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Proceedings

Ed. Steve Raaymakers

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1st International Ballast Water Treatment R&D Symposium

IMO London: 26-27 March 2001

Symposium Proceedings

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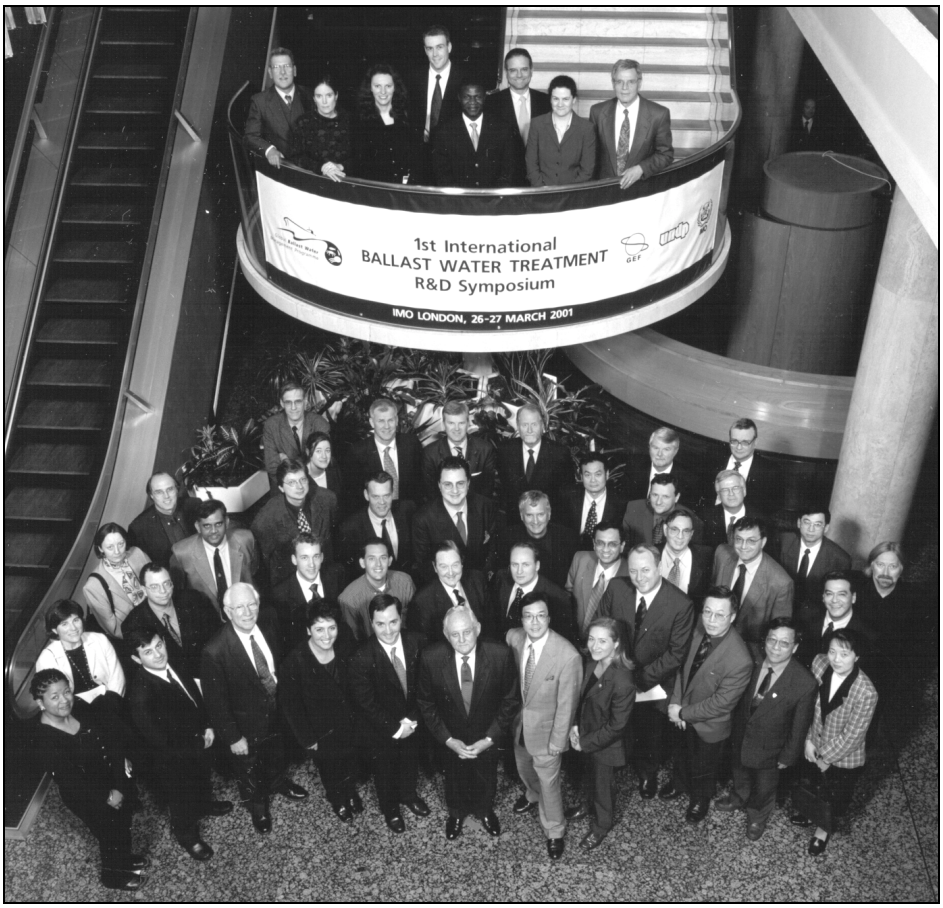
- Mr Steve Raaymakers for initiating the concept, coordinating all aspects of its organization and chairing key sessions.



Some of the delegates at the Symposium - nearly 200 attended

Foreword

Mr. Dandu Pughiuc
Chief Technical Adviser, Global Ballast Water Management Programme

The introduction of harmful aquatic organisms and pathogens to new environments, including via ships' ballast water, has been identified as one of the four greatest threats to the world's oceans. The main management measure to reduce this risk, as recommended under the existing IMO ballast water guidelines, is ballast exchange at sea. It is widely recognized that this approach has many limitations.

It is therefore extremely important that alternative, effective ballast water treatment methods are developed as soon as possible, and significant research and development (R&D) efforts are underway by a number of establishments around the world. However, there are no formal mechanisms in place to ensure effective lines of communication between IMO, the R&D community, governments and ship designers, builders and owners on this issue. These are vital if the R&D effort is to succeed.

To help address this situation, the GloBallast Programme Coordination Unit convened the 1st International Ballast Water Treatment R&D Symposium at IMO headquarters in London on 26 and 27 March 2001. This was the first time that the world's leading experts in the specialised field of ballast water treatment came together at an international conference. Twenty six papers were presented, covering all of the main technologies currently being researched and updating the latest results from the major R&D projects. The symposium attracted nearly 200 participants.

The papers contained in this Symposium Proceedings provide a very useful information resource for all parties interested in the topic of ballast water treatment, management and control. The symposium was hailed as a major success and participants requested that it become a regular event held every one to two years. We are currently exploring options for this.

Ballast water transfers and invasive marine species are one of the most serious environmental challenges facing the global shipping industry. I am pleased that the outcomes of the symposium are providing important catalysts for progressing the new international ballast water convention and for moving us closer to a practical solution to the 'ballast water problem.'

Symposium Objectives

The Objectives of the symposium were to:

- Update the current status of BWT R&D around the world.
- Enhance communication links between IMO, member countries, the R&D community and ship designers, builders and owners on BWT issues.

Major outcomes

The general picture that emerged from the symposium was as follows:

- All of the various potential ballast water treatment technologies are currently at a very early stage of development and significant further research is required.
- It is likely to be some years before a new ballast water treatment system is developed, proven effective, approved and accepted for operational use. Ballast water exchange will therefore remain a primary method for some time yet, despite its limitations.
- It appears that any new ballast water treatment system will involve a combination of technologies, for example primary filtration or physical separation followed by a secondary biocidal treatment.
- The current global budget for ballast water treatment R&D (about US$10 million) is insignificant compared to the global costs of marine introductions (likely to be at least in the tens of billions of US$).
- There is a desperate need to develop and implement international standards and procedures for the evaluation and approval of new ballast water treatment systems.

Symposium Programme

Monday 26 March 2001: Day 1

08:15-09:00 Registration

Opening & Keynote Speakers

Chairman: *Mr Koji Sekimizu, Director, IMO Marine Environment Division*

09:00-09:15 Opening Statement: *Mr William O'Neil, Secretary General, IMO*
09:15-09:45 Keynote Address: Ballast Water Treatment - The Needs of the Shipping Industry: *Mr Alec Bilney, ICS*
09:45-10:00 Introduction, Background and Objectives of the Symposium: *Mr Steve Raaymakers, GloBallast PCU*

10:00-10:30 Tea/coffee

Session One: Ballast Water Treatment – An Overview
(each presentation 20-25 min + 5-10 min questions)

Chairman: *Mr Denis Paterson, Founding Chairman, IMO MEPC Ballast Water Working Group*

10:30-11:00 Ballast Water Treatment - An Overview of Options: *Dr Geoff Rigby, Reninna Consulting*
11:00-11:30 Ballast Water Treatment - Can the R&D Community Deliver?: *Dr Thomas Waite, Univ. of Miami*

Session Two: Physical & Mechanical Treatment Systems
(each presentation 20-25 min + 5-10 min questions)

11:30-12:00 Ballast Water Treatment by Filtration: *Dr Jose Matheickal, Singapore Environmental Technology Inst.*
12:00-12:30 Ballast Water Treatment by Ozonation: *Mr Aage Bjørn Andersen, DNV*

12:30-13:30 Lunch

Session Two continued

Chairman: *Mr Dandu Pughiuc, Chief Technical Adviser, GloBallast PCU*

13:30-14:00 Ballast Water Treatment by Heat – an Overview: *Dr Geoff Rigby, Reninna Consulting*
14:00-14:30 Ballast Water Treatment by Heat – EU Shipboard Trials: *Dr Peilin Zhou, Univ. of Newcastle*
14:30-15:00 Ballast Water Treatment by Heat – NZ Shipboard Trials: *Mr Doug Mountfort, Cawthron Institute, NZ*
15:00-15:30: Ballast Water Treatment by De-Oxygenation: *Mr Wilson Browning, Browning Transport Management*

15:30-16:00 Tea/coffee

Session Two continued

Chairman: *Mr Steve Raaymakers, Technical Adviser, GloBallast PCU*

16:00-16:30 Ballast Water Treatment by Multiwave Lamps: *Mr Ben Kalisvaart, Berson UV-techniek*
16:30-17:00 Ballast Water Treatment by Electro-ionisation: *Dr Joseph Aliotta, Marine Environmental Partners*
17:00-17:30 Ballast Water Treatment by Gas Supersaturation*: Dr Anders Jelmert, Norwegian Inst. of Mar. Research*

17:30-18:30 Discussion Panel for Day One

18:45-19:00 Official Group Photograph – IMO Delegates' Lounge

19:00-21:00 Reception – IMO Delegates' Lounge

Tuesday 27 March 2001: Day 2

08:45-09:00 Housekeeping

Session Three: Chemical Treatment Systems
(each presentation 20-25 min + 5-10 min questions)

Chairman: *Mr Dandu Pughiuc, Chief Technical Adviser, GloBallast PCU*

09:00-09:30 SeaKleen®, a Potential Natural Biocide for BW Treatment: *Dr David Wright, Univ. of Maryland*
09:30-10:00 Peraclean®Ocean, a Potential BW Treatment Option: *Dr Rainer Fuchs, Degussa*
10:00-10:30 BWT with Currently Available Biocides: *Mr Bill McCracken, Mich. Dept. of Environmental Quality*

10:30-11:00 Tea/coffee

Session Four: Hybrid Systems & Multidisciplinary Approaches
(each presentation 20-25 min + 5-10 min questions)

Chairman: *Mr Dandu Pughiuc, Chief Technical Adviser, GloBallast PCU*

11:00-11:30 Great Lakes Ballast Technology Demonstration Project: *Ms Allegra Cangelosi, NE/MW Institute*
11:30-12:00 Testing of BWT Technologies at Large Scale: *Dr Thomas Waite, Univ. of Miami*
12:00-12:30 Shipboard Trials of BWT Systems by Maritime Solutions: *Mr Richard Fredricks, Maritime Solutions*
12:30-13:00 Effects of Cyclonic Separation and UV Treatment: *Dr Terri Sutherland, Fish. & Oceans Canada*

13:00-14:00 Lunch

Session Four continued

Chairman: *Mr Denis Paterson, Founding Chairman, IMO MEPC Ballast Water Working Group*

14:00-14:30 The OptiMarin System: *Mr Birger Nilsen, OptiMarin*
14:30-15:00 BW Treatment R&D Activities on US Pacific Coast: *Mr Scott Smith, WA Dept. of Fish & Wildlife*
15:00-15:30 BW Treatment R&D Activities in Japan: *Mr Takeaki Kikuchi, Japan Assoc. of Marine Safety*

15:30-16:00 Tea/coffee

Session Five: Ship Design and Operational Issues
(each presentation 20-25 min + 5-10 min questions)

Chairman: *Mr Steve Raaymakers, Technical Adviser, GloBallast PCU.*

16:00-16:30 Ballast System Design for Flow-through Exchange: *Mr Greg Armstrong, Three Quays Marine Services*
16:30-17:00 Simulations of Ballast Water Treatment: *Prof. Arne Holdø, Univ. of Hertfordshire*
17:00-17:30 Ship Design Considerations to Facilitate Ballast Water Management: *Mr Alan Taylor, AT & Assoc.*

17:30-183:0 Discussion Panel, Conclusions and Recommendations

18:30 Close Symposium

Contents

Papers presented

Disclaimer

Papers have been included in these Proceedings largely as submitted, with basic editing and formatting only, and without technical review.

Neither the International Maritime Organization nor the GloBallast Programme take any responsibility whatsoever for any statements and claims made in these papers, for the quality, accuracy and validity of data presented, or for any other contents of these papers.

Ballast Water Treatment – An Overview of Options

Geoff Rigby[1] & Alan Taylor[2]

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1. Treatment options being researched

The project covers essentially all of the management and treatment options that have practical significance at the present time. These include ballast water exchange, heating, filtration, hydrocyclones, ultraviolet irradiation, chemicals, use of fresh or treated water and shore based or dedicated ship treatment.

2. Timeframe of project

The review covers work that has been reported over the past 10 years and up to the present time. This project has only recently been completed.

3. Aims and objectives of the project

The main objective of this work has been to review the current status and technical effectiveness of appropriate treatment technologies and to develop indicative cost data for use of these options as a basis for comparison and selection by ship owners and operators. For the cost comparisons, the project considers three ship sizes; a Cape Size Bulk Carrier, an LNG Carrier and a Container Vessel.

4. Research methods

Details of the various techniques, together with the cost comparisons that have been used in the studies are provided in the published report, entitled 'Rigby, G.R. and Taylor, A. H. 2000. *Ballast Water Treatment to Minimise the Risks of Introducing Nonindigenous Marine Organisms into Australian Ports– Review of Current Technologies and Comparative Costs of Practical options*. AQIS Ballast Water Research Series Report No. 13, AGPS Canberra'. This is available from Agriculture, Fisheries and Forestry – Australia (AFFA), www.afffa.gov.au.

5. Results

The results are summarised below and complete details are included in the published report.

Technical efficiency

Exchange of ballast water at sea in its various forms can replace between approximately 95% and close to 100% of the original water. The efficiency of removal of organisms (as distinct from replacement of water) is a complex issue and has been shown to vary for particular ships, type of

exchange option and types of organisms. Given this complexity it is unlikely that a direct link between the efficiency of water replacement and organism replacement will become a universal reality and consequently any standards for adoption will need to address this issue.

It is important to note that even if it is assumed that the efficiency of removal of organisms is the same as the water replacement efficiency in ocean exchange, large numbers of harmful organisms may still be present in the water discharged into the receiving port and pose a significant residual threat even though the risk has been significantly minimised. This is especially true when ballasting occurs during an algal bloom in the ballast uptake port. There are some concerns about the particular location where exchange takes place with the effect of the organisms on the receiving environment and the possible effects of "fresh" organisms taken on during the exchange process on the receiving port. In some cases the process of exchange may present an even worse scenario than discharging the residual originally ballasted organisms. The development of guidelines for effective exchange zones is currently a priority of the Australian Research Advisory Group Research Program and the Working Group on Ballast Water at IMO. The role of sediments in the exchange process is also an area of concern and further work to evaluate this issue is in progress.

The use of waste heat from the ship's main engine jacket coolers to heat ballast water can provide a very effective and environmentally attractive treatment option, and is especially suitable for treatment on international voyages involving voyage durations of about 10 days or longer, or for use to heat up small quantities of ballast water by circulation prior to discharge (such as passenger or container ships). Other options using higher temperatures than those possible with the continuous flushing mode have been developed and preliminary testing has taken place. These have the potential to offer significant effective alternative options in the very near future.

Continuous self cleaning filters to separate various sized organisms have attracted a great deal of attention overseas and have been demonstrated at a relatively large scale ($340m^3/h$). At the current stage of development, separation efficiencies (overall particle count) varying between 82%-95% (50μm) and 74%-94% (25μm) have been achieved, with corresponding biological removal efficiencies of 80% to over 99% for the various organisms tested. Improvements in filter design are continuing and improved separation efficiencies are likely in the future.

Hydrocyclones have been proposed as an alternative to filtration, although initial tests in small prototype cyclones have given limited and inconclusive data. The results of recent trials using a $200m^3/h$ OptiMar hydrocyclone on the C/S *Regal Princess* will assist in the evaluation of this technology.

Although ultraviolet irradiation has been proposed for ballast water treatment only limited small scale tests of relevance to ballast water have been reported to date. Water clarity presents one of the biggest challenges to the effectiveness of this technology. Work to date with *Gymnodinium catenatum* cysts has not been encouraging. Pre-treatment of the water using filtration or hydrocyclones prior to UV treatment is likely to be necessary in most cases to improve clarity of the water and hence overall efficiency and effectiveness.

A number of biocides/chemicals (including hydrogen peroxide, chlorine, chlorine dioxide, ozone, glutaraldehyde, copper/silver ion systems) have been tested for effectiveness. Test work with some organisms on the Australian Marine Target Species List (MTSL), although effective in some cases, requires high impractical concentrations or poses significant safety, environmental or operational problems.

Alternative water supplies using either fresh or recycled industrial process water can provide a very effective means of organism control and may be attractive in some specific cases.

Shore based or dedicated treatment ships have some potential attractions, however limited availability, high cost of the installation, treatment quality control and practical shipboard operational difficulties will impose severe restrictions on further development and likely widespread implementation of such options. This option may prove attractive for oil tankers in some cases where

ship infrastructure already exists to handle "dirty ballast water" in shore based treatment plants which could be converted to handle clean ballast water.

Cost effectiveness

The cost effectiveness of various treatment options has been based on an assessment of the capital and operating cost components associated with use of the particular treatment techniques.

The estimated costs are based on the volume of ballast water on board the ship, except in the case of the container vessel where a cost has been indicated for the quantity of ballast water actually replaced or treated, as container ships do not usually completely discharge their ballast water in port.

Exchange of ocean water in its simplest form (with no additional equipment) provides the most cost effective option (2.46-3.74^{c}/m^3). These costs are reduced by approximately 50% (for the empty/refill option) if gravity ballasting can be accomplished. The capital costs associated with additional equipment can result in an increase up to approximately 31^{c}/m^3. Safety of the ship must always be ensured before any form of ocean exchange can be undertaken. All costs quoted are in A$.

The heating /flushing process provides the next most cost effective heating option at 5.56^{c}/m^3. Use of the Hi Tech system involving recirculation, higher temperatures and additional heat exchange equipment has been estimated at < 9^{c}/m^3.

Continuous backflushing filtration with a relatively high capital cost component is estimated at 11.74 to 32.05^{c}/m^3, whereas data for hydrocyclones indicates a cost of 10.77 to 43.70^{c}/m^3.

Use of utraviolet irradiation on its own is estimated to cost between 16.26 and 52.1^{c}/m^3, whereas when it is combined with filtration the cost increases to 28.00–84.15^{c}/m^3 and with the hydrocyclone from 27.03 to 95.8^{c}/m^3.

It is noted that the costs for the container ship are relatively high compared to the other ships (where additional capital equipment is required) since the quantity of water treated is quite low. It may be possible to reduce some of these capital costs by reducing the capacity of the new equipment. However this aspect would need to be considered as part of the development of the BWMP to allow the optimum overall outcome to be achieved.

The use of fresh water of between 83^{c}/m^3 and $1.20/m^3 would generally be regarded as prohibitively high, but the estimated cost of using recycled process water at 6.9^{c}/m^3 in a particular application is potentially quite attractive.

Chemical treatment, based on operating cost alone has been estimated to cost between 24^{c}/m^3 and $40/m^3.

Land based treatment estimates have suggested costs in the vicinity of 34^{c}/m^3 to $13.80/m^3, and 54^{c}/m^3 for a dedicated treatment ship. It is noted that these costs are very heavily dependent on additional infrastructure and collection costs and require close scrutiny for particular ports and specific requirements.

An assessment of the overall effectiveness of a particular treatment option needs to take into account both the technical and cost effectiveness in the context of the specific ship's design and ballast arrangements. A table summarising this data has been developed.

The relatively high costs of some options (resulting from the equipment capital costs) will probably mean that preference will be given to those involving little or no capital. However standards which take into account biological effectiveness will ultimately have an influence on the most appropriate choice. It is important to note that the shipping industry has currently generally accepted the costs of ballast water exchange as being reasonable. Treatment technologies involving significantly higher costs will have a direct impact on freight rates.

The capital cost accounts for a large proportion of the overall cost of retrofitting equipment to existing ships for some treatment options. This situation will be less of an issue in relation to a new ship where new designs can be readily included and the additional capital may be very minor compared to the total cost of the ship.

6. Conclusions and recommendations

Exchange of ballast water is the primary and generally the most cost effective treatment method identified by IMO and countries that have some form of ballast water control in place. However, its effectiveness and efficiency of organism removal is questionable in many circumstances. The use of waste heat from the ship's main engine in a heating/flushing mode can provide a cost effective option with effective organism control, especially on international voyages of about 10 days or longer, or ships discharging small quantities of water. Heating using recirculation systems will offer significant effective alternative options in the near future. The capital costs associated with other treatment options, combined with the current demonstrated levels of organism removal, killing or inactivation suggest that more information will be required before widespread adoption by the shipping industry is likely. The implementation of an effective set of treatment and sampling standards, together with development of a Ballast Water Management Plan for each ship will play key roles in the future implementation and effective control of ballast water. The incorporation of improved design criteria to facilitate appropriate treatment options on new ships together with ongoing research, development and demonstration of current and alternative technically and cost effective treatment options will form an essential part of the international ballast water management and control strategy.

7. References

Rigby, G.R. & Taylor, A.H. 2000. Ballast Water Treatment to Minimise the Risks of Introducing Nonindigenous Marine Organisms into Australian Ports– Review of Current Technologies and Comparative Costs of Practical options. *AQIS Ballast Water Research Series* Report No. 13. AGPS Canberra.

(A detailed list of other references is included in the published report)

Ballast Water Treatment by Filtration

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1. Treatment options being researched

Singapore Environmental Technology Institute (ETI), in collaboration with the Maritime and Port Authority of Singapore (MPA) and National University of Singapore (NUS) has been working on a multi-faceted R&D project on ballast water management. One of the objectives of this programme is to develop an effective ballast water treatment system for onboard use.

The primary treatment system being considered is based on screen filtration technology. Various secondary treatment options such as UV, ultrasonic and biocides are also being studied to compliment the filtration process. This paper will focus on screening technology.

Screen filtration has been in use for over 20 years with screens having filtration capabilities of 40 micron and larger. Advances in manufacturing technology of woven or slotted stainless steel screen over the last decade have enabled filters to remove particles down to 10-micron range. Automatic self-cleaning screen filtration is gaining popularity now as they have a small footprint even for filtration, including large flow rates, and are simple to operate and less complex in terms of piping and valving. The backwash water loss can be as low as 1% of the total throughput volume.

There are a variety of self-cleaning filtration systems available on the market, each with its own unique screen construction and self-cleaning design. However, the basic principle behind the technology remains fairly simple and common. The screen captures the suspended particle by straining. The differential pressure (dp) across the screen increases as the screen becomes loaded with the particles. A differential pressure sensor activates the cleaning mechanism, when the differential pressure rises to a predetermined value. Clever engineering designs allow the screen to be cleaned section-by-section or element-by-element, thus not interrupting the main flow. The backwashing takes no more than 1-2 minutes and the screen element returns to its original state. Backwashing is affected either using a portion of the filtered water, by compressed air or by a combination of two.

Although, self-cleaning screen systems have been widely used in marine applications including shipboard uses, its' application in ballast water treatment is a technically challenging one. A dedicated ballast water filtration system must be able to handle very high flow rates under low operating pressure using very fine mesh screens.

Although technically challenging, the concept of preventing the entry of marine organisms into the ballast tank in the first place, merits attention. Mechanical filtration does not generate any by-products or associated environmental problems and is safe to the crew. With innovative filtration system

designs, it is most likely that the existing ballast pumps can be used to pump the water through the screen filter as the additional head loss by introducing a screen filtration may range from 0.5 to 1 bar.

Screen filtration systems have been previously tested, (Cangelosi, 1998), using ship-mounted and barge-mounted ballast filtration systems. Also, a clear consensus is emerging that several alternative technological options for pathogen inactivation (e.g., UV, ultrasound) would require a pre-filtration stage for effective removal of larger particles in ballast water (Buchholz et al., 1998).

2. Timeframe of the project

Phase 1: Evaluation of various filtration systems and development of design criteria for shipboard treatment systems :1998-2000

Phase 2: Development of prototype filtration systems for onboard use and demonstration: 2001-2002.

3. Overall aims and objectives of the project

The major goals of the overall research programme are,

1. To develop a set of strategies for the control of transfer of non-indigenous species via ballast water for Singapore shipping and port interests. This would allow Singapore flagged ships, and the Port of Singapore to develop safe, efficient ballast water management options that are cost effective. Singapore flagged ships will require a selection of ballast water management options, depending on the type of shipping, and ports of call.
2. To demonstrate ballast water management schemes at suitable scale in order to generate treatment effectiveness, and reliability data, as well as life cycle costs.
3. To transfer ballast water management technologies and schemes to local industries
4. To act as a regional centre for coordinating research and development on ballast water management. To cooperate with, and coordinate efforts with ongoing studies in Australia, Japan, and the USA.

4. Research methods

A major focus of this project is to develop cost effective ballast treatment technologies for onboard applications. A dockside pilot treatment facility was commissioned in April 1999, to evaluate candidate technologies and to help developing a new treatment system for shipboard treatment. The facility is located in the Singapore Maritime Academy (SMA) campus at Sembawang, Singapore. The pilot plant can handle flow rates up to 50 tonnes/hour. This flow rate was selected, as it would allow a number of system modifications and optimization experiments in relatively short period of time. The treatment facility includes two automatic self-cleaning mesh filters and a multimedia pressure filter with automatic air augmented backwash system. The facility also includes automatic controls and data-logging capability to monitor the treatment system performance on a continuous basis. Figure 1 shows the pilot plant facility at Sembawang, Singapore.

The pilot scale studies included:

1. Evaluation of treatment efficiency at variable screen sizes and of systems using various screen geometry and backwash designs.
2. Study of flow characteristics and fouling rates at different suspended solids loading levels and size distribution.
3. Modification of screens and filtration systems to optimize flow and minimize fouling.

5. Results

Feed water quality

Seawater quality at Sembawang was monitored at regular intervals over tidal cycles (Table 1).

Table 1. Seawater quality at Sembawang.

Time (11-1-99)	Turbidity (NTU)	Tide Height (m)	Temp. (°C)	Salinity	pH
1 pm	14.03	1.37	29.8	28.54	7.76
2 pm	12.34	1.48	29.9	28.75	7.90
3 pm	11.12	1.61	29.9	28.45	7.79
4 pm	9.00	1.76	29.8	28.96	7.75
5 pm	7.23	1.93	29.8	27.56	7.81
6 pm	4.35	2.06	30.0	28.01	8.00
7 pm	2.25	2.11	29.4	27.06	7.73

It can be seen that the seawater turbidity varies considerably, depending on the tidal levels and reaches around 14 NTU at low tide. The particle size distribution of seawater was also monitored at different tidal levels. The results are shown in Figure 2. The mean particle size varied from 5 microns to 12 microns with time and the peak values were observed at low tide. The test facility, therefore, provides a platform to study the filtration technologies under different solids-loading conditions.

Use of surrogates for estimating organisms removal in ballast water filtration

Evaluation of treatment processes for marine organisms removal can be done directly by measurement of organisms of concern in the feed water and in the filtered water. This will provide a direct assessment of the removal capability of screen filtration systems, but its' use has many practical limitations. The organisms of concern could vary geographically and it may prove to be difficult to measure all the organisms in seawater on a routine basis, not to mention the uncertainties involved in organism recovery using various sampling techniques. Moreover, this will require sufficient number of organisms of concern to be present in the test waters so that log removal capabilities can be accurately calculated. Spiking of feed water with the organisms of concern is one way to overcome this problem, but this will require large-scale culturing of these organisms and safe disposal of treated water that may contain the harmful organisms.

Another technique for assessing the potential for removal of marine organisms is through the use of surrogate measurements in place of counting of organisms of actual concern. Use of less expensive and less complex surrogate measurements may reveal as much as or more than measuring the organisms of actual concern, especially from the practical point of view.

A number of surrogate indicators of filtration performance for surface water treatment trains have been used in the past (Li et al., 1997; Hibler and Hancok, 1990; Patania et. al., 1995). The simplest is turbidity. However, the removal of turbidity by screen filtration need not be synonymous with removal of marine organisms because turbidity causing particles can be much smaller than these organisms. This result is that screen filters are able to remove most of the organisms while passing particles in the micron-sized and sub-micron range that cause turbidity. Therefore turbidity removal cannot be a surrogate for organism's removal in ballast water filtration. However, turbidity can influence the hydraulic performance of screen systems and this issue is discussed in a later section. A more sophisticated method, but still avoiding the biological issue is the use of particle size distribution measurement and this is discussed in the following section.

Particle size distribution analysis as a surrogate measure for filtration efficiency

Assessment of filtration efficiency can be made on the basis of particle size distribution measurement of the seawater, before and after filtration (Tiehm et al., 1999; Kaminski et al., 1997; Ben et al., 1997). The screen filtration process removes particles, including microorganisms, by physically straining out the particles and trapping them in the filter. Because particle removal is accomplished primarily by straining based on the size of the particles and of the screen openings, particle size, shape and pliability will be more important than the biological nature of organisms. Thus properly conducted particle size distribution analysis can be an effective measurement for determining the efficiency of screen filters.

Particle size distribution measurement can be effectively used, either by measuring the size of particles in feed and filtered seawater or by measuring the size of a particular type of particle (biological surrogates, inorganic particles etc) that was seeded into the feed water. The analysis can be carried out on-line to permit detailed observation of filtered ballast water quality and temporary, short-term changes in that quality. A simple particle counter with a built-in data acquisition system can be connected to the inlet and outlet of the treatment system and can be used to record the filtered water quality for further reporting purposes. Measurement of particle size distribution in the treated water, therefore, can form the basis of monitoring filtration systems onboard ship, while the seeding of surrogate particles and subsequent particle size analysis can form the basis of filtration system verification and approval protocols. A similar surrogate approach was proposed in USEPA's Surface Water Treatment Rule Guidance Manual (USEPA, 1989) and has become a favoured means of filter evaluation among many in the water treatment field.

