Current Position

A National *Seasearch* Steering Group was established in 1999, bringing together all those with an interest in developing the *Seasearch* programme. Members of the Steering Group are: statutory conservation bodies (English Nature, Countryside Council for Wales, Scottish Natural Heritage and Joint Nature Conservation Committee), the Environment Agency, NGOs (Marine Conservation Society and The Wildlife Trusts), the Marine Biological Association (MarLIN), diver training organisations (BSAC, SSAC, PADI and SAA), Nautical Archaeology Society and independent marine life experts. The Group is developing a national programme to involve and train divers in marine life surveys and ensure quality data is gathered and utilised effectively to further our knowledge about our marine environment. The *Seasearch* programme is tiered in 3 levels - Observer, Surveyor and Expert. Training and expeditions can therefore be tailored according to the marine biological and *Seasearch* experience of the volunteer diver.

In 2002, a series of pilot training events (see **Table III**) took place throughout the UK.

Table III Seasearch training events (No = Course number; O = Observer Level; S = Surveyor Level)[3]

No/Level	Location	Date	Tutors	Participants
0203/O	Kimmeridge, Dorset	11/5/02	Peter Tinsley, Victoria Copley	9
0204/O	St Abbs, Scotland	11/5/02	Calum Duncan	4
0206/O	Lewes, Sussex	18/5/02	Robert Irving, Kate Cole, Bryony Chapman	13
0207/O	Lewes, Sussex	19/5/02	Robert Irving, Kate Cole Bryony Chapman	16
0209/O	Macduff, Scotland	25-26/5/02	Calum Duncan	18
0210/O	Heanor, Derbyshire	26/5/02	Chris Wood, Paul Biggin	14
0211/O	Anglesey, North Wales	8/6/02	Kirsten Ramsey, Lucy Kay	2
0214/O	St Abbs, Scotland	6-7/7/02	Peter Tinsley	5
0213/O	Norfolk	30/6/02	Chris Wood	?
0202/S	Anglesey, North Wales	11-12/5/02	Kirsten Ramsey, Rohan Holt	8
0208/S	Lewes, Sussex	25-26/5/02	Robert Irving, Kate Cole Bryony Chapman	13
0212/S	N Berwick, Scotland	8-9/6/02	Calum Duncan, Neil Cowie Christine Howson	8
0205/S	Kimmeridge, Dorset	15-6/6/02	Peter Tinsley	Cancelled

Feedback from the pilot training events was overwhelmingly positive. A number of expeditions were also organised including: MCS Members Dives to the Isle of Wight, Lands End, Sark, St Abbs, Llyn Peninsula, Bardsey and Skomer; Seasearch pink seafan surveys off Cornwall and South Wales; MCS Scotland co-ordinated expeditions to Loch Goil, Loch Roag in Lewis, Cape Wrath and the Isle of May; and *Seasearch* dives in South Wales, Devon, Dorset and Sussex. *Seasearch* reports are in production for many of these projects.

Although at first the idea of biological recording underwater is intimidating to some, *Seasearch* can be as simple or involved as participants wish, from a single dive to a week-long expedition. In fact, particularly with the development of the *Seasearch* Observer level discussed above, provided accurate position fixing, time, depth and simple habitat recording is carried out, the Marine Conservation Society intimate that "any dive can be a *Seasearch* dive". The range of stakeholders on the National *Seasearch* Steering Group and support given to the project clearly demonstrates its potential.

The Marine Conservation Society looks forward to development of a *Seasearch* database compatible with Marine Recorder to capture the wealth of *Seasearch* data generated since 1998.

BASKING SHARK AND TURTLE WATCH

Basking Shark Watch is a sightings scheme launched by MCS in 1987 to encourage those that live, work or holiday on or near the sea to report basking shark location, behaviour and size on dedicated recording cards to MCS. Since project inception, MCS has collated 4,220 records cataloguing 17,424 shark sightings, enabling mapping of geographical and temporal variation in surface sightings in UK coastal waters. In 1998, the *Basking Shark Watch* database helped secure protection for the world's second largest fish in UK waters under the Wildlife and Countryside Act. A full report on the MCS *Basking Shark Watch* project 1987-2001 from which the following information was drawn will be published shortly[4].

The intensity of scheme promotion, advertising and extent of direct mailing for the period of the project is summarised in **Table IV**.

Table IV Promotional effort for Basking Shark Watch 1987-2001

Year	Number of report cards sent to MCS	Promotion
1987	102	Scheme begun in Autumn
1988	396	Direct mail & media
1989	509	Direct mail & media
1990	360	Direct mail & media
1991	298	No direct mail; high media
1992	130	Little effort; limited media
1993	77	Not promoted
1994	64	Not promoted
1995	130	Media & Advertising
1996	171	Media & Advertising
1997	168	Little effort; limited media
1998	508	Little effort; limited media
1999	423	Little effort; limited media
2000	247	Little effort; limited media
2001	471	Re-launch of scheme: Direct mail, advertising & dedicated staff post

The actual number of sharks recorded each year is illustrated in Figure 2.

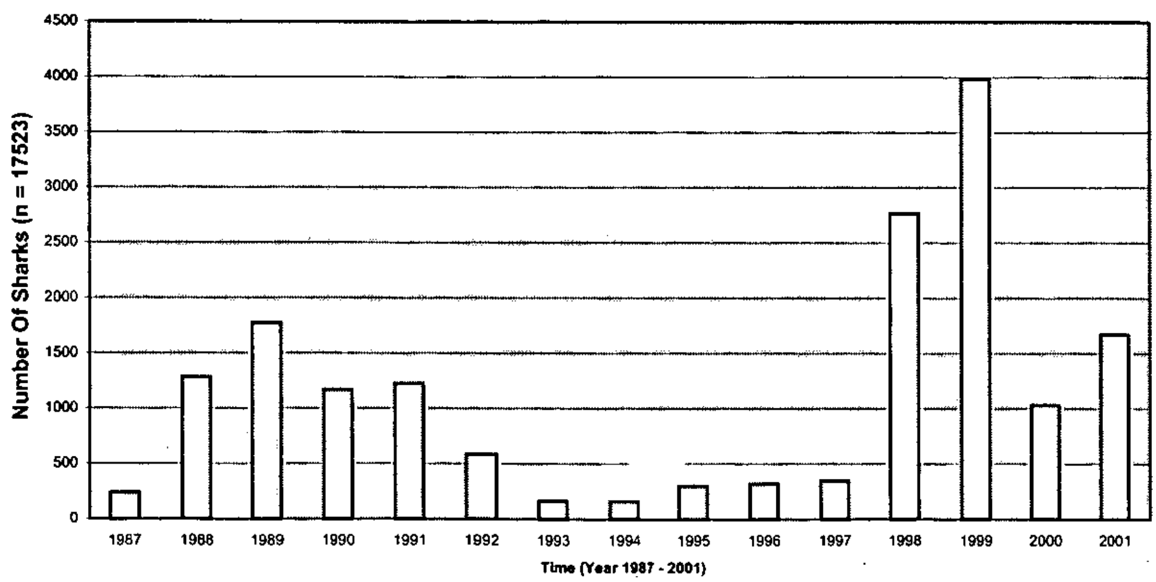

Figure 2 Number of basking sharks reported each year between 1987-2001

Hotspots are apparent around the coast of Cornwall and Devon, the Isle of Man, the Firth of Clyde and, to a lesser extent, around the Hebrides. Taken as a whole, sightings over the past 15 years show a potential 10 year cycle, with peaks in numbers of basking sharks reported in 1989 and 1999 and an all time low in 1993. During the period of low reported shark numbers, there had been project promotion, indicating that this cycle may not be directly linked to project promotion, but may indeed be a natural phenomenon.

In keeping with the lead partner status of MCS for the UK Marine Turtles Grouped Species Action Plan, there is now scope to record sightings of leatherback and hardshell (green, loggerhead, hawksbill etc) turtles on an updated *Basking Shark and Turtle Watch* reporting card. The Marine Conservation Society looks forward to similar success with the new *Turtle Watch* facet of the sightings project.

CONCLUSION

Whilst the nature of community environmental monitoring schemes raises issues of data quality, detailed guidelines and support minimise error and consolidate the invaluable role of the public in generating meaningful conservation databases. The overall goals of generating quality-controlled baseline data on a large spatial and participative scale and raising both public and political awareness of marine conservation issues through the MCS projects detailed above must be balanced with any concomitant lack of scientific rigour associated with community marine conservation projects. Although data generated from MCS projects often cannot be tested statistically, they always raise important questions that ensure marine conservation topics remain in the media spotlight and on the agenda of politicians and decision-makers.

ACKNOWLEDGEMENTS

The Marine Conservation Society is extremely grateful to all those who have contributed their valuable time in helping out on *Beachwatch*, *Adopt-a-Beach*, *Seasearch* or *Basking Shark Watch* over the years. Many thanks are also due to Countryside Council for Wales, Environment Heritage Service Northern Ireland, PADI Project Aware, The Crown Estate, The Community Fund, English Nature, Environment Agency, Scottish Natural Heritage and DEFRA's Environmental Action Fund for funding the Marine Conservation Society projects discussed and report production. The author would also like to thank Karen Riley, Gavin Saville, Sam Fanshawe, Chris Wood, Bryony Chapman and Rebecca Higgins.

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A community-based beach clean-up in Indonesia

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SYNOPSIS

Litter pollution was severe in both the littoral and sub-littoral zones of Ambon Bay in the Maluku Province of eastern Indonesia. There is evidence that, at least in the littoral zone, it has an impact on underlying macrobenthic, meiobenthic and diatom assemblages. A community clean-up event, which was attended by the Minister of State for Population and the Environment and the Governor of Ambon, and involved local people, members of the navy and army, university students, staff from the health Department and representatives from NGOs, was effective in clearing litter from shores adjacent to several villages in Ambon Bay. Litter levels were monitored for a period of six months after the clean-up, during which they remained low.

INTRODUCTION

Coastal pollution and over-exploitation of natural resources are major problems in Indonesia. The north coast of Java is particularly badly affected and suffers from heavy metal, sewage and litter pollution, degradation of coral reefs by fishers using explosives as a means of catching fish and coastal erosion. High nutrient loads there appear to have been responsible for a dramatic shift from the productivity of a macrobenthic coral reef community to a micro-pelagic community in Jakarta Bay[1]. However, degradation of coastal areas is by no means limited to Java. Those spread as widely apart as Bali, North Sulawesi, South Sulawesi and the Maluku have become problem areas due to unplanned and uncontrolled human development.

The present study is based on Ambon Bay in eastern Indonesia. It was undertaken in 1994/1995 before the race riots on Ambon. The island had a population of over a million at that time with an annual growth rate of 1.5%. The Bay itself is divided into two parts: the inner Bay and the outer Bay. The inner part is characterised by mud flats and mangroves and the outer part by mangroves. There is a series of villages around almost the entire Bay.

The objectives of the study were:

1. To measure the extent of litter in the littoral and sub-littoral zones;
2. To measure the impact of litter on biological assemblages
3. To assess the effectiveness of a community education programme, which included a beach clean-up, in reducing litter along shorelines.

METHODS

Estimates of litter pollution

Counts were made of the numbers of items of synthetic litter, including plastic objects, footwear, cans, bottles, light bulbs and pieces of net and rope.

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Emeritus Professor Stewart Evans has a personal chair in 'Research and Outreach in Biology' from the University of Newcastle upon Tyne. Prulley Uneputty is a lecturer at Universitas Pattimura, Indonesia. She is currently studying for a PhD at the University of Queensland, Brisbane.

Measures were made at two sites in the littoral zone: Poka in Inner Ambon Bay and Seilale in Outer Ambon Bay. The transects were made at each site during the period of low tide from the strand line vertically down the shore to low water (spring tides). They were about 25m apart (horizontal distance). Quadrats, measuring 1 x 1m, were laid down at 10m intervals along transects. Items of litter were counted in each of them.

There were five study sites at which estimates were made of litter in the sub-littoral zone: Halong, Poka, Waiheru in the Inner Bay, and Airsalobar and Seilale in the Outer Bay. Litter was collected by casting a beach seine net, measuring 24 x 7m, from the water's edge at low tide (spring tides). Ten cast were made at each site at intervals of about 20m along the shore. Items of litter were removed from the net and counted. Each item of litter was also measured. This was done so that estimates could be made of the maximum areas of sea floor that were covered, assuming that there was no overlap caused by items lying on top of one another.

Biological impacts of litter

Comparison were made of the macrofauna, meiofauna and diatoms in 10 pairs of quadrats, 0.5 x 0.5m, 0n the upper shore at Poka. One quadrat of each pair was in an area that was covered by plastic litter and one was in an adjacent area (within 5 – 10m) that was not covered. The covered sites were ones at which the plastics were partially buried and appeared to have been there for at least several days.

Macrofauna was sampled by digging sediment from the quadrat to a depth of 25cm and then sieving it through a sieve with a mesh of 0.5mm.

Meiofauna was sampled by using a spatula to scrape samples of about 20g of sediment from the surface of each quadrat. They were then preserved in a solution of 4% formalin containing Rose Bengal. Subsequently, sub-samples of about 1g of sediment were removed and weighed (wet weight). They were then stirred in filtered seawater using a magnetic stirrer for about 1 minute in order to release the organisms from the sediment particles. They were then filtered through a 63μm mesh.

Additional 20g sediment samples were scraped from the surface for counts of diatoms. Sub-samples of about 2g were weighed (wet weight) and washed in distilled water. They were then washed in 70% nitric acid.

The beach clean-up.

The event was based at four villages: Galala, Halong, Poka and Rumah Tiga. It was organised by the office of the Governor of Ambon, and took place on Saturday, November 26, 1994. It started with addresses by the Minister of State for Population and Environment, Mr. Sarwono Kusumaatamdja, the Governor of Ambon, drs. M.A. Latuconsina, and the Secretary of the Municipal Council of Ambon, drs. H. Aponno, to the volunteers who were about to undertake the clean-up. They included: members of the Health Department, environmental NGOs, students from Pattimura University, members of the army and navy, and local people.

A litter monitoring programme started at Galala on the day before the clean-up event. Unfortunately, the locations of the three remaining sites were unknown until the day of the event and it was not possible to measure litter at them before it. However, in order to gauge the effectiveness of the clean-up event measurements were made in two areas at Ruma Tiga; one was on part of the shore that was cleared of litter and one was on part of the shore that was not cleared of it. Measurements were made at each site on the day of the event and then 1, 2, 4, 12 and 24 weeks after it. Ten 1 x 1m quadrats were placed at 10m intervals along the strand line and items of litter counted in them.

RESULTS

Litter pollution.

Litter tended to collect in dense quantities along strandlines and, to a lesser, the upper part of the littoral zone. Lower levels of the shore were relatively litter free. However, substantial quantities of litter collected in the sub-littoral zone. Densities were particularly high at Halong (Table 1), although overall they were less than those recorded along strand lines.

Table 1. Numbers of litter items, and potential percentage cover, in the sub-littoral survey.

Site	Items/m²	Percent cover
Poka	0.3	1.9
Waiheru	0.2	1.0
Halong	0.7	7.2
Airsalobar	0.4	2.8
Seilele	0.1	0.4

Impact on biological assemblages.

Where litter smothered the upper shore, it caused marked changes in the fauna and flora of the underlying sediment:

Macrofauna. Decapod crustaceans and oligochaetes were dominant members of the infauna of litter covered areas but neried and spionid polychaetes dominated control areas.

Table 2. Numbers of the some macrofaunal organisms per quadrat in sediment beneath beach litter and sediment that was not covered by litter.

Taxon	Litter covered	Control (no litter)
Nereidae	0.3	4.5
Spionidae	0.2	3.6
Oligochaeta	2.8	1.3
Latirus sp.	0.6	0
Pectinidae	0	0.3
Decapoda	5.8	0.5
Uca lactea	0.5	0.2
Hyperiidae	0.4	1.1

Meiofauna were more abundant in surface sediment from beneath litter than control areas. Mean numbers per sample were 13.0 in the litter covered areas, compared with 2.4 in the litter free areas.

Conversely, diatoms were more abundant were more abundant in the control areas (mean = 15.1 per sample) than the areas covered by litter (mean = 8.3 per sample).

The Beach Clean-up.

The clean-up event was effective in clearing shores of litter. Up to about 50 people were involved in clearing litter at each study site. They worked for about two hours collecting litter in piles on the shore and then burning it. The effect is evident from data collected at Galala. There were significantly lower densities of litter after the clean-up event than before it ($P<0.001$; Mann Whitney U Test). Similarly, there was significantly less litter on that part of the shore that was cleaned at Rumah Tiga than on adjacent, uncleaned shore ($P<0.05$; Mann Whitney U Test).

Members of villages continued to keep the shores clean of litter throughout the 24-week monitoring period. The amount of litter that was recorded decreased progressively for the first four weeks and then remained low. It was evident that areas adjacent to study sites were also cleaned. Thus, the amount of litter in the uncleaned area of shore at Rumah Tiga decreased until, by week 12, it was no more polluted than the cleaned area there. However, this area was apparently neglected after week 12. Levels of litter returned to those that had been recorded at the time of the clean-up event.

DISCUSSION

Pollution from domestic waste is severe in Ambon Bay. The source of litter is at least partly local because Evans *et al.*[2] found that densities of litter on shores correlated positively with the sizes of human populations in adjacent villages. However, the city of Ambon is also a major source of litter. Siwabessy[3] estimated that the city's inhabitants produced 693.9m^3 of litter per day, and 65.3 m^3 was deposited in the sea. Since Ambon Bay has poor flushing characteristics (Hamzah and Wenno[4]), litter than reaches the sub-littoral probably accumulates there, forming offshore sinks of litter of the kind described in the Bristol Channel (Williams et al.[5]) and the Mediterranean Sea (Galil et al.[6]). Such sinks may be ecologically significant because litter smothers the sediment and, at least on the upper shore, this causes changes in underlying assemblages of macrofauna, meiofauna and diatoms.

However, litter is only one of several causes of chronic pollution in Ambon Bay. Concentrations of heavy metals, such as cadmium, copper, lead, mercury and zinc are high in sediments, and have accumulated in gastropods and fish[3]. There is also evidence of tributyltin contamination from anti-fouling paints used on boat hulls[2]. Oil pollution is high in part of the Outer Bay where there is a refinery, and the decline of some populations of molluscs and crabs has been attributed to it[3]. Further concerns relate to heavy siltation which has been attributed to reclamation of land from the sea and levelling of steep slopes on the island. The rate of siltation has been 23.8mm per year, and of erosion of the coastline in some areas, 1.7 – 2.3m per year[3]. Biological indications of degradation are evident. In the past, the Bay was a source of fish bait, supporting the open sea tuna fishery but production of fish bait fell dramatically from 23,753kg in 1976 to 518kg in 1990[3]. Evans *et al.*[2] suggested that high incidences of the isopod ectoparasite *Renocila* sp. on the Sergeant major fish *Abudefduf saxatalis* were indirect consequences of pollution stress.

The long-term solution to degradation of Ambon Bay will depend in apart on measures that will reduce the input of pollutants at source. Legislation will be necessary and the provision of facilities, such as efficient garbage disposal facilities. However, increased awareness of the problem by both policy-makers and the public at large will be needed before such systems can either be developed or implemented. Environmental education undoubtedly has a role to play in achieving these aims, and it has been described as the key to the solution of environmental problems[7]. It is through it that a new ethic, in which humankind is prepared to live in harmony with the natural world, can be developed.

Environmental education in schools and universities is obviously important but its impact is delayed until the students are in decision-making or influential positions in society. Community education is necessary therefore because it of its more immediate impact and because it can involve all sections of society[8]. However, it will be necessary to target different groups by using different techniques. Local communities can certainly become involved in managing coastal areas adjacent to their villages. This has happened effectively in the Philippines, where local communities have set-up and managed marine reserves[9]. Similarly, it was shown here that village communities from coastal areas of Ambon Bay were effective in removing litter from adjacent shores over a period of at least 24 weeks. In many cases, pollutants are distant in origin and the solution is beyond the actions of local communities. It is important therefore that campaigns that aim to raise awareness of environmental issues are targeted as widely as possible and reach a wide cross-section of the general public, politicians and decision-makers.

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Environmental knowledge in the people of Pacific Islands

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SYNOPSIS

Environmental knowledge (i.e. knowledge of local bird life) is well developed in the local population of Vanuatu. They were able to ecognise native birds (both common and uncommon species) from colour illustrations and distinguish them from non-native Australia species, which do not occur in Vanuatu. Young ni-Vanuatu had good environmental knowledge and performed as well as older generations. This would suggest that their knowledge of the environment is acquired from an early age. A similar study was undertaken in the Suva region of Fiji. In this case, environmental knowledge was generally poor but there were indications that younger people performed less well than older ones. This would suggest that environmental knowledge is being progressively lost, perhaps as a result of new culture and non-traditional pastimes.

INTRODUCTION

The long-term health of the environment is dependent upon the active and positive participation of the general public. In recent times there has been a populist belief that responsibility for the environment lies mainly with governments, ecologists, academics and environmental campaign groups. I believe that there will be enormous benefits in 're-establishing' the lay public's close affinity with the environment and encouraging their involvement in environmental management processes. Public involvement will improve trust of the scientific process and convince the public that their views are valued[1]. Involvement will aid the implementation of policies through better understanding and support[2] and the incorporation of a public viewpoint will undoubtedly add quality to the decision-making process[3].

However, public involvement in the scientific process will depend on a scientifically literate public and, in the western world, environmental knowledge at least is low[4,5]. Gigliotti have commented[6] that 'we seem to have produced a citizenry that is emotionally charged but woefully lacking in basic ecological knowledge'. The extent to which poor knowledge can be attributed to our 'western life-style' is, however, unknown. In the present study, I compare environmental knowledge in people from island in two countries in the Pacific where there are different levels of western influence. First, the island of Espiritu Santo on Vanuatu where most people live at subsistence level and depend on the local environment for food and other resources. Second, in the Suva region of Viti Levu on Fiji, where there is more western influence and most people commute into Suva to work. They no longer have the same reliance on the local environment.

METHODS

The study period lasted from September – November 2000. Knowledge of birds was tested by showing people colour illustrations of species that occur locally (i.e. on their islands) and illustrations of non-native (Australian) species that have never been recorded either on Vanuatu or Fiji. Only men took part in the tests because previous studies had shown that, at least on Vanuatu, men have better knowledge of bird life than women[7]. The illustrations were taken from Bregulla[8], Doughty *et al.*[9],

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Gareth Douglas has a B.Sc. (Honours) degree in Zoology from the University of Newcastle upon Tyne. He has undertaken field research on the avifaunas of Vanuatu and the Kimberley region of northwest Australia.

Slater[10] and Watling[11] were used to depict the different species. Overall, 29 illustrations were shown to each interviewee; 21 of them were local species (either Vanuatuan or Fijian) and 8 were Australian species.

Interviews were conducted on a 1:1 basis to prevent collusion between individuals and they were shown the illustrations one at a time. Mixed groups were interviewed including children and older members of the community. The ages of interviewees were recorded. They were asked to respond 'yes' or 'no' based on their belief whether or not the species occurred on their island.

Table I – Species used in tests of environmental knowledge in Vanuatu and Fiji. Assessments of common or uncommon (U=Uncommon; C=Common) were based on the literature.

Species No.	*Vanuauan Species*	*Abundance*	*Fijian Species*	*Abundance*
1	Red-bellied Fruit Dove	C	Collared Lory	C
2	Red Jungle Fowl	C	Red-headed Parrot Finch	C
3	Green-winged Ground Dove	C	Swamp Harrier	C
4	Vanuatu Fruit Dove	C	White Collared Kingfisher	C
5	Pacific Imperial Pigeon	C	Spotted Fantail	C
6	Barn Owl	C	Vanikoro Broadbill	C
7	Indian Mynah	C	Grey-backed White-eye	C
8	Vanuatu Kingfisher	C	Golden Dove	C
9	White-throated Pigeon	C	Wattled Honeyeater	C
10	Peregrine Falcon	C	Polynesian Triller	C
11	Black-headed Mannikin	C	Fiji Warbler	C
12	Vanuatu White-eye	C	White throated Pigeon	C
13	Rufous-brown Pheasant Dove	C	Fiji Shrikebill	C
14	Vanuatu Mountain Pigeon	U	Friendly Ground Dove	U
15	Vanuatu Flycatcher	C	Multi-coloured Fruit Dove	U
16	Vanuatu Megapode	C	Red Avadavat	C
17	House Sparrow	C	Golden Whistler	C
18	Vanuatu Mountain Honeyeater	U	Java Sparrow	U
19	Santa Cruz Ground Dove	U	Pink-billed Parrot Finch	U
20	Santo Mountain Starling	U	Polynesian Starling	U
21	Chestnut-breasted Mannikin	U	Fan-tailed Cuckoo	U

Table II. Australian species used a controls in the tests of environmental knowledge used in both Vanuatu and Fiji.

Glossy Ibis	Yellow-breasted Sunbird
King Quail	Lotus-bird
Buff breasted Pitta	Bee-eater
Dollar Bird	Plumed Pigeon

STUDY AREAS

Vanuatu

Nine villages were visited on the island of Espiritu Santo. 'Santo' lies to the north of the Vanuatu archipelago which contains some 80 islands. Santo is the largest island of Vanuatu at 3,677 square kilometres and has a population of 30,000 people, many of these people live in Luganville, the second largest town in Vanuatu. It is also the most mountainous island in Vanuatu and many parts are inaccessible although there are also large tracts of land which have been developed for agricultural purposes. The majority of the population still live in small villages and are heavily reliant in subsistence farming. A number of bird species are endemic to this island. A list of villages where interviews were carried out and numbers of men interviewed can be found in Table II.

Fiji

Viti Levu is Fiji's largest island with an area of approximately 10,400 square kilometres and a population of around 580,000. A significant proportion of these people live in Suva which is also the main administrative and political centre for the country. The island is divided by a central mountain range; the eastern side is wetter and with much of the rainforest, whilst the western side consists mainly of open grassland. All interviews were conducted in villages on the eastern side of the island. 6 villages were visited a list of which can be seen in Table II along with the number of men interviewed in each village.

Table III – Villages surveyed and number of men interviewed in each village

Espiritu Santo, Vanuatu		*Viti Levu, Fiji*	
Village	*Number interviewed*	*Village*	*Number interviewed*
Benmol	12	Colo I Suva	9
Butmas	12	Nabukavasi	12
Chapuis	8	Naikorokoro	8
Fanafo	14	Namosi	11
Knicka	9	Tamavua	8
Monixil	11	Walioku	9
Sarakata	11	Shark Bay	16
Sarete	9		

RESULTS

Environmental knowledge in Vanuatu and Fiji

Men from the island of Santo had excellent knowledge of the local avifauna. Almost all of those interviewed on Santo recognised the majority of the illustrations of Vanuatuan species. The large majority of species received >50% correct responses, that is, people recognised them as local species and responded 'yes' when shown illustrations of them (see Table III). Conversely, most people realised that the Australian species were not members of the local fauna. They responded 'no' to them. None of these Australian species received >25% positive responses. There were, nevertheless, two local species, Chestnut-breasted Mannikin *Lonchura castaneothorax* and Santo Mountain Starling *Apolonis santovestris*, that also received <50% 'yes' responses. The explanation may be that the former species is an introduced species (probably as an escapee from aviaries) which has a limited distribution and is therefore not well-known, while the latter one is rare and is limited to mountainous areas in the centre of the island. As might be expected, knowledge of species that were classified as common was significantly better than that of uncommon ones (W=196, P<0.01; Mann Whitney U Test) (Table III).

In contrast, people interviewed in Fiji had difficulty in identifying resident species. Only five bird species (Collared Lory *Phigys solitarius*, Red-headed Parrot Finch *Erythrura psittacea*, Swamp Harrier *Circus approximans*, White-collared Kingfisher *Halcyon chloris* and Spotted Fantail *Rhipidura spilodera*) received >50% 'yes' responses. These are all common species and, as would be expected, overall common species were significantly better known than uncommon ones (W=175, P<0.01; Mann Whitney U Test) (Table III). Fijian men were more successful in providing 'correct' answers (i.e. they answered 'no') to illustrations of Australian species. However, this is almost certainly due to their tendency to answer 'no' to most birds shown to them (Fijian or Australian), rather than a positive identification that these were not native species.

Table IV– Mean percentage of males responding positively to species grouped according to their abundance category (Table I).

	Common species		*Uncommon species*	
Species	*n*	*Mean +/- SE*	*n*	*Mean +/- SE*
Vanuatuan	16	88.5 +/- 2.6	5	58.6 +/- 6.7
Fijian	15	41.5 +/- 5.9	6	12.0 +/- 1.7

Knowledge in relation to age

Interviewees in Vanuatu showed no significant variation in their knowledge of birds across different age groups. Even young children had good knowledge. The scores obtained by children were on average, as good as those obtained by older members of the population. Consequently, coefficients of correlation between age and percent correct responses were small and not significant for both the Vanuatuan and non-native (Australian) species. In contrast, older Fijian men were better able to recognise birds than younger ones. This was the case in responding to illustrations of both native Fijian species and Australian ones. In this case, coefficients of correlation were significant.

DISCUSSION

The results of these surveys were markedly different. Ni-Vanuatu have excellent knowledge of the local bird life, Fijians have poor knowledge.

Interestingly, and of note, was the varying knowledge between the different age groups interviewed in Fiji. In Vanuatu, there was no discernible difference between the age groups from young to old, whilst in Fiji, there was much less knowledge amongst the younger members of the population. It seems likely that this has been brought about by cultural change and a more 'westernised' population. It seems that the younger members of the population now no longer have the knowledge of birdlife that their forefathers are still exhibiting. Youngsters in Vanuatu appear to be retaining this knowledge perhaps because of the flow of knowledge which is still passed through generations. This is primarily because many people in Vanuatu still rely upon the forest and environment for their survival and as a food source. The apparent decline in environmental knowledge in Fiji is an alarming trend although it matches many of the findings of other studies carried out in 'western' populations. Heslop, Birchenough & Evans (in preparation) highlighted this in a survey in the United Kingdom with evidence that even those who have recently left or remain in full-time education have a poor environmental knowledge. Modern education techniques are focussing less on knowledge of the natural environment surrounding us despite the fact many members of the public are now much more informed concerning the wider global environmental issues such as 'global warming'.

ACKNOWLEDGEMENTS

I would like to thank Professor Stewart Evans and Dr Andy Birchenough for their help and encouragement over the years and the people of Vanuatu and Fiji for their patience and ever willing. I would also like to thank Mr Mike Fidler and Autosmart Ltd. for their financial backing, support and enthusiasm.

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Improving environmental knowledge

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SYNOPSIS

Calls for increased community involvement in managing the environment will depend ultimately on an environmentally literate general public. It was shown here that schoolchildren and young people, and some other adult groups, had poor abilities to name common organisms from colour illustrations of them. Nevertheless, there are some groups in society, such as fishers, and ornithologists, whose professions or hobbies bring them into close contact with wildlife, who had good knowledge. It is argued that these people have specialist knowledge and can make important contributions to environmental planning and decision-making management processes. However, greater public participation in these processes will require improved environmental knowledge in the lay public and therefore new educational initiatives are needed. There were improvements in knowledge of birds in children from Tyneside when they were involved in one such initiative, local bird surveys. The knowledge of their parents also improved over the same period, presumably because they helped their children in the identification of bird species. The results of the surveys and experience gained from taking part in them were used by the children to develop management proposals for a habitat of conservation importance in North Tyneside.