Although particle size analysis of treated ballast water can be used to routinely evaluate ballast water filtration performance without parallel use of biological or inorganic surrogates, use of surrogates together with particle size measurement may be recommended as means of verifying and approving any ballast filtration technologies. However, more research is needed for the selection of such biological surrogates that can closely represent the actual organisms of concern, in terms of size, shape and pliability. We have developed a simple protocol to mass-culture cysts of non-toxic dinoflagellates (*Scrippsiella* sp.) that can resemble toxic dinoflagellate cysts. Toxic dinoflagellates are of big concern to many countries as they can survive in ballast tanks for several months. However, dinoflagellates represent only one size range (20-50 micron) and more research is needed to develop other suitable biological surrogate species to cover the entire filtration size range.

It is also likely that some inorganic surrogates can resemble the marine organisms of concern, in terms of size and shape distribution. We are studying the use of fluorescent polymer microspheres and Arizona Coarse Dust Particles as surrogates to evaluate screen filtration performance for removal of marine organisms. Cultured marine organisms belonging to different size categories are used to study the reliability of such inorganic surrogates for determining organism removal in screen filtration.

From the above discussions, it can be noted that particle size distribution analysis / counting may be a useful tool in evaluating various screen filtration technologies, simply because screen filtration separates particles based on size and shape.

Particle retention efficiency of self-cleaning screen system

The mesh opening sizes used in our filtration experiments ranged between 10 and 300 microns. The filtration efficiency of the screens was measured by analysing the particle size distribution of raw and treated seawater using a particle size analyser that works on the principle of laser ensemble light scattering. The particle size distribution was calculated after conducting sufficient number of measurements to allow statistical analyses.

Representative particle size distribution curves for raw and screen filtered seawater are given in Figure 3. It can be seen that screen filtration can effectively restrict the passage of particles above certain size, thus showing the potential of this technology for ballast water treatment.

Results from these studies indicate that the minimum particle size to be removed becomes a critical parameter in application of the filtration technology. Applying a concept of percentage (%) removal is normally not required, as a properly designed screen element with uniform pore size, would retain all particles larger than the screen opening, under optimal operating conditions. However, the filtration efficiency also depends on the characteristics of materials being removed from seawater. It is important to note that biological materials including the marine organisms are of compressible nature. This may result in some organisms passing through the mesh openings if the operating conditions are not optimum. For example, we have observed that excessive differential pressure (dp) development across the screen can cause leakage of the retained particles. Therefore, when setting performance standards for screens, it is suggested that size of the smallest "target" organisms, be determined, and a screen system would be required to utilise a mesh of that size or smaller. However, % removal efficiency can be used as an additional requirement to make sure that the screens are operated under optimal conditions.

An equally important consideration for this treatment technology selection is the mechanical performance of the system. The operating environment of a ship as well as ballasting requirements are totally different from a land-based application. The screen fouling rates, robustness, loading sensitivity, backwash efficiency, total volume throughput etc. are important factors that affect the treatment technology selection. We have been monitoring the operational characteristics of the treatment systems, under varying conditions. Representative results from such studies are given in Figure 4.

It can be seen from Figure 4 that the hydraulic flux of water drops as the screen plugs, necessitating a backwash cycle to recover the flow. A properly designed system can restore the original flux after a quick backwashing. In this particular case, there was no indication of irreversible plugging of the screens. It can also be noted that the turbidity levels have significant effect on the filter performance. At higher turbidity levels the backwashing frequency was higher even when the pore size of the screens were higher than the size of turbidity causing particles . Effect of turbidity on screen performance was studied in detail and the results are given in the following section.

Effect of seawater turbidity on hydraulic performance of screen filtration systems

Seawater turbidity has a significant impact on the hydraulic performance of screen filtration systems. The turbidity levels of seaports can reach very high levels if the shipping volume is high and / or if there are ongoing reclamation/dredging operations near to the ports. Although the turbidity causing particles can be very small in size and most of them will pass through the typical screen elements, it contributes heavily to the solid loading on the screen elements. As the filter cake forms on the screen surface, these small particles can bridge the pores within the large particle matrix, thus contributing to the increase in differential pressure. The result of this plugging is more frequent backwashing of the screens.

The backwash water loss (% volume) was determined using various screen elements under different feed water turbidity levels. The backwash losses were determined by measuring the backwash volume per cycle of backwash and multiplying this volume with the number of cycles per hour of operation. The results are shown in Figure 5.

It can be seen that different screen elements resulted in different backwash water losses. Backwash water losses reached as high as 20% when a 25-micron screen was used under high turbidity conditions. This may limit the application of such finer screen elements for ballast water treatment, if the water to be treated is of very high turbidity. It is possible that a more effective backwashing system design might overcome this problem. Effect of turbidity on performance of 50-micron screens was much smaller and caused only 12% of the backwash water loss. Effect of turbidity on 100 micron and 200-micron screen performance was minimal.

Particle retention at different filtration stages

Screen filters function by straining. Over the course of the filtration process, the particle removal efficiency of the screen can improve with time. Particles retained in the earlier stages of filtration can bridge the pore openings and contribute to cake formations, which effectively reduces the pore size and increases the depth of filtration. On the other hand, screen performance can degrade over time due to the unloading of particles due to the screen's inability to retain particles at increased differential pressures. This is especially true when the particles retained are of compressible nature. We have monitored the performance of screen filtration at different intervals of a single cycle of operation. The experiment was carried out under different differential pressure setting of the system.

It can be seen that the filtration efficiency improved with time as expected during the cake formation. However, when the screen was subjected to a high differential pressure, the retained particles were released into the filtered water stream, thus reducing the filtration efficiency considerably. It is therefore important to note that the optimum differential pressure setup to meet the hydraulic performance objective may not be the optimal for marine organisms removal in screen filtration.

Surrogate particles for determining organism removal in filtration systems

Removal of biological organisms is the primary purpose of filtration of ballast water. Because particle removal is accomplished primarily by straining on the basis of sizes, it may be possible to use carefully selected biological or inorganic surrogate particle for system verification and filtration efficiency determination. Monitoring of removal efficiency can be determined by particle counting and/or particle size distribution analysis before and after filtration.

In order to have a realistic standardized test, surrogate particles must be chosen which simulate the characteristics of the field particles as much as possible. Some of the candidate test particles for ballast water filtration evaluation are listed below.

Challenge Particles (microns)	Size Range (microns)
AC Coarse Test Dust (ISO 12103-1, A2)	0 – 200
AC Fine Test Dust (ISO 12103-1 A4)	0 - 80
Iron Oxide particles	0 - 5
Latex Spheres	various
Polystyrene microspheres	various
Surrogate marine organisms	various

The ideal candidates would be surrogate marine organisms of varied size ranges. These organisms must be amenable to large-scale culturing and must be suitable for standardised testing protocols. We have been developing protocols to develop surrogate organisms to represent the cysts of toxic dinoflagellates (size range of 20 – 50). These studies have resulted in a protocol that would allow mass culturing of dinoflagellate cells (*Scrippsiella* Sp.) and their subsequent encystment. (10^6 / L). These cysts and cells are currently being evaluated for their use as surrogate organisms for filtration efficiency of various screen systems (10 – 100 micron range). Attempts are underway in our laboratories, to develop additional biological surrogate categories that would allow us to test the filtration systems using other mesh openings. The results of such studies will be reported elsewhere (Matheickal et. al., 2001)

Although, biological surrogates offer a number of advantages, there are considerable practical hurdles to overcome in order to use these tools in a standard verification protocol. Development of such surrogate cultures are often time consuming. It also requires a standardised protocol for culture development and storage.

Another alternative is the use of polystyrene microspheres or Arizona Coarse Dust Particles (AC Test Dust) for screen challenge tests. Fluorescent polystyrene microspheres have been used for evaluation of bag filtration and cartridge filtration to determine their efficiency in removing *Cryptosporidium* oocyst (Li et al., 1997). The removal efficiency of the filters for microspheres was determined by counting the microspheres using a hemacytometer under an ultraviolet (UV) microscope. It was observed that polystyrene microspheres of certain size (4-6 microns) can be used as a reliable surrogate for determining *Cryptosporidium* oocyst removal in filtration processes.

Arizona Coarse Dust particles combined with particle size analysis/counting can also be used as a surrogate measure for evaluating the screen filtration efficiency. Because AC Test Dust has characteristics common to many applications, its' low cost (S$ 40 / Kg) and availability not withstanding, it is often used for testing of screen element performance for filtering particles from water, and also covers a wide range of particle sizes (1 – 200 microns).

Although microspheres and AC Test Dust offer many good characteristics of surrogates, their use as surrogates for marine organisms has not yet been studied. We are presently evaluating the use of fluorescent polymer microspheres and AC Test Particles for their reliability as surrogates for removal of dinoflagellates in filtration systems. A lab scale test rig, as shown in Figure 7, is used for these studies. Our preliminary results (data not shown) indicate that inorganic surrogates can reasonably well represent the removal of marine organisms in the range of 10 – 200 microns, in filtration processes. Detailed results from these studies will be reported elsewhere (Matheickal et al., 2001).

Long-term performance issues that must be considered

As with any process application, the risk of upset conditions always exists under long-term operation of filters. While some screen filter manufacturers utilize perforated media it must be realized their ability to handle relatively high differential pressure is limited, and may result in collapse. By incorporating innovative welding and other screen element manufacturing techniques, some elements appear to withstand high differentials under long-term operations.

Although some flat sheet screen elements had shown excellent self-cleaning efficiency, certain others showed a gradual blocking of screens over long duration of operation. Inefficient backwashing and non-optimal screen weaving may be responsible for such blinding of screens. Figure 8 shows the photograph of a screen element that had lost most of the porosity due to such blinding. It also shows that the screen elements need to be manually cleaned occasionally, after taking it out of the pressure vessel. Design of onboard screen system therefore needs to incorporate features that would allow the crew to carry out such operations with minimum effort.

Corrosion of screen elements is also an important issue in terms of long-term performance. For example, it was observed in our studies that stainless steel (316L) screen elements are prone to corrosion which results in splitting of the screens. Figure 9 shows a screen element that developed corrosion and screen splitting.

6. Conclusions & recommendations

Our studies showed that self-cleaning screen filtration is a potentially effective treatment technology for ballast water management. The studies also showed that "*off-the-shelf*" technologies, that are currently available in the market, are not designed to meet the requirements of normal ballasting operations. Considerable modifications and system re-engineering will have to be made to develop a dedicated ballast water filtration system. Well designed screen elements and effective backwashing systems will need to be developed to maintain a constant initial flux of water, even after a large number of backwash cycles. Properly designed screen elements can restrict the passage of all organisms above the mesh size, if the operating conditions are optimal and if the differential pressure settings are correctly set. The results also showed that seawater turbidity and particle size distribution have profound effect on screen performance. Systems designed for freshwater operations, where the turbidity levels are much lower, may not perform efficiently in highly turbid seaport waters.

Long-term operation problems need to be considered when designing a screen filtration system for onboard use. Stainless Steel 316L may not be a suitable material for screen element construction for ballast water filtration.

When setting performance standards for screen, it is suggested that the size of the target organism, be determined, and a screen system would be required to utilize a mesh of that size or finer. Because screen filtration systems do allow modular screen elements, different target organisms could be easily accommodated by ships using this technology. That is, screen sizes could be easily changed to allow ships to operate under many different ballast water management regimes.

Particle counting and/or particle size distribution analysis can be used as a reliable surrogate for monitoring the effectiveness of screen filtration systems. Such particle counters and associated sensors can be easily incorporated into a shipboard filtration system. Reports generated by such monitoring equipment can be used as a routine check of the effectiveness of screen filtration.

Verification of screen filtration efficiency and approval of filtration systems can be based on surrogate particle challenge tests and subsequent particle size distribution and analysis of feed and outlet streams. Polystyrene microspheres and /or AC Test Dust Particles can be used as surrogates for determining the removal efficiency. Biological surrogate categories that can represent different size ranges may also be used to determine the filtration efficacy. However, more research and development effort is required to develop protocols for large scale culturing of such surrogate organisms.

7. References

Ben Aim, R., Vigneswaran, S., Prasanthi, H. & Jegatheesan, V. 1997. Influence of particle size and size distribution in granular bed filtration and dynamic microfiltration. *Wat. Sci. Tech*., 36(4), pp. 207-215 .

Buchholz K. et al 1998. *Ballast Water Secondary Treatment Technology Review, Report to Northeast Midwest Institute.* Washington DC, USA.

Cangelosi, A.A, Knight T.T., Balcer M., Carlton J.T., Gao X. & Reid D. 1999. Biological test results from the Great Lakes ballast technology demonstration project. *Proceedings of First National Conference on Marine Bioinvasions*. MIT, Cambridge, USA.

Hendricks, D.W. et al 1999. *Biological Particle Surrogates for Filtration Performance Evaluation: AWWA Research Foundation report*. Denver, USA.

Hibler, C.P. & Hancock, C.M. 1990. Waterborne Giardiasis. In: *Drinking Water Microbiology*, G. Mc. Feters, Ed. Springer-Verlag. New York, USA.

Kaminski, I., Vescan, N. & Adin, A. 1997. Particle size distribution and wastewater filter performance. *Wat. Sci. Tech.,* 36(4), pp. 217-224.

Li, S.Y. et al 1997. Reliability of surrogates for determining Cryptosporidium removal. *JWWA*, 89(5), pp. 90-97.

Matheickal et al 2001. Selection of surrogate particles for ballast water filter evaluation. To be presented in the *First International Conference on Ballast Water: Best Practices and Future Directions, Singapore November 1-2, 2001*.

Patania, N.L., et al 1995. Optimisation of filtration for cysts removal. *AWWA Research Foundation report*. Denver, USA.

Tiehm, A., Herwig, V. & Neis, U. 1999. Particle size analysis for improved sedimentation and filtration in waste water treatment. *Wat. Sci. Tech*., 39(8), pp. 99-106.

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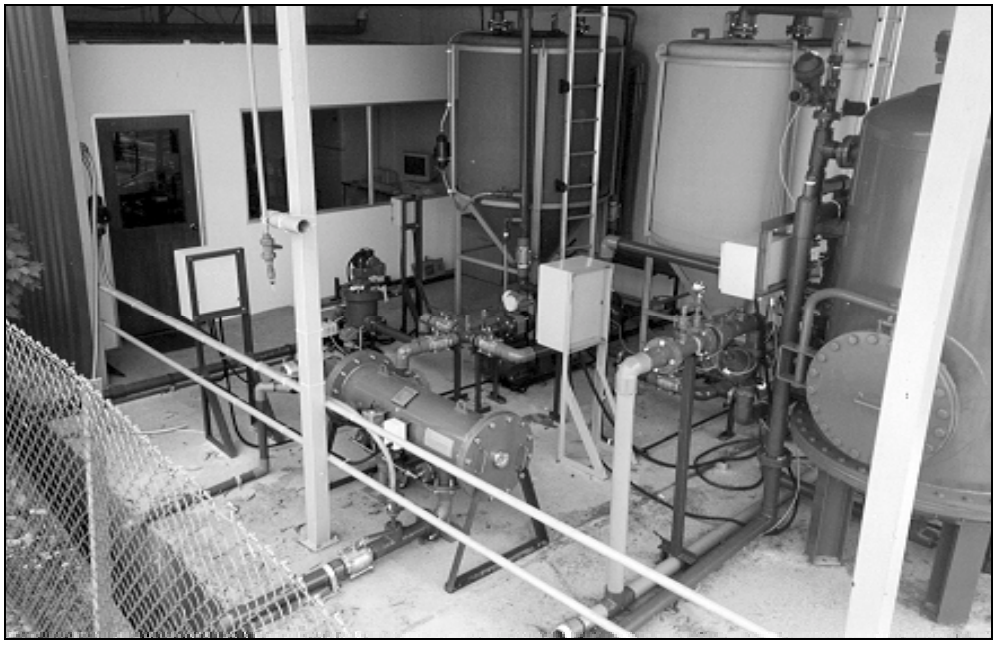

Figure 1. Pilot scale ballast water treatment facility located at Sembawang, Singapore.

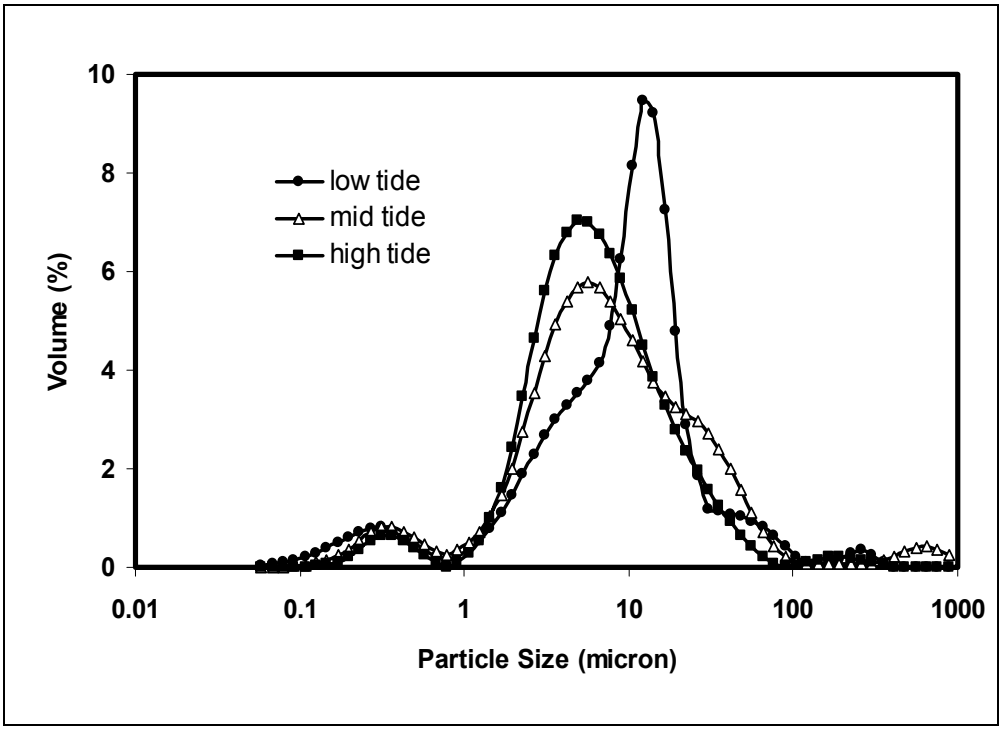

Figure 2. Particle size distribution of feed seawater.

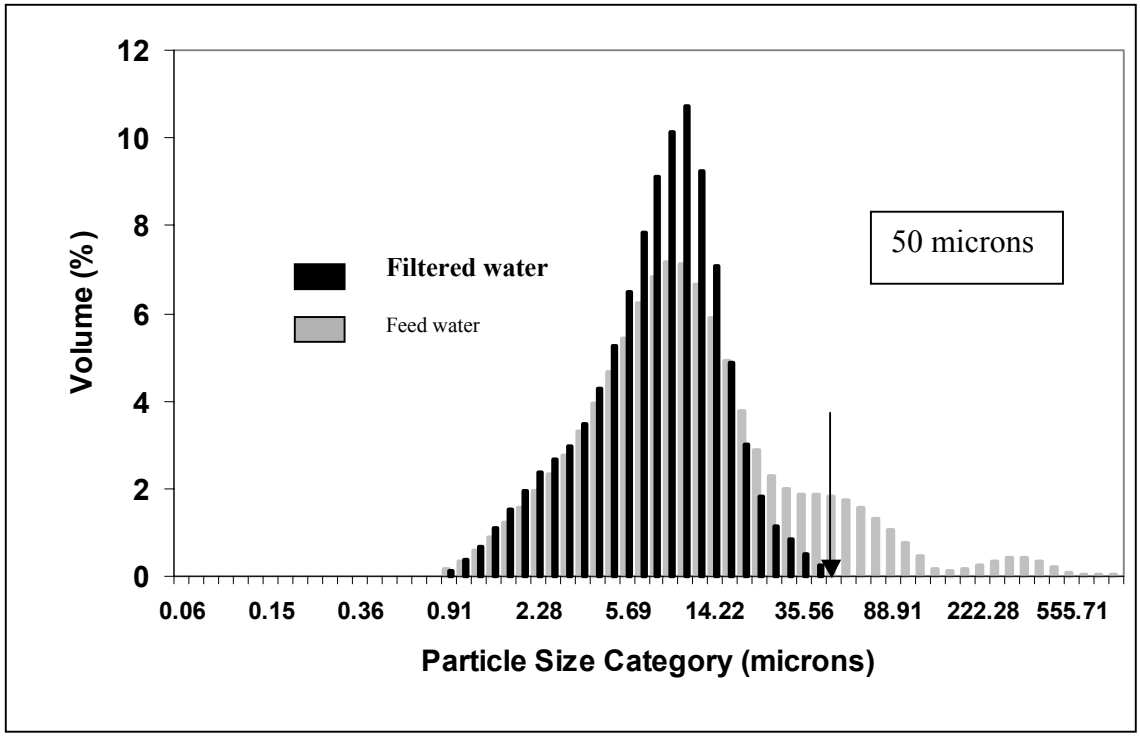

Figure 3. Representative results from particle size distribution of raw and screen filter treated seawater under optimal operating conditions (mesh size = 50 microns) .

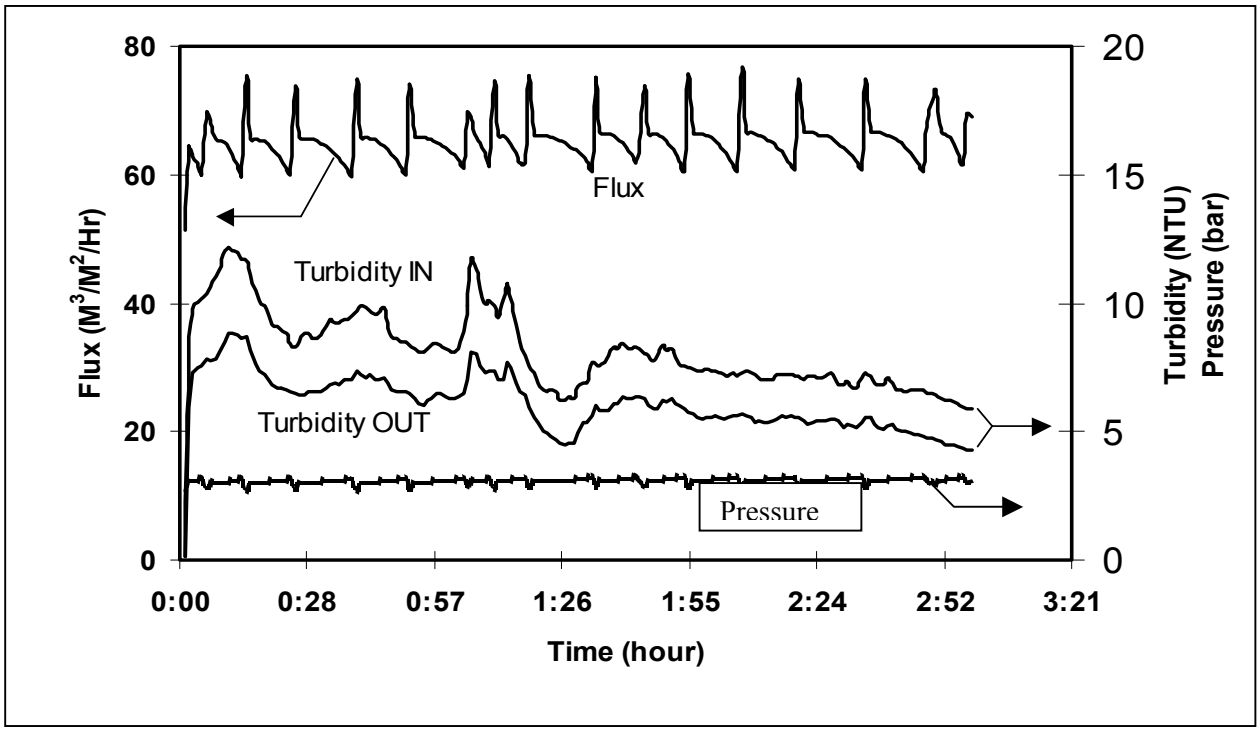

Figure 4. Operational characteristics of automatic self-cleaning screen filtration system.

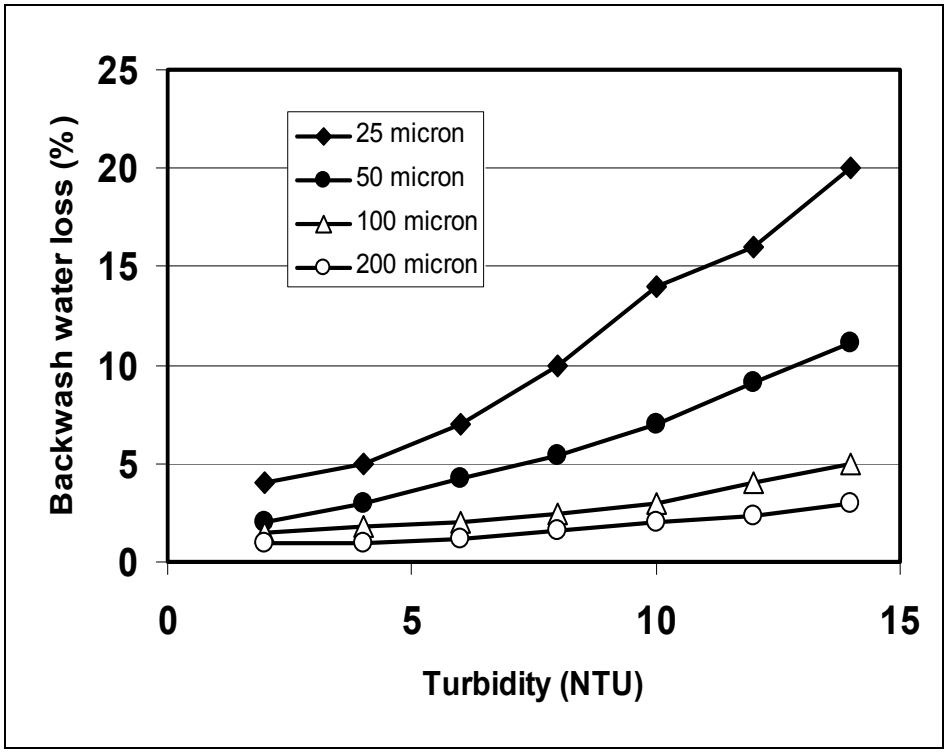

Figure 5. Backwash water loss under different solids loading conditions (flux: 60 $M^3/M^2/Hr$; line pressure: 3 bar).

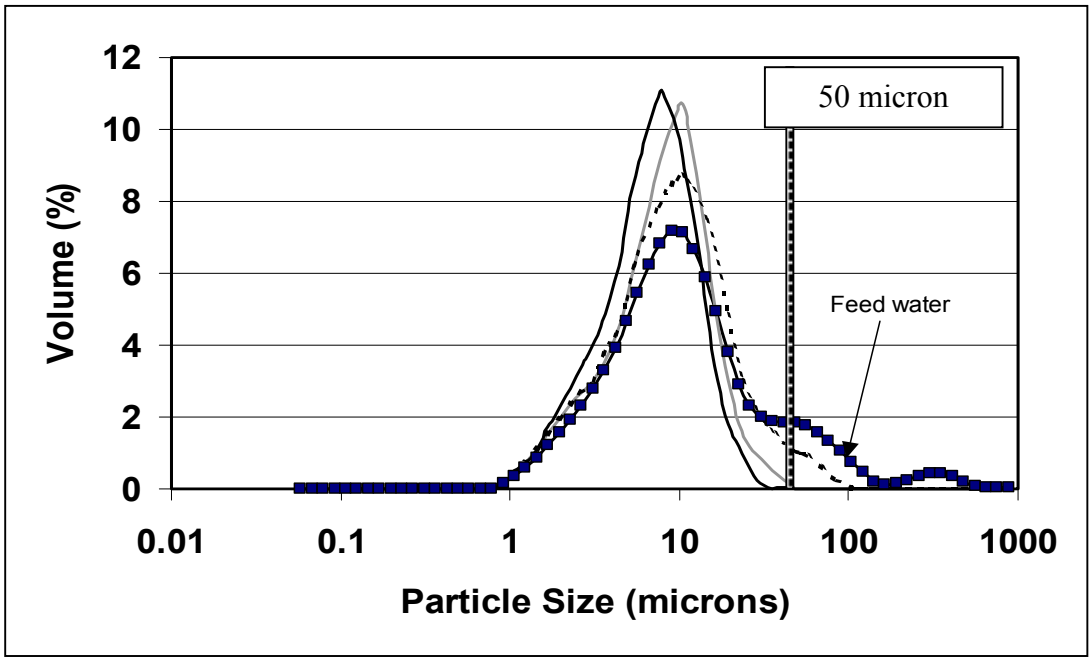

Figure 6. Particle retention at different stages of filtration (—— : after backwash; ——: middle of the cycle; ------ : before backwash).

Figure 7. Lab-scale test rig for filtration performance evaluation.