INTRODUCTION

Environmental knowledge was once an important environmental asset. It was well-developed in communities that operated at subsistence level[1] and was used by them in managing their natural resources [2]. Fishers in such communities provide one example in which environmental knowledge was particularly well-developed. It included knowledge of the behaviour, precise locations and timings of fish spawnings[2,4] and the behaviour and biology of crabs[5]. Relevant information was incorporated into local management measures by, for example, restricting fishing to certain seasons, placing taboos on eating certain species, allowing a proportion of the catch to escape or excluding small individuals from the catch so that they could reach maturity (and therefore breed) before they were harvested [6,7,8].

However, environmental problems have become increasingly global in modern times and, as a consequence, local knowledge of it has become less relevant [8]. Evans[10] suggests that most people in the developed world have little affinity with the environment and, while some groups such as farmers still have specialist knowledge of it[11], environmental knowledge is generally regarded to be poor [12,13,14,15].

Ironically, there are increasing calls for greater involvement of the lay public in science-related debate and environmental planning and management processes from both scientists[1] and government[16]. It has been suggested that there are lessons to be learned from the past and that modern environmental management practices would benefit from increased community involvement [4,15,16]. However, the public must be well-informed about the environment before it can make meaningful contributions to its management and this will only be feasible with an improvement in environmental knowledge in the lay public [17]. There is an urgent need therefore for new educational initiatives that will reverse the decline in environmental knowledge.

The present study addresses these issues in three parts: (i) firstly, it investigates environmental knowledge, in this case the ability to name common birds, marine fish, mammals and trees from colour illustrations of them, in social groups that have different amounts and kinds of contact with the environment; (ii) secondly, it examines how extensive is environmental knowledge, in this case the ability to name common birds, in schoolchildren; (iii) thirdly, the study examines issues that relate to an educational initiative, in which schoolchildren undertook surveys of local bird life, and addresses how effective are bird surveys in improving knowledge of birds? And can knowledge and experience gained from surveys, be used in developing management strategies for local areas of conservation importance?

Authors' Biography

Dr Andy Birchenough is Coordinator of the initiative '*The North Sea: Our Joint Responsibility*' based at the Dove Marine Laboratory, University of Newcastle upon Tyne. The project aims to increase understanding of marine environmental issues and enhance feelings of responsibility towards the seas by involving community groups in marine ecological research projects.

METHODS

These studies were carried out between October 2000 and September 2001

(i) Environmental knowledge in different social groups.

Tests of environmental knowledge were given to members of 9 social groups, which differed from one another in the extent to which they were likely to come into contact with the natural world. Groups were divided into sub-groups on the basis of educational background and age. Tests involved asking people to write down the names of common organisms from colour illustrations of them. They were carried on 1:1 bases to prevent collusion between interviewees. The 'test' organisms consisted of 10 land birds, 10 shore birds, 10 marine fish, 5 mammals and 5 trees.

The groups were as follows (abbreviations for them are shown in brackets):

Students reading Biological Sciences at Newcastle University. There were two sub-groups. One sub-group (SB1) consisted of first year students, who had embarked on degree courses and had A level (or equivalent qualifications) in Biology (and other subjects), they were tested approximately two months after leaving school.. The second sub-group (SB3) was of final year students who had been reading biological sciences for more than two years. Students in both sub-groups were under 21.

Students reading English at Newcastle University. There were two sub-groups: (i) first year students (SE1) who were tested approximately two months after leaving school; and (ii) third year students (SE3) reading the same degree course. All students were under 21. These students had backgrounds in the Arts and had not studied ecology either at school or university.

Athletes. They were members of local (North Tyneside) athletics' clubs. They were divided into three sub-groups: (i) Under 21 with formal educational qualifications (A1); (ii) 21-45 with formal qualifications (A2); and (iii) 21-45 with no formal qualifications (A3). Although athletes spend much of their leisure time 'out of doors', they would not be expected to have close affinities with wildlife or environmental issues.

Women's Institute. They were members of the Jesmond (Newcastle upon Tyne) branch of the Institute. There were two sub-groups: (i) >46 with formal educational qualifications (W1); and (ii) >46 with no formal qualifications (W2). They would not be expected to have special interests in wildlife.

Sea-anglers. They were members of the Sea-anglers' Federation and/or local angling clubs. There were three sub-groups: (i) 21-45 with formal educational qualifications (SA1); (ii) 21-45 with no formal qualifications (SA2); and (iii) >46 with no formal qualifications (SA3). Sea-angling as a hobby focuses on one specific group of organisms, marine fish, but it also involves people spending long periods of time in close contact with the environment.

Fishers. They were commercial fishermen working on boats that operated from North Shields' fish quay. There were two sub-groups: (i) 21-45 with formal educational qualifications (F1); and (ii) 21-45 with no formal qualifications (F2). Their professional interest is in commercially important marine fish.

Nature wardens. They were wardens who were managing local nature reserves in northeast England. There was a single group, all of whom were 21-45 and had formal educational qualifications (NW). Their educational backgrounds and professional interests are in environmental management.

Ecologists. They were academic staff, teaching and research interests are in ecology, in departments of Biological Sciences at Newcastle University. There was a single group: >46 with formal qualifications (Ec).

Ornithologists. They were members of local (North Tyneside) bird-watching clubs. There were two sub-groups: (i) 21-45 with formal educational qualifications (O1); and (ii) >46 with formal qualifications (O2). Their hobby focuses on one group of organisms, birds, but it involves people spending much of their leisure time 'out of doors'.

(i) Knowledge of schoolchildren

Knowledge of birds was tested by asking children to write down the names of 18 bird species, which were shown to them as colour illustrations. The children were from three schools in Ilkley (Yorkshire). Six of the test species were common garden birds, six were lowland farmland species and six species were shore birds (including waders and seabirds). The tests of knowledge were carried out in class during school time, under the supervision of class teachers.

(ii) Bird surveys

Surveys of garden birds were carried out by children, either 12 (n = 58) or 13 years old (n = 160) from two schools on Tyneside. Each class was given a one-hour illustrated talk on identifying garden birds, and each pupil was provided with an identification aid. Children were then asked to record the numbers of each species of bird seen either in their garden or nearby parkland in four separate 15-minute recording sessions during the forthcoming weekend. Knowledge of garden birds was tested in each of the participating children both before and after the surveys (as above). The test was restricted to common garden birds that they were likely to encounter during the surveys. The same birds were included in both the before and after tests. None of the children was aware that they would be tested on the second occasion. Some of the parents (n = 125) were also asked to perform the same tests as the children before and after the surveys, since it was suspected that some of them would assist their children in the surveys. These tests were carried out as individual interviews.

A group of volunteers from the children (n = 10), who had taken part in the surveys, carried out brief surveys of the birds inhabiting the sand dune system at Seaton Sluice. The dunes, which extend for about 3km, are managed by Blyth Valley Council. They are well-used by dog-walkers and are popular among beach users during the summer. The group met with a senior biology teacher from one of the participating schools to consider recommendations for the future use of, and the conservation of birds at, Seaton Sluice sand dunes. The teacher acted as rapporteur for the group but avoided influencing its discussions or recommendations

RESULTS

(i) Environmental knowledge in different social groups.

There were considerable differences in scores obtained by different social groups in these tests. Young people (sub-groups of undergraduates, SB1, SE1 and SE2, and the <21 sub-group of athletes, A1) performed poorly (Table I). They were able to name less than a third of the species shown to them. Groups whose professions involved close contact with wildlife (fishers, ecologists and nature wardens) and those whose hobbies gave them similar experience (sea-anglers and ornithologists) performed better than those groups (athletes and members of the Womens' Institute) whose professions or hobbies did not bring them into contact with nature (Table I). There is no evidence that school educational background affected the performance of individuals in these groups. Sub-groups, whose members had formal education qualifications performed no better than those whose members lacked them in the cases of athletes (A2 v. A3) sea-anglers (SA1 v. SA2), fishermen (F1 v. F2) and Women's Institute (W1 v. W2) ($P>0.05$ in each of the four comparisons; Wilcoxon Matched-Pairs Signed-Ranks Test) (Table I).

Table I. Mean overall scores for each of the sub-groups, which were based on age (<21, 21-45 or 46-65) and educational background (formal qualifications or no formal qualifications) (see Methods).

Under 21	*21-45*		*46-65*	
Formal	*Formal*	*No formal*	*Formal*	*No formal*
Athletes (A1): 24.6				
Stud. Eng I (SE1): 29.4				
Stud. Eng III (SE3): 29.8				
Stud. Biol. I (SB1): 30.9				
	Athletes (A2): 36.6			
		Athletes (A3): 42.3		
				Womens' Inst (W2).: 47.6
Stud. Biol. III (SB3): 49.1				
			Womens' Inst. (W1): 51.9	
	Sea anglers (SA1): 60.9			
		Sea anglers (SA2): 63.0		
				Sea anglers (SA3): 64.3
		Fishermen (F2): 69.5		
			Ecologists (Ec): 69.6	
	Fishermen (F1): 71.8			
	Nat. wardens (NW): 72.3			
			Ornithologists (O2): 72.5	
	Ornithologists (O1): 76.3			

Not all sub-groups had the same knowledge of species. With the exception of the mammals, which were well-known to almost everyone interviewed, some sub-groups showed specialist knowledge for certain groups of organisms. Ornithologists (O1) had excellent knowledge of both land and shore birds and of trees (Table II). Fishers (F1) of the same age group and educational background had good knowledge of marine fish, and also of shore birds and were more familiar with shore birds than the land birds (Table II).

Table II. Percent correct responses, of sub-groups of Ornithologists, Fishers, Athletes and members of the Women's Institute, to each group of organisms to which they were tested. Abbreviations of the sub-groups are included in the text (see Methods)

	21-45			*45-65*
	Ornithologists O1	***Fishers F1***	***Athletes A2***	***Women's Institute W1***
Land birds	97	45	46	68
Shore birds	90	73	26	65
Marine fish	32	95	13	23
Mammals	89	81	88	93
Trees	83	49	35	70
	76.3	69.5	36.6	51.9

(ii) Knowledge of schoolchildren

The knowledge of birds among the schoolchildren tested was poor. The majority of them were unable to name more than 25% of the birds correctly (Fig 1). There was also relatively little improvement with school age in the abilities of children to name the birds (Fig. 1).

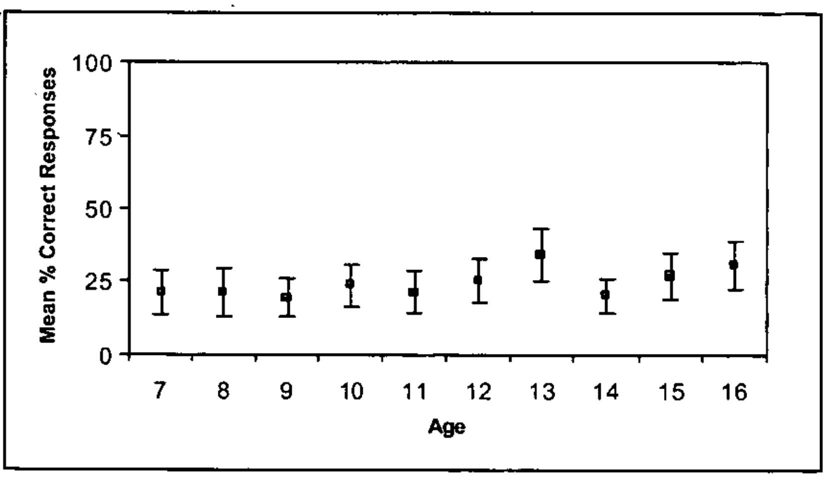

Fig.1. Mean percent correct responses to colour illustrations of birds in schoolchildren aged 7 – 16 from Ilkley.

(iii) Bird surveys

Involvement in the bird surveys evidently increased knowledge of bird species in those who participated. Children from Tyneside showed significant improvements in their abilities to name birds after the census than before it ($P<0.001$; Mann Whitney U Test) (Table III). Parents knowledge was initially higher than that of their children but, nevertheless, it too improved significantly following the surveys ($P<0.001$ in both cases) (Table III).

Table III. The scores of children and parents in tests of knowledge of birds before and after the survey of garden birds.

Number tested	*Mean score (percent)*	
	Before	***After***
	Children	
217	31.1±0.2	48.0±0.2
	Parents	
125	59.6±0.3	67.0±0.3

The group that carried out additional surveys of the sand dunes at Seaton Sluice noted that, despite the relatively small number of bird species there, two of them, the skylark and the song thrush, were in national decline. Plastic litter was a problem at the site, and paths which criss-crossed through the dunes appeared to be damaging the habitat by exposing sand, which was then wind blown. There were too few information boards and they were in poor condition. The following recommendations were made:

(i) People and dogs should be restricted to certain areas of dunes only, and walkways through the dunes (possibly wooden ones), giving access to the shore, should be provided;
(ii) There was a need for more litterbins and these should be cleared frequently. Information on penalties for littering should be displayed;
(iii) New, attractive information boards should be provided, giving information about the animals and plants that live in the dunes.

Discussion

The results of this study suggest that there are considerable differences in environmental knowledge of different social groups in society. A number of studies have reported disappointingly low levels of public knowledge[12, 13, 14] and this is echoed in the present study in the abilities of people in some groups to name common organisms from colour illustration of them. There are, nevertheless, some groups that have specialist knowledge, and they achieved higher scores. This was not only true of people, such as fishers, nature wardens and ecologists, whose livelihoods bring them into close contact with wildlife but those, such as sea-anglers and ornithologists, whose hobbies give them similar experience. Their knowledge almost certainly goes well beyond the ability to recognise common species. In the case of fishers, for example, it may include knowledge such as the precise locations and timings of spawning aggregations and the migrations of fish[3]. Such knowledge should be treated as a resource and there are increasing numbers of examples in which it has been incorporated into resource management plans or assessments, including planning fisheries cooperatives in Japan[18], fisheries management in Denmark[19]. 'Non-scientific' knowledge of other informed groups in society have similar potential. Opinions of volunteer ornithologists has been used to influence the UK Government's Arable Options of the Countryside Stewardship Scheme through recommendations made in the British Trust for Ornithology's Crops for Wintering Birds project[20]. Similarly, the specialist knowledge of farmers can benefit assessments of the environmental impact of the Environmentally Sensitive Areas Scheme[21] and the development of Local Biodiversity Action Plans[11].

Direct contact with the environment is certainly important because environmental knowledge was related to the experience of groups such as ornithologists and fishers. In addition to their excellent knowledge of land and shore birds, ornithologists had good knowledge of trees. Fishers were more familiar with marine fish than all other groups tested, and they were the only group that had better knowledge of shore birds than garden birds.

The performance of young people in both parts of the study was poor. Firstly, sub-groups of undergraduate students were able to name less than a third of the species shown to them. Secondly, schoolchildren tested had relatively poor knowledge of common birds and there was surprisingly little improvement in knowledge during the period of formal school education. These findings confirm Lock's[22] fears that knowledge of indigenous animals in UK children is poor. He attributes this to deficiencies in the education system. The impacts of this lack of knowledge may be far-reaching. Arcury [13] found that people's attitudes towards the environment were linked to their knowledge of it, and Heslop et al.[15] have pointed out that it is unrealistic to expect people to care for the local environment if they are unaware of the organisms that live in it.

Not surprisingly, there have been repeated calls for improvements of the quality of environmental education in schools to reverse the decline in environmental knowledge[23, 24]. However, there is little evidence that it is succeeding in achieving this goal. There have been few signs of a better-informed public since Holdren and Ehrlich[25] complained of the monumental failure of biological education in influencing the opinions of politicians and industrialists on environmental issues. Schools should not, in any case, be the sole focus of drives to improve environmental knowledge. Evans & Birchenough[1] point out that there is a need for initiatives that involve all groups and ages in society. The bird surveys in the current study evidently achieved this objective, even though it was aimed initially at children. It resulted in increased knowledge of birds in parents as well as in the participating children, presumably because parents assisted their children in the surveys. Evans et al.[7] have shown previously that knowledge gained from children can influence the attitudes of their parents towards re-cycling wastes, suggesting that joint projects may be a beneficial means of transferring information from children to adults.

The management proposals developed by the children who took part in the surveys demonstrate that even young members community groups have the potential to contribute towards local environmental planning and management processes. I believe that recommendations made by the children for management of sand dunes are responsible and mature and, if they were adopted, would benefit bird conservation and biodiversity in the area.

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Fisheries Science and Fishers' Knowledge

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SYNOPSIS

This paper is a study of the relationship between fisheries science and fishers' knowledge, with particular reference to the contested issue of fish stock assessments in contemporary European fisheries. The paper is made up of five sections: in section one, I outline the methodological controversy between scientific ecological knowledge (SEK) and traditional ecological knowledge (TEK); in section two, I examine the credentials of fisheries science; in section three, I examine the credentials of fishers' knowledge; in section four I examine three ways in which the relationship between fisheries science and fishers' knowledge has been conceptualised; and in section five, I conclude that although the antagonism between fisheries science and fishers' knowledge is diminishing, it is for mutual gain rather than out of intellectual conviction.

PART I – METHODOLOGICAL CONTROVERSY BETWEEN SEK AND TEK

In the west, ever since the Enlightenment, a dualist theory of knowledge has prevailed, in which scientific knowledge has been sharply distinguished from non-scientific knowledge. Applying this distinction to ecology, a series of contrasts has been drawn between scientific and practical ecological knowledge. Scientific ecological knowledge (SEK) has been characterised as objective, rational, detached, analytical, reductionist, open, abstract, value-free, mechanistic, neutral, universal, rigorous, quantitative, experimental, and systematic; by contrast to traditional ecological knowledge (TEK) which has been characterised as subjective, intuitive, engaged, synthetical, holistic, closed, concrete, value-laden, spiritual, partial, localised, sketchy, qualitative, empirical and anecdotal[1,2,3].

In such characterisations, SEK is often portrayed as a superior form of knowledge to that of TEK[1]. However, during the last 30 years, there has been an increasing tendency for TEK to be portrayed as a superior form of knowledge to that of SEK, especially in the context of the developing world. As Agrawal[3] explained: "Where 'western'...science, technological might, and institutional models...seem to have failed, local knowledge and technology – reified as 'indigenous' - are often viewed as the...best strategy in the old fight against hunger, poverty and underdevelopment". Moreover, according to its more radical advocates, TEK represents a form of resistance to the 'imperialism' or hegemonic dominance of western science, associated with capitalist exploitation[4].

However, some writers have criticised such dichotomies between scientific knowledge and traditional knowledge. For example, Agrawal[3] rejected the distinction as fundamentally flawed, pointing out that some indigenous knowledge is abstract, while much science is concrete; that indigenous knowledge is often open, while some science is closed (he referred to "the dogmatism and intolerance of science towards insights and methods of inquiry outside established institutionalized science"); and that, like indigenous knowledge, science always operates within a specific context.

Holm[4] also threw doubt on the distinction between SEK and TEK. For one thing, he claimed that western social scientists often reconstituted TEK, by applying western tests of validity to purge it of its obvious errors. For another thing, Holm[4] observed that some of the distinctions drawn between SEK and TEK could equally well be drawn between different disciplines within the western scientific community – in particular, between natural scientists ("hard-nosed number crunching...positivist...the orthodox natural-science types") and social scientists ("soft bellied, story telling, critical humanists...the marginalised social-science types"). Indeed, this is why, argued Holm, western social scientists, especially anthropologists, often champion TEK, because they identify with indigenous communities' marginalisation at the hands of western quantitative science: "the well-meaning and anti-imperialist social scientist becomes one with the savage."

In this section, we have found that there is a deep rooted (if contested) distinction between scientific and traditional conceptions of ecological knowledge; that this distinction is overlaid with perceptions of power struggles between

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dominant and subordinated interests; and that it is also connected to a division between natural scientists and social scientists within western science. As we shall see in the following pages, each of these findings is relevant to the issue of the conflict between fisheries science and fishers' knowledge.

PART II – THE CREDENTIALS OF FISHERIES SCIENCE

Let us now turn from the general issue of ecological knowledge to the special issue of fisheries knowledge. Here the dichotomy is between fisheries science and fishers' knowledge. In Part II, I examine the credentials of fisheries science; in Part III, I examine the credentials of fishers' knowledge; and in Part IV, I examine three attempts to conceptualise the relationship between the two. In each of these analyses, my principal focus is on the issue of fish stock assessments.

So far as commercial fishing is concerned, the main purpose of fisheries science is to estimate fish stock levels, in order to provide management with the necessary data to set total allowable catch (TAC) limits and quotas for particular species. This is because the role of management is to optimalise long term yield by regulating the relationship between fish stock levels and fishing effort. The goal of optimalisation was formularised by Beverton and Holt in 1956, which "represented the pinnacle in the abstract operalisation of fisheries management". All that was needed to apply the Beverton and Holt formula was to estimate the total fish stock, and so, since 1956, "the estimation problem became the core of fisheries science"[5].

However, in the early 1990s, two complicating factors emerged from international bodies such as the North Sea Commission (NSC) and the Food and Agriculture Organisation (FAO) – the precautionary approach (1995) and the ecosystem approach (2000). The precautionary approach requires action to be taken to protect fish stocks even where the evidence of a threat to them is not (yet) conclusive, because if we insist on waiting until there is conclusive proof, it might be too late to save the stock. The precautionary approach brought two new constraints into fisheries science. First, it introduced an 'official' element of uncertainty into stock assessments where previously there had 'officially' been certainty. Second, the precautionary approach entailed a shift from optimalising production to conservation and risk management, and "the most important outcome to be predicted...was accordingly not catch but spawning biomass'[5].

But these adjustments to accommodate the precautionary principle did not fundamentally alter the quantitative foundation of fisheries science. The extent to which fisheries scientists continued to pursue a quantitative path, can be gleaned from the following statement in 2001 by Dr Joe Horwood[6], Chief Fisheries Advisor to the Department of Food, Rural Affairs and Agriculture (DEFRA) at the Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Lowestoft Laboratory: "The mature spawning biomass (SSB) is to be managed above 150,000 tonnes, and not to be allowed to fall below 70,000 tonnes. When the stock is above 150,000 tonnes, a TAC will be set consistent with a fishing mortality rate (F) of 0.65 per year (ie 44% of the stock will be caught each year)".

The ecosystem approach requires scientists to look at fish stocks in the light of the whole marine environment, which considerably complicates their task. ICES has set up a new Advisory Committee on Ecosystems to oversee this task. But, according to Degnbol[5], two different responses to the ecosystem approach are emerging. One response is to try and assimilate the ecosystem approach, like the precautionary approach, within the existing methodology of fisheries science, by "developing models, with new layers of complexity, which include all relevant processes and effects and this enables ecosystem effects to be predicted"[5]. The second response is to abandon the existing methodology of fisheries science, and, ceasing to try to measure fish stocks quantitatively, instead seek to monitor indicators of ecosystem health:

The first response is problematic, because of the inordinate cost of the much more wide-ranging research data that it would require. Indeed, even with unlimited funding, it may be impossible for fisheries scientists to fully understand marine ecosystems, because of their intrinsically unpredictable and chaotic nature. The second response requires much less funding, because it would involve the use of indicators – by means of regular quality status reports - to measure the pressure of fisheries on the ecosystem. Some progress has already been made in fashioning such indicators, for example by the UN Commission on Sustainable Development (UNCSD) in 2001; the Organisation for Economic Cooperation and Development (OECD) in 1993; the Marine Stewardship Council (MSC) in 1998; the US National Marine Fisheries Service (NMFS) in 1999; and the FAO in 1997.

In this section, we have shown how fisheries science sets about assessing fish stocks; how it has assimilated the precautionary approach; but how it faces difficulties in adapting to the ecosystem approach. In the next section, we examine the case for an alternative source of knowledge of fisheries – that supplied by fishers rather than scientists.

PART III – THE CREDENTIALS OF FISHERS' KNOWLEDGE

Analysis of the credentials of fishers' knowledge is partly negative and partly positive. The negative part consists in exposing the shortcomings of fisheries science. The positive part consists in demonstrating the value of fishers' knowledge. Let us begin with the negative part. Criticisms of fisheries science come from both inside and outside the ranks of fisheries scientists. From inside the scientists' ranks, a telling critique was published anonymously in *Fishing*

News in February 2001, written by "a former fisheries scientist with many years of stock assessment". This ex-fisheries scientist first explained the five sources of data used by fisheries scientists:

1) "Information on the catches of the various species by the various countries"
2) "Information on the amount of fishing effort expended by the fishing fleets"
3) "Information on the age composition of the catches"
4) "An estimate of the amount of fish discarded by the vessels involved in the various fisheries"
5) "An estimate of the size of the recruit year classes"

(*Fishing News* 23/2/01: 7).

Then he showed how fragile some of this data is. For example, on (1), catch data, and (4), discard data, he pointed out that this data is collected from fishers, but fishers "are not obliged to allow scientists access to their catches or to take them to sea to estimate discards. Fishermen have it in their power to deny scientists the data they require to set quotas" (*Fishing News* 23/2/01: 7). The implication, that scientists cannot rely on the accuracy of the data they receive on either catches or discards, was drawn by Gerard Biais, a fisheries scientist from L'Institut Francais de Recherche pour L'Exploration de la Mer (IFREMER), who attributed what he described as "the lack of accuracy of predicted changes in fishing mortality in catch forecasts" at least in part to unquantified discards and misreporting/underreporting of catches[7].

On (3), age composition of the catches, the anonymous ex-fisheries scientist claimed that in the UK, the rate of sampling to determine the age composition is woefully below the ICES guidelines of one sample per 200 tonnes of each fish species landed, while in other countries, the situation is worse – "throughout the EU...other major fishing nations do little or no sampling of their catches" (*Fishing News* 23/2/01: 7). On (2), fishing effort, he argued that even less is known: "fisheries scientists know absolutely nothing at all about fishing effort. They know nothing about how the effort of a pair trawler compares with that of a single boat trawler; how twin rig effort compares with seine netting; and how the effort of one country's vessels compares with that of others" (*Fishing News* 23/2/01: 7). Finally, with regard to (5), the size of the recruit year classes, he pointed out that because fish stocks are still assessed separately, "the effect of changes in one stock is not reflected in changes in others...Fishery scientists continue not to factor this information into the calculations...The fact that they don't factor in for species interactions in the calculations is a fundamental flaw" (*Fishing News* 23/2/01: 7, 5).

The anonymous ex-fisheries scientist made three additional critical observations. First, he criticised fisheries scientists for failing to publish the error factor in their calculations: "The fact that they never give an estimate for the error would lead one to believe that it is so large that the estimate is more or less meaningless" (*Fishing News* 23/2/01: 7). Second, he claimed that the system of peer review is not used for fish stock assessments, thereby casting doubt on their reliability. This criticism was echoed by Ad Corten[8], an ICES fisheries scientist employed by the Netherlands Institute of Fisheries Research (RIVO), who argued that there was a strong element of collective solidarity at the working group meetings, closing ranks against contentiousness: "Openly questioning the reliability of someone else's data would spoil the spirit of comradeship on which the functioning of the working group depends". Third, the ex-fisheries scientist claimed that scientists from EU member states are not always independent, but are "often briefed by their governments and have a political agenda". As a result, he claimed, "Stock assessment is not science, it's simply a very flawed statistical exercise...The whole thing is political" (*Fishing News* 23/2/01: 5).

So much for criticism of fisheries science from within the ranks of fisheries scientists. Let us now turn to criticism of fisheries science from outside the ranks of fisheries scientists, where we find two sources of criticism – from social scientists, and from fishers. Social scientists question the methodology of fisheries science. Acheson and Wilson[9], for example, criticised what they call the methodology of 'numerical management' employed by fisheries scientists, which focuses exclusively on fish stock levels, and sees a linear relation between the extent of fishing effort and the level of stocks. They argued that no such linear relationship has yet been proven: "There have been cases where large year-classes of fish came out of small parent stocks. In other cases, increases in effort have apparently had little effect on recruitment, as in the Maine lobster fishery"[9].

Fishers have also criticised the methodology used by fisheries scientists. First, they have questioned research surveys which trawled the same strips of the sea year after year, ignoring the fact that fish stocks may have moved somewhere else. Skipper John Buchan from Peterhead expressed this complaint in August 2001: "Bearing in mind that the UK marks the southern extremity in which cod are known to inhabit, the slightest change in salinity level or water temperature could result in a small but very significant northward movement of stocks. If scientists return to the same areas in the southern sections of the North Sea for their samples, this trend might not be detectable" (*Fishing News* 17/8/01: 1).

The second methodological charge made by fishers is that the data on which fisheries scientists work is invariably "at least two years out of date". This charge was made by Irish FPO leaders who complained about the scientific case for the continuation of the Irish Sea cod closure in 2001: "According to FPO bosses, the science for the Irish Sea was outdated and had taken no account of the two years of measures aimed at improving the mixed fisheries" (*Fishing News* 9/11/01: 15). The third methodological charge is more basic – that even if the methods and the data were improved, the scientists would still be unable to deliver reliable advice on stock levels, because the marine ecosystem is too complicated to be fully understood (as Degnbol[5] pointed out above). Among these complications are environmental factors, which fisheries scientists are frequently accused of ignoring, because fishers are easier targets.

But fishers' animus against fisheries scientists more often takes the form of disputing their assessment of particular stock levels. For example, in February 2002, Frank O'Doyle (General Secretary of the Irish Fishermen's Organisation) described the assessment of Irish salmon stocks as "highly inaccurate", and the proposed quotas as "a shot in the dark" (*Fishing News* 8/2/02:4). Similarly, many British fishers voiced their anger in 2002 at the scientists' assessments of cod stocks around the UK. For instance, Nathan de Rozarieux (Chief Executive of the Cornish FPO) demanded an in-year increase in the cod quota, because of the abundance of cod in the southwest: "the scientists must look at the English Channel and the Bristol Channel cod stock figures again. If the scientists and officials speak to our fishermen and join them on the boats they will see that there is plenty of cod" (*Fishing News* 15/3/02: 16). Jim Portus (Chief Executive of the South West FPO) reported that his members' beam trawlers were catching 'unprecedented" amounts of cod as a by-catch (*Fishing News* 17/5/02: 3).

Having completed our account of the negative side of the credentials of fishers' knowledge - the perceived shortcomings of fisheries science – we must now turn to the positive side of the case – a demonstration of the value of fishers' knowledge. The main point to be made here is that if fisheries science cannot in itself encompass all the chaotic parameters of a dynamic marine ecosystem, fishers' knowledge could provide an alternative source of understanding. Palsson[1] argued along these lines: "Given the level of uncertainty and the limits of scientific ecological knowledge, it is reasonable to try to draw upon the knowledge of those who are directly involved in resource use on a daily basis. After all, they are the ones who are likely to have the most reliable information as to what goes on in the system at any particular point in time". Similarly, Degnbol[5] recommended the use of fishers as monitors of eco-system health – ie to "identify indicators of pressures on the fisheries reserves, which reflect the perspectives of users while having scientific validity".