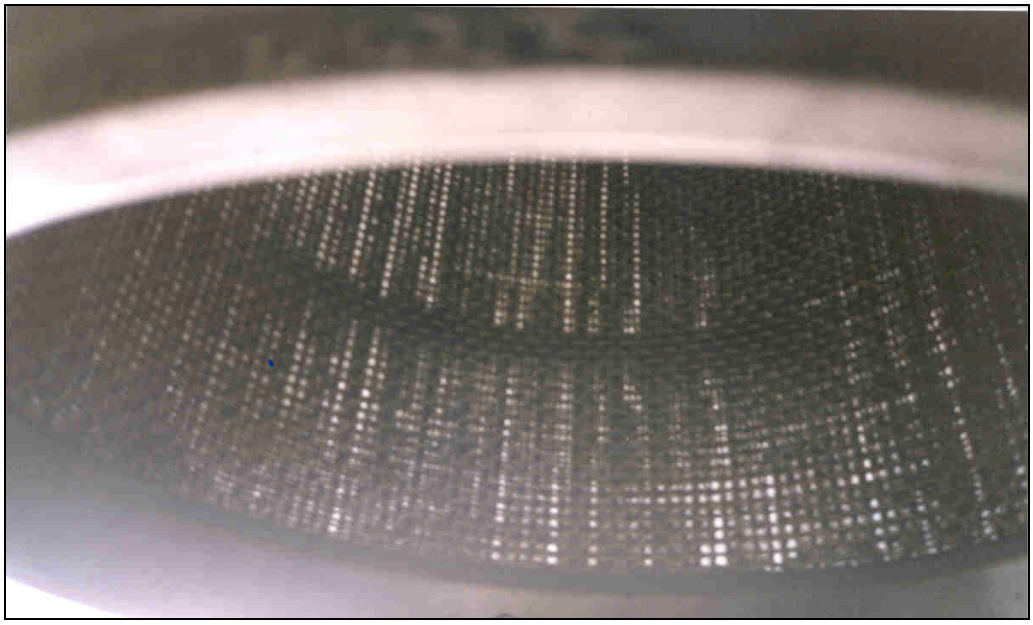

Figure 8. Gradual blocking of screens due to ineffective backwashing systems.

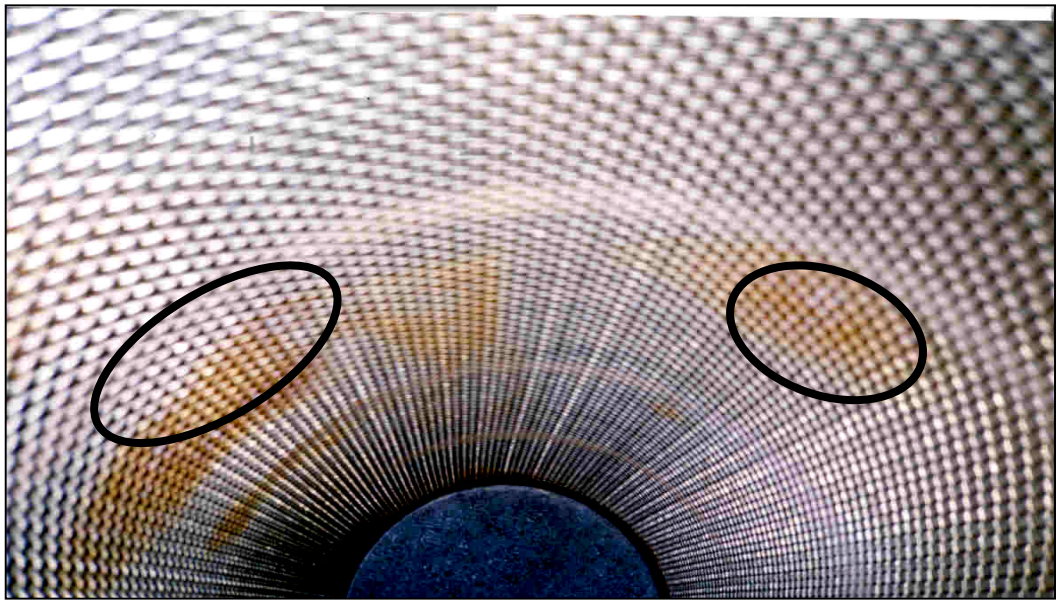

Figure 9. Corrosion of Stainless Steel 316L screens upon long-term exposure to seawater.

Ballast Water Treatment by Ozonation

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1. Treatment options being researched

This study explored the potential of using the chemical of O_3 (ozone) in the treatment of ballast water.

2. Timeframe of the project

The project was carried out in the period between November 1999 and May 2000.

3. Aims and objectives of the project

The objectives of our investigation were to assess the use of ozone as a method for ballast water treatment reflecting possible constraints with respect to efficiency and operational feasibility.

4. Research methods

General

The work included an assessment of the application from a conceptual point of view and an assessment of its potential as a treatment measure based on laboratory studies. The latter included:

- Testing ozonation efficiency with several groups of organisms relevant for ballast water treatment.
- Short term testing of corrosivity of treated water.

Our work recommended a further in-depth assessment on possible changes in corrosion characteristics following ozone treatment. Such a study has been conducted but is not included here. Tests were intended to provide information as directly applicable to a full-scale as possible.

Operational feasibility

Ozonation of ballast water represent a chemical treatment option. It differs from some of the other such options as it is generated at location of application. The increased use of ozone in other applications has initiated a development of equipment for the production of ozone (ozone generators). In some of the older literature references, the method is rejected on basis of lacking operational feasibility (size/ weight), complexity and costs. The validity of these arguments may now be reconsidered as illustrated by the comparison between "old" and "new" technology:

Specification	**"Old"**	**"New"**
O_3 Production	0.82 kg/ hr	1 kg/ hr
O_3 Concentration	6 %	12 %
Energy consumption	12 kWh	8.5 kWh
O_2 consumption / kg O_3	14.5 m3	6.6 m3
Weight	2,100 kg	100 kg

Occupational aspects

Ozone acts as a primary irritant, affecting mainly the eyes, upper respiratory tract and the lungs. Many people exposed to airborne ozone rapidly develop a headache, which often disappears after a few minutes in fresh air. Reduction in lung function due to scar tissue forming in the lung may occur due to long-term exposure to ozone at concentrations above 0.2 ppm, or a single high exposure.

The permissible exposure level (PEL ref. The Material Safety Data Sheet) or time weighted concentration for ozone to which workers may be exposed is 0.1 ppm averaged over 8 hours 5 days a week. The short-term exposure limit is 0.3 ppm averaged over 15 minutes. The concentration of 10 ppm in air is generally accepted as immediately dangerous to life or health. Ozone can be detected in air by its distinctive odour at concentrations of about 0.02 ppm. However, olfactory fatigue occurs quickly and odour is therefore not a reliable detection of ozone concentrations in air. Modern ozone generators are manufactured in accordance to relevant safety requirements.

Ozone treatment of ballast water – assessment methodology

Water was pumped from a feeding tank supplied with seawater collected at 50m depth in the outer Oslofjord (i.e. clean water with low content of organic matter). The ozone/oxygen mixture was injected into the pumping line through a Venturi ozone injector. Microorganisms were then injected into the flow line, approximately one meter downstream of the ozone injection point. Larger organisms were introduced manually into the ozone treated water.

The hose length after injection of organisms was approximately 10m to obtain residence times comparable to a full-scale installation. Volume of water in each test-tank was 40l - 100l, giving test duration of approximately two minutes per tank. After filling of test-tanks, water was sampled regularly for oxidant concentration measurements.

Reaction-rates of ozone and its short half-life (5.3 sec) in seawater make accurate direct measurements of ozone a problem. Both brominated and chlorinated oxidants formed, will interfere with ozone measurements in seawater. On the other hand, both these chlorine- and bromine-compounds are powerful oxidants that will function as active disinfectant for a long period after ozonation (see review in Jenner et al., 1998). It was therefore decided to use the total residual oxidant (TRO) concentration reported as milligrams of free chlorine per liter as a measure for concentration of active disinfectant. TRO was determined by the colourimetric DPD method.

Table 1. Organisms used in tests.

	Group	**Species name**	**Comment**
Planktonic algae	Dinoflagellates	*Amphidinium carterae*	The group Dinoflagellates includes several toxins producing species. Culture from Univ. Oslo.
		Gymnodinium galatheanum	
	Diatoms	*Ditylum brightwelli*	Include several important ballast water species. Culture from Univ. Oslo.
	Flagellates	*Prymnesium parvum*	Blooms regularly in a fjord system on the southwestern coast of Norway. Produce high levels of toxins, which cause high mortality of salmon in fish farms. Possible ballast water organism. Culture from Univ. Oslo.
Animals	Planktonic crustacea	*Artemia salinas*	Commonly used in standard toxicity tests. Larvae hatched in laboratory.
		Acartia tonsa	Commonly used in standard toxicity tests. Larvae hatched at SINTEF.
	Benthic crustacea	*Carcinus maenas* (adult)	Ballast water organism, introduced to American west coast probably pumped as planktonic larvae. As these were not available, adult specimens were collected close to Fredrikstad.

Samples from tanks with treated water and control tanks with untreated water were taken at predetermined intervals. Observations and measurements were:

- Count of number living (and dead) individuals.
- In vivo fluorescens of algae samples
- Regrowth tests of algae.

5. Results

The length of the period where organisms and/or steel is exposed to ozone is essential both for the disinfection and the corrosion processes. According to Oemcke & van Leuwen (1998) (referring earlier works) this relation is usually represented as: $C^n . t_p$ = constant (expressed as mg . minutes/l) where C = concentration of oxidant residual, n = constant (typically = 1), t_p = time in minutes taken to effect a given percent kill.

The quality of available water when ships load ballast tanks will affect the C·t value. Results from test will be presented as C·t.

Ditylum brightwelli

The diatom *Ditylum brightwelli* was used in total eight experiments. In vivo measurements of fluorescens show a distinct reduction after a few minutes of treatment. Ct values less than 10 resulted in 70 % reduction and Ct values between 50 and 500 resulted in fluorescens comparable to untreated water with no organisms added or lower. Regrowth experiments of treated samples (see Figure 1) indicated no growth of treated organisms under ideal conditions (light, temperature, and nutrients). When Ct was below 10 (test T9, Ct = 9.5), regrowth was observed in the culture after a period of 14 day.

Gymnodinium galatheanum

The dinoflagellate Gymnodinium galatheanum was used in two tests, T3 and T4 with different ozone dosage. The results from in vivo fluorescens measurements in T3 are presented in Figure 1 and regrowth results from both T3 and T4 in Figure 2. The results indicate that Ct values over 40 are sufficient for treating of *G. galatheanum*.

Amphidinium carterae

The dinoflagellate *Amphidinium carterae* was used in two tests; T5 and T6. The results indicate that Ct values necessary for disinfecting *A. carterae* are between 40 and 100.

Prymnesium parvum

The flagellate *Prymnesium parvum* was used in two tests, T11 and T12. There were observed no regrowth in the *Prymnesium* tests at any Ct values (see Figure 5). The lowest Ct value (T11) sampled was 4. From the *in vivo* fluorescens measurements the necessary Ct values to disinfect natural populations of *Prymnesium* was estimated to be between 40 and 70 (Figure 4).

Acartia tonsa

Acartia was used in nine tests indicating necessary Ct values around 50 for Acartia treatment. Results from one of the tests are presented in Figure 6.

Artemia Salinas

Artemia was used in six tests and Ct values were varying between 200 and 2500 probably because of age of cultures and oxidant demand in cultures.

Oxidant residuals decay in seawater and corrosivity

Ozone reacts with seawater and produces a number of corrosive compounds (e.g. several forms of chlorine). Organic and other compounds from natural and anthropogenic origin will consume oxidants and reduce the time when organisms and metal are exposed to ozone. This will reduce the efficiency of a given ozone dosage, but also reduce corrosion in ballast tanks caused by residual concentrations of bromine and chlorine oxidants.

According to Oemcke & van Leuwen (1998) the decay of oxidant residual (y) can be modeled by an exponential equation:

$$y = ce^{-kt}$$

where k is the decay constant for the residual with denomination hr^{-1}. Higher values mean faster decay of TRO. Decay constants found in experimental work and literature cited in Oemcke & van Leuwen (1998) indicate measurable TRO concentration over several days in ballast tanks after treatment. Figure 7 presents examples for the oxidant decay found in our tests.

The oxidant decay in water with no organisms added (Figure 8) reflects the situation after ballasting during the winter season (low oxidant demand in water) in ships with coated ballast tanks. The initial concentrations of oxidant was 5 and 1.2 mg Cl_2/l. Decay constant in the first experiment with highest initial TRO was much higher than the second test. Seawater used in the two experiments was of different batches. The first batch had been stored for three weeks and bacteria growth was observable, while seawater used in the last experiment was collected two days before the experiment. Higher organic content will increase rate of TRO decay.

The estimated time for oxidant decay indicate that the timeperiod with efficient concentrations of oxidant in ballast tanks in real service may be from a few hours up to 2 days. After 2 days most of the oxidant have vanished and will not be efficient for increasing the corrosivity of the seawater. The decay rate is a function of ballast water characteristics (presence of organic compounds, metal ions and organisms). In polluted water the decay rate will be higher compared to clean water.

- Practicability/utility (in terms of suitability for use on-board a ship or shore-based facility).
- Cost effectiveness (expressed as US$/tonne of ballast water treated).
- Safety implications of the technology researched.

6. Conclusions and recommendations

Summary of biological test

Summary of Ct values necessary to disinfect different organisms is shown in Table 2. Most of the results were corresponding to results for other organisms found in literature. Oemcke & van Leuwen (1998), however, found significant higher Ct values for Amphidinium. This could be caused by differences in cultures (oxidant demand) and other characteristics of the culture used.

Table 2. Ct values for disinfection of tested organisms using ozonation of seawater.

Organism	**Ct (mg·min/l)**
Ditylum brightwelli	50 - 500
Gymnodinium galatheanum	40 - 50
Amphidinium carterae	40 - 100
Prymnesium parvum	40 - 70
Acartia tonsa	300 - 1000
Artemia salinas	200 - 2500

Sea water characteristics: pH = 8.1 - 8.25, t = 16 - 18°C

Our work recommended a further in-depth assessment on possible changes in corrosion characteristics following ozone treatment. Such a study has been conducted but is not included here. These studies did suggest a change in corrosion characteristic but did not provide evidence for increased corrosion in a modern ballast tank.

Tests were intended to provide information as directly applicable to a full-scale arrangement as possible. Such a study was recommended and is scheduled to be undertaken during year 2001.

7. References

Anon. 1997. Heat treatment solution for infected ballast water. *MER-Marine Engineers Review*, p.15.

AQIS (Australian Quarantine and Inspection Service) 1993. *Ballast water treatment for the removal of marine organisms.* Report No.1. Ballast Water Research Series. Canberra, Australia.

Bolch, C.J. & Hallegraeff, G.M. 1993. Chemical and physical treatment options to kill toxic dinoflagellate cysts in ships' ballast water. *J. Marine Env. Engg*. 1, pp. 23-29.

Gollasch, S. 1997. *Removal of barriers to the effective implementation of ballast water control and management measures in developing countries*. IMO Report, 195 pp.

IMO 1997. *Guidelines for the control and management of ships' ballast water to minimize the transfer of harmful aquatic organisms and pathogens. IMO Assembly Resolution 868 (20).*

Jenner, H.A., Whitehouse, J.W., Taylor C.J.L. & Khalanski M. 1998. Cooling water management in European power stations. *Hydroecologie Applique*, 10 (1-2): pp. 1-225.

Oemcke, D.J. & van Leeuwen, H. 1998. *Potential of ozone for ballast water treatment*. CRC Reef Research Centre and the Ports Corporation of Queensland, 40 pp.

Oemcke, D. 1999. *The treatment of ships' ballast water*. EcoPorts Monograph Series No. 18, Ports Corporation of Queensland, Brisbane, 102 pp.

Rigby, G., Steverson, I. & Hallegraeff, G. 1991. Environmental problems and treatment options associated with the international exchange of shipping ballast waters. *The Nineteenth Australian Chemical Engineering Conference, Newcastle, Australia*, CHEMECA 91, pp. 221-230.

Rigby, G., Steverson, I., Bolch, C.J. & Hallegraeff, G. 1993. The transfer and treatment of shipping ballast waters to reduce the dispersal of toxic marine dinoflagellates. In: *Toxic Phytoplankton Blooms in the Sea,* Smayda, TJ & Shimizu, Y (eds). Elsevier Science Publishers B.V.

Rigby, G.R., Taylor, A.H., Hallegraeff, G.M. & Mills, P. 1995. Progress in research and management of ships' ballast water to minimise the transfer of toxic dinoflagellates. In: *Harmful Marine Algal Blooms,* Lassus et al (eds). Lavoisier, Intercept Ltd.

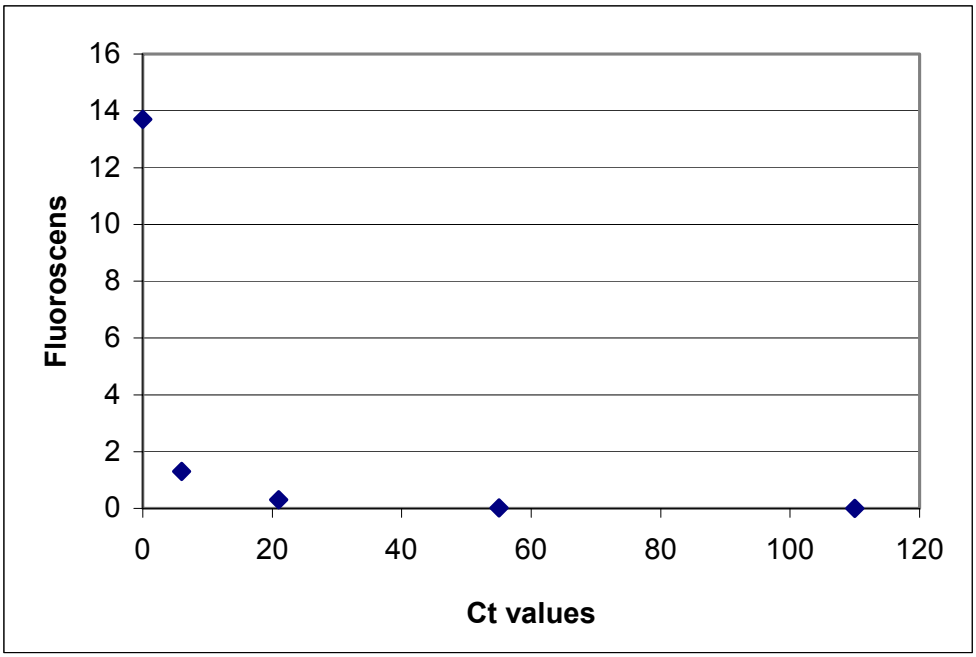

Figure 1. In vivo fluorescens measurements in test T3 with Gymnodinium galatheanum.

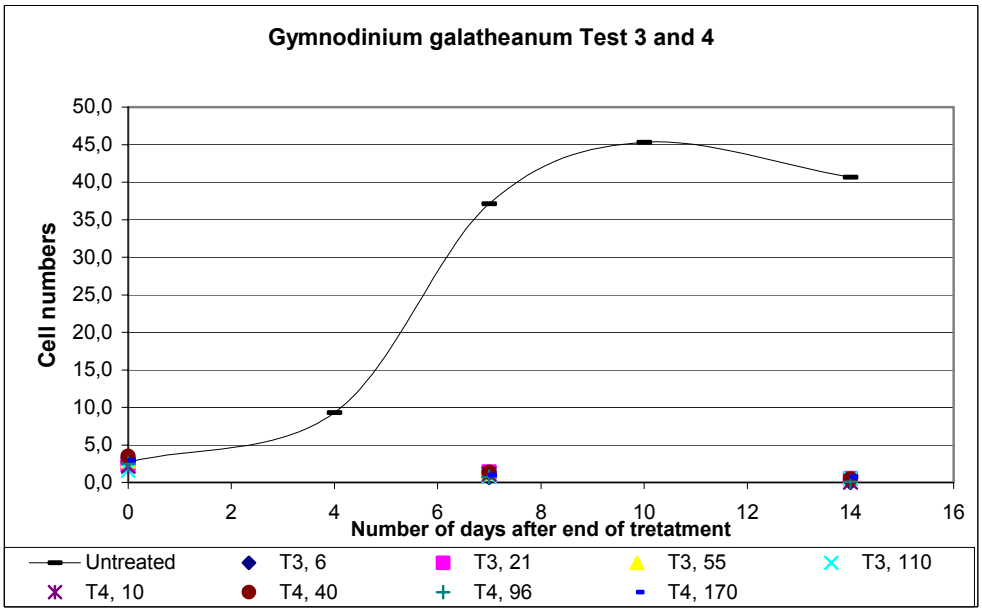

Figure 2. Regrowth after treatment of G. galatheanum cultures. Number in legend after test number shows Ct values.

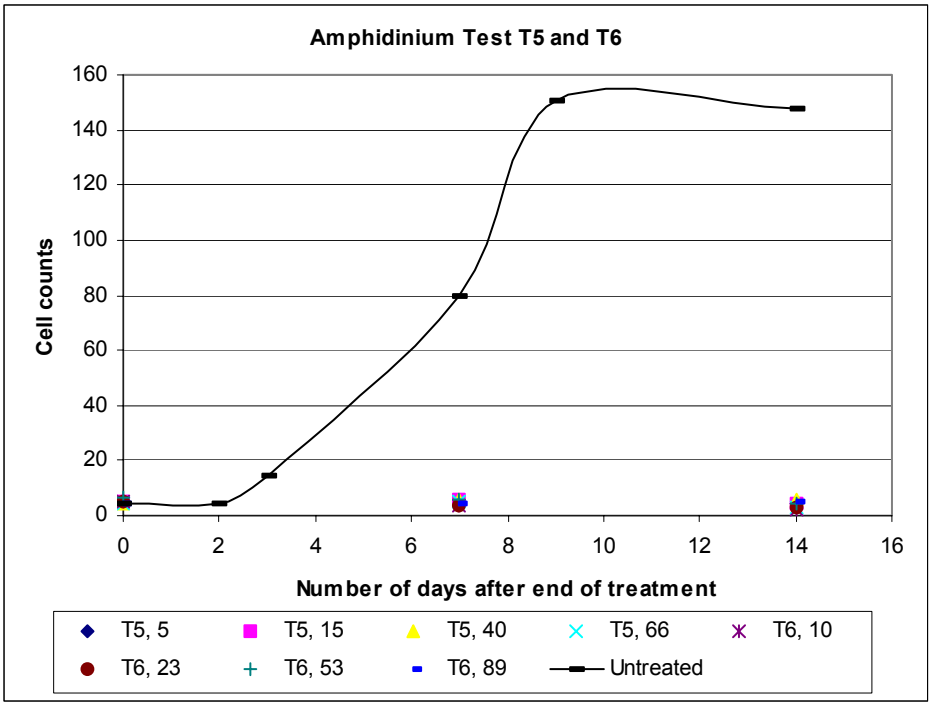

Figure 3. Regrowth after treatment with ozone**.**

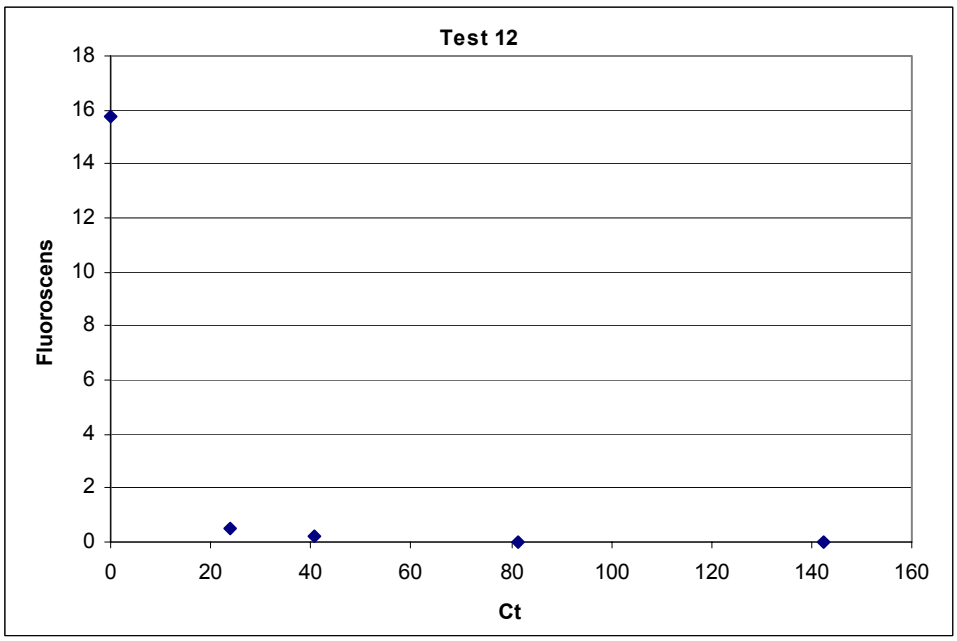

Figure 4. In vivo fluorescens measurements of Prymnesium cultures treated with ozone.

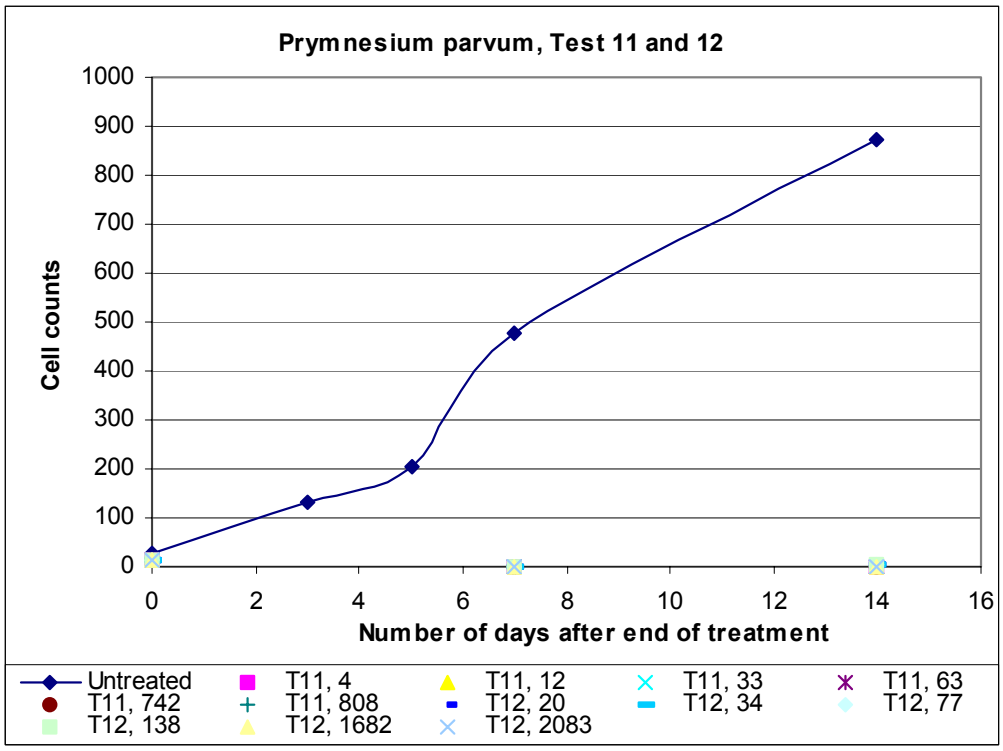

Figure 5. Regrowth of Prymnesium parvum, T11 and T12.

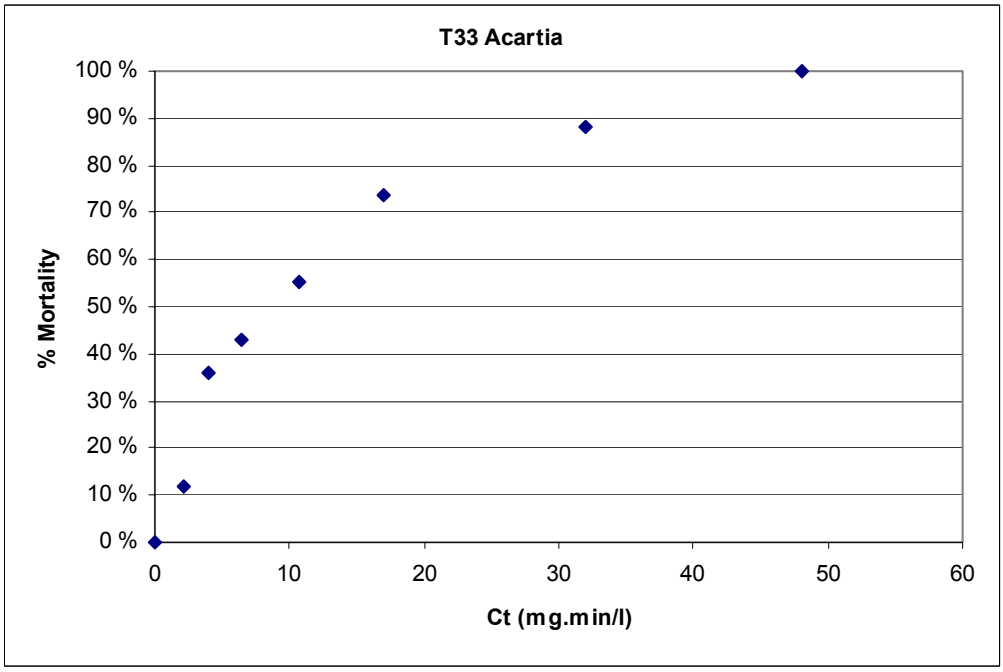

Figure 6. Acartia mortality with increasing contact time.