However, Hamish Morrison (Chief Executive of the Scottish Fishermen's Federation (SFF)) expressed reservations about an ecosystem approach to fisheries management, fearing that it could place the whole burden of maintaining the health of the marine environment on the shoulders of fishers, though he added that if and when an ecosystem approach is implemented, fishers' knowledge must be used in it: "it is essential that an effective and durable policy concerning the marine ecosystem must be informed by fishermens' practical experience. Only fishermen spend all of their working lives in the marine environment. For all practical purposes, fishermen are themselves a part of the marine ecosystem" (*Fishing News* 24/5/02: 2).

To conclude, in this section of the paper, we have examined many of the criticisms that have been levelled by various stakeholders at fisheries science, particularly in its focus on fish stock assessments, and we have also examined several arguments purporting to show the value of fishers' knowledge. What remains to be done is to examine the attempts that have been made to conceptualise the relationship between fisheries science and fishers' knowledge.

PART IV – THREE MODES OF CONCEPTUALISING THE RELATIONSHIP BETWEEN FISHERIES SCIENCE AND FISHERS' KNOWLEDGE

There are three ways in which the relationship between fisheries science and fishers' knowledge has been conceptualised: political hierarchy; epistemological synthesis; and social integration.

a) Political Hierarchy

Political hierarchy is a conceptualisation of the relationship between fisheries science and fishers' knowledge in which one of them is acknowledged to be superior to the other. Generally speaking (at any rate in the west), fisheries science is acknowledged to be superior to fishers' knowledge, though occasionally it is the other way round. The reason why this is so is because of the high prestige of science compared with practical experience. Policy makers will only command respect if they have science on their side. As Healey[10] put it, "in present-day Canadian fisheries management, the policy decisions of the minister must be backed up by scientific evidence if they are to carry any weight of authority."

Note that this situation has nothing to do with whether fisheries scientists are *actually* closer to the truth of fish stock assessments than are fishers. What matters is the public's *perception* that it is more rational to found fishing policy on a scientific, rather than a non-scientific, basis. In fisheries policy, as in most other policy areas, there has to be a point of closure – ie. a final decision has to be made – and investing authority in fisheries science is a more acceptable means of bringing about closure than would a system of investing authority in fishers' knowledge. Scientific knowledge can be presented in a coherent, definitive and comprehensive form, whereas fishers' knowledge is invariably anecdotal, sketchy, and fragmented. So it makes obvious administrative sense for fisheries managers to adopt scientific data rather than non-scientific data as their baseline.

Moreover, this hegemonic dominance of fisheries science is often endorsed even by fishers themselves. First, many disputes between fishers and scientists are essentially over the respective merits of different scientific assessments rather than conflicts between fisheries science and fishers' knowledge. For instance, in April 2002, Spanish fishers claimed that scientific assessments of the Gran Sol hake fishery undertaken by a Spanish research vessel, showed a much healthier stock than did ICES survey evidence (*Fishing News* 26/4/02; 6). In other words, the Spanish fishers, far from challenging fisheries science, were positively endorsing it.

Second, fishers often call for better, rather than less, fisheries science. For instance, Jim Portus argued that the problem with multiannual quotas was that "scientists had to be given the tools and funding to provide accurate data...the true 'science' isn't there yet" (*Fishing News* 7/6/02: 3). Similarly, the comment made by Alan McCulla (Chief Executive of Anglo North Irish FPO) on the CFP reform proposals – that "any further measures would need to be based on stronger science than that underpinning the highly controversial quota system" (*Fishing News* 14/6/02: 19) – implies that 'strong' science is acceptable.

Third, fishers frequently appeal to fisheries science to support their claims against what they see to be politically motivated regulators. For instance, Alex Smith (President of the SFF), expressing his outrage in December 2001 at the European Commission's proposals to cut prawn quotas on the west coast of Scotland and the North Sea, stated that "Fischler [Franz Fischler is the EU Fisheries Commissioner] says that the proposals are based on scientific advice, but that is just nonsense – the scientific advice was that both North Sea and west coast prawns are healthy, and they in fact recommended an increase in the North Sea TAC" (*Fishing News* 14/12/01: 16). Hugh Allen (Secretary of the Mallaig and North West Fishermen's Association) said that the Commission's proposed 25% cut in the prawn TAC, had "turned the science on its head...The Commission continually tells us that management must be based on the scientific advice, but they have completely rejected the advice...The fact is that the science is good for the prawns" (*Fishing News* 14/12/01: 16). Similarly, the Scottish White Fish Producers' Association (SWFPA) accused the Commission of playing fast and loose with fisheries science: "either scientific advice is listened to and implemented or it is not used at all...it certainly should not be used when the Commission feels so inclined and otherwise ignored" (*Fishing News* 14/12/01:16).

The European Commission's decision to allocate TACs to deepwater species aroused even more anger among Scottish fishers. In a letter to Franz Fischler, George MacRae (Secretary of the SWFPA) said that "There is no credible scientific advice which would justify a TAC system for the deepwater fishery being set in place." The agreement to divide the TACs up was, he argued, founded on "raw, crude, political expediency" (*Fishing News* 28/6/02: 3). The SFF attacked the Fisheries Council for "casual disregard for the ecological risks described in the scientific advice", and it denounced the Commission for "'cynicism and hypocrisy of the worst kind', by rejecting scientific advice which has all recommended effort control rather than catch limits" (*Fishing News* 12/7/02: 2).

Summing up the first conceptualisation of the relationship between fisheries science and fishers' knowledge – that of political hierarchy - we have found that it entails a general acceptance that scientific evidence is trumps. Recognition of the sovereign place of fisheries science is widespread, embraced not only by scientists and officials, but also by many (most?) fishers themselves, although on occasion some fishers have been driven to assert the superiority of fishers' knowledge, as we saw in Part II. However, it is essentially a *political* hierarchy, not an *epistemological* hierarchy. That is to say, fisheries science is accepted by most stakeholders as superior in weight, less because it is 'true', than because it carries a higher status than fishers' knowledge, and thereby it facilitates closure of debate and an orderly decision making process. In this sense, it could be said that the real sovereign is not science but politics – science is used as a pawn by all sides in the power game of fisheries politics. This is a point made by Dr Adriaan Rijnsdorp, a Dutch fisheries scientist from the Netherlands Institute for Fisheries Research (RIVO), when he attacked the European Commission's policy on the North Sea cod closure. Rheinsdorp "criticised the policy decision making process in Brussels where 'political expediency' rather than science dictated the process. 'It appears that the policy comes first and then they try to justify this by reference to science, rather than the other way round'" (*Fishing News* 2/11/01: 2).

Let us now turn to the second conceptualisation – epistemological synthesis - where we might expect to find a more unalloyed pursuit of the 'truth'.

b) Epistemological Synthesis

The second way in which the relationship between fisheries science and fishers' knowledge has been conceptualised is epistemological synthesis. This entails the blending together of the two forms of information to produce a better overall understanding of fish stocks. The main spur to such a conceptualisation has come from the recent emphasis on the ecosystem principle. According to Bundy[11], "It is now being recognised that, given the huge gaps in 'formal knowledge', we have to look to other forms of knowledge to complement the scientific approach...One form of other knowledge...is associated with small-scale fishermen who have spent many years on the water, fishing and observing at close hand...There is a huge potential source of knowledge that resides within fishing communities". Palsson[1], too, extolled the value of this epistemological synthesis, arguing that "Science and practical knowledge should be seen as complementary and interactive sources of wisdom, not mutually exclusive".

In the UK government's response to the EU Commission's Green Paper on CFP reform, explicit endorsement is given to the need to incorporate fisher's knowledge into ICES advice: "The UK believes there is great scope for improvement in the quality of advice coming from ICES and for greater inclusion of fishermen's experience and expertise" (*Fishing News* 5/10/01: 6). The Scottish Fishermen's Federation (SFF) provided a very good example of fishers' knowledge already being supplied to ICES for 'incorporation' into the scientific modelling of stock assessment: "the SFF is asking its skipper members to provide information on four aspects of stocks; abundance, size, size range and geographical distribution. SFF chief executive Hamish Morrison said the deadline was tight and the scientists needed the information by 17 September so that it could be coordinated into the process" (*Fishing News* 31/8/01: 2).

One of the most systematic attempts to achieve a synthesis of fisheries science and fisher's knowledge was described in 1999 by marine scientist Rejeanne Camirand (employed at the Maurice-Lamontagne Institute, Department of Fisheries and Oceans, Mont-Joli, Quebec). Camirand[12] dubbed it an "ethno-science approach", employed to "harness and analyse" the fishers' knowledge of the lobster fishery of Magdalen Islands in Quebec in 1995-1997: "The principal objectives were to build a data base of information provided by lobster fishers, to make this information available to biologists and to evaluate the possibility of integrating this type of knowledge to stock status assessments".

However, such 'syntheses' may be one-sided. For example, in the case of the Magdalen Islands lobster fishery, the fishers' knowledge had to be processed ("in a Microsoft Access database") in a disaggregated format acceptable to the fisheries scientists ("classified into 220 variables"); who made use of it in *their* stock calculations ("the biologists...then used the data in the assessment of the lobster stock status"); which enabled them to finesse *their* opinions ("helping us to refine our interpretations"); giving added weight to *their* conclusions ("increased the credibility of the scientific findings"); and making *their* policy recommendations acceptable to fishers ("contributed to the success of...stronger conservation measures to which fishers were very receptive")[12]. Moreover, it is claimed that such a synthesis devalues fishers' knowledge, by forcing it into an alien straitjacket. Palsson[1] has argued along these lines, asserting that fishers' knowledge is fluid and intuitive, and therefore very difficult to pin down and put into boxes. By trying to make it user-friendly for scientists, we also perpetuate its inferiority[1].

We must now turn to the third and final conceptualisation of the relationship between fisheries science and fishers' knowledge – social integration – where we find the emphasis lies in reconciling the two different modes of understanding through various kinds of social interaction between the two contesting parties.

c) Social Integration

In the third conceptualisation, the focus is on the way in which social interaction between scientists and fishers breaks down barriers and elicits common ground. Such social integration takes two forms: dialogue; and teamwork.

Dialogue occurs when fisheries scientists and fishers meet to discuss issues of mutual interest. Sometimes these meetings are organised as briefings in which scientists explain to fishers the reasons behind their stock assessments for the following year. For example, in October 2001, ICES scientists briefed the SFF at the Fisheries Research Services (FRS) Marine Laboratory in Aberdeen, and scientists from the CEFAS laboratory in Lowestoft briefed the NFFO, on the ACFM fish stock assessments for 2002. At other times, the meetings are interpreted as opportunities for fishers to brief scientists. For instance, Barrie Deas (Chief Executive of the National Federation of Fishermen's Organisations (NFFO)) took this view of a meeting held in May 2002 between CEFAS scientists and the NFFO executive (*Fishing News* 24/5/02: 4).

But for the most part, dialogic meetings are intended to be genuinely two-way processes. This was certainly the case with the meeting at the ICES headquarters in Copenhagen organised in August 2002 by the North Sea Commission Fisheries Partnership (NSCFP). This meeting was attended by ICES scientists, industry representatives, and a team of independent scientists from North America. On the one hand, the ICES scientists were questioned on their preliminary assessments of cod, plaice and saithe stocks in the North Sea by both fishers and independent scientists, while on the other hand, discussion took place on "ways of bringing the knowledge and experience of the fishing industry into the stock assessment process and making the procedure even more open and transparent" (*Fishing News* 6/9/02: 1). Those who participated in this meeting confirmed its two-way character. For instance, David Griffith (General Secretary of ICES) said that "Fishers and scientists can and must speak openly to each other, and listen carefully to one another. Both parties can (and did) learn a lot from each other, and the meeting was extremely valuable to the ICES assessment proces" (*Fishing News* 6/9/02: 1).

This may be the model for one of the European Commission's proposals in its recent CFP review - to set up Regional Advisory Councils (RACs), which have been described by Franz Fischler as ideal fora for co-operation between scientists and fishermen (*Fishing News* 12/7/02: 15). It seems clear, however, that the Commission did not intend these RACs to go much beyond being 'talking shops', in that it explicitly stated that "The Commission and Member States will not be bound by the recommendations, opinions or reports of the Regional Advisory Councils"[13]. Fischler tried to put a reassuring spin on the Commission's statement, by declaring that "If the committees are able to agree on something and give clear, common advice, then I don't see how the Commission could reject such advice." However, he added that the Commission would need "clear evidence" that the advice would not encourage unsustainable fishing (*Fishing News* 14/6/02: 1).

The second form of social integration between fisheries scientists and fishers is teamwork – ie working together on the stock assessments. A good example of such teamwork comes from the Canadian Department of Fisheries and Oceans (DFO): "A multidisciplinary teamwork approach is basic to the DFO stock assessments. Data are analysed by teams with members drawn from DFO and outside. Stock assessments are reviewed in meetings of scientists and fishers. These meetings include university-based scientists and fishers knowledgeable of the stocks. These participants from outside DFO see all of the data analyses and results. Once discussion is complete, stock status reports are completed, reflecting the results of the peer review...Stock status reports receive final editing at the Canadian Stock Assessment Secretariat"[14].

However, critics of the DFO system have claimed that the extent of genuine social integration in it is severely limited. For instance, Hutchings et al[15] have pointed out that fishers and other non-scientists are effectively marginalised by the 'insiders': "the integration of outsiders in the assessment is not nearly as complete as Doubleday et al imply. First, assessment documents are not written in a form readily accessible to non-scientists. Second, in Atlantic Canada, involvement of non-DFO scientists can range from a full review of assessment documents received prior to assessment meetings (a good practice) to a simple response to general open invitations to attend meetings and provide comment (a considerable less effective practice)...[Third] involvement by non-DFO employees in actual stock assessment data analysis, ie running and tuning Virtual Population Analysis (VPAs), is rare, if it occurs at all. Thus, in practice, the production of, and the ability to comprehensively review, stock assessment documents remains a DFO 'in house' affair in many important respects".

Summing up this section, we have found that of the three ways in which the relationship between fisheries science and fishers' knowledge has been conceptualised, the first, political hierarchy, entails that fisheries science is trumps, but often for political rather than intellectual reasons; the second, epistemological synthesis, implies that fisheries science and fishers' knowledge can be fused to provide a closer approximation to the 'truth' about fish stocks, but invariably turns out to be an alienating takeover of fishers' knowledge by a domineering fisheries science; and the third, social integration, entails that interaction between fisheries scientists and fishers will uncover the common ground that unites them, but frequently ends up as talking shops in which fishers are marginalised.

PART V – CONCLUSION

It is clear from this analysis of fisheries science and fishers' knowledge that much of the antagonism between them remains, reflecting a deeper conflict between scientific ecological knowledge and traditional ecological knowledge. However, there are signs that this antagonism is diminishing, as both fisheries scientists and fishers recognise the value of co-operation. Fisheries scientists are increasingly seeing that by working more closely with fishers, they may be able to obtain more extensive and more reliable data from them. For their part, fishers are increasingly seeing that by working more closely with fisheries scientists, they may be able to influence the scientific advice that is sent to fisheries managers. In other words, there is potentially a win-win situation in closer relationships between fisheries scientists and fishers. However, such collaboration, when it does occur, is less a meeting of minds, than a mutual exchange of benefits.

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Fishers' participation in the management of North Sea fisheries

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SYNOPSIS

If fisheries are managed carefully and with regard for the future, the sea can provide a sustainable source of fish. However, all too often the sea is over-fished. There is too great an investment in catching and processing facilities, resulting in a decline in the fish stocks.

In the North Sea, fisheries are managed through the Common Fisheries Policy (CFP). The objectives of this policy were contradictory from the very beginning. A complex, bureaucratic and expensive system of management has been put in place which has failed to prevent an expansion in fishing capacity and failed to protect the fish stocks. Many stocks are now exploited outside safe biological limits and if current trends continue some of them will collapse.