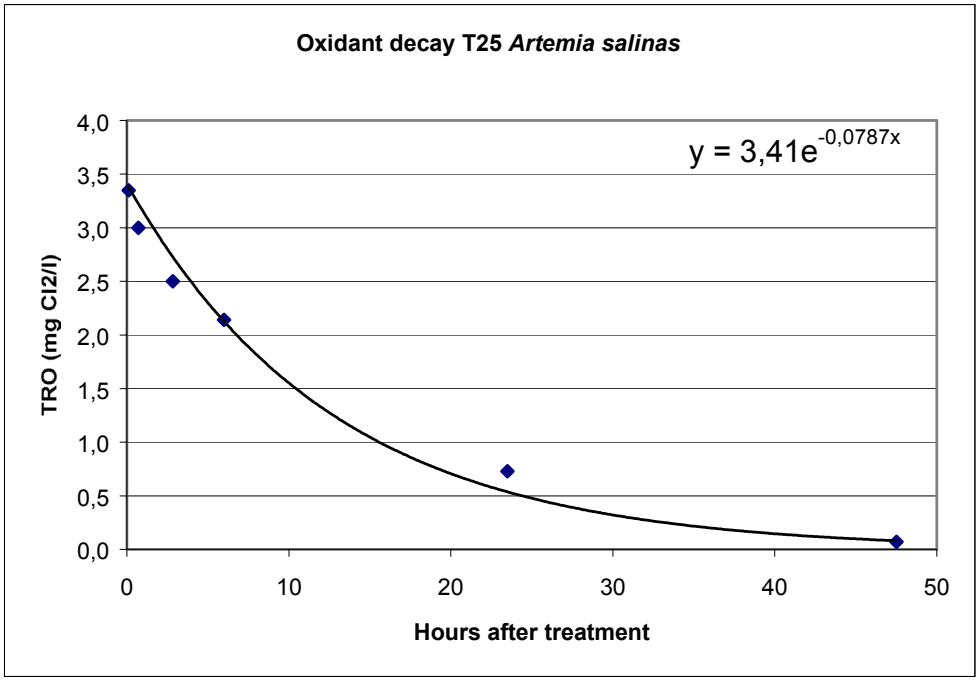

Figure 7. Decay of oxidant in Test 25 with Artemia. Initial TRO concentration was 5 mg Cl_2/l and density of newly hatched Artemias in test bulbs: 100 - 150/100ml.

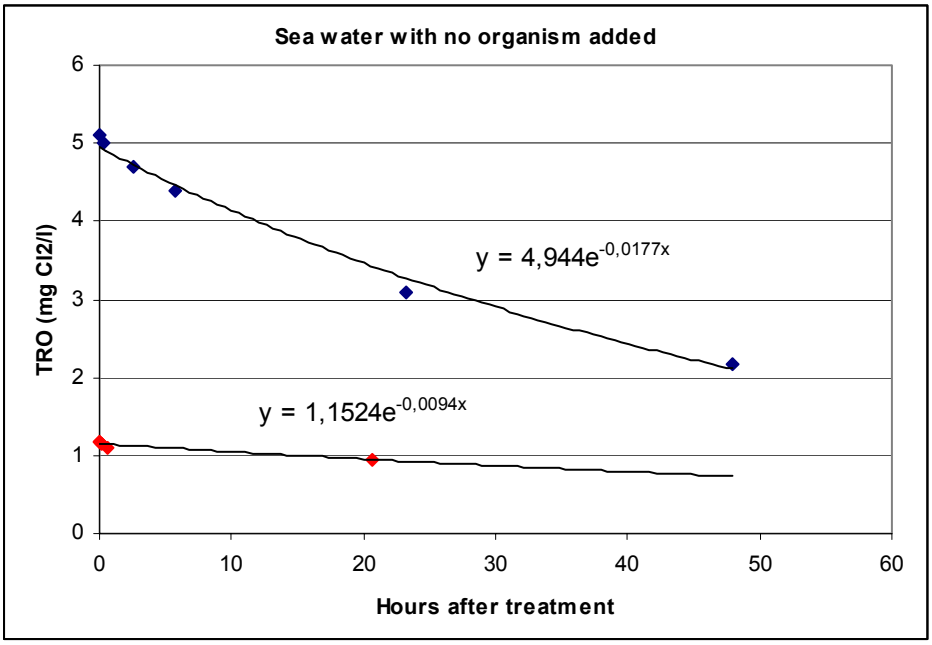

Figure 8. Decay of oxidant in two different batches of clean seawater. The first test was with initial TRO: 5 mg Cl_2/l. Sea water characteristics: salinity 32.5, pH 8.15, observable bacteria growth. Second test: initial TRO 1.16 mg Cl_2/l. Sea water characteristics: salinity 33.9, pH 8.2, no observable bacteria growth.

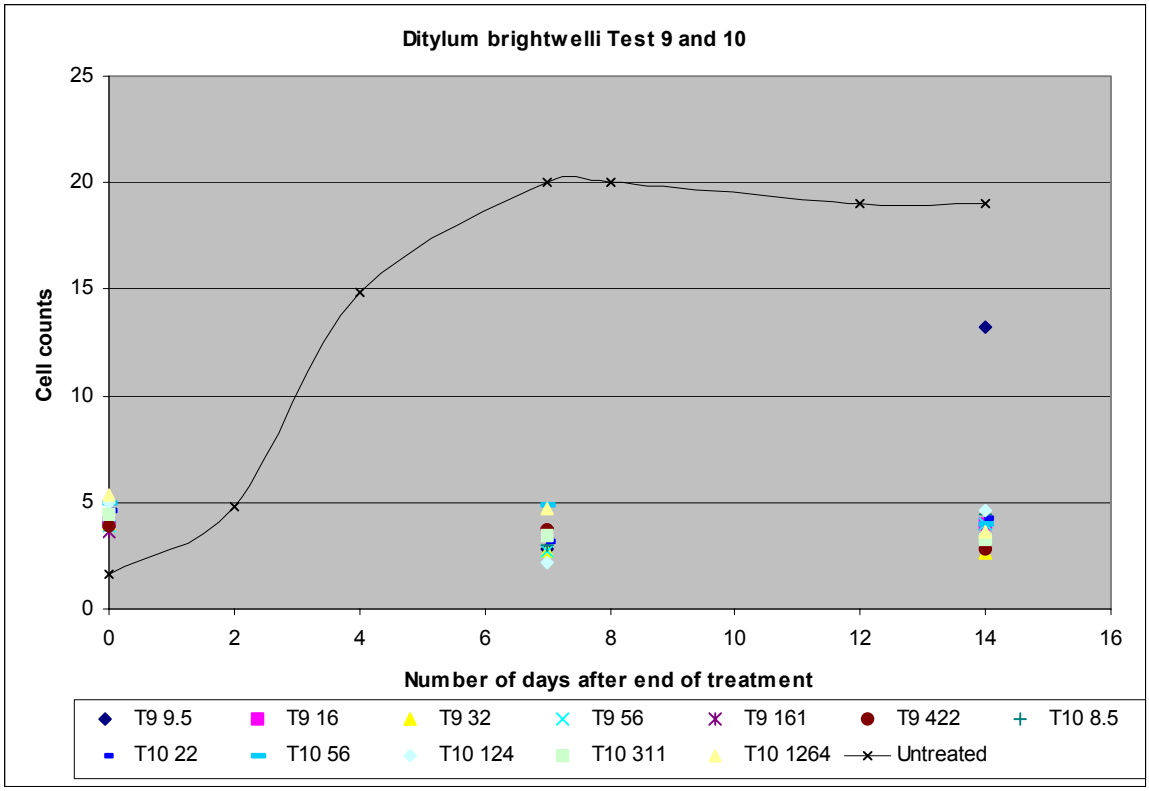

Figure 9. Regrowth of samples from test 9 and 10. Numbers in legend after test no. represent Ct value of sample.

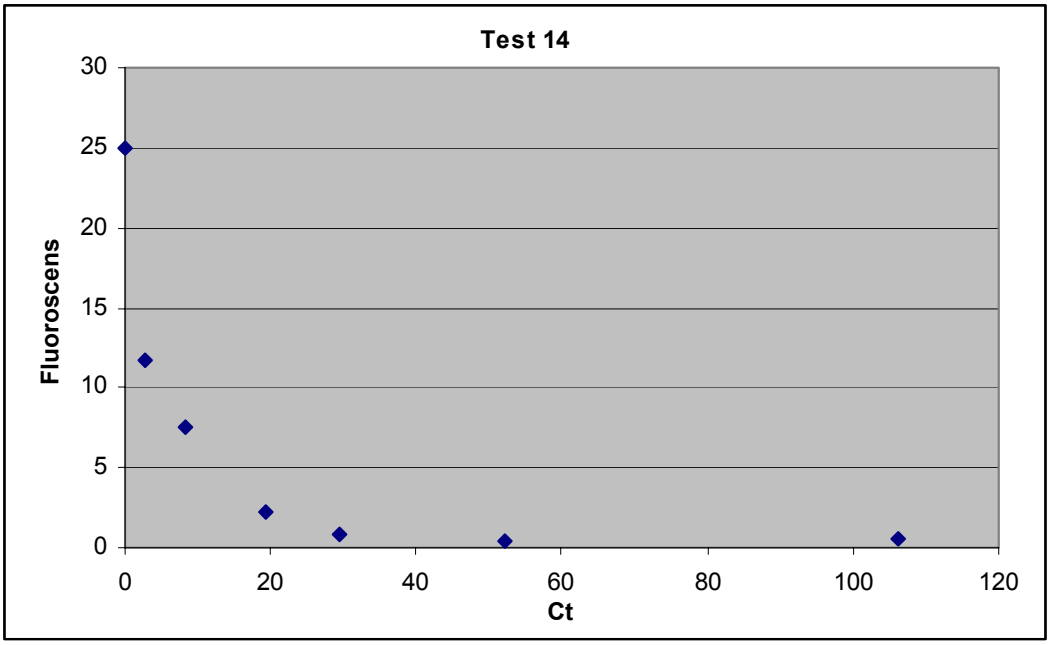

Figure 10. In vivo fluorescens measurements test T14.

Ballast Water Treatment by Heat – an Overview

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1. Treatment options being researched

This review covers the use of waste heat from a ship's main engine to kill harmful organisms in ballast water.

2. Timeframe of the project

The review covers work carried out by the authors over the past years as well as recent work reported by other workers.

3. Aims and objectives of the project

The main objective of this work has been to assess, evaluate and demonstrate the option of heating ballast water to a temperature sufficiently high to minimise or eliminate the translocation of harmful organisms.

4. Research methods

The pioneering work in this area was based on time-temperature laboratory studies and shipboard trials with *Gymnodinium catenatum* cysts and other phytoplankton algae by Bolch and Hallegraeff (1993); Rigby (1994) and Hallegraeff (1998) together with thermodynamic analyses of available heat from the main engine of the 140,000 DWT BHP bulk Carrier, *Iron Whyalla* by Rigby and Taylor (1993) to assess the various modes of heating. This work resulted in the development of an optimum arrangement for international voyages where the hot water from the main engine cooling circuit is flushed through each tank (Figure 1). Full scale ship trials were undertaken to confirm predictions (Rigby *et al*., 1998, 1999). In addition to these studies, a number of other options involving the recirculation of water through additional heat exchangers utilising waste heat and steam (in some cases) have been proposed.

Sobol *et al*. (1995) have proposed a system involving two plate heat exchangers using hot water from the ship's main engine, together with steam to heat the ballast water to 70^{O}C. This system has not been tested to date. Thornton (2000) has proposed a system involving an additional exchanger and

holdover tank of limited capacity to heat the water to 65^{O}C (or lower temperatures, if desired). Various alternatives utilising waste heat from the engine cooling system and substituting ballast water for external ocean water or heat recovered from jacket and charge air cooling have been suggested to provide the required heating. Pipework additions and modifications are required to facilitate the ballast water flows. The on-board system pumps ballast water from the bottom of the ballast tanks and returns it to the top, and relies on the ability of the design to pump and therefore heat all of the water through the treatment system. Although it is claimed that thermal stratification prevents mixing of the treated water within the ballast tank, the efficiency of heating and the extent of non-mixing has yet to be demonstrated for a particular level of overall treatment efficiency.

Mountfort *et al*. (1999, 2000), have examined the time- temperature relationship required to kill a number of model organisms. A demonstration sea trial using a recirculation system and additional heat exchanger has been carried out on the Union Shipping Ltd 29000 ton roll-on roll off vessel *Union Rotoma*. Two matching aft-peak tanks each having a capacity of 100m^3 were connected to a heat circuit whereby ballast water was pumped through a heat exchanger and returned to the tank. The exchanger was heated with available steam generated from two boilers heated by the ship's exhaust gas and an oil fired auxiliary boiler.

5. Results

The laboratory work carried out by Bolch and Hallegraeff (1993); Rigby (1994) and Hallegraeff (1998) identified that most phytoplankton algae tested including diatom *Skeletonema costatum*, dinoflagellates *Amphidinium carterae*, *Gymnodinium catenatum* and *Alexandrium catenella*, and the golden brown flagellate *Heterosigma akashiwo*, in the vegetative stage could be readily killed at temperatures as low as 35°C and treatment times in the range of 30 minutes to several hours. In addition, significant mortality was also achieved with *Gymnodinium catenatum* and *Alexandrium catenella* cysts using longer incubation times (several hours) at temperatures as low as 35 to 37.5°C, with total mortality achieved at 38^{o}C after 4.5 hours.

Two shipboard trials on the *Iron Whyalla* were undertaken between Port Kembla in New South Wales, Australia and Port Hedland in Western Australia and between Mizushima in Japan and Port Hedland. On-board microscopic observation of heated water samples (Rigby *et al*., 1998, 1999), showed that none of the zooplankton (mainly chaetognaths and copepods) and only very limited original phytoplankton (mainly dinoflagellates) survived the heat treatment. The original organisms were reduced to flocculent amorphous detritus. Subsequent culturing efforts on the heated ballast tank samples only produced growth of some small (5μm) diatoms and colourless ciliates which are considered to be of little consequence. Although no toxic dinoflagellate cysts were present in the tanks, based on earlier laboratory experiments, it is probable that these would have been effectively killed by the temperatures achieved during the heating trial, since essentially all of the water reached 37-38^{O}C.

In addition to the effects of heating, this approach is also very effective in exchanging the original ballast water at the same time. Observation showed that 90-99% of the original plankton taken on during ballasting was removed by flushing.

Heating of ballast water as described above also has the added advantage that organisms contained in sediments would also be subjected to these temperatures (in fact higher temperatures are experienced at the bottom of the tanks where the ballast water is pumped into the base of the tanks).

The heating/flushing option is best suited for international voyages where there is adequate time to heat all of the tanks. It would be less appropriate for bulk carriers on domestic coastal trips or on international routes involving short voyage times, as there would be insufficient time to complete the heating operation in all tanks. Similarly, ballast water heat treatment may be less effective for ships traversing areas where ocean temperatures are very low (less than 15 to 20^{O}C), as this could increase the heating time or reduce the final temperature.

Trials carried out by Thornton (2000) using an on-board system (operating at $20m^3/h$ for 18 hours) with one of the 350 tonne ballast tanks on the Australian bulk carrier MV *Sandra Marie* on a voyage from Sydney to Hobart in May 1997 showed significant plankton mortality (estimated at 80-90% successful) in the treated tank. Phytoplankton was dominated by the dinoflagellates *Ceratium tripos*, *Protoperidinium*, the diatom *Chaetoceros,* the flagellate *Dictyocha*, while the zooplankton was dominated by copepods and larval molluscs (Hallegraeff, in Thornton 1997).

From the samples collected it was not possible to determine whether the residual living plankton material in the treated tank resulted from not treating some of the water, or perhaps whether the treatment conditions (50 seconds at 50^OC) were insufficient for complete mortality of some plankton.

The laboratory work of Mountfort *et al*. (1999, 2000) concentrated on the free-swimming or dispersive forms of the model organisms (seaweed *Undaria pinnatifida,* mollusc *Crassostrea gigas* and starfish *Coscinasterias calamaria*), which were considered most likely to be spread through the entirety of a ballast tank. It was concluded that effective treatment would be one that is either long ($\geq$ 16 h at $\leq 36^OC$), medium (10 min to 16h at 36-45^OC) or short duration ($\leq$10min at $\geq 46^OC$).

Based on this work, and discussions with the Union Shipping Ltd it was concluded that a plant could be built to accommodate a medium term heat treatment on the 29000 ton Roll-On Roll Off vessel *Union Rotoma*. Two matching aft-peak tanks each having a capacity of $100m^3$ were connected to a heat circuit whereby ballast water was pumped through a heat exchanger and returned to the tank.

The sea trial undertaken by Mountfort *et al*. (2000) between Wellington and Auckland where the tank temperature increased from 24^OC to 42^OC over a 10 hour period, demonstrated that all of the seeded *C. calamaria* starfish larvae were killed. In the control tank after 70h, numbers of larvae and zooplankton had decreased to just over 60% of the original population.

6. Conclusions and recommendations

Heat treatment offers one of the few practical treatment options available to the shipping industry that is likely to be able to eliminate many of the harmful organisms in ballast water in a cost effective way. Several design options are possible for various ships, voyages and organisms. The techniques are especially important for consideration in new ship designs, but also offer immediate options for some existing ships and voyages with minimum cost implications compared to other alternative options that are not likely to achieve the same level of control. Heat treatment also shows promise for being able to eliminate many of the problems with harmful organisms contained in difficult to remove tank sediments.

7. References

Bolch, C.J. & Hallegraeff, G.M. 1993. Chemical and physical treatment options to kill toxic dinoflagellate cysts in ships' ballast water. *J. Marine Env. Engg*. (1) pp. 23-29.

Hallegraeff, G.M. 1998. Transport of toxic dinoflagellates via ships' ballast water: bioeconomic risk assessment and efficacy of possible ballast water management strategies. *Mar. Ecol. Prog. Ser*. 168 pp. 297-309.

Rigby, G.R. & Taylor, A.H. 1993. *Shipping ballast water-heating as a means of destroying toxic marine organisms*. BHP Research Tech. Note. BHPR/ENV/TN/93/005. 7pp.

Rigby, G.R. 1994. Possible solutions to the ballast water problem. *AQIS Ballast Water Symposium Proceedings, Canberra, 11-13 May*.

Rigby, G.R., Hallegraeff, G.M. & Sutton, C.A. 1998. Novel ballast water heating and sampling trials on the BHP ship MV *Iron Whyalla*. *AQIS Ballast Water Research Series, Report No.11*.

Rigby, G.R., Hallegraeff, G.M. & Sutton, C.A. 1999 Novel ballast water heating technique offers cost-effective treatment to reduce the risk of global transport of harmful marine organisms. *Mar. Ecol. Prog. Ser.* 191 pp. 289-293.

Sobol, Z., Wladyslaw, K. & Bohdan, W. 1995. *System for destruction of microorganisms occurring in ballast waters*. Paper presented at IMO MEPC 38.

Thornton, G. 1997. *Ballast water trial on M.V. Sandra Marie*. 11pp.

Thornton, G. 2000. *Ballast water decontamination-using heat as a biocide*. Paper presented at Sea Australia Conf. Sydney, Aust. 1-3 Feb.

Mountfort, D.O., Dodgshun, T., Gibbs, W. & McCallin, B. 1999. Towards a feasible heat treatment system for ships' ballast water. *Proc. Workshop on Ballast Water Problem-Where to from here? Ports Corp. of Qld*. EcoPorts Monograph Series. No. 19. July.

Mountfort, D.O., Hay, C., Taylor, M., Buchanan, S. & Gibbs, W. 2000. Heat treatment of ship's ballast water: development of a model based on laboratory studies. *J. Marine Env. Engg*. In press.

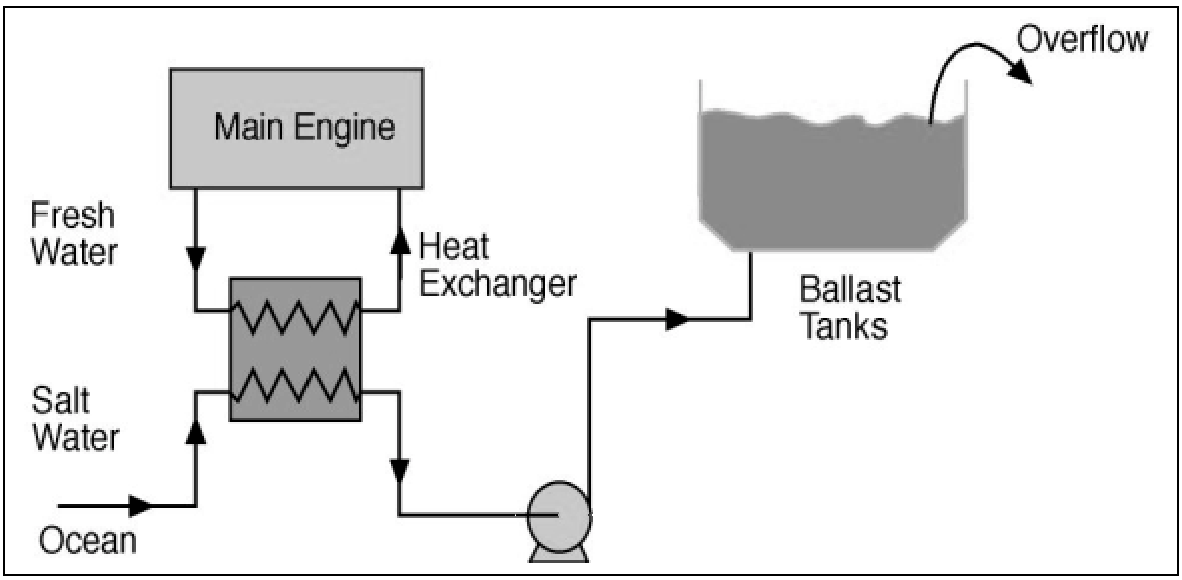

Figure 1. Heating circuit used to simultaneously flush and heat ballast water on the Iron Whyalla (Rigby et al., 1998, 1999).

On Board Treatment of Ballast Water (Technologies Development and Applications)

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1. Treatment options being researched

All treatment options will be examined and analysed at the initial stage of the project, six of which will be further investigated in laboratories and subsequent sea trials. The six treatment methods are:

- High temperature treatment
- Biological de-oxygenation
- Combination of UV/US
- Ozone treatment
- Hydrogen peroxide treatment (Oxicide method)
- Hurdle technology

2. Timeframe of the project

Three years, commencing from the beginning of 2001.

3. Aims and objectives of the project

The aims and objectives of the project are:

- To investigate methodologies and technologies for preventing the introduction of nonindigenous 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 on board ballast water treatment methods which have a minimum impact on ship operations.
- To produce guidelines for crew training and criteria for selecting an appropriate ballast water management method.

Main outputs of the project:

- Comprehensive documents with detailed description of individual treatment methods. The documents will present all facts necessary for ship operators to make a rational choice of ballast water management strategy.
- Treatment equipment, system designs and design tools. The equipment and systems developed in this research will be ready for commercial application on the completion of the project.
- Reports and recommendations to the European Commission, ICES, IOC, shipowner associations, and other public domains, including regional bodies such HELCOM, OSPARCOM and BBCMBS, and further to influence IMO regulations through governmental authorities. The reports and recommendations will address limitations of ballast water treatment onboard ships, environmental, economic impacts, risk and safety issues.

4. Research methods

The project consists of 6 work packages from state of the art research to technical development, laboratory test/demonstration, full-scale sea trials and results dissemination and recommendations.

Research consortium: 25 partners from Europe include expertise from academic, marine consultants, research institutes, equipment manufacturers, classification societies, shipowner associations and shipping companies.

5. Results

The following presents the results of a Feasibility study on a thermal plant installation on an oil tanker.

The main objective of the feasibility study is to conduct a preliminary design of an apparatus that will perform rapid heat treatment for the incoming ballast water of an oil tanker. Based on the results of this study and design, a cost analysis is performed along with conclusions and recommendations for further development of such a system.

Vessel description

The oil taker used in this study is *Seaprincess* owned by Thenamaris. The table below lists the main technical data of the vessel relevant to the study.

Table 1. Seaprincess technical data

Private built:	SAMSUNG CORP	**Beam:**	47,80 m	**No. of ballast tanks:**	14 SBT
Date built:	1996	**Draft:**	22,80 m	**98 % capacity:**	168,131 m3 1,057,512 bbls
Class:	ABS	**Products:**	Crude oil	**Coiled:**	YES
DWT:	147,834 t	**Number of segregations:**	3	**Cargo pumps:**	3 x 3500 m3/h
GRT :	80,637 t	**Main engine:**	HUND MAN B & W / 6S70 MC(MKVI)	**Inert Gas System:**	Yes
NRT :	45,963 t	**Double hulled:**	YES	**Segregated Ballast Tanks:**	Yes
LOA:	274,118 m	**No. of cargo tanks:**	12 + 2 SLP	**Crude Oil Wash:**	Yes

To perform the proposed thermal treatment process for sterilizing the marine organisms, heat exchanger systems are required. The main heat sources on board this vessel are from the auxiliary

boilers and the main engine. The process of heating the ballast water could be carried out with three options:

1. During ballasting at the cargo discharge port.
2. During the voyage, between ports.
3. During de-ballasting at the cargo loading port.

The second scenario is eliminated due to several disadvantages of mechanical complicity and large of amount of heat required when ballast water circulation is required. The third option is also put aside at the moment because port authorities may require sampling of ballast water before giving permission for discharge. Thus, the first option remains where the most demand of steam onboard occurs, as ballast water is taken in while the cargo oil is being discharged.

With the use of heat exchangers during the ballast intake process, ballast water must be heated to a specific temperature for the treatment and then cooled to a certain temperature before it enters the ballast tanks. Nevertheless there are some difficulties that must be solved for a successful design. High flow rates during ballasting will impose a major challenge to the design because the heat available is limited. Another obstacle on this design is the ambient seawater temperature. The system designed must be able to work well with a very low sea water temperatures.

Temperature selection for the rapid ballast water heat treatment

Temperature selection for this rapid seawater treatment is also an issue. Based upon the relevant literature review there are several lethal temperatures which have been selected for each of the variations of ballast water heat treatment. According to the marine scientists who have studied the treatment option, the lethal temperature is a function of time that the organism will be exposed, the species of organisms that are to be killed and the heat available from vessels. From a previous study for a treatment option during the voyage, non-indigenous organisms were exposed to 35^{o}-50^{o}C for several minutes. In the case of treating the water during ballasting the holding time under a certain temperature is only 3-4 seconds; so a higher targeted treatment temperature must be applied.

All marine organisms consist of cells incorporating water in a larger extend as well as a plethora of biological macromolecules. The problems concerned this study mainly concentrate on marine micro-organisms examples of which are Volvox 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 targeted temperature around 65^{o}C for a period of a few seconds is most certainly going to denature the proteins thus destroying the micro-organisms (and all other life forms!). Denaturation of proteins is a biological process shown in everyday's life, such as boiling an egg. Denaturation of protein often 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 intermolecular bonding in a protein system. Figure 1 shows the phenomenon of denaturation.

Treatment option

From the above analysis, the following system description is derived. Figure 2 presents the basic idea of a plant that is able to perform rapid heat treatment at a temperature with an efficient and economical consideration.

Seawater enters the vessel through the sea chest and passes from the ballast pump (1); then it goes to a pre-heater (2), which acts as an economizer. The steam heater (3) provides the heat energy to the system. Inside the steam-heater sea water is heated to a targeted temperature (65^{o} to 70^{o} C). From the steam heater it goes back to the pre-heater where treated water donates its thermal energy to the

incoming water. Two benefits are brought by with the pre-heating arrangement. Firstly, the thermal energy required is minimized as the inlet water is pre-warmed by the treated water. Secondly, the performance of the treatment system and heat energy required is independent of the outside sea water conditions. Because the temperature difference between the inlet and the outlet of pre-heaters remains a constant of 10 ^{o} C. Thus great economy can be achieved and no thermal stress issue as the treated water leaves the system with a temperature only few degrees higher than the sea water temperature. During deballasting there is a bypass pipe (4) that connects the ballast tanks directly to the pump that sends the water to the overboard discharge.

The design of the actual system is far more complicated than the conceptual plan and in order to be compatible with the specified vessel, other known as "tailor-make" design, several things must be taken into consideration.

Ballast capacities & arrangement considerations for the plant onboard M/T Seaprincess

The heat treatment of ballast water will be performed during the ballast take-in before the seawater enters the ballast tanks. As shown in Figure 2 the position of the heat exchangers is after the ballast pumps. During de-ballasting the water from the ballast tanks will be by-passed from the heat treating system and sent to the overboard discharge directly.

The selection of the heat exchangers relies on the flow rate and the type of fluids passing through them. "M/T Seaprincess" is equipped with two ballast pumps having a capacity of 2000m^3/h each. During the ballast take-in operation, which is done in parallel with cargo discharge, only one ballast pump is used, therefore seawater enters the ballast tanks in a rate of approximately 2000 m^3/h. Although this flow rate varies with the ship's operation, it should be taken as a targeted flow rate of the system design.

Temperatures

In this system, treatment will commence inside the heat exchanger(s) where the seawater has been raised to 55^{o}C. The targeted temperature of 65^{o} & 70^{o} C must be achieved inside the steam heaters and will eventually kill/inactivate most of the unwanted living organisms in the water.

As discussed early, energy required for the treatment system is independent of sea water temperature. However, sea water temperature does affect the size of the treatment system. The seawater temperature chosen as input to the system is within 5^{o} to 8^{o} C, which is lower than the temperature assumed from ship manufactures for different system designs on ships.

Available energy

A crucial factor that may limit the performance of the treatment system is the availability of thermal energy onboard "M/T Seaprincess". The main energy supply during ballasting and cargo handling operations in this vessel comes from the two auxiliary boilers that produce 2 × 40,000 = 80,000 kg/h saturated steam at 16 bars. The steam requirements during cargo discharge vary according to the pumping rate, the quantity and the temperature that the cargo oil. The three steam turbine driven cargo pumps consume 3 × 18,468 = 55,404 kg/h, plus the heating coils that maintain the temperature of the crude oil by consuming no more than 23,390 kg/h of steam. A small fraction of steam is also required for other purposes on board the vessel during cargo discharge and ballasting operations. Of course all the above are theoretical values that may hardly used in the ships' normal operations. The average steam consumption for a fully loaded vessel discharging dense crude in a relative cold outside temperature oil with full pumping power is about 70,000 to 75,000 kg/h of saturated steam. The available energy left for the proposed ballast water treatment is between 5,000 and 10,000 kg/h saturated steam. The amount of steam available for treatment will continuously increase as cargo oil comes out from the cargo tanks.

If the ballast water treatment procedure were to be done non-simultaneously with the discharge of the cargo oil then almost all the energy from the two boilers would be available for the treatment. This

would be the most favorable scenario, but the procedure is different to realise in practice. The ballast take-in process with full tanks requires approximately 28 hours; it is a time-consuming, non-earning process that owners and operators prefer to carry out at the same time as cargo discharge. Apart from that there are other reasons why ballasting and cargo discharge are done simultaneously. During cargo discharge the vessel's displacement is continuously altered, leading to an emergence that is counterbalanced by ballast water. This is done in order to maintain the structural integrity of the hull and to keep the propeller and rudder immersed for immediate departure after the discharge of crude oil. This is also done to take advantage of the gravity forces and allow the tanks, which are under water line to fill with ballast water without the use of the ballast pumps. Therefore, the ballast treating procedure must be accomplished in parallel with cargo discharge and consume only the remained steam.

Heat exchanger selection

The heat exchangers used in the systems are designed for two purposes. The first stage of heat exchangers works as economizers transferring heat from the treated water to the incoming seawater. The second bench of steam heat exchangers performs as heaters by exchanging thermal energy between the pre-heated seawater and the saturated steam from the auxiliary boilers. Two most typical types of heat exchangers in the marine industry, shell & tube and plate heat exchangers, could serve the purposes of the treatment system.

The effort to locate any heat exchangers onboard "M/T Seaprincess" would resemble the requirements for the proposed ballast treating system. The existing system could not be utilized for this purpose. There is only one water heater for general cleaning purposes but it is designed for a small flow rate and different temperatures.

System description

Based upon the characteristics of the ballast system and the requirements of the treatment system, the plate heat exchanger (PHE) models are recommended by a heat exchanger manufacturer for both the pre-heating and heating of seawater. Figure 3 shows the arrangement of the thermal treatment system in combination with the ballast system.

Heat exchanger thermodynamic calculation shows that two pre-heaters connected in parallel, and owed by three steam heaters connected again in parallel are required perform the treatment process. The ballast water system remains unchanged except for adding a bypass water line that connects ballast pumps with a treatment system. Additional pipe work is installed on board to distribute steam from the auxiliary boilers to the three steam heaters. During deballasting the system is isolated by closing the appropriate valves and the process takes place undisturbed.

In considering the amount of steam available for the heating process, the treatment flow rate is restricted to 1231m^3/h and the maximum treatment temperature is chosen as 65 ^{0}C. The required amount of steam is 24,999 kg/h (i.e. 3 heaters × 8,333 kg/h). The steam consumption exceeds the available steam of 8,000 kg/h during a full cargo discharge so the designed treatment capacity 1231m^3/h can not be achieved until the cargo discharge steam requirement is reduced to 55,001 kg/h (i.e. 80,000 – 24,999). However, during the peak demanding period of steam for cargo discharge, high ballasting rate is not required. Thus, ballasting with the thermal treatment can commence during cargo discharge at lower flow rates and reach gradually the systems design flow rate. During cargo discharge part of the ballasting procedure is carried out by gravity, so by adjusting the valve openings the optimum flow rate is achieved at every instant.

Space requirements and positioning of the system

The main components of this system are the 5 heat exchangers with the following dimensions:

2×pre-heaters = 2× (4.565×1.150) = 10.5 m^2

3×steam heaters = 3× (1.114×0.470) = 1.57 m^2

Total space required = 12.07 m^2.

Additional spacing for piping, heat exchanger gapping and all the other equipment involved (valves, monitoring systems etc) is necessary, and needs to be designed according to the mandatory legislation from the Classification Societies. As a thumb rule, space necessitated for a heat exchanger system is about at least twice the space of the heat exchanger. This space on the M/T Seaprincess has to be located by a cooperation between marine engineers and naval architects, in order to make the necessary conversion and installation. A quick look in the blueprints of the vessel revealed that adequate space is available inside the pump room. In the case of a new-building the above will not be an issue at all.

Capital and Running Costs

Capital costs

The capital cost of the system includes the heat exchangers, piping required, valves, monitoring systems and other components. Due to the limitation of information for the exact system requirements (e.g. piping length, valves required and etc) for the vessel in question, the capital cost cannot be estimated precisely. However, the major components and most expensive parts of the system are the heat exchangers estimated at:

2× pre-heaters = 2× £65,500 = £131,000

3× steam heaters = 3× £23,500 = £70,500

Total cost for the 5 heat exchangers is £201,500. In addition to the above, another major cost is the labor for installation and machinery space conversion. This will vary from yard to yard. The entire capital cost should be minimized in the case of a new-built ship.

Running costs

Running costs for the system include fuel consumption of the auxiliary boilers and maintenance (divided into work-hours and spare parts). In more detail, fuel consumption will vary with the rate and quantity of ballast water. Fuel consumption is estimated for the worst case (8 ^oC seawater temperature, heavy ballast condition and 1231 m^3/h flow rate). For such ballasting conditions, the total capacity of 56,654.5 m^3 will require 46 hours to fill at the flow rate of 1231 m^3/h. The fuel consumption by the boilers in producing the required steam (24,999 kg/h) is 1562 kg/h. For the total ballast heat-treatment the fuel required is 46 hours × 1562 kg/h = 71.852 tonnes of fuel (380 cSt). Taking the bunk price at US$160/tonne, it gives 11,496 US$. This is equivalent to US$0.16 per tonne of ballast water. The price of treatment is not so attractive but compared with the total fuel requirements of this vessel it is minute. Furthermore, heavy ballast condition is not a common practice for the vessel's operation and it is only used under extreme weather conditions to maintain stability. The normal ballast requirements vary from 55% to 70% of the full load and thus reducing the cost of ballast water treatment by 30% to 45%.

Disadvantages of the system

Such a ballast treatment system has never been designed or tested before, any disadvantages have not been reported. Several problems may need further investigation:

- The titanium material is used for heat exchangers which may have extensive deposit on plates when seawater is above 50^oC.
- The design requirements limit this pressure drop to 2.5 bars for each pass. From the results of calculation, the pressure drop in the pre-heaters is 2.42-2.43 bar and it is 3 bar for the steam heaters. Due to the above data further adjustment of the ballast valves or modification of the entire ballast-piping network may be considered.
- At start period, the system needs to be filled with seawater and isolated from the rest of ballast network. The water must be re-circulated with the aid of ballast pumps until all the heat

exchangers reach their target temperatures. After that the valves must be gradually open and allow seawater to pass though the system; then the full scale treatment can commence. It is estimated that this initial stage takes about hour.

Ballast water treatment during discharge

Treating ballast water during deballasting process was discussed early. This case had been omitted due to the following reasons.

Release of heated water from ballast tanks may be of environmental concern because the hot water would be lethal to organisms living immediately near the vessel. Organisms located further away would not encounter lethal temperatures but would, nevertheless, be subjected to additional stress and elevated oxygen requirements; at the same time, available oxygen would be reduced because warm water holds less oxygen than cold water. And also some port authorities may need the ballast water be treated before the ship entering their ports.

Thermal releases from ships are not currently regulated, although other sources are controlled. Legislation related to thermal releases is directed primarily at power plants that use local water to cool their machinery and continually release heated water back into a river or estuary.

By examining the results of the designed treatment system, it is clearly shown that most of the heat in the treated ballast water is dissipated in the pre-heaters. The temperature of the water leaving the system is only 9.2^{o}C to 9.8^{o}C higher than that of sea water. Therefore, it is likely that the deballasting water treating process can be accomplished with minimal environmental impact. Actually, if that is the case, it would have an advantage over the treatment during ballasting process as all steam from the auxiliary boilers would be available for use.

If the system is proved a effective and reliable option for ballast water treatment and accepted by internationally recognised organizations, treating ballast water after entering to a port should not be an issue.

6. Conclusions and recommendations

A preliminary feasibility study on the thermal treatment of ballast water has been performed. It has reached the conclusions that the proposed high temperature treatment is an efficient and effective method for on board ballast water treatment. Further investigation on using the sea water cooler on board as the pre-heat exchanger will be conducted and also to re-design the ballast system, in order to optimise flow rates of the ballast pumps, ie to keep one pump with a full design capacity of 2000 m^3/h and reduced the other one's capacity to suit ballast treatment purpose. The measure of using sea water cooler and a small size ballast pump will reduce the system's capital and running costs significantly.

7. References

National Research Council 1996. *Stemming the Tide: controlling introductions of non-indigenous species by ships' ballast wate*r. National Academy Press, Washington D.C.

Anon. 1997. Heat treatment solution for infected ballast water. *MER-Marine Engineers Review*, p. 15.

Australian Quarantine & Inspection Service 1993. *Ballast Water Management*. Ballast Water Research Series Report No. 4. AGPS, Canberra.

Australian Quarantine & Inspection Service 1993. *Ballast Water Treatment for the Removal of Marine Organisms.* Ballast Water Research Series Report No. 1. AGPS, Canberra.

Australian Quarantine & Inspection Service 1993. *Shipping Ballast Water Trials on the Bulk Carrier Iron Whyalla*. Ballast Water Research Series Report No. 3. AGPS, Canberra.

Australian Quarantine & Inspection Service 1994. *Ballast Water Symposium Proceedings*. AGPS, Canberra.

Australian Quarantine & Inspection Service 1993. *Ballast Water - Technical Overview Report*. Ballast Water Research Series Report No. 2. AGPS, Canberra.

Gutteridge, Haskins & Davey Ltd. 1992. *Report on Ballast Water Treatment for the Removal of Marine Organisms*.

Bolch, C.J. & Hallegraef, G.M. 1991. *Chemical and Physical Treatment Options to Kill Toxic Dinoflangellate Cysts in Ships Ballast Water*.

McGeorge, H.D. 1995. *Marine Auxiliary Machinery*. 7th Edition, Utterwoth-Heinneman.

Reeds, J. 1999. Hull of a Problem. *Geographical: The Magazine that Explores the World,* p.26

Australian Minerals and Energy Environment Foundation. *The Global Response to the Ballast Water Issue: Implications for Australian Bulk Explorers.* AMEEF Occasional Paper Number 10.

King, G.A.B. 1976. *Tanker Practice - the Construction Operation and Maintenance of Tankers*, 6th Ed. Stanford Maritime Limited, London.

Eastop, T.D. & McConkey A. 1993. *Applied Thermodynamics for Engineering Technologists*, 5th edition. Longman.

Alfa Laval 1996. *Plate Heat Exchangers vs. Shell & Tube Heat Exchangers for Marine and Power applications*. Technical Information (19-1-1996)

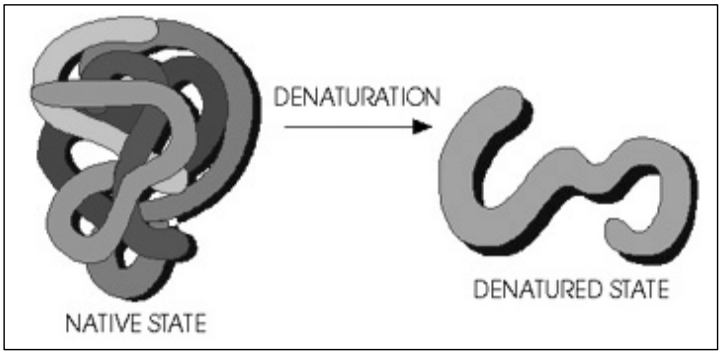

Figure 1. Organism denaturation

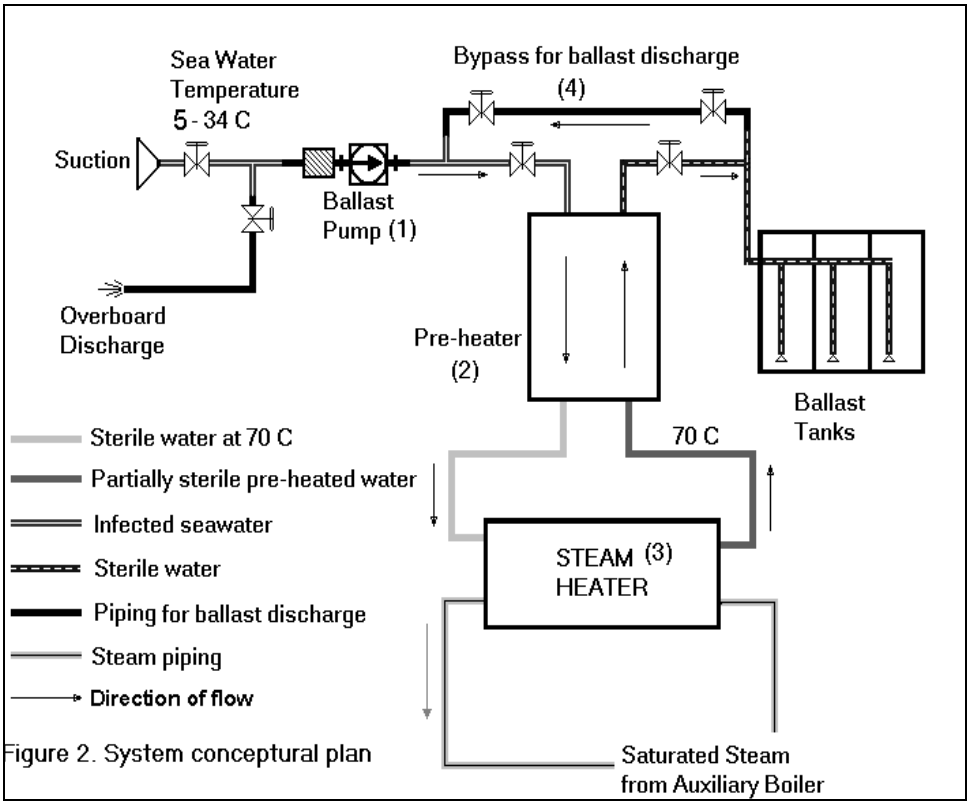

Figure 2. System conceptural plan

Figure 2. System conceptual plan.

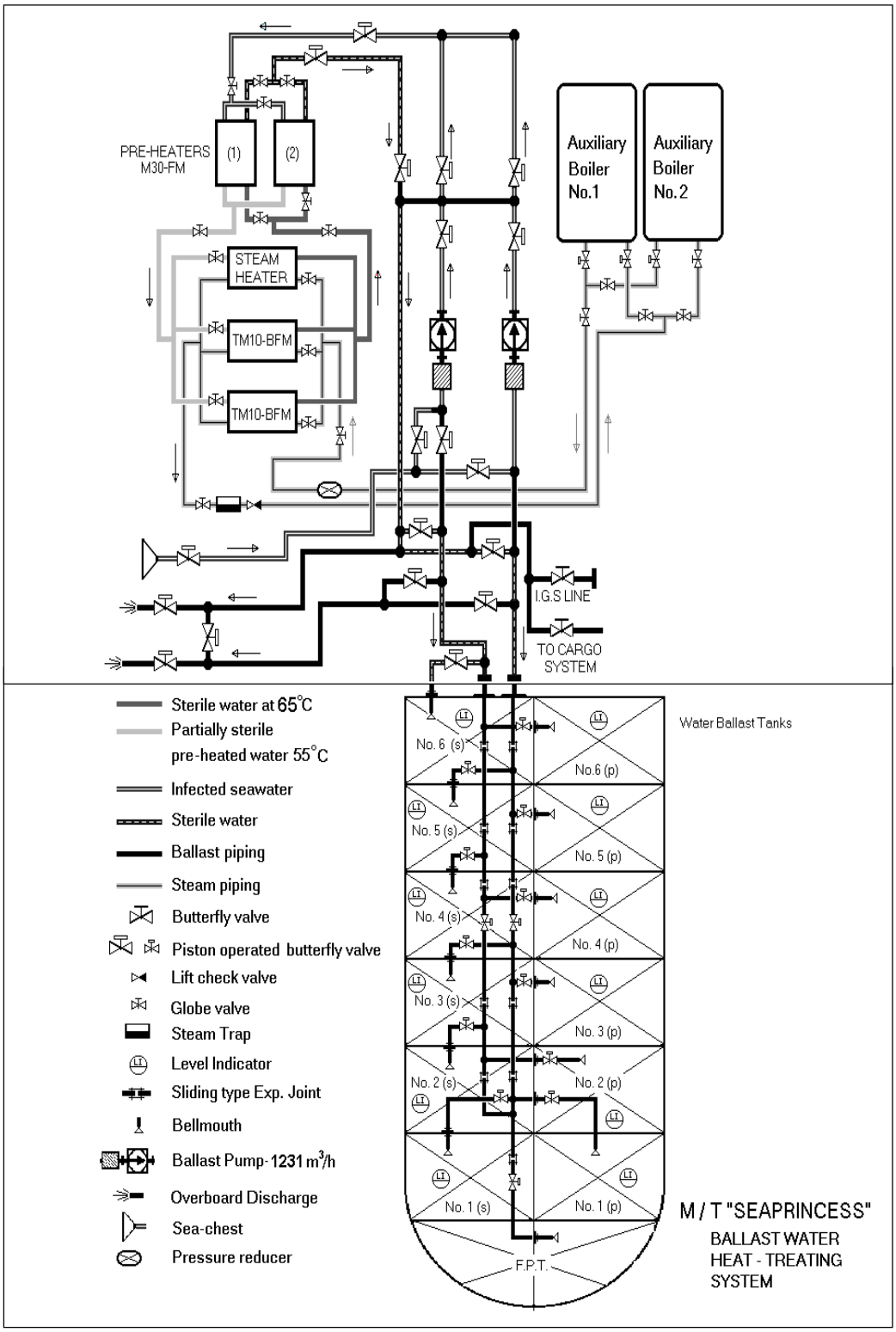

Figure 3. M/T Seaprincess ballast water heat treating system

Ballast Water Treatment by Heat - New Zealand Laboratory & Shipboard Trials

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1. Treatment options being researched

This paper reviews research on the use of heat to kill organisms in ships' ballast water.

2. Time frame of the project

This paper review and presents research results obtained since 1998.

3. Aims & objectives of the project

In the past decade substantial advances have been made in the area of heat treatment of ballast water by Australian workers (1,4-6). The aims and objectives of this project are to:

- Describe the progress we have made in the area of heat treatment since 1998.
- Review work from laboratory studies in which parameters for effective heat treatment of ballast organisms were developed.
- Review the outcome of trials conducted using after-peak tanks on the roll-on roll off vessel *Union Rotoma* during a coastal voyage in New Zealand in period, February 1998 are reviewed.
- Present some early results describing the effects of treating ballast water using steam coils fitted to wing tanks of the chemical carrier *Iver Stream* during a voyage from Japan to New Zealand in February 2001.

This paper compares the two approaches of the onboard treatment in terms of efficacy, practicality, and cost. Technical difficulties and design limitations arising from the trials are also highlighted.

4. Research methods

For laboratory studies we focussed on the free-swimming or dispersive forms of the life cycle of target organisms. These included the Asian kelp, *Undaria pinnatifida* and the Pacific oyster (*Crassotrea gigas*) representative of an invasive seaweed and mollusc respectively, and *Coscinasterias calamaria*, a New Zealand native starfish closely related to the northern Pacific seastar. Viability after exposing larvae or zoospores to heating was determined by staining (larvae) or by germination of spores to produce plantlets (*U. pinnatifida*).

On board heat treatment of ballast in trials on the *Union Rotoma* were conducted by heating one of two matching after peak tanks (capacity, 100 m^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 two boilers heated by ship's exhaust gas and an oil-fired auxillary boiler. The heating trial was conducted on a coastal run between Wellington and Auckland in February 1998. Both control and test tanks were seeded with starfish (*C. calamaria*) larvae with the pump delivering about 7 $m^3.h^{-1}$ in the circuit to each tank for 30 h. Ballast from the test tank was then passed through the heat exchanger for 15 h, after which the exchanger was turned off. This resulted in an increase in the temperature of the tank contents from 24°C to 42°C (exchanger on) which held for 15 h after the exchanger was turned off. Live organisms in the control and heated tanks were determined by previously described staining methods (2).

Trials on the chemical carrier *Iver Stream* (32,000 tons) were conducted during passage from Japan to New Zealand using wing ballast tanks that had originally been designed for cargo, each of which had a capacity of 1500 m^3 and integral stainless steel heating tubes fitted to their bases. Trial 1 in which No. 6 starboard tank was heated and No. 7 portside tank was the unheated control, was initiated on the 18.03.01 (19° 27.8' N; 143° 55.0' E) and completed on the 22.02.01 (03° 18.5'S; 153° 37.0' E). Trial 2 conducted by heating No. 6 portside tank with No. 7 starboard as the control, was initiated on the 24.02.01 (12° 54.0' S; and completed on the 1.03.01 (37° 36.3 E; 173° 04.6' E). Tanks were separated by empty tanks which had previously carried cargo. In trial 1 heat was applied by passage of steam through tank coils at 2.5 bar, and in trial 2 at 4 bar. In both trials heating was applied for a period of 80 h. Temperature, salinity and dissolved oxygen were determined at 1 m depth intervals in the control and heated tanks. Temperature was recorded using the ships' instrument (HERMetric UTI Mk3-LBI, Switzerland). Where appropriate, salinity was recorded using a salinity meter (Model 140, Orion Research Corp) and dissolved oxygen by oxygen meter (YSI model 58, Yellow Spring Instrument Co., Inc. Ohio).

Water samples, representing bottom, mid and upper tank levels were taken using a van Dorn sampler (5 L capacity). One sample consisted of composite hauls from each depth situation. Samples were filtered sequentially through a 100 micron mesh to collect zooplankton and a 20 micron mesh to collect phytoplankton and zoospores. Cysts of dinoflagellates were collected by placement of traps at the bottom of each tank. Each trap consisted of a 50 ml syringe barrel secured in a vertical position in a weighted plastic test-tube rack. Live zooplankton were determined either by staining with neutral red and examining by light microscopy as previously described (2) (shipboard determinations), or by counting samples preserved with formalin (in laboratory). Organisms were considered live if they stained with neutral red and showed motility (shipboard) or by intactness of body and organs (preserved specimens).

5. Results

Laboratory studies

Our approach at the laboratory level was to investigate the effects of various heating regimes on a selection of organisms related to (or representing) potentially invasive species (eg northern Pacific seastar). From the results of the laboratory trials it is possible to develop parameters for onboard heating experiments. Zoospores or larvae were exposed to a range of temperatures and survivorship determined. A negative log-linear response of survival versus time was obtained and the lethal time for producing a 99.9 % kill ($Lt_{99.9}$) was determined from the slope (k) of the plots and the intercept on the y-axis ($\log p_o$) for each temperature. Plots of log of $Lt_{99.9}$ versus lethal temperature ($LT_{99.9}$) for the test organisms were negative log linear and were compared to that based on published values for germination of *Alexandriun catenella* cysts (temperature range, 36-42°C). The plots showed that above 40°C the survival potential of the various species ranked; *C. gigas* > *A. catenella* > *C. calamaria* > *U. pinnatifida.* Below 40°C the ranking of Pacific oyster shifted down through the order with decreasing temperature. The slope of the plots was then used to predict $Lt_{99.9}$ for the various species at 36°C at the lower limit of experimental values. The predicted $Lt_{99.9}$ of the most heat resistant organism at this temperature was 16.6 h (*A. catenella* cysts) and least resistant, 3.2 h (*U. pinnatifida*). A detailed description of the laboratory based studies on heat treatment appears elsewhere (2, 3).

Heating trials on the Union Rotoma

From the laboratory studies it was deduced that a treatment which would effect a near complete kill of the most resistant ballast organisms could be of long (≥ 16 h at ≤ 36°C), medium (10 min to 16 h at 36-45°C) or short duration (≤ 10 min at ≥ 46°C). From a shippers perspective the short-term treatment was perceived as impractical, but both the long and medium term treatments were considered possible options. In a medium term treatment applied to after peak tanks on the *Union Rotoma,* counts of *C. calamaria* larvae and zooplankton showed some decrease after 30 h pumping with the heat exchanger off. However when the exchanger was turned on, the numbers declined rapidly, so that within 12 h at which time the tank temperature had reached 38°C, all of the organisms had been killed. In the control tank after 60 h, numbers of larvae and zooplankton decreased to just over 60% of that initially present.

In terms of energy usage the treatment required cut-in of the oil-fired auxillary boiler providing 0.5% extra steam generation (Table 1).

Table 1. Energy budget for steam usage during treatment trial on the Union Rotoma

Steam from exhaust gas heating kg h^{-1}	Steam from oil fired boiler kg h^{-1}	Total kg h^{-1}	Ship needs kg h^{-1}	Treatment needs kg h^{-1}	% of steam from oil-fired boiler[a]
2000	125	2125	1800	325	0.58

[a] Represents ~ 0.5% of the total fuel usage for steam generation equivalent to about 0.25 tons

Heating trials on the M/T Iver Stream

The results of the heating trials during transequatorial southbound passage of the ship are shown in Figure 1. The figure also shows temperature in the control tanks over time and the corresponding seawater temperatures. In the first trial conducted north of the equator, at the point of heating, the tank temperature was 23°C, and after 80h it had increased to 34.5°C. At the same time the temperature of the control reached 30°C. During the experiment seawater temperature increased from 28°C to 30°C. In both the heated and control tanks there was virtually no temperature gradient with depth. This is reflected in the very small standard deviations for the data points which are means of temperatures taken over 1 m depth intervals through the entire depth of the tank. In the second trial the initial temperature of the tanks was 30°C as was the seawater temperature, and at the time heating was turned off (80 h) the heated tank had reached only 31°C. The control tank temperature had fallen to 28°C, and the seawater temperature had declined to 22°C.

The substantial deviations in the data points for the heated tank (Trial 2, Figure 1) can be explained by the thermocline (Figure 2) which showed that the top layers reached temperatures as high as 33°C, but the temperature at the bottom never exceeded 31°C. Such layering was not observed in the control. Survivorship of zooplankton determined for the control and heated tanks throughout the 1st trial is shown in Figure 3. Both in the upper, middle, and bottom samplings zooplankton numbers declined with time but in the heated tank numbers declined substantially after the heat was turned on. Similar results were obtained for Trial 2 although substantial survival of organisms was observed in the bottom layers. The results of survival of phytoplankton cysts and seaweed propagules remain to be determined.

Because of safety considerations measurements of salinity and oxygen using standard equipment were not possible. This particularly applied to Trial 1. For all samplings the salinity range was 34.1 to 34.4‰. The range of oxygen was 5.6 to 6.2 mg L^{-1} with the higher values occurring at lower temperatures.

The amounts of fuel oil consumed for each trial are shown in Table 2. The higher costs associated with the first trial relate to difficulties in obtaining the desired steam pressure (4 bar). This problem

was rectified in the second trial. In the second trial a blocked steam pipe required clearing after 30 h into the heating cycle causing a temporary loss of heating.

Table 2. Fuel consumption and costs for the Iver Stream trials

Trial Number	*Total fuel consumed (tons)*	*Ballast volume (m^3)*	*Steam pressure (bar)*	*Cost ($ US)*	*Cost per ton of ballast ($ US)*
1	4.2	1300	2.5	756	0.58
2	2.9	1407	4.0	522	0.37

6. Conclusions and recommendations

In evaluating the heating options for the onboard treatment of ships' ballast water this paper suggests that important considerations are sea temperature and the degree of mixing of tank contents. Improvements to tank design ensuring optimum heating of all tank contents with minimum fuel consumption is still required if heat treatment is to be considered as a serious option for ballast water treatment. An essential component of this will be the need to incorporate a system for mixing tank contents so that they can be uniformly heated. In the tank recirculation system used on the *Union Rotoma* this was afforded by a pump which circulated the tank contents back to the tank after passage through a heat exchanger. In the system operated on the *Iver Stream* mixing could be achieved by building in a device as simple as a thermosiphon. Heat wastage is another important factor to consider in developing and operating a heat treatment system. This is highlighted in the second trial on the *Iver Stream* in which there was almost no net increase in temperature over the 80 h heating cycle. This was due to decreasing temperature of seawater during the southward passage of the ship from the equator. In contrast there was net heating in the first trial aided by increasing sea temperatures during the heating cycle.