One of the main causes of failure has been a reluctance to seek advice by those managing the fisheries. There has been a lack of economic analysis and especially an unwillingness to evaluate the costs and benefits of different management measures. Strong reliance has been placed on a narrow scientific approach, which has neglected interactions between species in the mixed fisheries of the North Sea. Heavy political control has been exerted over management, and technical advice has often been ignored.

Perhaps the key omission from the CFP has been the lack of any involvement of stakeholders and especially fishers themselves. Fishers are in close contact with the resource, and have an unequalled knowledge of conditions on the fishing grounds and the strengths and weaknesses of different management measures. However, because they have not been involved in management decisions, and have seen them imposed from above, they have often not complied with them.

Reforms are being proposed for the CFP. However, more of the same is promised, with the imposition of stronger control measures and a tightening up of surveillance and enforcement. Though reference has been made to the need for transparency and stakeholder involvement the only positive recommendation in this regard is for the establishment of Regional Advisory Councils. Control will remain with the Council of Ministers and the European Commission.

The North Sea Commission Fisheries Partnership brings scientists and fishers together from around the North Sea to consider the state of the fish stocks and to discuss effective control measures. Established in 2000, the Partnership has already made great progress in involving fishers in the process of stock assessment. In the absence of any initiatives from the European Commission to involve fishers directly in management, the setting up of regional partnerships between interested stakeholders may be the only way of achieving improvements in the way fisheries are managed.

INTRODUCTION

The sea is an important source of food, and one which is sustainable. Fish stocks can renew themselves if the fish are allowed to mature, spawn and produce young in sufficient numbers. Sensible management, with the co-operation of fishers themselves, can reduce the impact of fishing and ensure that the resource will last.

Nevertheless, fisheries often over-exploit the fish stocks on which they depend. Fish are free-living and mobile. They cannot be claimed as property by any individual fisher or community until they are caught. With free access to fish then the number of fishers increases, catching technology and efficiency improves and a race for fish develops. Fish are then removed at a rate faster than they can reproduce themselves.

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Unregulated fishing usually results in over-investment in both vessels and processing facilities. Costs rise rapidly but are underpinned by a shrinking biological resource. Governments are tempted to provide subsidies which encourage even heavier exploitation of the fish stocks. Unless strict controls are imposed upon fishing, the result is a decline in both the fish stocks and the fishing industry.

Fishing also has an effect upon the wider ecosystem. Trawling and dredging may degrade habitats and destroy vulnerable flora and fauna. The removal of fish and other organisms, both deliberately and inadvertently (as a by-catch), affects their abundance and the diversity of the ecosystem. Fishing may particularly affect charismatic fauna such as seabirds, seals and cetaceans, provoking strong public protest. There may be pressure to curb fisheries because of environmental concerns.

It has become commonplace for governments and international agencies to intervene in fisheries and place strong controls upon the harvesting of fish. Output controls are imposed to regulate the species, quantities and sizes of fish landed. Input controls are introduced to restrict access to the fishery and limit fishing effort. Regulations are put in place to reduce the capture of young fish. These measures demand a heavy investment by governments in collecting information on the state of fish stocks, agreeing control measures, and then policing the regulations introduced. There are particular problems in gaining agreement to the controls and ensuring fairness in their application, especially where several nations exploit the same fish stocks.

This paper looks at the current system for managing the shared fisheries of the North Sea. It suggests that these fisheries will only be sustainable if fishers and other stakeholders play a stronger and more co-operative role in their management.

THE EUROPEAN COMMON FISHERIES POLICY

Many fisheries within the eastern North Atlantic, the Baltic and the Mediterranean fall within the jurisdiction of the European Community and are governed by the Common Fisheries Policy (CFP). This has the following broad objectives:

- to increase productivity by promoting technical progress,
- to ensure a fair standard of living for the fishing community,
- to stabilise markets,
- to assure the availability of supplies,
- and to ensure that there is no discrimination between fishers from different member states.

Environmental protection must also be integrated into all Community policies. There is an obligation to protect and conserve living marine aquatic resources and to provide for their rational and responsible exploitation.

The CFP starts from the premise that Community waters are open to all member states. However, one anomaly is that the policy currently limits access to the coastal waters around each state, and excludes new member states from waters they have not traditionally fished. Each member state carries responsibility for managing fisheries in inshore waters.

From the start, it was evident that the objectives of the CFP were incompatible or contradictory. Thus, the CFP aims to:

conserve fish stocks,
but promotes greater fishing activity

modernise the fleet,
but limits fishing effort

implement conservation measures centrally,
but requires member states to enforce them locally

maintain employment,
but reduces fleet capacity

ensure a good income for fishers,
when the supply of fish is declining

prohibit discrimination,
but discriminates on access to fishing.

The economic objectives of the policy have been especially contentious. Apart from the aim of ensuring a fair standard of living for the fishing community there has been no explicit standard set for economic performance. The economic and social strategies for the fishing industry have remained the responsibility of member states, which have pursued different and conflicting approaches. In some member states, subsidies for the building or modernisation of fishing vessels and the removal of taxes have provided significant advantages for fishers. Differences in national policies have resulted in subsidised and non-subsidised vessels fishing alongside one another, on the same grounds, sharing the same markets.

FISHERIES MANAGEMENT UNDER THE CFP

Under the CFP management takes place from the very top. The key decisions are taken by a Council of Ministers from the member states of the Community. Thereafter, the implementation of the CFP rests with the European Commission in Brussels through the issue of regulations which should be observed and implemented by member states. Under the policy, a complex, centralised and bureaucratic system of fisheries management has developed, but has not always been observed by all the states involved.

In the waters of the North Sea (including the eastern English Channel and the Skaggerak) exploitation of the fish resources must be shared between Belgium, Denmark, France, Germany, The Netherlands, Sweden, and the United Kingdom (member states of the European Community) and Norway (which is outside the Community). A license to fish is issued to each fishing vessel and restrictions are placed on fishing power. Effectively, these measures restrict access to the resource and control fishing capacity. However, fish stock conservation and allocation of the resource is mainly achieved through a system of output controls or Total Allowable Catches (TACs). The TACs are then supplemented by technical conservation measures which protect young fish. The latter include minimum mesh sizes, minimum landing sizes and the closure of areas to fishing. The system of TACs is very important as it provides the means to allocate resources between member states and between the Community and Norway. The TACs are determined on the basis of independent scientific advice provided by the International Council for Exploration of the Sea (ICES).

The procedures for collecting scientific data are co-ordinated across countries. Fish landings are monitored and the sizes and ages of fish examined at fishing ports. Research vessels measure the abundance of young fish and spawners. Sampling takes place on board commercial fishing vessels to determine what is caught but discarded at sea. The same scientific rigour cannot be applied to all stocks. Inevitably for some the availability of data falls short of what is required for a full assessment. For such stocks the TACs may be set to correspond to earlier catches, simply as a precautionary measure. Moreover, even for those stocks for which scientific data are available there are difficulties with the analyses which are applied. Often, the fish stocks, cod, haddock, whiting, saithe, plaice and sole, are treated separately. Yet it is known that they interact with one another. Many different species are caught by the same fishing gears, and it is impossible to fish upon one species without affecting others. In the mixed fisheries of the North Sea there are inevitably scientific uncertainties about the state of the different stocks, and doubts about the measures which might best protect them.

Essentially, the fishery scientists set out to define limit and reference points for each fish stock. Limits are set for both spawning stock biomass (SSB, the total mass of spawning adult fish) and fishing mortality (F, the rate at which fish are removed by fishing). A harvest control rule is then applied, where safe biological limits for sustainability are defined by setting a minimum SSB and a maximum F. The choice of fishing mortality and the TAC then set should depend on the size of the SSB. Such a harvest control rule attempts to limit political influences upon management. Rather than simply specify the status of the stocks, the advice from ICES is given in terms of a number of management options. These are forwarded through the European Commission, advised by its Scientific, Technical and Economic Committee on Fisheries (STECF), to the Council of Ministers of the Community. The Council takes account of broader social and political considerations, and the views of third party states like Norway, in setting annual TACs for individual species. These TACs are then allocated as quotas to member states through the principle of Relative Stability, which divides them up through an agreed formula. The allocation of the quotas to fishers themselves may then be passed on to fishers' organisations. Within member states there is scope for the imposition of additional controls, provided these are compatible with the CFP.

Recently, in the eastern North Atlantic, the European Commission has developed a strategy of imposing recovery plans for stocks it considers to be threatened. Intensive measures are imposed, to be followed by more minor adjustments. There is a wish to move towards measures which will be stable over several years, avoiding the sudden cuts in TACs and the imposition of additional technical measures which has characterised recent management. There is current concern over North Sea cod, which has already resulted in strong reductions in TACs and the seasonal closure of large areas to protect spawning fish. There are also plans to greatly reduce fishing effort in the near future.

The whole system for assessing the state of the fish stocks, rendering scientific advice, taking management decisions, and then enforcing the controls is expensive in relation to the size and importance of the industry. It is also a closed system. Fishers, fish buyers and processors, consumers of fish, and environmental interests are excluded. At the December Council Meeting, at which the main management decisions are made, fishermen gather at the entrance of the Commission building to lobby their national representatives. There is no opportunity for them to play a more direct role.

THE OUTCOME OF THE COMMON FISHERIES POLICY

The CFP has achieved some important successes. Systems have been put in place for sharing the fish resources between member states and between fishing fleets. The concept of Relative Stability allows the allocation of fixed percentage shares in the resource to member states on the basis of historical fishing patterns. Within the CFP procedures have also been developed for policing catches and landings, for restructuring fleets, for marketing fish and for maintaining employment within fishing communities. Urban and rural regions dependent on fishing have been targeted for better economic and social cohesion. A framework of international agreements has been put in place to protect EU interests in third country and international waters and to negotiate new fishing opportunities and promote joint ventures. Overall, the policy has provided a basis for political compromise to take place. This is both its main strength and its main weakness.

Since the beginning there has been strong and consistent criticism of the CFP. All too often, the management measures selected and implemented by the Commission have been chosen for the wrong reasons. High and unsustainable TACs have been allocated to appease fishers. Technical measures of doubtful efficacy which are difficult to enforce have been imposed to avoid facing up to the need to reduce fishing mortality substantially and permanently. At present, ICES scientists come forward late in the year with a series of catch recommendations, prompting almost immediate decisions on catch measures, which are taken behind closed doors. Fishers are allocated their quotas just before each fishing year begins and are unable to plan in advance. These deficiencies have led to a heavy decline in almost all fish stocks.

In a Green Paper on the future of the CFP (Ref.1), the European Commission has admitted the shortcomings of the policy and argued for its reform. In a frank analysis the Commission has agreed that the policy has not delivered the sustainable exploitation of fish resources and will need to be changed if it is to do so. The Commission accepts that many fish stocks are exploited outside safe biological limits and if current trends continue some of them will collapse. It realises that the fishing capacity of the Community fleets far exceeds that required to harvest fish in a sustainable way. It acknowledges that the current position has resulted, to a large extent, from the Council of Ministers allocating annual catches in excess of those proposed by the Commission on the basis of scientific advice. It also accepts that fleet management plans have been short of those required. The Commission goes on to underline the resultant economic fragility of the fishing industry, resulting from over-investment, rapidly rising costs, and a shrinking resource, reflected in poor profitability for the industry and steadily declining employment in fishing communities.

WEAKNESSES IN THE COMMON FISHERIES POLICY

One of the principal causes of failure has been the weakness in information and advice presented to the fishery managers. The Commission has identified a lack of analysis of economic aspects of management measures, poor knowledge of the interactions between species in the mixed fisheries of areas like the North Sea, and a lack of understanding of the relationship between fishing effort and fishing mortality and hence the setting of the appropriate TAC. In part, this problem of inadequate knowledge and advice has resulted from the Commission's own lack of expertise. It has been obliged to seek information on management measures from experts within member states which may have particular points of view. For setting limits upon fishing reliance has been placed upon ICES, a long-established, intergovernmental scientific organisation, which is independent but which must restrict its advice to narrow scientific concerns over the state of fish stocks. ICES cannot provide sound advice on the management of the fisheries themselves, as it operates without economic expertise and without extensive consultation with fishers. In introducing some management measures the Commission does not seem to have taken any independent advice on their likely benefits in terms of conservation or their costs to fishers. In future advice must be drawn from a wider knowledge base, and must involve cost/benefit analysis of the options and be followed by evaluation of the outcome.

A particular example of the Commission acting on poor advice was the imposition of seasonal closure of cod spawning areas in the North Sea in the spring of 2001. The selection of these areas and the timing of the closures were inappropriate. Moreover, the displacement of fishers to other grounds created problems for other species, with heavy discarding of species like haddock but without any reduction in the capture of cod. Fishers pointed out that to be successful in conserving cod the area closures had to be accompanied by a reduction in fishing effort. They were right, but their comments were ignored.

The Commission believes it has relied too heavily on output controls, in the form of TACs, and the establishment of measures such as mesh sizes, closed areas and closed seasons, rather than input controls which limit fishing effort. The setting of TACs, which are passed on to fishers as individual quotas has a number of disadvantages, especially for mixed fisheries where several species are being caught. Chief amongst these is the problem of discarding. If a quota for one species has already been landed, while quotas for others remain open, then fishers have to discard the first species over the side of the fishing vessel if they are to carry on fishing. The discarded fish will have been injured and will almost certainly die. Fishing mortality has occurred but may not be recorded. The only other option available to fishers in these circumstances is to land fish illegally – as so-called 'black fish'. These catches go unrecorded. Discarding may also take place where the fish which are caught are below the minimum landing size. This is especially likely to take place in a mixed fishery, where the mesh size of the net may have been set to retain adults of one species, but which will also retain juveniles of a larger species. The consequence is further mortality of fish which may go unrecorded. Where the catch is significantly larger than the actual monitored landings then it is important that the difference is known. The recording of discards and unreported catches can only be achieved with the full cooperation of fishers.

The Commission has acknowledged that the current fleet in the North Sea is much too large. Technological progress is continually improving fishing efficiency. Modern fishing boats are more powerful, handle bigger, more efficient fishing gears and are better equipped with fish-finding equipment than their forerunners. The capacity of the fleet to catch fish is growing. The Commission addressed the problem of excess capacity through its Multi-Annual Guidance Programme (MAGP).This attempted to measure fishing capacity of vessels through their tonnage and engine power. Despite reductions in both tonnage and power, the efficiency of fishing vessels continued to increase. The reductions were also undermined by aid programmes in some member states, which provided subsidies for new construction, modernisation and running costs.

The Commission has experienced particular difficulties over the monitoring and control measures put in place to enforce regulations. Control activities have essentially been left to member states. Different legal systems, different cultures and unwillingness by some member states to invest in fisheries protection has resulted in insufficient and discriminatory systems of control. Inspectors employed by the Community itself have not been permitted to conduct independent inspections. Fishers have perceived the system of controls to be unfair and in many instances have not complied with them.

Perhaps the largest measure of blame for the lack of success of the CFP may be directed at the heavy control exerted by the Council of Ministers. Even when advice has been sound, and the Commission has advocated sensible measures, the decisions taken collectively by the ministers of member states have been dominated by short term political thinking. Ministers have been prepared to sacrifice the need for conservation in favour of short term political gain.

A BETTER SYSTEM OF MANAGEMENT

One view, which has been put strongly by some fisheries economists, is that many of the problems of the CFP would be resolved by the introduction of individual fishing rights. The introduction of resource rents, where fishers pay for the right to fish can introduce a competitive element which is not present with open access, and may lead to reductions in fishing effort. It is not the purpose of this paper to review the advantages and disadvantages of transferable quota systems. The creation of a market in quotas undoubtedly introduces economic efficiencies. However, there are social and political implications which have to be considered. Trading in quotas can lead to their accumulation under a few dominant owners, who may not have particular regard for the welfare of fishing communities. Moreover, although their introduction would facilitate the sharing of the resource it would not necessarily assist in conservation of the fish stocks, which is the main problem for the CFP.