As a result of this study the following are recommended for future consideration in the heat treatment of ships' ballast water:

- The need to optimize the tank heating and recirculation system to minimise thermocline development and heat loss.
- The need to trial in cold-temperate seas.
- The need for more research into heat tolerance of ballast organisms and understanding of the impacts of "fast" and "slow" treatments.

7. References

Bolch, C.J. & Hallegraeff, G.M. 1993. Chemical and physical treatment options to kill toxic dinoflagellate cysts in ships' ballast water. *J. Marine Env. Engg,* 1 pp. 23-29.

Mountfort, D.O., Hay, C., Taylor, M., Buchanan, S. & Gibbs, W. 1999. Heat treatment of ships' ballast water: development and application of a model based on laboratory studies. *J. Marine Environ. Engg.*, 5 pp. 193-206.

Mountfort, D.O., Dodgshun, T., Gibbs, W. & McCallin, B. 1999. Towards a feasible heat treatment system for ships' ballast water. *Proceedings of AAPMA meeting, Brisbane, May 5-6*, pp. 125-126.

Rigby, G., Hallegraeff, G. & Sutton, C. 1998. Ballast water heating and sampling trials on the BHP ship MW Iron Whyalla in Port Kembla en route to Port Hedland. *Australian Quarantine and Inspection Service (AQIS) Ballast Water Research Series, Report No 11*, pp. 1-39. Australian Government Publishing Service, Canberra.

Rigby, G. R., Hallegraeff, G. M. & Sutton, C. 1999. Novel ballast water heating technique offers cost effective treatment to reduce the risk of global transport of harmful marine organisms. *Mar. Ecol. Prog Ser*. 191 pp. 289-293

Taylor, A. H. 1996. Design considerations for ballast water control and treatment. *IMAS Paper* 10 pp. 23-29.

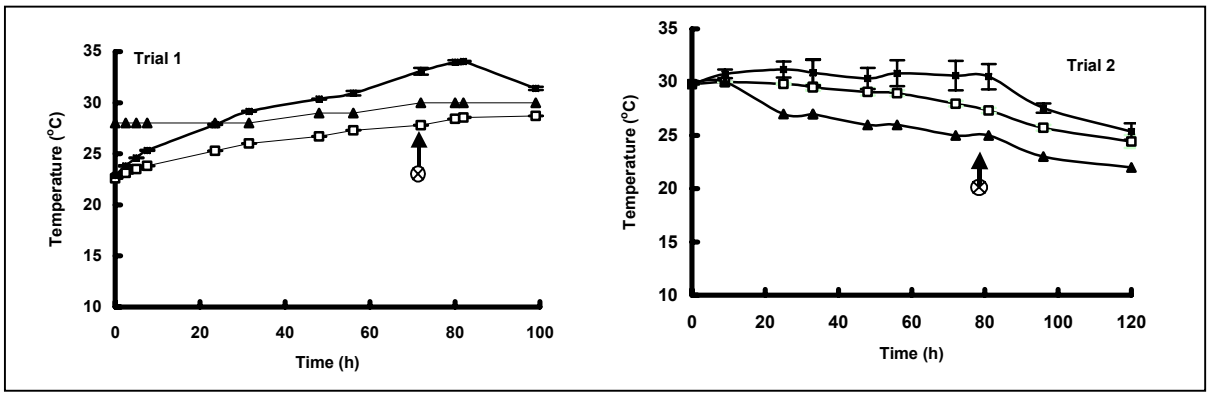

Figure 1. Temperature profiles in two treatment trials conducted on the M/T Iver Stream. Symbols: ■, heated tank; ❑, unheated tank; ▲, seawater. In the case of the heated and unheated tanks values are means of determinations taken at 1 m intervals throughout the entire depth of the tank ± 1 SD.

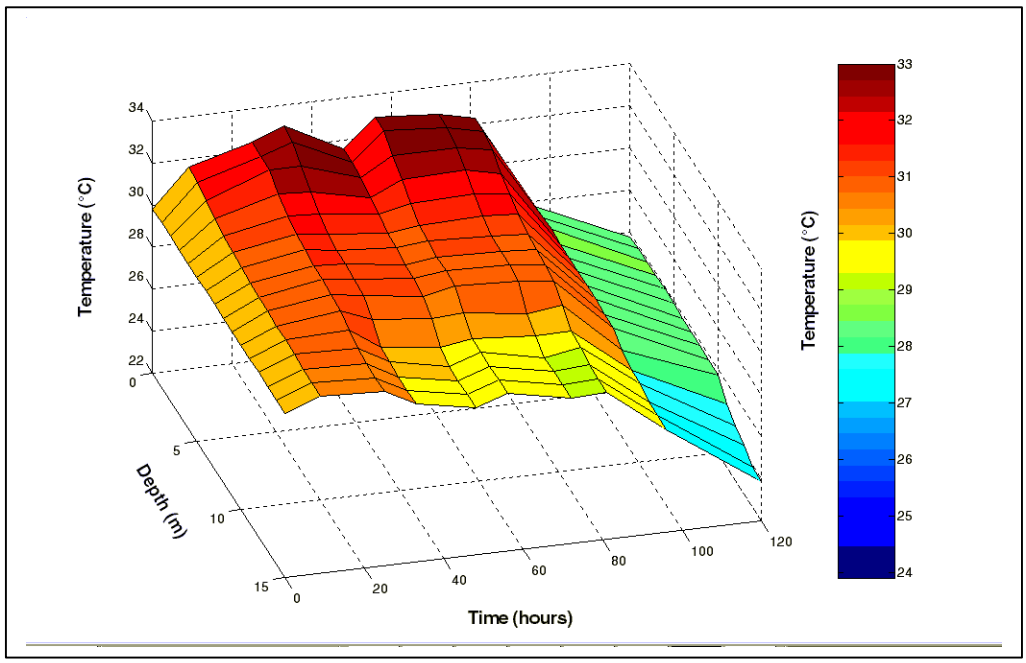

Figure 2. Temperature versus depth over time in the heated wing-tank of the Iver Stream (Trial 2). Each temperature was measured at 1 m depth intervals. Heat was applied at 0 h and cut at 80 h.

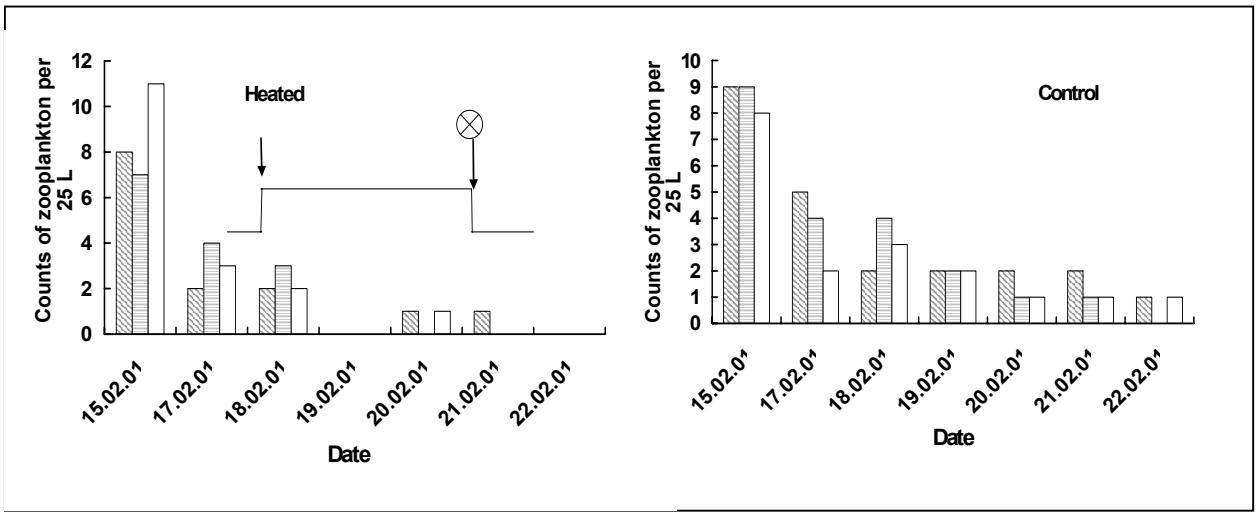

Figure 3. Bar graphs showing live zooplankton counts in the heated and control tanks (Trial 1). The points at which heat is applied and cut are indicated by the arrows. Counts were determined in three depth intervals: upper (shaded diagonal); middle (shaded horizontal) and lower (unshaded bars).

Ballast Water Treatment by De-oxygenation – The AquaHabiStat™ System

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1. Treatment options being researched

Mechanical; a 72 ton per hour high speed treatment system that uses a vacuum chamber to remove dissolved oxygen from ballast water resulting in a 10-day low oxygen condition within the ballast tank/ballast hold.

2. Timeframe of the project

The prototype research is complete. The project consisted of three 10-day time series tests that were completed May through July 2000, and two 10-day time series tests that were completed in December 2000.

3. Aims and objectives of the project

The engineering aim and objective of this project was to create a low cost, high performance, purely mechanical, full- scale ballast water treatment system, and to test the effectiveness of this system with two independent biological investigators as principles for the research. The design of the prototype AHS™ system was based on the principle of removing dissolved oxygen from ballast water during a typical ship voyage of ten days.

The testing of the prototype AHS™ system was designed to measure the effectiveness of the Aquahabistat's removal of oxygen, for elimination of various classes of microorganisms contained within water taken from the Elizabeth River, Virginia during the periods May through July, 2000 and December, 2000.

Detailed biological research and results can be found in "Biological Evaluation of the Effectiveness of the AquaHabiStat™ (AHS) System for Treatment of Ballast Water" (Gordon) and "AHS Supplemental Report" (Gordon) as summarized below.

4. Research methods

Overview

Microorganisms including zooplankton (>80 μm) and bacteria were monitored in treated and untreated water samples. Biological samples were analyzed by two independent laboratories operated within Old Dominion University, Department of Biological Sciences (ODU) and Hampton Roads Sanitation District (HRSD). The study monitored zooplankton populations and ATP levels (in the > 20 μm fraction and >10 μm fraction) in experimental pools containing approximately 20,000 liters of treated or untreated water.

Zooplankton samples from this study were collected by Old Dominion University using a plankton net, and were then split and sent to ODU and HRSD laboratories for analysis by microscopy.

Protocols for biological analysis -ODU laboratories

Pool sampling

A plankton net was used to collect samples at the surface and bottom of each pool. The sections of pool railing were used to measure distance towed for volume calculation. The water in the pools was monitored for water quality (dissolved oxygen, temperature, salinity, conductivity, and pH). Samples were obtained from tows conducted just under the surface and along the bottom of the pools. Samples were provided to the Hampton Roads Sanitation Department (HRSD) for comparative work.

1. Plankton Net: The mesh size of the net was 80 μm, its diameter was 10 inches and the length was 32 inches. Glass vials (46 ml) were clamped to the end of the net for sample collection.

2. Sample Collection: Experiments commenced 6/1/2000, 6/13/2000, and 6/26/2000 required a total of four tows for each pool. Microscopic evaluation conducted at ODU utilized one sample collected at the surface and one sample collected at the bottom for each pool and each day sampled. Two surface samples from each pool were collected for HRSD. In addition, a one-liter surface sample was collected from each pool during every sample date and brought back to ODU for ATP extraction and analysis to determine biomass.

3. Pool: Each pool sampled was 207 inches in diameter and 47.5 inches in height (ground to top of railing). Filled to capacity, the pools hold approximately 25,000 liters of water. However, the water level was never filled more than three-quarters. One pool served as the control containing ambient water from the Elizabeth River. Some of this water was directed through the treatment system and then pumped into a separate pool and thus contained treated water. A black plastic tarp covered each pool for the duration of an experiment.

4. Section of Railing and Sample Collection: The sections of railing were used to determine distance towed (volume sampled) by the net. Each section of railing is 59 inches and for experiments commenced 6/1/2000, 6/13/2000, and 6/26/2000, the plankton net was towed for a distance of three sections. The net essentially samples a cylinder of water, so simple calculations were used to determine the volume of water filtered.

5. Volume Calculation: Volume = $\pi r^2 * h$ [r = 5 inches (12.7 cm), h = 59 inches (149.86 cm)] $\pi(161.29)(149.86) = 75896.69 = 76$ liters is the volume of water sampled when the net is pulled along one section of railing. Usually, the net was pulled along three sections sampling a volume of 228 liters.

6. Dissolved Oxygen: Measured with a YSI model 51. The dissolved oxygen membrane was replaced before each new experimental run and the meter was calibrated as per the manufacturer's instructions.

Microscopic evaluation

Sample vials were brought back to ODU and read immediately in a counting chamber using an inverted microscope. When enumerating an entire sample vial, it was necessary to divide it into three separate aliquots because the counting chamber cannot accommodate an entire sample. Sub-samples or aliquots were removed from the 46 ml sample vial after being shaken. The sub-samples or aliquots then settled in the enumeration/counting chamber for approximately two minutes.

Sub-sampling:
Sub-sampling was necessary to save time during microscopic enumeration of meso-zooplankton at time 0 and one day post treatment. Two separate sub-sampling methodologies were utilized.

The first methodology required a five-ml sub-sample and was used to assess the numbers of copepods (adults and nauplii). The second methodology required a 20 ml sub-sample and was used to assess all other meso-zooplankton. Sub-samples were placed in the counting chamber and read. Copepod counts from the five ml sub-sample were multiplied by 9.2 to account for the entire 46 ml sample vial (9.2 * 5 ml = 46 ml). All other zooplankton counts from the 20 ml sub-sample were multiplied by 2.3 to account for the entire 46 ml sample vial (2.3 * 20 ml = 46 ml).

Zooplankton:
All microscopic enumeration focused on the largest zooplankton found in each sample. These are termed meso-zooplankton and are generally greater than 200 μm in length. The most abundant zooplankton are the adult stages of cyclopoid, calanoid, and harpactacoid copepods. Equally abundant are the larval or nauplii stages of these copepods. Copepods are categorized and tallied according to these two stages. All other zooplankton identified were placed into the following general categories: Barnacle nauplii, which encompass the early stage of a barnacle, polychaete larvae, ascidian, cladoceras, crab zoea, which encompass the early stages of a crab, shrimp larvae, and unknown.

Microscopic Enumeration:
All "dead" zooplankton were first enumerated. Those zooplankton not moving or slightly twitching were considered dead or non-viable. The sample was then preserved with Lugol's iodine and all zooplankton enumerated again. The difference in counts between the initial "dead" counts and the total preserved counts were the numbers of zooplankton alive and moving within the sample. When a sub-sample was used, it was preserved immediately after enumeration of dead zooplankton so that the same water was analyzed.

ATP extraction and analysis

Water samples from the surface of each pool were collected in a 1-liter media bottle. The samples were taken to ODU for analysis. Each one-liter sample was divided for filtration purposes and ATP extraction. Extracted ATP was stored in the freezer until the last day of sampling. All samples were then analyzed as a group.

Sample Filtration:
Each one-liter surface water sample was divided and 500 ml filtered through Whatman #1 filter paper, which retained organisms >20μm. Note: The filter paper was cut to fit the filtration apparatus.

ATP Extraction:
Filters were placed into glass scintillation vials containing five ml of boiling TRIS HCl buffer. Vials were marked to designate the five-ml level. Vials were boiled for five-minutes in a pan containing sand, which allowed for effective heat transfer. Once removed from the heat, deionized water was added until the five-ml mark was reached. This accounted for any water that evaporated during the boiling process. Vials were capped and then stored in the freezer.

ATP Analysis:
ATP was analyzed following the protocol detailed in *Standard Methods for the Examination of Water and Wastewater* (L. Clesceri)

Protocols for biological analysis –HRSD laboratories

Objective

To evaluate estuarine samples concentrated and collected by Old Dominion University from system pools (experimental ballast water) to determine the affect on organisms subjected to the AquaHabiStat ™ treatment process. HRSD will enumerate organisms in 45 mL vials received from ODU on several test days through an eight to ten day test period, using HRSD developed protocols, in order to validate separate protocols.

Study design

Samples in 45 mL glass vials collected by ODU personnel from system pools using a plankton net (control and treated) at the AquaHabiStat ™ test site will be examined for enumeration of live and dead copepods and meso-zooplankton. For each test day, replicate control and replicate treated samples will be collected.

Copepod and zooplankton determination

Laboratory Equipment and Reagents:

- Stereo Microscope with fluorescent bulb underlight-VWR Vista Vision SteroMicroscope 6.5 – 45 zoom w/ 10X eyepiece.
- Spot Plate, 9 Depression 85x100 mm with 1ml wells.
- 10 mL, non-sterile plugged disposable serological pipettes.
- Pipette bulb.
- Graduated cylinder, 50 mL.

Observation of pool samples:
The laboratory will receive four 45 mL vials for testing (2 control and 2 treated samples) for each scheduled testing day. For each pool sample a total of 10 ml from the 45 mL vial will be examined. Gently shake the sample vial to ensure good distribution of the content. Lower a 10 ml pipette into the sample simultaneously filling up the pipette. Take caution to not over flow the vial while lowering the pipette. Make sure that the pipette is lowered all the way to the bottom of the vial, as some of the content of the sample will begin to settle.

Have two specimen plates to be filled with sample side by side. Five wells of each plate are to be filled with 1 ml of sample for a total of 5 ml per plate. Do this in a random fashion between plates.

Using a stereo microscope, examine each well for alive and dead copepods, including adult, nauplii and larval stages of cyclopoid, calanoid, harpactoid and other copepods. Also examine each well for alive and dead mesozooplankton, including all larval and juvenile stages. Meso-zooplankton, ranges in size from approximately 80*u*m to 600 *u*m. Meso-zooplankton abundant in samples and enumerated include barnacle nauplii, polychaete larvae, Ascidian, crab zoea, shrimp larvae and other larvae stages of zooplankton, juvenille clams and marine worms (non-benthic). Biological Keys from Reference materials should be used as a guide during organism examination.

On the spot plate, view one entire well and count live and dead copepods and other live and dead zooplankton. With zoom feature scan the well for organisms, dead or alive. Record all alive and dead organisms for each well. Examine up to 10 wells for a total of 10mL. Measure out remaining pool sample from vial using a graduated cylinder. Add 10 mL (volume counted) to measured volume to obtain the total volume of vial. Record the total volume on benchsheet. Discard sample from plate and rinse into a waste container.

For testing on days toward the end of the test period, organisms may be more difficult to observe. Use tweezers to gently pull apart sample components for improved viewing or further dilute samples.

Data:
Bench sheets

While viewing the spot plates, keep a running tally of organisms divided into four main groups for each pool sample, alive copepods, alive zooplankton, dead copepods, dead zooplankton.

It may be necessary to subdivide two zooplankton groups into general groupings, based on observation such as larvae, worms, clams, etc. Record Analyst's name, analysis date and time on bench sheets.

Calculations

The total number of organisms contained in each sample vial is calculated:

$$\text{Total \# Organisms} = \frac{\text{Total Organisms Counted}}{\text{Total Volume Counted}} \times \text{Vial Volume}$$

Example:

$$\frac{\text{200 Live Copepods}}{\text{10 mL Subaliquot Counted}} \times \text{43 mL Vial} = \text{860 Live Copepods per 43 mL vial}$$

Data validation:

All calculations are routinely checked by a second person. Bench sheets are checked for completeness of required documentation including sample ID, sample collection date, analyst, analysis date.

Record keeping:

All records pertaining to the tests, including chain of custody records, bench sheets, graphs, summary reports, etc. are maintained in the CEL in custody of the project manager following calculation and data validation.

Data reporting:

Results are graphed over the eight to ten day test period.

Quality assurance

Sample QA:
All samples are collected in replicates to establish variability between sampling and analysis.

QA Statement:
HRSD adheres to a Quality Assurance and Quality Control Program designed to meet specific requirements applicable for each project. For field and laboratory work performed for AquaHabiStat™ system test samples, QA protocols including sample replicates, sample validation, data validation and chain of custody procedures are followed.

5. Results:

Overview

Three trials of the prototype AHS™ ballast water treatment system were carried out. The trials were begun on June 1, June 13, and June 26, 2000. Biological testing of the control and untreated pool samples continued for nine days after treatment to simulate a typical transatlantic voyage by bulk carrier.

Physical parameters

Temperature, salinity and pH: Temperature, salinity and pH ranges in the three experimental trials are summarized in Table 1.

Table 1. Temperature, salinity and pH range measured during the three experimental trials of the AHS™ system. Trial 1 was initiated on June 1, 2000, Trial 2 on June 13, 2000 and Trial 3 on June 26, 2000. ND=no data.

Parameter range	Trial 1	Trial 2	Trial 3
Control Temperature (°C)	20.2-22.0	23.9-27.3	26.6-28.1
Treated Temperature (°C)	20.8-21.9	24.5-26.2	26.5-28.0
Control pH	6.0-7.6	6.6-7.8	ND
Treated pH	5.9-8.0	7.5-8.0	ND
Control Salinity	18.8-19.0	18.1-18.4	19.5-19.7
Treated Salinity	19.0-19.0	18.3-18.4	19.4-19.7

Dissolved Oxygen: Dissolved oxygen (D.O.) in the control tank averaged 7.8 ppm on day zero (Figure 1). D.O. in the treated tank generally remained at 1 ppm or below during the course of the study (Figure 1).

Zooplankton

Copepods:

Copepod counts showed a substantial decrease in numbers of living copepods and copepod nauplii on initial sampling (Day 0; Figures 2&3). This initial decrease was 75% based on the counts obtained by the HRSD lab and 67% based on counts obtained at Old Dominion University. The decrease in copepod numbers was statistically significant on day 0 (p=0.01) and on day 1 (p=0.04) based upon a paired t-test comparing the combined data from all experiments. Numbers of live copepods and copepod nauplii reached zero on day two (Figure 2) or three (Figure 3) in the treated samples. Although numbers of living copepods or copepod nauplii decreased in the control sample as well, living copepods or copepod nauplii were observed in the control pools until day eight (Figure 3) or nine (the end of the sampling period; Figure 2).

Other Zooplankton:

Zooplankton counted other than copepods included barnacle nauplii, polychaete larvae, ascidian, cladoceras, crab zoea, shrimp larvae, and unidentified zooplankton. These organisms also showed a substantial decrease on day 0 with a 51% or 75% decrease observed by the ODU and HRSD laboratories, respectively (Figures 4 &5).The decrease in other zooplankton numbers was statistically significant on day 0 (p<0.02) and on day 1 (p<0.01) based upon a paired t-test comparing the combined data from all experiments. No viable organisms in this group were observed in treated samples after day two (Figure 4) by the ODU laboratory. The HRSD laboratory detected low numbers of living organisms in the treated sample until day 9. The number of living zooplankton was substantially reduced in the treated samples in comparison to control samples.

ATP

During the test series run May through July 2000, total ATP was determined in conjunction with the third replicate experiment only. As measured in this study, ATP is a proxy for biomass in the >20µm size fraction. This size fraction includes the zooplankton counted microscopically as well as smaller zooplankton and some phytoplankton. The trend in ATP concentration was similar to the observed trends in live zooplankton numbers. ATP levels were lower immediately after treatment and decreased to nearly zero in the treated sample by day three. ATP levels also decreased in the control but remained high compared to the treated sample throughout the experiment.

ATP measurements were then repeated in two separate test series during the month of December 2000. The results of these additional ATP determinations were similar to those reported in the previous study. Somewhat less reduction in ATP was observed however. In the original study ATP levels were reduced by 100% after ten days of treatment. In the subsequent experiments the reduction

was 73% and 85%. The difference may be due to natural variation, lower water temperature or the use of filters that retain smaller plankton. In any case we now have repeated the ATP measurements and shown an average reduction after AHS treatment of 86% for three experiments. In the summer testing microscopic counts showed 100% reduction of copepod and other zooplankton and more rapid attrition of these organisms in AHS treated water.

6. Conclusions and recommendations

The ultimate recommendation is to deploy the AquaHabiStat™ system on current vessels to reduce further invasions from taking place worldwide.

The results from testing and running the prototype have shown that the system is flexible and adaptable to pre-treatments and post-treatments. The mechanical design should allow for easy operational management by the crew of a vessel.

The system is also flexible enough that if a tighter biological standard were necessary, then other systems could be designed inline with this one. One pre-treatment design might be a hyper-oxygenation tank that would cause cysts to open if any anaerobic conditions appear under actual operations that would be considered negative.

The unit is very practical, involving only two water pumps, one vacuum pump, and one vacuum chamber, all of which can be installed without shipyard facilities.

7. References:

Andrew, G., Rule, A., & Hogg, P. 2000. *Biological Evaluation of the Effectiveness of the AquaHabiStat™ (AHS) System for Treatment of Ballast Water.* Technology Applications Center, Old Dominion University.

Andrew, G. 2001. *AHS Supplemental Report*. Old Dominion University.

Clesceri, L. et al. (eds) 1989. *Standard Methods for the Examination of Water and Wastewater*. 17th edn. pp. 10-40 - 10-42. APHA-AWWA-WPCF.

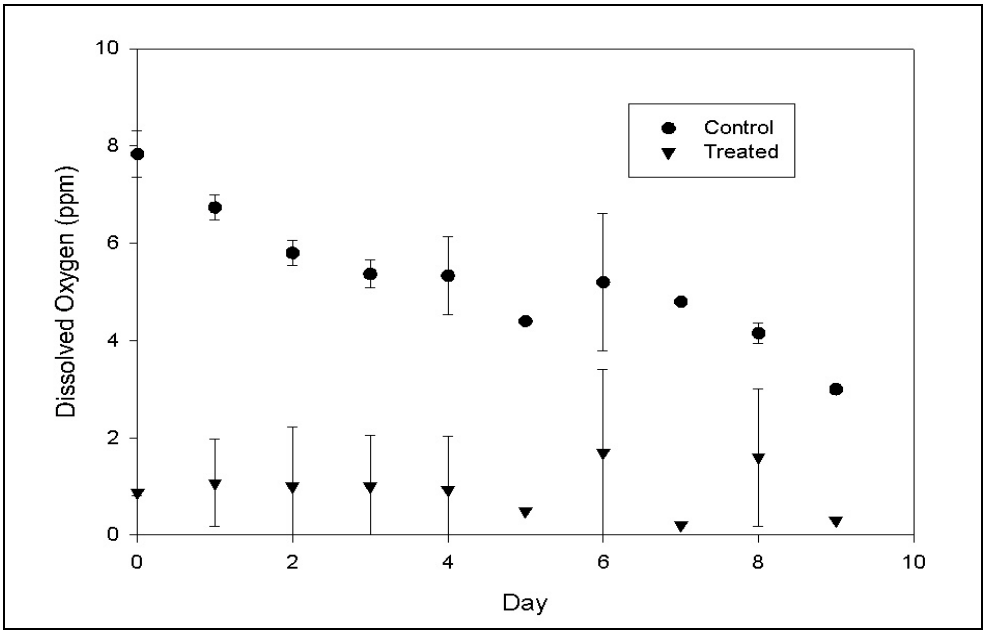

Figure 1. Dissolved oxygen concentrations in control and treated tanks.
The average value for three trials is shown. Error bars are the standard deviation

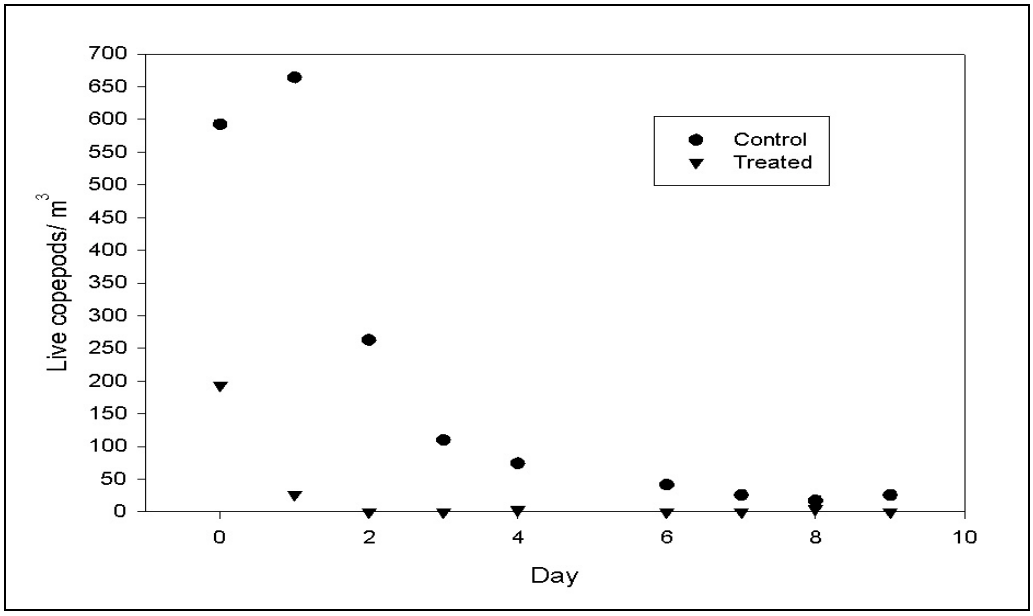

Figure 2. Live copepod numbers in control and treated tanks determined by the laboratory at Old Dominion University. The average value for three trials is shown.