At a workshop held in 1999 (Ref.2), a group of European fishery biologists, economists, social scientists and representatives of fishers agreed on the desirable characteristics of a new holistic system of fisheries management for the North Sea.

An holistic system of fisheries management would:

- conserve the fish stocks,
- retain the diversity of the ecosystem,
- ensure the long term viability of the industry,
- involve stakeholders in management,
- devolve responsibility to a local level,
- maintain social equity and cultural values,
- pay for itself.

The emphasis on stakeholder involvement stems not from any idealistic emphasis on equity and fairness but from a realisation that fishers have expert knowledge which is essential for management of the fisheries. At the very least, their cooperation is required to establish the numbers of fish caught rather than landed. They also have a wide knowledge of the state of the fish stocks in the areas in which they fish and a wide knowledge of the advantages and disadvantages of different control measures, including whether they are enforceable. Without fishers involvement they will tend to regard the control measures as having been imposed from on high, through a system susceptible to political pressure, run by bureaucrats with little knowledge of what takes place at sea on the fishing grounds. There is a risk that a culture of non-compliance may develop, where fishers pursue their own individual interests without regard for the common good. From this analysis it is evident that a key feature of any reform of the CFP should be a commitment to co-management, consultation, and consensus building. Stakeholders must be allowed to participate in management. They include not just fishermen and those with an investment in fisheries, but also those with an interest in the marine environment, its habitats, and its flora and fauna, and those from the wider community.

Such participation is best achieved regionally. In the case of the CFP it should be possible to separately manage regional seas, such as the Baltic, the North Sea, and the Mediterranean, with the full participation of all the interested parties.

The involvement of fis hermen and others in fisheries management has become commonplace in other countries. In the United States, following an extension of national jurisdiction over coastal waters in the mid– 1970s, the system of fishery management, including the process of producing scientific advice, has been open to public participation. A system of Regional Fishery Management Councils has been established (eight in all). The Councils include the fishing industry, environmental NGOs, and the general public as members, and they develop fishery management plans for approval by the Secretary of Commerce.

The Canadian stock assessment process has also become open. There is participation of interested parties in every steps of the stock assessment process. Fishery management advice is provided by an independent body, the Fisheries Resource Conservation Council (FRCC) with a membership of 60% fishing industry and 40% fishery scientists (including economists). The FRCC holds extensive public consultations on the results of the assessments and related management measures. The FRCC formulates its advice in closed sessions, not open to the public, but the advice itself is made public.

Thus, in assessing the state of the fish stocks and then applying effective and appropriate management measures it is important to open up discussion between scientists, fishers and fisheries managers and especially to involve fishers in any decisions which are taken. It will not always be possible to achieve consensus, but at the very least all the relevant views will have been heard, and the process of reaching a decision will have been transparent.

REFORM OF THE CFP

The European Commission has recently produced a draft Council Regulation on the conservation and sustainable exploitation of fisheries resources under the CFP, and an accompanying 'roadmap' which indicates the main objectives for future CFP reform.

The roadmap points out that the objectives of the CFP are best met through measures aiming at responsible and sustainable fisheries, which are economically viable and competitive and provide a fair standard of living for those who depend on fishing. It also stresses the need for openness and transparency, the participation of stakeholders, and accountability through a clearer definition of responsibilities. It then proposes a series of measures:

- A new multi-annual framework for the conservation of resources and management of the fisheries, setting longer-term targets for the management of fish stocks.
- Strengthening of technical measures to reduce catches of young fish, by-catches and discards.
- Incorporating environmental concerns into fisheries management, based on indicators of environmental impact.
- An action plan for the improvement of scientific advice on fisheries.
- New rules on the granting of aid to the fleet, reducing the use of public aid.
- Measures to limit fleet capacity within agreed reference levels.
- Limited access to inshore waters to be maintained.
- A new regulatory framework for control and enforcement, with greater cooperation between member states and new powers for Commission inspectors.
- The establishment of Regional Advisory Councils to ensure greater stakeholder involvement at the regional and local level.
- A European Code of responsible fisheries practice.

These proposals have not met with universal approval. Many fishers believe that the Commission is taking an unduly pessimistic view of the state of fish stocks. That the proposals are unduly bureaucratic and likely to result in regulations which are much too strong. Fis hers are especially concerned at the proposal to greatly reduce fishing effort and to manage fisheries through new systems of effort control in addition to TACs. They believe that the reform proposals fail to take sufficient account of their socio-economic consequences. The future CFP should reflect the central role played by fishing and fishers in the coastal economy and should involve the industry more significantly. There is support for the proposal to improve scientific advice, both to improve the biological models underlying the recommendations on fishing mortality which lead to the TACs and to support multi-annual management plans. There is also support for the concept of Regional

Advisory Councils, tempered by concern that these may become too large and that the Commission may not heed the advice provided.

It is disappointing that the Commission has recognised the need for greater transparency and stakeholder participation, but has done so little to bring these about. It is evident that the current system of top-down management will continue, and that there are no plans to involve fishers and other stakeholders directly in management.

STAKEHOLDER INVOLVEMENT

In coastal waters it is commonplace for fishers to play a part in fisheries management. Thus, in England and Wales local fisheries committees have been established to manage the inshore fisheries. In Scotland, inshore management bodies can be formed by fishers themselves to manage local shellfish stocks. However, in offshore waters there are no such arrangements. An Advisory Committee on Fisheries and Aquaculture has been established by the European Commission, but it is large, meets only infrequently and has exerted little influence upon management.

It is evident from a recent survey carried out by Tom Rossiter of Aberdeen University that fishers feel strongly that they are not sufficiently involved in important aspects of the CFP. They recognise the need for controls on fishing but dislike the anomalies that result. They are especially disturbed at being required to discard high quality fish of marketable size because they do not have sufficient quota to be allowed to land them. They are upset by the haggling between ministers which precedes the annual imposition of management measures. They believe that their views are not sufficiently taken into account by managers and scientists, whom they see as remote, powerful and out of touch with conditions on the fishing grounds.

In 1998, at a conference on "The Scientists and the Fishermen" a suggestion was put forward that there should be a standing forum to enable fishers and scientists to meet one another regularly. Such a forum would enable scientists to consult fishers at an early stage on the advice to be given on the state of fish stocks. It would bring fishers closer to the workings of the expert groups concerned with fisheries management. It would promote discussion of management measures, drawing upon the practical experience of fishers, as well as the technical expertise of scientists. And, it would enable the management of the fisheries in the North Sea to be discussed thoroughly by those with the strongest interest in them. This suggestion was subsequently taken forward by the North Sea Commission (NSC), a group of local authorities with an interest in fishing. The NSC Fisheries Partnership held its first meeting in Bergen Norway in April 2000.

The Partnership consists of national fisheries research organisations from countries around the North Sea, representative fishers' associations, and the North Sea Commission, supported by specialist advisers. The Partnership is coordinated by Aberdeenshire Council. Funding was obtained from the European Regional Development Fund under the Interreg IIIB Programme for the North Sea, a community initiative promoting trans-national co-operation on spatial development. Matched funding is provided by the participants. The Partnership has the following objectives:

- to improve the exchange of views between fishers and fishery scientists,
- to bring fishers and scientists from different member states together,
- to further develop scientific advice on the state of North Sea fish stocks, making full use of information contributed by fishers,
- to evaluate the benefits and costs of different fisheries management measures,
- to progressively involve other stakeholders in discussions of the management of fisheries.
- to work for the implementation of more effective and more sustainable fishery management measures, taking full account of biological, social and economic factors.

The Partnership has initially focused on improving relations between scientists and fishers. In a major step forward it has, over the past two years, joined with ICES to consider the assessments for North Sea fish stocks at an early stage, before the scientific advice on the stocks has been formulated. This year (2002), fishers and scientists from the Partnership, aided by a group of independent experts, reviewed the assessments and presented their observations to ICES. The Partnership was first provided by ICES with extracts from the Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak. The independent, international team of three scientists was asked by the Partnership to assess the quality of three of the stock assessments, for cod plaice and saithe in the North Sea.

At a subsequent meeting between the Partnership and ICES, scientists described the process of assessing fish stocks and then reported their preliminary findings on the state of cod, plaice and saithe. The ICES scientists answered questions from the independent experts and members of the Partnership, and then took part fully in free discussions of the assessments.

The independent scientists concluded that the ICES assessments were thorough and technically sound. They provided the important information necessary for effective management of the stocks. A series of recommendations were presented, relating to the presentation of the assessments, the use of alternative models, and the provision of additional data and were then summarised in a report from the independent scientists.

Fishing industry representatives also gave their opinions on the assessments and the process. They expressed general agreement with the assessment results for cod and saithe, but there were differing views on the state of the plaice stock. Particular concern was expressed over the way reference points for the stocks were established. The advice which flows from the assessments is geared to these reference points, and is crucial for fisheries management, but the reference points were originally set without the involvement of industry.

These discussions between the Partnership and ICES have met their main objective of making the assessments more open and transparent. They have also identified additional data that might improve the assessments. The involvement of independent scientists has reassured fishers of the quality of the assessments and enabled all aspects of them, even the most technical, to be explored. Fishers have been able to comment on the format of the assessments. They have opined that if the assessments are to become fully transparent then their format, presentation and language will need to be changed. Fishers have also emphasised the need for care in describing the state of fish stocks.

Within the Partnership, fishers have volunteered to assist with the provision of additional and improved information from the fisheries. Both they and the scientists have seen advantages in fishers being present at an early stage in any stock assessments to provide supporting information on the fisheries. Fishers have also pointed to the valuable information held in their log books, and have urged that it be used. Scientists too have benefited from these discussions and have recognised the value of engaging with fishers in the joint collection of data and in cooperative research.

This initiative by the Partnership is now being taken further forward. It is clear that the ICES Assessment Working Groups would benefit from having available to them additional technical and scientific information gathered directly from the fishing fleets, with participation from fishers themselves. Projects are already underway to gather this information in several North Sea states. A joint Study Group on Fishers' Information is now being established to coordinate this process, decide on the kinds of information which would be most useful to the working groups, and to consider how best these new kinds of data could be collected, analysed and applied. The information would essentially be of two kinds;

Firstly, hard data are required on the operation of the fishing fleet, including accurate catch data (taking account of misreporting, discarding and high grading), effort data, technical information on the gears fished, and information on the grounds fished. Some of these data may be obtainable from conventional log books or from satellite data (provided ways can be found to gain access to these), but in some cases they may need to be collected directly from fishers. Specially selected vessels may provide data from reference fleets. Fishers may be persuaded to carry out biological sampling to supplement that done by biologists. New time series of data might be developed for particular fleet segments, and made available for the stock assessments.

Secondly, data are required on the views of fishers on the current abundance and distribution of fish. Though such data must be treated with caution, and collected with particular care, they can provide assessment scientists with the most up-to-date picture on the state of the stocks.

The Joint Study Group is being established by the NSC Fisheries Partnership and ICES specifically to:

- decide on the kind of information from the fishing fleets which would be most valuable to the assessment working groups,
- consider how best these new kinds of data could be collected, both from external sources (log books, satellite data) and from fishers themselves,
- begin the process of coordinating the collection of these data, through national agencies,
- investigate the potential for applying these new data in the stock assessments.

Fishers will participate in this Joint Study Group, which will report both to ICES and the Partnership. Representatives of ICES and the Partnership will co-chair the Group. The Joint Study Group will concentrate on fishers' knowledge in the context of the North Sea, but will not exclude participation from both fishers and scientists whose main interests lie in other areas.

There has already been an initiative from fishers themselves, with the support of the Partnership, which sets out to provide scientists with up-to-date views of the fishermen on the state of the stocks. Europêche, an alliance of European fishers, has issued a questionnaire to fishers from member states around the North Sea, seeking their views on the abundance of key species in different areas. The data have then been compiled and forwarded to ICES scientists to assist them in providing advice on the state of the stocks. In 2001, the results of the survey was especially valuable in confirming the tentative view of scientists that saithe were more abundant in parts of the North Sea.

Much progress has been made by the Partnership in bringing fishers and scientists together to discuss and improve assessments of the state of fish stocks. The success of the Partnership is owed in large part to its adopting Chatham House Rules for the discussion of controversial issues. Fishers' representatives and scientist working for member states are able to join in free discussions with independent participants, without their views being quoted or applied in other contexts. It has also been advantageous to adopt a regional approach and concentrate on the problems of the North Sea, which are distinctly different from those of other seas like the Baltic and Mediterranean. However, the same approach, with other regional partnerships, may be successful in other areas.

The next step for the Partnership is to involve in its discussions those who take decisions on fisheries management measures in the North Sea. These include administrators from the European Commission and from member states, who provide advice to the Council of Ministers. There are a series of major issues which need to be discussed in the immediate future, and which will be addressed by the Partnership. They include:

- the reduction of discards in the mixed fisheries of the North Sea,
- multi-annual management plans and harvest control rules, which will replace short-term decision-taking and provide greater stability in management,
- better management of fishing effort,
- evaluation of the costs and benefits of various fishery management approaches,
- preventing the misreporting of catches and adopting measures to reduce illegal fishing.

There are other subjects which need to be addressed by the Partnership, including marine environmental issues within the North Sea. For this, the Partnership intends to bring in stakeholders representing environmental interests.

CONCLUSIONS

Complex issues in the management of the North Sea fisheries can only be resolved by bringing fishers and other stakeholders together. The North Sea Commission Fisheries Partnership has demonstrated the great progress that can be made in assessing the state of the stocks by involving fishers. The open reviews which have taken place have brought benefits for both fishers and scientists, opening up a process that was formerly conducted behind closed doors. It is likely that other contentious issues, in other areas and contexts, may also be resolved by getting all the interested parties to work together.

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Fishers' traditional knowledge informs Clyde Sea science

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SYNOPSIS

An account is given of the thinking behind various projects that have been accomplished recently in the Clyde Sea area that have involved fishers co-operating in scientific researchers. In particular, examples are drawn from work on the *Nephrops* and *Ensis* fisheries locally. The perceptions of commercial fishers towards seals interfering with fishing gear have also been researched recently and methodological pitfalls and issues raised by all these experiences are highlighted. One difficulty, for instance, arose when trying to disentangle observations relating to the two seal species (grey seal and common, or harbour, seal) since these were rarely differentiated by respondents. This clearly highlights the need for observer training. Differences in attitudes between different groups of fishers (like trawlermen *vs* creel fishers) and the difficulties that this causes, are also be highlighted. The potential for using commercial fishers, not only as repositories of traditional knowledge, but also as sources of new and novel observations and as a data-gathering resource for scientific research in the future are explored.

The involvement of stakeholders in local fishery management is an issue that is currently exciting much interest, both here in the UK and in Europe. If marine ecosystems are to be managed effectively then dialogue needs to be generated between groups that have hitherto been suspicious of one another's motives. The benefits of increasing stakeholder (in this case fisher's) involvement with marine scientists are reciprocal: scientists gain increasing respect among fishers for their science as being soundly rooted in reality and therefore having relevance to the 'real world', while scientists can draw on centuries of accumulated first-hand knowledge of changing conditions in the field. The preparedness of fishers to be co-operative with scientists in the Clyde has had wide benefits and points the way forwards for fisheries management.

INTRODUCTION

The Marine Station at Millport has had a long and distinguished history in marine biological scientific research, education and public access, since its inception in 1884. In 1970, the Universities of London and Glasgow took over the premises that had been vacated by the (then) Scottish Marine Biological Association (SMBA, now SAMS). The *raison d'être* of the Station thereafter became three-fold: *viz.* teaching, research and specimen supply. The teaching function of UMBSM, though pre-eminently at tertiary level, has always included an element of secondary- and even primary-level commitment. In more recent years, as part of a wider attempt to reach-out to other sectors (summer schools for foreign students, adult education groups) the Station has been at the forefront in developing inclusive educational initiatives to improve community involvement in science [1,2]. Sadly, the understanding of science by the general public (and its presentation in the popular press) remains very poor. It is imperative that initiatives are taken to build bridges between interest groups, across which accurate information can flow in both directions, if we are to avoid misinformation and ignorance prejudicing proper decision-making processes that affect us all (often profoundly).