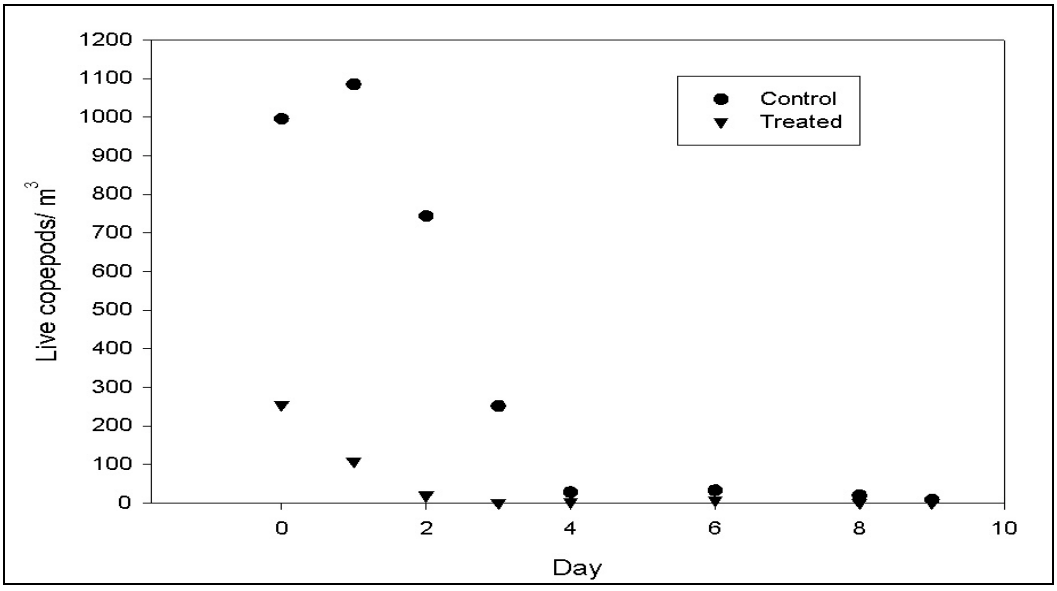

Figure 3. Live copepod numbers in control and treated tanks determined by the laboratory at Hampton Roads Sanitation District. The average value for three trials is shown

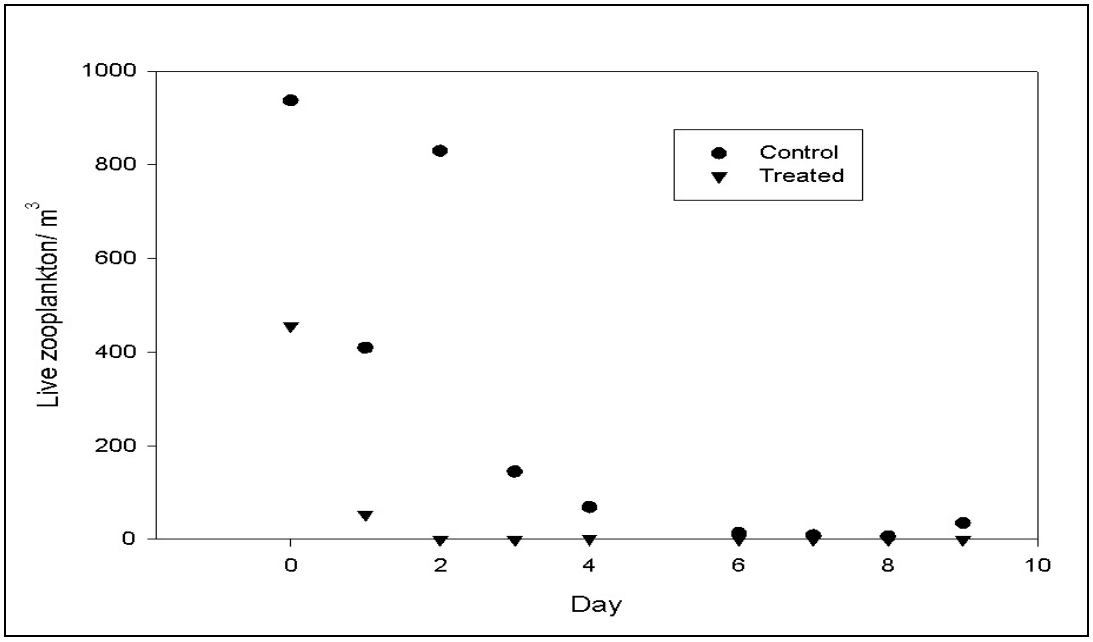

Figure 4. Live zooplankton (other than copepod) numbers in control and treated tanks determined by the laboratory at Old Dominion University. The average for three trials is shown.

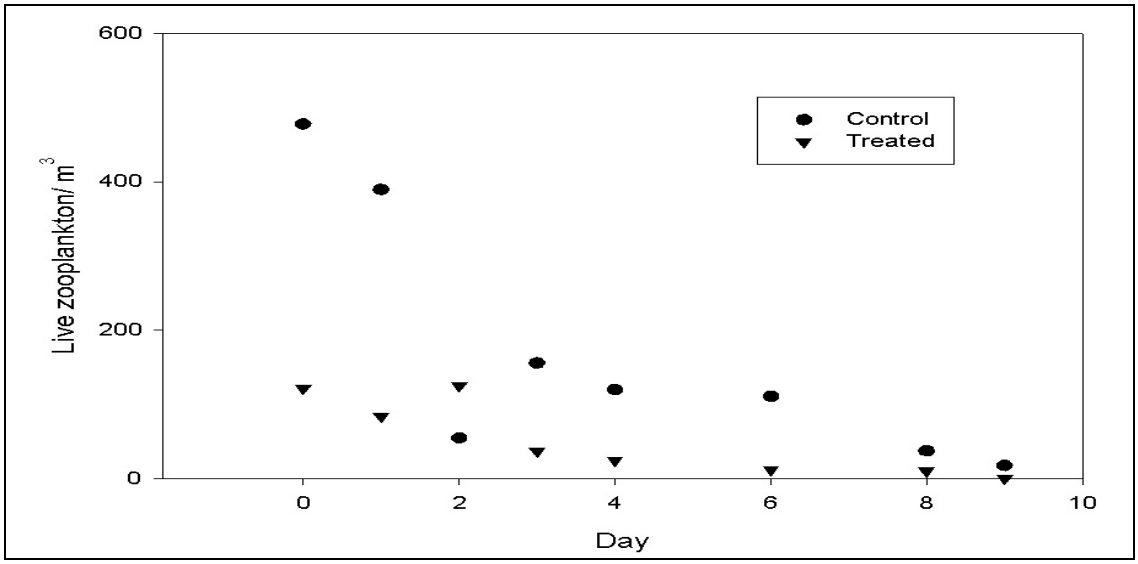

Figure 5. Live zooplankton (other than copepod) numbers in control and treated tanks determined by the laboratory at Hampton Roads Sanitation District. The average for three trials is shown.

Ballast Water Treatment by Electro-Ionization

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1. Treatment options being researched

Ballast water treatment presents technological challenges to current state-of-the-art technologies because of the unique chemical and physical characteristics of ballast water (Emcee and van Leeuwen, 1998), and the large number and diversity of organisms. Many options are available such as the oxidative action of halogens (e.g. chlorine), ozonation (O_3), oxygen depletion, biocides, floatation separation, filtration, acoustic methods, electrical pulses, ultraviolet radiation and heat. However, to date none have risen to the challenges imposed by the scale of the problem.

The paper explores the use of EIMS™ (Electro-Ionization Magnetic Separation) Technology, a treatment method that has previously been used to disinfect land-based freshwater effluents such as cooling tower water and a variety of wastewaters emanating from industry. However, to date, the technology has never been modified and applied to marine or estuarine waters. This study presents initial results on the effectiveness of the Electro-Ionization Technology component of the EIMS Technology in treating microbes (prokaryotes and eukaryotes) in seawater and gives a system process flow design that has been optimized in light of these preliminary trials. In short, we present a unique Electro-Ionization Treatment System that has the potential to effectively treat ballast water in an on-board treatment system. With further refinement and modification, the system could be used in shore-based and tender-based treatment systems. The process flow design presented is sensitive to the numerous constraints imposed by the volumes of ballast water requiring treatment and to the huge numbers of diverse biota contained in ballast.

2. Aims and objectives of the project

This study is a progress report of the research being conducted with a pilot treatment system located at the Oceanographic Center of Nova Southeastern University, Ft. Lauderdale, Florida. The system is supplied and designed by Marine Environmental Partners Inc., a water treatment company located in Florida. The main objective of the study was to evaluate and demonstrate the effectiveness of Electro-Ionization Technology (EIT) in killing microbes similar to those found in ballast water. The long-range goal of the study is to design the best available technology treatment system for ship, land-based and tender installations.

The small-scale pilot unit was designed to balance killing efficiency with process parameters that were realistic for ballast treatment. In other words, the Electro-Ionization Treatment System developed as a result of numerous trials, had to be efficient, in terms of killing capacity, but also considered the need for a range of throughput treatment capacities that address site-specific requirements. Thus, vessel layouts, separation of ballast tanks, location of ballast tanks and different ballast tank systems. Moreover, effectiveness, crew, robustness for use on ships and with seawater, and the need to achieve at least a 95% kill or inactivation were all considered.

3. Research methods

Treatment system

Components for the Electro-Ionization Treatment system were supplied by Marine Environmental Partners Inc. (MEP), Fort Lauderdale, Florida. The major components of the test system comprised a 150-gallon (566 liters) contact tank containing the seawater to be treated (300 liters per run) and a CLORINOXYL^{R} gas generator module that was used to generate gas vapor ions. A photograph of the test system is given in Figure 1 and a schematic diagram of the apparatus is illustrated in Figure 2.

The CLORINOXYL^{R} module is made up of two reaction systems; the NI-OX/L^{TM} gas generator and the CLORIN^{TM} gas generator. The NI-OX/L^{TM} gas generator draws in atmospheric air and ionizes it into various species of ionized oxygen and nitrogen. The various singlet molecular oxygen species, ionized nitrogen, free electrons (released during the gas generating reaction) nitroxyl ions and peroxyl ions (e.g. O_2^-, O_2^{--}, N_2^+, e^-, H_2O_2, OH^-) are highly reactive oxidizing species and capable of damaging biologically active materials. In addition, reactive ions of chlorine are also generated via the CLORIN^{TM} generator that is thought to produce inter-reactive hybrid complexed species such as ClO_X^- (chloritic vapors). Again, the reactive ions of ClO^-_X have a high degree of biocidal activity. The exact species and concentrations of O, N and Cl in the Clorinoxyl gas mixture are unknown at this time. These are in the process of being identified and quantified by independent test laboratories.

During system development, the test system was optimized by running the NI-OX/L^{TM} generator alone, the CLORIN^{TM} generator alone, and both units together as the CLORINOXYL^{R} module. Reactive gases were fed into the holding tank containing seawater via the differential pressure injectors and treatment contact times ranged from once through at 60 GPM (designated as 2 minute contact time) to 15 min. The pumping system had a flow rate of approximately 60 GPM (240 liters per minute) implying that it took at least 1.25 minutes for the entire tank containing 300 liters to be processed on a flow-through basis. The possibility that some killing was due to the high-pressure pumps employed in the system was considered, however, preliminary data (not given) suggests that this kill rate was very low.

The CLORIN^{TM} electrolysis gas ion vapor generator (utilizing a uniquely modified electrolysis process) used small volumes of concentrated brine to generate and release reactive chlorine, oxygen and hydrogen vapor ions. The level of chlorine generated was dependent on the concentration of brine used in the Clorin^{TM} reservoir. Concentrated brine solution (204 g per liter), while effecting 100 % kills, generated unacceptably high levels of residual chlorine after treatment (approximately 50 ppm). Thus, the operating parameters of the CLORIN^{TM} unit were adjusted to reduce chlorine levels after treatment. In other words, the system was fine tuned such that killing was optimized when both units (NI-OX/L^{TM} and CLORIN^{TM}) were used together (as the CLORINOXYL^{R} module) while reducing chlorine ionized gas levels such that chlorine residuals were always less than 1.5 ppm. This was achieved by diluting the saturated brine to 44 g per l. Chlorine levels were analyzed after every sampling using the N, N-diethyl-p-phenylenediamine (DPD) ferrous titrimetric method as described in Eaton et al. (1995). According to these authors, the minimum detectable concentration is ca. 18 μg per l Cl as Cl_2 per l although normal working detection limits may be slightly higher.

Assessment of effectiveness

Test organisms

All tests were conducted at the Oceanographic Center of Nova Southeastern University. Water was withdrawn from the boat basin off the channel leading to Port Everglades, Florida. This water (salinity ca. 32 g per l) was either tested fresh, using the indigenous organisms, or after seeding with ca. 50 l of seawater containing much higher numbers of bacteria, algae and protozoa. This water was obtained from tanks containing mixed culture of bacteria, algae and protozoa. The water in these tanks was enriched with nutrients (mainly N and P) allowing microbes to attain much higher densities. However, later tests only used fresh seawater since, as pointed out earlier, this water contains over 1 million microbes per ml.

Microorganisms are ideal test organisms since they are abundant and diverse. The bacteria are small (ca. 1 μm) prokaryotic cells and are protected by a semi-rigid cell wall rich in peptidoglycan. The eukaryotic protists, on the other hand, are larger (generally 3 – 100 μm) and contain an array of cell types from naked amoebae to diatoms with their protective silica walls. The entire list of protists considered in this study included amoebae, ciliates, heterotrophic flagellates, autotrophic flagellates, diatoms and dinoflagellates. The protists contain organisms that can exist as resistant cysts such as in the case of dinoflagellates. Moreover, nutritional diversity within the protists is large. Some are heterotrophs (i.e. consumers), some are autotrophs (i.e. photosynthetic producers), while others are mixotrophs (i.e. consumers and producers). Given the diversity of forms within the microbes as a whole and their huge abundances, it is assumed, without evidence at this time, that if microbes are successfully killed it is likely that the less robust viruses and macroinvertebrates would also be killed. Even if this assumption is incorrect, the huge number of microbes in coastal marine waters qualify them as suitable test groups with which to fine tune the system design and verify that the treatment is doing considerable biological damage.

Enumeration methods

Microbes were counted before (controls) and after treatment using the following methods. Bacteria were counted by standard plate counting method. For each treatment or control, three replicate samples were collected. Each sample was serially diluted through sterile filtered seawater and appropriate dilutions (giving between 30 and 300 colonies per agar plate) were plated out using 0.1 ml aliquots onto Marine Agar 2216 (Difco Laboratories, Detroit, MI). Inoculated plates were incubated at 22 C for 7 days and the number of colonies (colony forming units, cfu) recorded. When corrected for dilution, this count of cfu is an approximation of the number of bacteria present in the original sample. It should be noted, however, that plate counting, which relies on the growth of bacteria in the laboratory, seriously underestimates the true number of bacteria in the original sample. It does provide a useful index of abundance and it can be assumed that any bacteria not amenable to laboratory cultivation were probably also killed by the treatment.

Protists were counted by enrichment cultivation using methods fully documented in Rogerson and Gwaltney (2000). In brief, water samples were shaken to disperse protists and 50 μl aliquots were pipetted into the sterile wells of a 24 well tissue culture flask. Each well contained sterile seawater and a small cube (ca. 1 mm^3) of malt yeast agar (0.1 g malt extract, 0.1 g yeast extract, 15 g non-nutrient agar in 1 l seawater) to provide nourishment. These conditions promoted the growth of attendant bacteria that in turn fed any protozoa present in the 50 μl drop. By incubating the samples in the light, growth of any autotrophic algae in the inoculation aliquot was enhanced. As was true for the bacterial counting method, no single method is going to be appropriate for the growth of all protists.

As before, the method gave an index of abundance. It was assumed that when no organisms grew in the laboratory all were killed by the treatment. The method gave a count of total protists that included amoebae, heterotrophic flagellates, ciliates, diatoms, dinoflagellates and various green algae (motile and non-motile). After incubation in the light for at least one week, the number of wells positive for the above groups was recorded. By assuming that each protistan population in a well originated from a single cell in 50 μl, the number of protists was estimated from $N= (n \times 10^3)/V$ where N is the total protists per ml, n is the number of positive scores for different protists, and V is the total volume deposited into all 24 wells (in this case 1,200 μl).

Test runs

The contact tank was filled with 300 l of seawater and the Clorinoxyl™ module components were run separately to optimize their performance (as NI-OX/L or Clorin™ generators). Thereafter, the Clorinoxyl™ module was tested with both components operating together. Run times were usually once through at 60 GPM (designated as 2 minute contact time), 5-minute contact time and 15-minute contact time although some runs omitted the 2-minute contact time sample. A control sample was

always taken after filling the contact tank and before switching on the circulating pumps. All samples were taken in triplicate. Initial test runs, particularly those used to fine-tune the test system, used both the bacterial counting method and the protistan counting method. However, it became evident that the two microbial groups (bacteria and protists) had similar sensitivities. This is indicated in Figure 3 that compares the survival curves for bacteria and protists over a 15-minute contact time treatment. Since the protistan count was time-consuming, subsequent tests were conducted with only bacteria counts until the treatment parameters were optimized for bacteria survival. All data was converted to percentage survival levels to normalize for differences in the numbers of organisms at time zero.

4. Results

The CLORIN^{TM} gas generator, releasing reactive hybrid-complexed species of Cl ions in to the water, was very effective at killing both protists and bacteria when the electrolytic cell used saturated brine. In all cases, 100 % kills of both microbial kills were found within less than 5-minutes. However, these trials produced unacceptably high levels of residual chlorine, between 30 and 50 ppm. The challenge became one of developing a treatment module, CLORINOXYL^{R}. This module used the killing power of the NI-OX/L^{TM} unit (which converted atmospheric air into reactive forms of O and N, and released free electrons) and enhanced the kill rate (and reduced treatment contact time) by bleeding in reactive Cl species from the CLORIN^{TM} unit. By using the Clorinoxyl^{TM} module and a 1/5 dilution of saturated brine in the Clorin^{TM} unit, background levels for residual chlorine were usually less than 0.3 ppm at the short contact time treatment runs. Increasing treatment contact time to 15 minutes increased the residual levels to ca. 1.3 ppm (Figure 4).

By optimizing the operating parameters of the individual test units, only allowed limited adjustment of flow rate into the NI-OX/L^{TM} unit and the option of different brine dilutions in the Clorin^{TM} unit, a data set was collected using replicate runs (n = 3) using bacteria as the test organism. This data is summarized in Figure 5. It should be noted that the error terms (standard errors) around the data points are sometime large. Since the contact tank was well mixed, it unlikely to be due to patchiness of microbes within the tank. Rather, it is a function of the error associated with the plate counting method.

Even so, it is clear that over the test period, all treatments caused a significant reduction in the number of detectable bacteria. The NI-OX/L treatment was the least effective. After 5 minutes, there was no significant reduction in bacteria although after 15 minutes contact time the bacteria level was reduced to less than 10 %. The Clorin^{TM} treatment, using diluted brine, produced a dramatic reduction in bacteria. After 5 minutes contact time, the levels were below 5 % of the original count and after 15 minutes contact time 100% kills were obtained. It is important to note that a 100% kill is better expressed as below detection. It is possible that a few bacteria remained below the detection level of the method.

The CLORINOXYL^{R} module treatment (that utilizes the killing power of the NI-OX/L^{TM} unit with the enhanced kill rate of the Clorin^{TM} unit) produced the most rapid kill rate with dramatic reduction in bacteria. Because of the large counting errors, additional runs are planned with the CLORINOXYL^{R} module to establish statistically significant difference when compared to the individual components of the CLORINOXYL^{R} module. Regardless, the data to date suggests that the CLORINOXYL^{R} module treatment can affect a rapid kill with dramatic reduction in bacteria. Using the CLORINOXYL^{R} module, around 95% of the bacteria were killed after just 2 mins.

It must be remembered that this treatment system used a recirculating design, so that not all of the water in the tank (300 l) would have passed through the injectors where most contact, and hence killing, occurred. In other words, a single pass through the treatment system produced a dramatic killing effect. Moreover, to obtain these kill rates in just 2 mins suggests that residual killing may have been occurring within the reservoir tank.

5. Conclusions and recommendations

This is the first application of Electro-Ionization Technology (a component of the EIMS Technology that is currently used for land based applications in the Industrial Sectors) to the treatment of marine waters. The initial results are promising since they show impressive kill rates of the bacterial population reducing the indigenous population to less than 5% within just 2 min.

Since seawater contains on average 1 x 10^6 bacteria per ml it follows that there were ca. 3 x 10^{11} bacteria in the treatment tank and that 2.9 x 10^{11} were killed (assuming that bacteria enumerated by the plate counting method were representative of all bacteria in the water). Similarly, since earlier trial showed that protists were equally susceptible to the treatment, it is likely that the method also killed some 430 million of the 450 million protists expected to be in the treatment tank.

These are initial figures and clearly future trials must focus on confirming these preliminary numbers. Moreover, the realities of treating the massive volumes of ballast water being pumped from ships, and the complexities of the chemical and physical characteristics of ballast water, may require that the core Electro-Ionization Technology (EIT) be complemented with additional EIMS^{TM} (Electro-Ionization Magnetic Separation) components provided by affiliate companies. These complementary technologies could be integrated with the EIT to achieve the ultimate goal of inactivating all ballast organisms.

Many of the known alternate treatment options have failed to rise to the challenge imposed by the scale of the problem. Likewise, they generally fail to satisfactorily address practicality, cost, footprint, safety, consistent removal efficiency and corrosion. In association with EIT, it may be possible to eliminate these drawbacks.

Other treatment options at present generally rely on filtering out larger organisms, treatment with biocides, electronic pulses, ozonation, or treatment with ultraviolet light. Most developing treatment options rely on combinations of these methods. The EIT treatment might be enhanced by considering solids removal prior to EIT treatment.

Some available treatment options, although promising on the small scale, are not feasible when scaled up. Ozonation is effective but relies on long contact times making the treatment of large volumes problematic. Chlorine is an effective biocidal agent, but in non-complexed and/or in large amounts is hazardous to marine life when flushed out to sea. Others have considered using the heat from engines for on-board treatment. Although trials are promising in that cysts of toxic dinoflagellates were shown to be killed at 38 C after 4.5 h (Hallegraeff et al. 1997), the method is unlikely to be feasible until the design of ships is changed.

Precise information on current technologies under development is scant since this proprietary information is usually protected by patent and confidentiality agreements. Marine Environmental Partners Inc. is concentrating on further improving the Electro-Ionization Treatment Test System. The data (Figure 4) show that to achieve consistent chlorine residue levels less than 0.3 ppm, a run time of less than 5 min is required. A short run time is essential to handle the volumes of ballast water requiring treatment and future trials will concentrate on kill rates using a single pass. The test system is currently being modified to allow such samples to be collected. Moreover, modifications are being made to allow the flow rate of the pumps and gas flow at the injectors to be monitored and altered. In this way, conditions for more rapid killing can be accomplished.

The initial trials of the Electro-Ionization Treatment system have demonstrated that the method is appropriate for marine waters and that impressive kill rates of microbes (over 95%) can be achieved on a once through flow. The data generated to date confirms that the treatment system can be further modified to improve this kill rate and a one-pass system is being developed. To this extent, we have planned a series of confirmatory runs utilizing once-through treatment. The survival data to be collected during these runs will now include viruses, dinoflagellates, and other protists and a range of macroinvertebrates.

The initial tests have verified that EIT is effective at bench scale level. The next step is to place a modified (and improved) pilot treatment system in installations either dockside or on-board ship. Capability of scaling to practical application has been at the forefront of all steps of research and development of this system. Once a pilot system is subjected to the various physical and temporal conditions encountered in actual ballasting operations, we can finalize an Electro-Ionization Ballast Treatment System that meets or possibly sets the standards for ballast water treatment.

Although the test treatment system, as it now stands, is most appropriate for on-board treatment, the technology has application for Port Authority shore-based treatment and tender installations. Marine Environmental Partners has begun the process of adapting the EIT Technology for these applications.

6. References

Armstrong, E., Rogerson, A. & Leftley, J.W. 2000. The abundance of heterotrophic protists associated with intertidal seaweeds. *Estuarine, Coastal and Shelf Science* 50: pp. 415-424.

Ballast Water and Shipping Committee. 2000. *Summary and recommendations on ballast water discharge standards to the aquatic nuisance species task force, November 2000*.

Bratbak, G. & Heldal, M. 2000. Viruses rule the waves – the smallest and most abundant members of marine ecosystems. *Microbiology Today* 27 pp. 1171 – 1173.

Eaton, A.D., Clesleri, L.S. & Greenberg, A.E. 1995. *Standard methods for the examination of water and wastewater*, 19th edition. American Public Health Association, American Water Works, Water Environment Federation.

Geller, J. B. & Carlton, J.T. 1993. Ecological roulette: the global transport of no indigenous marine organisms (release of ship ballast water threatens ecosystems in ports). *Science* 261: p.78.

Hallegraeff, G.M. & Christopher, J.B. 1991. Transport of toxic dinoflagellate cysts via ships' ballast water. *Marine Pollution Bulletin* 22: pp. 27-30.

Hallegraeff, G.M., Valentine, J.P., Marshall, J-. A. & Bolch, C.J. 1997. Temperature tolerances of toxic dinoflagellate cysts; application to the treatment of ship's ballast water. *Aquatic Ecology* 31: pp. 47-52.

Oemcke, D. & van Leeuwen, J. 1998. Chemical and physical characteristics of ballast water: implications for treatment processes and sampling methods. *CRC Reef Research Technical Report* pp. 1-44.

Rogerson, A. & Laybourn-Parry, J. 1992. Bacterioplankton abundance and production in the Clyde Estuary, Scotland. *Archiv f. Hydrobiologie* 126: pp. 1-14.

Rogerson, A. & Gwaltney**,** C. 2000. The numerical importance of naked amoebae in the planktonic waters of a mangrove stand in southern Florida. *Journal Eukaryotic Microbiology* 47: pp. 235-241.

Ruiz, G.M., Carlton, J.T., Grosholz, E.D. & Hines, A.H. 1997. Global invasions of marine and estuarine habitats by non-indigenous species; mechanisms, extent and consequences. *American Zoologist* 37: pp. 621-632.

Figure 1: Photograph of the Electro-Ionization Treatment system showing the contact tank and the Clorinoxyl™ module comprising two components, the Clorin™ gas generator and the NI-OX/L™ gas generator.

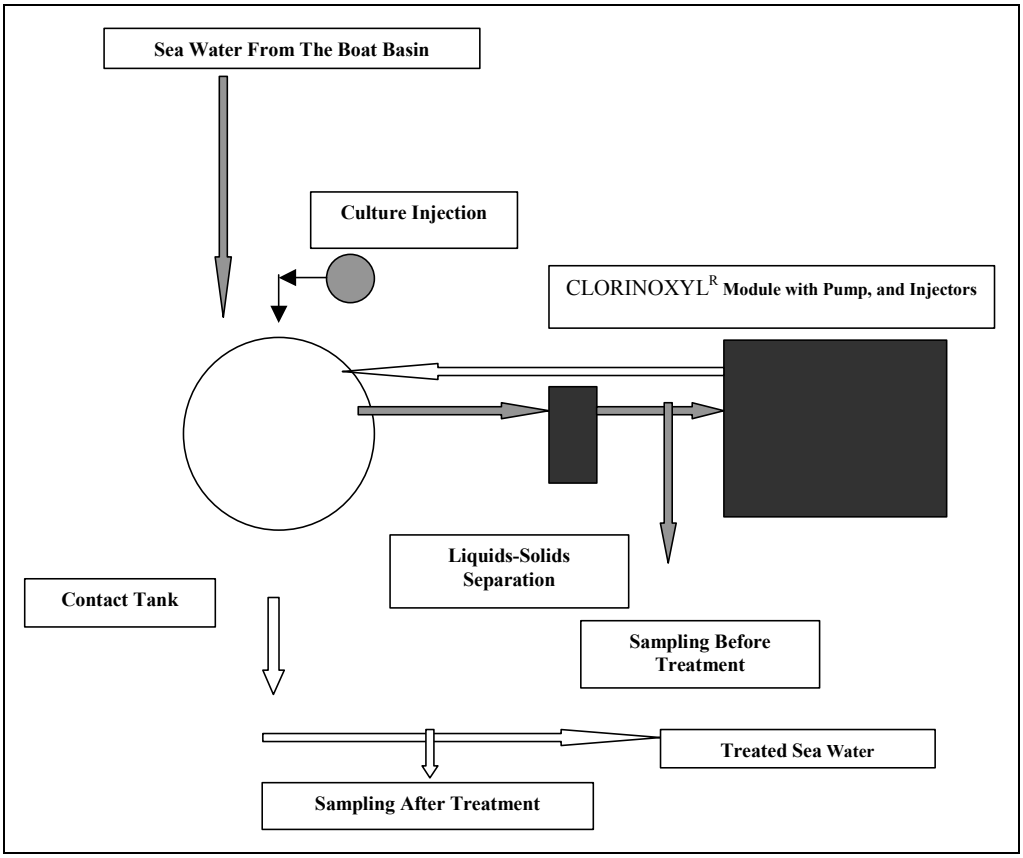

Figure 2: Schematic diagram (not to scale) of the Electro-Ionization Treatment system showing the path of water flow through the system.