Coincident with this guiding philosophy at UMBSM has been a growing appreciation in wider scientific circles of the benefits to be accrued from a consideration of traditional knowledge resident in the community, particularly relating to understanding fisheries issues [3]. In the past, an atmosphere of suspicion and antipathy has prevailed between scientists and fishers; each complaining that the other failed to understand the other's point of view properly. This potential for antagonism has increased in recent years with the growth of the Green Movement and the ever expanding scope of legislation emanating from national parliaments and Europe, concerning fisheries management and nature conservation. If there is one group that fishers trust less than scientists then it is probably conservationists!

Recent years, however, have also witnessed the emergence of a political paradigm that seeks to defuse such tensions. Concepts like 'stakeholder', 'community involvement', 'ecosystem management' are commonplace now in official
prognostications. Hopefully, we are in the process of turning a significant corner. Doing away with concepts of 'us' and

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'them' will take time but the realisation that our finite world is too small, and our capacity to do it unsustainable harm is so great, that anything other than a partnership approach to environmental issues should now be regarded as indefensible.

Drawing on this philosophy, this paper highlights some recent (good and not so good) experiences centred around fishery-related projects that have only been possible due to the co-operation of the local fishing fleet which have drawn on traditional knowledge of fishers to help advance our scientific understanding of issues of mutual concern.

THE BACKGROUND

UMBSM fisheries researches linked with the Clyde fishing fleet

The history of collaborative research with fishers done by the Millport laboratory has been summarised by Marrs *et al.*[4]. Prior to the 1990s the level of collaboration was largely limited to requests to leave areas free from fishing for short periods whilst experiments were carried out, or occasional requests for assistance in supplying specimens for our research and teaching requirements. The major fishery in the Clyde Sea area nowadays is that for Norway lobsters (*Nephrops norvegicus*) or 'prawns' as they are called in Scotland (Fig. 1); whitefish stocks having been severely depleted.

Fig. 1 A typical catch from a Clyde Sea *Nephrops* trawl; note undersized fishes and non-target invertebrates (Photo: M. Bergmann)

The Clyde Sea area represents one of the main grounds of the Scottish prawn fishery. In recent years, UMBSM-based projects on *Nephrops* stock assessment[5] and discarding practices[6] would not have been possible without the active participation of helpful skippers and the full co-operation of the Clyde Fishermen's Association. Sadly, conflicts between *Nephrops* fishers using different fishing methods remain firmly entrenched. There is no love lost, for instance, between trawlermen and creel fishers.

In addition, most recently, basic research at UMBSM on deep-burrowing bivalve molluscs (principally razor clams *Ensis* spp.) have been done specifically to gather necessary data on an incipient fishery before major exploitation of the resource by hydraulic dredging is allowed. This could not have been done without the collaboration and advice of a particular fisherman who was developing appropriate commercial gear. In addition to the potential for hydraulic dredging, there is a SCUBA diver-based fishery for *Ensis* locally. Razor clams are either hand-picked by divers or extracted from the submerged sand by salting their positions. There is local conflict in this largely unregulated fishery too between diver fishers with different attitudes, viz. asset strippers and those more responsible individuals who seek to harvest the resource more sustainably by being deliberately selective of size and / or being prepared to leave particular patches untouched voluntarily.

THE ISSUES: CO-OPERATION AND COMMUNICATION

i) The issue of trust and trustworthiness. How trustworthy are people?

In the past, scientists and fishers have undoubtedly seen the world through different eyes (the former with rose-coloured spectacles according to the latter). On the one hand, scientists are trained sceptics and deal with probabilities; they seek to disprove hypotheses. On the other, fishers tend to entertain only personal certainties, they have grown used to a culture of the underhand and their tales can still sometimes be the stuff of legend.

That scientists never take anything at face value is a necessary requirement of their methodical approach and should not be seen as evidence that other people's word is necessarily untrustworthy. In a recent questionnaire survey of mine on seal / fisheries interactions in the Clyde (explained in detail below), it was clear that respondents were not differentiating between the two species of seal occurring locally (i.e. the grey seal and the common, or harbour, seal). These two species have different biologies, including diets and behaviour; something that is clearly impossible to discern from undifferentiated data, no matter how detailed and interesting the observations recorded. This clearly points up the need for training of respondents if the most is to be gained from such feedback opportunities. Any follow-up survey would clearly need to take this message on board.

A shared understanding not least necessitates a shared language and vocabulary. Colloquialisms and 'common' parlance terminology can obscure issues. A fisherman recently told me that local seals ate sea-grass. This is unlikely to be true, a) since seals are carnivorous, and b) because sea-grasses do not occur in any significant quantity locally. But does the term 'sea-grass' mean the same to me as to the fisherman?

ii) Problems of representativeness. How trustworthy are the data?

Even given co-operation, an ever-present issue concerns representativeness of small sample sizes. Scientists are much exercised by these considerations which underpin their statistical confidence in the results obtained. To give examples, in the fishing effort project recently completed by Dr Sue Marrs, automatic data loggers were fitted to 18 (out of a fleet of about 72) vessels. The discards project of Drs Sabine Wieczorek and Melanie Bergmann was able to sample year-round from only three commercial trawlers as well as our own research vessel (being time and, in this case, woman-power constrained). My seals questionnaire generated responses from (only!) 30% of fishers circulated. The Clyde Sea *Ensis*-dredging work could only benefit from one commercial hydraulic dredger, since that is all there was.

Trawler skippers have preferred tows and individual practices, trawlers have different power and gear configurations and some skippers are more successful than others. How typical are the habits of those who volunteer co-operation with scientists? Are those skippers who are prepared to be helpful more efficient or responsible than the average fisher? When reliance is put on voluntary co-operation, there is always the danger that the results will not necessarily be amenable to direct extrapolation to a whole fleet. There is nothing much that can be done about this, except be aware of it and try to factor-in such considerations to subsequent analyses, especially since resources are usually limiting. But it as well to realise that data 'raised to the fleet' can only ever be an approximation of the truth. What must be relied upon, however, is the integrity of any data that are recorded (has the logger been deliberately switched off?). This requires a lengthy period of confidence building until mutual trust, always a fragile commodity, is achieved.

iii) Openness versus commercial sensitivity and confidentiality

Since commercial fishing is a competitive activity, there is often a problem concerning disclosure of information. Scientists seek openness and transparency; fishers traditionally value obscurantism. In the case of the local *Nephrops* fishery, as a result of UMBSM scientists working with the fleet, Dr Sue Marrs was able to generate more accurate stock assessments that, for the first time, used input parameters that took into account the marked spatial heterogeneity of the stock. In the case of this data-logger work with the *Nephrops* trawler fleet, logbooks that remained confidential to UMBSM were kept by co-operating skippers. These were vital to accurate data interpretation. In the case of the diver-based *Ensis* fishery locally, trust was built up between co-operating fishers only after giving (and adhering to) strict reassurances that detailed site and catch information would not be publicly disclosed. The seals questionnaires included personal information on skippers and their boats which were guaranteed not to be retained on computers (to accord with requirements of the Data Protection Act) and no comments that were used in the scientific analysis were personally attributed.

iv) The vital need for communication and feedback between scientists and fishers

The Clyde seals / fisheries questionnaire survey can usefully be taken as a model here. Firstly, the survey grew directly out of concerns voiced by the fishermen themselves about the impacts that seals were having on their catches locally. It was therefore regarded as timely and perceived as relevant. It had the full backing both of the Clyde Fishermen's Association and the Clyde and South West Creel Fishermen's Association. A pilot version was trialled both in-house (among experienced scientists) and through the Officers of both Associations and the questions posed and wording used refined in order to reflect all aspects of the issue, identify and remove ambiguities etc in order to be as user-friendly as possible. It was circulated, not directly by us, but via the medium of the relevant Association's mailings. Prepaid return envelopes were included and skippers were exhorted by their Associations to co-operate fully. As a result a 30% return rate was achieved. This compares with the more usual return rates of 1-2% for unsolicited questionnaires. Once these returns had been received they were processed rapidly. Data for the two fisheries methods were analysed separately and each participating skipper received personally (certainly within a couple of months; some completed forms were slower coming in than others, delaying final data collation) the distillation relevant to his gear. Full comparative analyses were furnished to each Association. A popular article summarising the gist of the results was published as soon as possible in the popular press[7] and a full scientific analysis submitted to a scientific journal[8]. Thus the respondents remained fully appraised of what was going on and were able to feel that their contributions were worthwhile, without having to wait a year or more for the final outcome.

v) The problems of sometimes poor communication between fishers: internecine feuding between proponents of different fishing gears

The long-standing antagonism between trawlermen and creel fishers locally (and nationally) has been alluded to already. The latter tend to view the former as asset strippers, while the former often view the latter as nuisance litterers of the sea bed. A rather injudiciously headlined article that appeared in *Fishing News*[9] (written by another) seeking to publicise the results of our work[6] on discards from the local *Nephrops* fishery was immediately pounced on by the two groups of fishermen locally. The trawlermen, with whom we had collaborated to obtain the data, were up in arms - seeing the report as unduly pillorying their activities - while the creel fishers were gleeful at the apparent vindication of their premise that trawling was a wasteful method of fishing for this shared resource.

Both groups of fishers, of course, have legitimate claims to make a living. Perhaps their harmonious co-existence can only be achieved ultimately by segregation and zoning of specified areas for specified fishing activities. The concept of 'No-take' zones is one which is gaining ground and it seems very likely that certain sites designated as fragile, like maerl beds and nursery grounds, will need to be protected from the damaging effects of towed demersal trawls and dredges whilst perhaps allowing exploitation using static gear to continue. Any such zoning of fishery activities would be likely to create dissent among fishers unless they could be convinced first of it being in their own ultimate self interest. Working in partnership with scientists, fishery managers (and conservationists!) would hopefully expedite the finding of a workable solution to the problems faced[10].

vi) Injudicious publicity and misunderstandings can inadvertently generate misinformation

Communication can have a down-side. Lines may get crossed, especially if ambiguities are contained in reported comments. Clarity of language is all. Even clear messages can be misinterpreted. The 90% (i.e. 9 out of 10) discard to saleable catch ratio representative of the Clyde *Nephrops* fishery that was secondarily reported in the *Fishing News* article was correct and was based on our data as published in the primary scientific literature. This was, however, interpreted by one indignant Clyde skipper in a letter to *Fishing News* as meaning that 90 tonnes of *Nephrops* material was discarded for every one landed (i.e. 90 to 1). Our scientific paper made clear, as did the article reporting it in the *Fishing News*, that most of this discard was invertebrate non-target species (Fig. 1). But this detail was also lost on many fishers who misinterpreted the newspaper article, many of whom reacted angrily to us, when what was really at fault was the way the article had been presented by the newspaper (something over which we had no control).

Conclusions

The above experiences highlight the fact that we still have a long way to go before we can achieve the desirable goal of ecosystem management with stakeholder inclusion[10]. That the route towards this goal will be a rocky one, beset with pitfalls and strewn with tripwires for the unwary can be guaranteed. The most important thing remains the establishment of trust. That only comes with time, and only happens between honest people who respect one another's integrity and objectives. Its retention requires prompt and efficient communication. In this, efficient feedback remains a key element. The problem is that those fishers who are unconvinced as to the value of co-operation with scientists are often the most vocal, are probably those who would not volunteer to collaborate and who, thereby, exclude themselves from priority feedback loops designed to keep participants abreast of developments. Fishers have long memories. That is at once their attraction as repositories of traditional knowledge and their problem. Too often in the past they have felt let down by scientists and this may colour their preparedness to co-operate in future. Sometimes that has stemmed from the fact that scientists have not come up with interpretations that suited their individual prejudices. The public must realise that 'Trust in Science' can only be achieved if practising scientists treat everything as suspect. People, unfortunately, still tend to view the inevitable uncertainties of scientists' 'ifs' and 'buts' as prevarication.

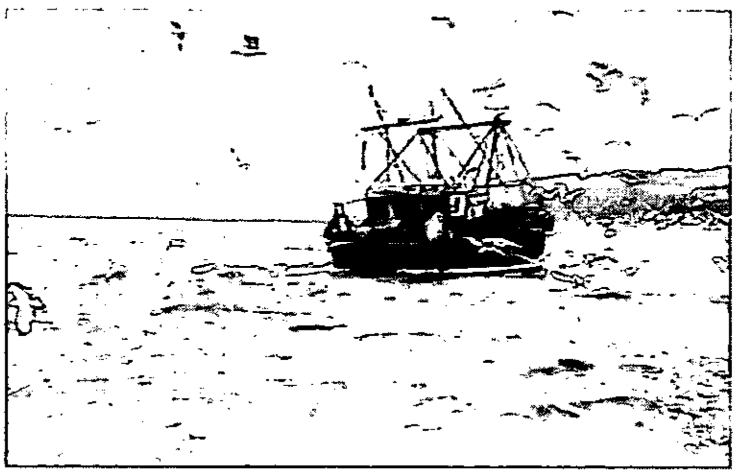

Fig. 2. A typical Clyde Sea prawn trawler going about its legitimate business. Clyde trawler discards generate *ca* 6,000 tonnes per year of food for seabirds, mostly herring gulls, locally (Photo: M. Bergmann)

There is a danger that increased public awareness of the environmental impacts of commercial fishing might well result in a shift in the perception of fishers from dignified seafarers (Fig. 2) to pillagers of the environment, i.e. fishers may soon suffer the hostility that farmers have increasingly faced in recent years[11]. Fishers thus face a public relations challenge ahead. Lack of communication is usually a key factor underlying human conflicts. But any communication channel that is established needs to be a two-way street. Scientists need to take on board the potential useful information source that traditional knowledge in the community (in our case, fishers) represents and, reciprocally, fishers need to appreciate that if science is going to be useful it has to be impartial and non partisan. We, therefore, still have educational hills to climb. That we have begun to see these strands coming together in the Clyde Sea is encouraging. It is due to the hard work and application of devotees who share a vision of the future in which conflicts can be resolved to the ultimate benefit both of mankind and of the environment which we must, of necessity, exploit to live. What is abundantly clear, however, is that **'Engaging the Public in Science'** is an urgent priority and one which needs increasingly to take centre stage as we move into the 21st century.

ACKNOWLEDGEMENTS

I am grateful to my colleague, Professor Jim Atkinson, for his helpful comments on an earlier draft of this manuscript. Dr Melanie Bergmann kindly supplied the illustrations and Mr Steve Parker converted them into electronic format.

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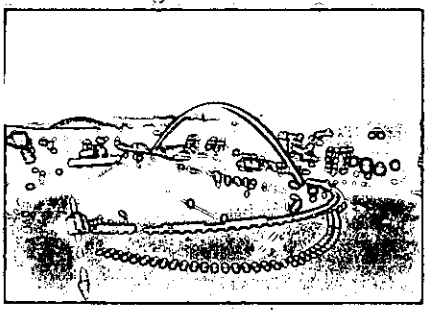

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Publisher

School of Marine Science and Technology
University of Newcastle upon Tyne, UK

Design and artwork David Houghton, Audio Visual Services
Photographs reproduced by kind permission of Graeme Peacock
Cover printed by Potts Printers, Stuart House, Tyne Tunnel Estate, North Shields, Tyne and Wear, NE29 7UZ, United Kingdom
Inset printed by Alphagraphics, Alphagraphics@newcastle, 19-21 Collingwood Street, Newcastle upon Tyne NE1 1JE, United Kingdom

Ref: 1279DH