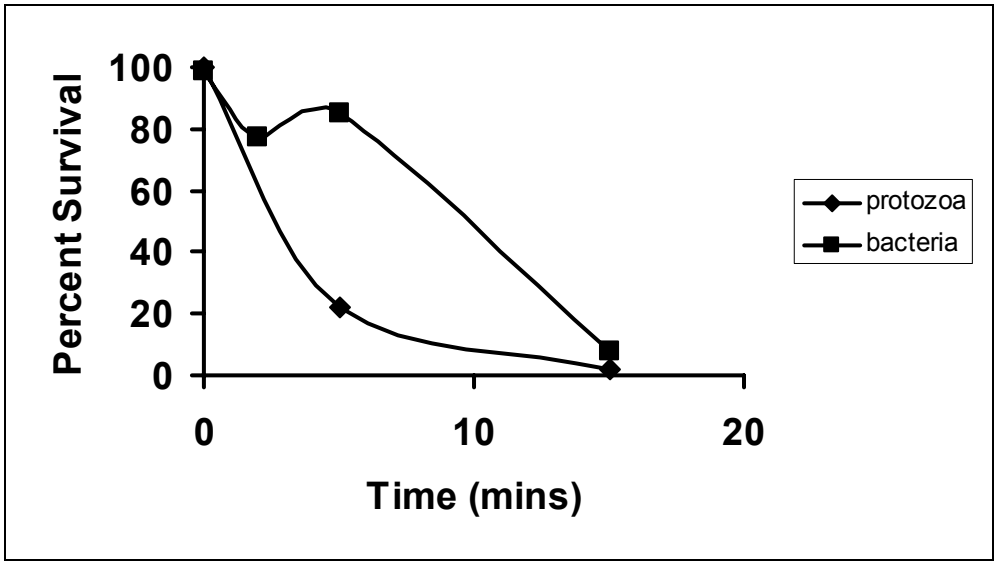

Figure 3: Comparison of survival rates of total protists (closed diamonds) and total bacteria (closed squares) after treatment with the NI-OX/L™ gas generator.

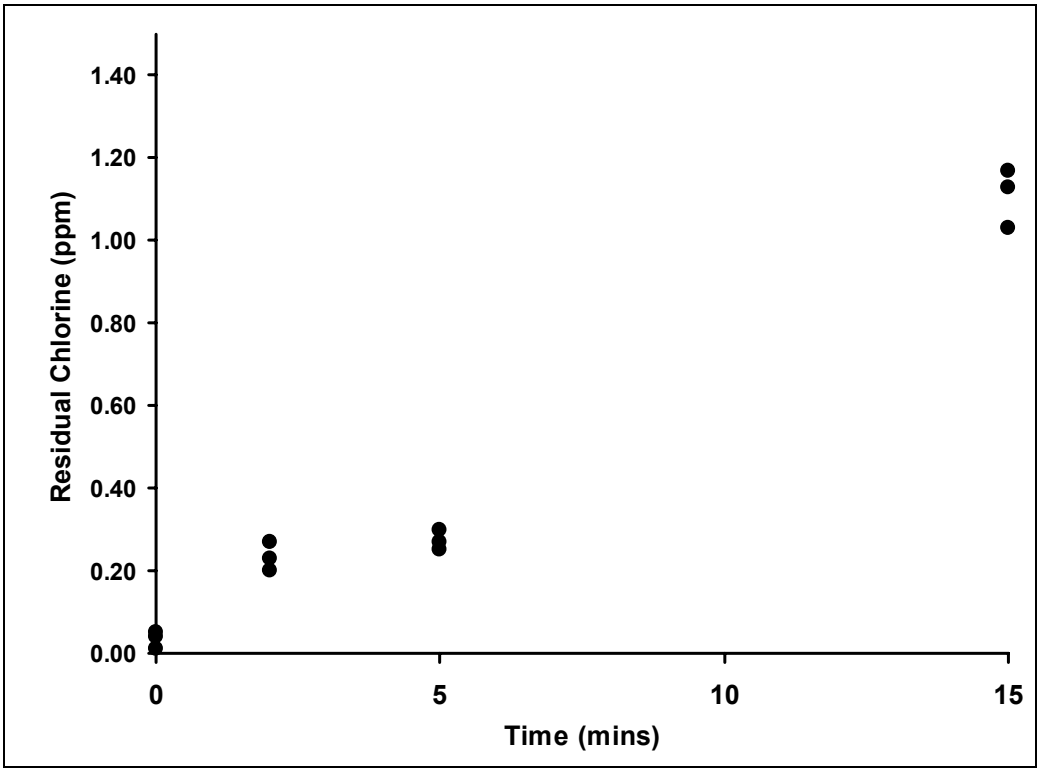

Figure 4: Levels of residual chlorine after the Clorinoxyl™ test runs. Levels were generally less than 0.3 ppm (at 2 minute contact time or once flow through at 60 GPM, and 5 minute contact time) when chlorine was generated from saturated brine (one-fifth dilution).

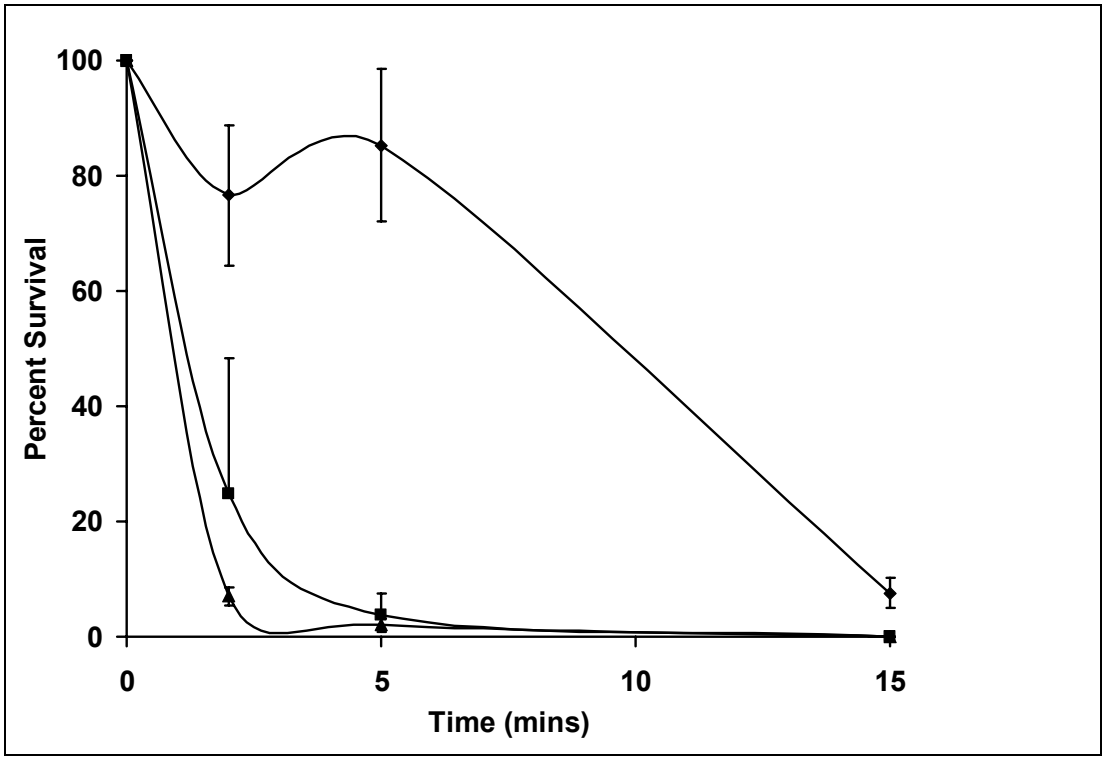

Figure 5: Comparison of three treatment runs on the percentage survival of total bacteria in 300 l of seawater. Closed circles represent the NI-OX/L^{TM} gas generator alone, closed squares the Clorin^{TM} gas generator and the closed triangles the Clorinoxyl^{TM} module. Means with standard errors (n = 3).

Ballast Water Treatment by Gas Supersaturation

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1. Treatment option being researched

Gas supersaturation. The working principle can be categorized under several modes of action:

- *Physical:* The main lethal effect on multicellular organisms is gas bubble trauma (GBT).
- *Mechanical:* During the creation of supersaturation, a surplus of small bubbles will be released into the water, leading to a flotation of organisms on which bubbles are entrapped in cavities.
- *Biological:* Organisms flotated to surface layers will be subjected to increased microbial activity due to increased bacterial numbers in surface film.
- *Hybrid system:* The method is planned as one part of a two stage hurdle technology, where UV treatment is the other component.

2. Timeframe of the project

November and December 2000 and Februray to June 2001.

3. Aims and objectives of the project

- To study the effectiveness of high levels (>115-120%) of gas supersaturation in killing organisms in ballast water.
- To study acute and chronic effects of various levels of air supersaturation on selected test organisms.
- To study acute and chronic effects of nitrogen supersaturation on selected test organisms.

4. Research methods

Newly hatched naupilus larvae of the brine shrimp *Artemia sp.* will be trensferred at a density of less than 200 larvae /l to vessels (20 litre) containing temperature stabilized sea water. In normal atmospheric pressure, the incubation water will initially be >130% air supersaturation. Duration of experiment will be 4 and 8+ days. Juveniles of blue mussel *Mytilus edulis* will be subjected to the same experimental regime.

As control, *Artemia* larvae from the same batch and juveniles of the blue mussel *Mytilus edulis* will be transferred to similar temperature controlled vessels with similar concentrations of organisms. The water will only be surface areated.

A similar set of experiments on the same organisms will be carried out with nitrogen as the gas creating the supersaturation.

Yet another set of experiments will be carried out in temperature-controlled vessels, which are kept at a pressure of 2 atm. Both air and nitrogen will be usd to establish supersaturation.

5. Results

At the current stage of the project only limited amounts of data is available. Some background information from the litterature is therefore provided.

Effects of gas supersaturation leading to gas bubble trauma have been reported for different groups of organisms like: Molluscs, (Malouf, et. al, 1972; Bisker and Castagna, 1985, Bisker and Castagna, 1987), shrimp (Lightner, et al., 1974), and fish (Weitkamp and Katz, 1980; Cornacchia and Colt, 1984; Saeed and Al-Thobaiti, 1997).

Chronic signs of GBT are usually encountered at supersaturation at levels of 38 – 76 mm Hg, (105-110%) while acute symptoms of GBT is encountered at levels > 76 mm Hg, or 110%.

While eventual cronic effects of low levels of supersaturation might have impacts for the ability of an organism to compete with indigenous species, the long time of exposure needed (often more than 30 days) means that such effects will be of litle value in a marine transportation context. Acute effects are however found in a relevant time-window (4-10 days).

Practicability

The method should be possible to implement both in existing and new vessels. The method may be implemented on a shore-based facility, where also the longer time hcronic effects of gas-supersaturation may be utilized.

Space

Regardless of gas choice, one would need space for a compressor of some size. If N2 or a N2-air mixture becomes the option of choice, a space for a nitrogen generator will also have to be found. Finally the UV-unit will occupy space.

Costs

The estimated running costs (power to gas compression/creation and UV) would be in the range of 2-5 cents/ton.

Environmental benefits

The outlet of the tanks will be completely without any harmful substances. Crew or operators will not need to handle dangerous chemicals.

6. Conclusions and recommendations

The method is believed to have a number of advantages, but several issues need to be clarified. It is unlikely that the method will be effective against microorganisms. It should therefore be considered as a method employed together with a method that is especially effective against microorganisms, like UV.

7. References

Bisker R. & Castagna, M. 1985. The effect of various levels of air supersaturated seawater on *Mercenaria mercenaria* Linne, *Mulina lateralis* Say and *Mya arenaria* Linne with reference to gas bubble disease. *J.of Shellfish Research* 5(2): pp. 97-102

Bisker R. & Castagna, M. 1987. The effects of air-supersaturated sea-water on *Argopecten irridans* Lamarck and *Crassostera virginica* Gmelin with reference to gas bubble trauma. *J. of Shellfish Research* 6(2): pp. 79-83

Cornacchia, J. & Colt, J.E. 1984. The effects of dissolved gas supersaturation on the growth of larval striped bass *Morone saxatilis* (Walbaum). *J. Fish Dis.* 7: pp. 15-27

Lightner, D.V., Salser, B.R. & Wheeler, R.S. 1974. Gas-bubble disease in the brown shrimp (*Paeneus aztecus*) *Aquaculture*, 4: pp. 81-4

Malouf, R. Keck, R., Maurer, D. & Epifano, C. 1972. Occurrence of gas bubble disease in three species of bivalve molluscs. *J.Fish Res. Board Canada* 29: pp. 588-9

Saeed M.& Al-Thobaiti 1997. Gas bubble diseas in farmed fish in Saudi Arabia. *Veterinary Record* 140(26): pp. 682-684

Weitkamp, D.E. & Katz, M. 1980. A review of dissolved gas supersaturation litterature. *Trans. Am. Fish Soc.*, 109: pp. 659-702

SeaKleen® - A Potential Natural Biocide for Ballast Water Treatment

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1. Treatment option being researched

Chemical (biocide)

2. Timeframe of the project

1996 – 2001

3. Aims and objectives of the project

Chemical options for ballast water treatment are limited because broad spectrum toxicity has to be accompanied by sufficiently rapid degradation to allow safe discharge in the destination port. Additionally, a potential biocide must be safe to handle within the confines of a ship and must not be corrosive to the structural components of the vessel. It must also demonstrate good cost effectiveness. We report here on four years of research into natural products as environmentally friendly biocides for ballast water treatment. Earlier work on juglone demonstrated a high degree of toxicity to a broad spectrum of aquatic organisms. Toxicity is maintained in freshwater over a broad pH range, and in estuarine water over a broad salinity range. More recent studies on a proprietary nutricide, SEAKLEEN® (Vitamar Inc., patent approved and pending) have demonstrated toxicity to a broad spectrum of marine and freshwater organisms. The product degrades below a toxic threshold within a period of time compatible with most voyages and is highly cost-effective.

4. Research methods

Toxicology

A wide variety of estuarine and fresh water organisms were exposed to a range of concentrations of SEAKLEEN® under static conditions in the laboratory. Most salt-water organisms were obtained from the culture facility run in conjunction with the state of Maryland (Department of Natural Resources) toxicity testing laboratory. Sheepshead minnow *(Cyprinodon variegatus)* eggs and larvae, copepods *(Eurytemora affinis)* and the estuarine and freshwater algae *Isochrysis* (strain T.iso) and *Neochloris* were all obtained from laboratory cultures and assayed under 16h:8h light/dark regime at 22^{O}C following range-finding tests.. Most fresh water assays were conducted on field-collected organisms from western Lake Superior during September 2000, although zebra mussel larvae were obtained from broodstock collected from Lake Erie in 1998 and spawned at the University of Maryland Chesapeake Biological Laboratory. Assays were conducted at 22^{O}C and were run in triplicate. Exposures of cysts of the dinoflagellate *Glenodinium* to SEAKLEEN® were conducted at the Kalmar

Marine Institute, Kalmar, Sweden (Prof. E. Graneli) where they were examined by epifluorescence microscopy.

In most cases tests were designed to identify a LC_{100} value for the biocide. For motile organisms, death was determined as a lack of movement under microscopic examination. Dinoflagellate *(Glenodinium)* cysts were examined for chloroplast degeneration by both light microscopy and epifluorescence microscopy. Dinoflagellate and algal cells were examined both for motility and for growth capacity as determined by chlorophyll a fluorescence. The latter was measured using a Hitachi F4500 scanning spectrofluorimeter at various time intervals following initial SEAKLEEN® exposure and under irradiation with fluorescent light.

The end-point of the "Deltatox"® bacterial assay is determined as the luminescence of modified *Vibrio fischeri* bacteria relative to untreated bacterial batches. Growth potential of naturally occurring bacterial assemblages was determined through counts of acridine orange-stained slides viewed through an Olympus fluorescent microscope.

Physical and chemical characteristics of SEAKLEEN®

Chemical degradation of SEAKLEEN® in both fresh and saline water, and the octanol:water partition coefficient of SEAKLEEN® and related compounds was followed using fluorimetry (Hitachi F4500 scanning spectrofluorimeter and gas chromatography/mass spectrometry (Hewlett Packard 5890 series II gas chromatograph coupled to a Hewlett Packard 5982 mass selective detector).

5. Results

A summary of toxicological data is shown in table 1. Results indicate that, for a broad range of prokaryotic and eukaryotic organisms the LC_{100} SEAKLEEN® appears to be in the range of 0.5-2mg L^{-1}. For unicellular organisms toxicity is characterized by an inability to grow under optimal conditions, or in the case of dinoflagellate cysts, the destruction of the chloroplast (Fig. 1).

The octanol:water partition coefficient (K_{OW}) for SEAKLEEN® and related compounds is approximately 2 indicating a high degree of hydrophyllicity. For example, consider the relationship:

$$C_W/C_S = K_{OC} \cdot f_{OC}$$

Where C_W = chemical concentration in interstitial water, C_S = chemical concentration in sediment, K_{OC} = partition coefficient for organic phase and f_{OC} = fraction of organic carbon in sediment, K_{OW} may approximate K_{OC}. Thus on a mass basis, partitioning of SEAKLEEN® between sediment and water would be approximately 100:1. Therefore, even with a suspended sediment load as high as 5g L^{-1}, a preponderance of the chemical would remain in the aqueous phase, thereby minimizing the need for filtration as a necessary pre-treatment.

6. Conclusions and recommendations

LC_{100} values between 0.5 – 2 mg L^{-1} for SEAKLEEN® indicate a consistent and high degree of acute toxicity to a broad range of aquatic organisms, both unicellular and metazoan, eukaryotic and prokaryotic. Octanol:water partition data indicate that the product has low hydrophobicity and would remain in the water column even in the presence of high suspended particulate loads. Its toxicity to a benthic amphipod such as *Leptocheirus plumulosus* signifies its potential for treatment of ships carrying a sediment residue in the ballast tanks with little water present, although its primary use would be against organisms suspended in the water column.

The high degree of acute toxicity means that the product can be administered in small amounts, close to 1 gram per metric tonne of ballast water treated, thereby making it highly cost effective (<$0.20/metric tonne treated). In light of the relative rapid natural breakdown of SEAKLEEN® and

the consistent nature of its toxicity to a broad taxonomic spectrum the product can be formulated to degrade to below toxic thresholds for a wide range of organisms within the normal time of passage of most cargo ships. The biocide is scheduled for trials in Baltimore harbor aboard the U.S. Maritime Administration ship "Cape May" in late spring /early summer 2001, with further trials scheduled for bulk carriers "at sea" later in the summer of this year.

SEAKLEEN® is an organic oxidant having no known corrosive properties affecting structural elements of a ship. It is a natural product produced by the human body, which degrades to a harmless pharmaceutical by-product. While registration is incomplete, preliminary mammalian studies indicate the lowest toxic rating recorded through the U.S. Environmental Protection Agency's registration process. Handling aboard a ship is, therefore, projected to be safe and straightforward. The product will be marketed as a soluble powder, which will be dissolved in a 55 gal. mixing drum prior to being pumped into the influent ballast water stream. Preliminary calculations suggest that one drum will treat ca. 10,000 metric tonnes of water at typical ballasting rates.

Peraclean® Ocean – a Potential Ballast Water Treatment Option

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1. Treatment options being researched

Various treatment options for ballast water have been suggested (Gollasch, 1997). Chemical treatment with Peraclean® Ocean is one potential method to effectively the organisms and pathogens in ballast water.

2. Timeframe of the project

The tests of Peraclean® Ocean as a chemical ballast water treatment option are part of an ongoing research project in Germany (1998 – 2001), that is funded by the industry (Degussa AG) and the German federal Ministery of Education and Research with the title 'Process for the removal of organisms from different waters'.

3. Aims and objectives of the project

This paper summarizes the laboratory results of an ongoing German research project, and provides details on the toxicological properties of Peraclean® Ocean.

4. Properties of Peraclean® Ocean

Peraclean® Ocean is a liquid biocide formulation based on peroxy acetic acid (PAA). PAA containing formulations are widely used in the food and beverage industry as well as in sewage treatment plants and other water treatment processes. They found wide application in the treatment of cooling water and as a pre-treatment of biologically contaminated waters prior to discharge into the environment. PAA is permitted in the USA as a secondary and indirect food additive at concentrations up to 100 mg/l.

Peraclean® Ocean is a fast-acting oxidising biocide effective against a broad spectrum of micro-organisms: bacteria, spores, yeasts and moulds, protozoa, algae and viruses (Block, 1991; Schliesser, & Wiest, 1979; Baldry, 1983). Peroxy acetic acid products are effective over a wide range of conditions. Peraclean® Ocean is most active at pH values of 5-7 but displays also good activity even under mildly alkaline conditions up to pH 9. Peraclean® Ocean remains effective even at temperatures of 4 °C and below. The microbial activity of peroxy acetic acid based products is relatively unaffected by organic matter, compared to other oxidising biocides (Block, 1991).

The shelf-life of Peraclean® Ocean is at least 1 year: more than 90% of the original activity is still present after one year`s storage at room temperature. Peraclean® Ocean is commercially available in

220l drums, 1 m^3 IBCs or in 20 m^3 bulk containers. Peraclean® Ocean is readily biodegradable according to OECD Screening Test 301 E guidelines.

Decomposition products of Peraclean® Ocean are acetic acid, oxygen and water:

$CH_3CO_3H + H_2O \rightarrow CH_3CO_2H + H_2O_2$

$2\ H_2O_2 \rightarrow O_2 + 2\ H_2O$

The hydrolysis by-products of Peraclean® Ocean are also readily biodegradable.

The half-life of Peraclean® Ocean is 10- 20 minutes in seawater depending on pH, salinity and temperature (Figure 1). In fresh water the half-life of Peraclean® Ocean is 12-24 hrs. Enhanced decomposition of Peraclean® Ocean may occur in contact with sediments.

Efficacy tests

Several studies showed that many organisms from different trophic levels can be found in ballast water tanks. For that reason the efficacy testing of a chemical treatment should include organisms from more than one trophic level (Voigt, 1999).

For a first evaluation of the performance of Peraclean® Ocean, the *Artemia* Testing Standard (ATS) was applied. This benchmark test uses the brine shrimp, *Artemia salina,* as indicator organism. The ATS involves 4 different development stages of the brine shrimp: adults, larvae, nauplius-stages, pre-incubated eggs and cysts. The results of the benchmark tests are summarized in Table 1.

Table 1: Results of Peraclean® Ocean on different development stages of the brine shrimp, *Artemia salina;* Values in brackets represent the highest mortality reached at the end of the experiment.

Testorganism Brine shrimp, *Artemia salina*	Parameter observed	Concentration of Peraclean® Ocean (ppm)	Max. Hatching Rate after 72 hrs	Time (hrs.) needed to reach 100% mortality
Cycts[1]	Hatching rate	350	3%	
	Survival of	700	0%	
	hatched Nauplii	1 400	0%	
Pre-incubated Eggs[2]	Hatching rate	350	9%	
	Survival of	700	0%	
	hatched Nauplii	1 400	0%	
Nauplii	Mortality	350		(97%)
		700		36
		1 400		8
Adults	Mortality	350		(38%)
		700		12
		1 400		8

1 = untreated control group: 52 +/- 8,4 %
2 = untreated control group: 47,4 +/- 2,2 %.

The ATS-data showed that the addition of Peraclean® Ocean at levels of above 350 ppm resulted in 100 % mortality of all *Artemia* live stages. The pH of the treated sea water is slightly reduced from pH 8.2 to 6.1, due to the acidic properties of Peraclean® Ocean.

After the initial tests, further experiments were carried out with a number of indicator organisms. The experimental designs applied included different salinities and temperatures. In each case, the experimental conditions represented optimum environmental conditions for the test species.

Experiments with nauplii of the brine shrimp, *Artemia salina*, indicated, that only 400ppm Peraclean® Ocean are required to reach 100% mortality under varying environmental conditions (Tab. 2).

Table 2: Experiments with Peraclean® Ocean in different water qualities. Testorganism: nauplii of brine shrimp (*Artemia salina*). Values represent average of 3 parallel experiments. Note: Observations were made after 1, 2, 4, 8, 12, 24, 36, 48 and 72 hours.

Testorganism Brine shrimp, *Artemia salina*	**Water Quality**	**Parameter observed**	**Concentration of Peraclean® Ocean (ppm)**	**Time (hrs.) needed to reach 100% mortality**
(Nauplii)	Salinity 13.5ppt Temp. 24°C	Mortality	400 800 1 200	16 8 4
(Nauplii)	Salinity 13.5ppt Temp. 32°C	Mortality	400 800 1 200	11 4 4
(Nauplii)	Salinity 31ppt Temp. 24°C	Mortality	400 800 1 200	36 19 5
(Nauplii)	Salinity 31ppt Temp. 32°C	Mortality	400 800 1 200	24 7 4

ppt= parts per thousand

Experiments with fertilised eggs of Atlantic herring (*Clupea harengus*) followed. The eggs were pre-incubated in clean water for one week to assure an undisturbed start of the larval development. In this case too, 400 ppm were sufficient to reach 100% mortality of the embryos. Concentrations as low as 200 ppm also resulted in mortalities above 98%, with the lowest kill rate (98.3%) being observed under marine conditions (Salinity = 31 ppt) and temperatures of 12°C (Tab. 3).

Table 3: Experiments with Peraclean® Ocean in different water qualities. Testorganism: pre-incubated eggs of Atlantic Herring (*Clupea harengus*). Values represent average of 3 parallel experiments. Note: Observations were made after 1, 2, 4, 8, 12, 24, 36, 48 and 72 hours. Values in brackets represent the highest mortality reached at the end of the experiment.

Testorganism Fertilised eggs of Atlantic Herring	**Water Quality**	**Parameter observed**	**Concentration of Peraclean® Ocean (ppm)**	**Time (hrs.) needed to reach 100% Mortality**
	Salinity 13.5ppt Temp. 5°C	Mortality of embryo	200 400 800	16 8 2
	Salinity 13.5ppt Temp. 12°C	Mortality of embryo	200 400 800	15 3 1
	Salinity 31ppt Temp. 5°C	Mortality of embryo	200 400 800	12 4 1
	Salinity 31ppt Temp. 12°C	Mortality of embryo	200 400 800	(98.3%) 1 1

Organisms of the zooplankton showed even higher sensitivities. The dosing of only 400 ppm Peraclean® Ocean resulted nearly instantly in 100% mortality of the testorganisms. After a maximum of 2 hours exposure time, all of the organisms were dead (see Tab. 4).

Experiments with phytoplankton cultures (indicator organism: *Chlorella* sp.) showed similar results: even 200 ppm Peraclean® Ocean killed the algae within 48 hours (See Tab. 5). However, higher

concentrations of Peraclean® Ocean (concentration range from 400 ppm to 1600 ppm) did not result in significantly faster eradication of the algae.

Table 4: Experiments with Peraclean® Ocean with plankton organisms. Testorganisms: crustaceans from freshwater and brackish water communities. Values represent average of 3 parallel experiments.

Testorganism	Water Quality	Parameter observed	Concentration of Peraclean® Ocean (ppm)	Time (hrs.) needed to reach 100% mortality
Freshwater Plankton (Cultures)	Freshwater, room temperature	Mortality	200	2
Cyclops sp. (Copepod)			400	1
			800	1
Bosmina sp. (Cladocera)	Freshwater, room temperature	Mortality	200	1
			400	1
			800	1
Daphnia sp. (Cladocera)	Freshwater, room temperature	Mortality	200	-
			400	2
			800	2
In situ Plankton Baltic Sea (wild catch)	Brackish water, about 13 ppt Sal.	Mortality		
Copepods (30% of taxa)	room temperature		400	< 1
			800	< 1
Nauplii (66% of taxa)		Mortality	400	< 1
			800	< 1
Cladocera (4% of taxa)		Mortality	400	1
			800	< 1

Table 5: Experiments with algae. Testorganism: *Chlorella* sp.. Parameter: photometric measurement of extinction at 3 different wave lengths: 750nm, 663nm and 645nm. The following results represent the average of three parallel experiments each.

Testorganism	Water quality	Parameter observed	Concentration of Peraclean® Ocean (ppm)	Time needed to reach 100% mortality
Chlorella sp.	Salinity: 31 ppt	Chlorophyll	200	48
	room	a and b	400	48
	temperature		800	48
			1 200	48
			1 600	48

5. Conclusions

The results of the experiments clearly indicate that Peraclean® Ocean is an effective biocide for the treatment of ships´ ballast water. It resulted in 100% mortality of different test organisms from different trophic levels at concentrations between 200 ppm and 400 ppm.

The short half-life of Peraclean® Ocean in sea water assures that even the discharge of great quantities of ballast water in sheltered areas with limited water exchange (e.g. harbours and bays) would not have a negative impact on thenvironment. Furthermore, the physical properties of Peraclean® Ocean (easy storage and long shelf-life) favour it for both, on board and land based ballast water treatments as a stand-alone method, or in combination with filtration and/or gravity separation.

Large-scale tests are planned in April 2001 onboard of the vessel 'Cape May' as part of the ballast water project 'Maritime Solutions Ballast Water Treatment System – A Shipboard Trial' in order to reconfirm the efficacy of Peraclean® Ocean under realistic conditions.

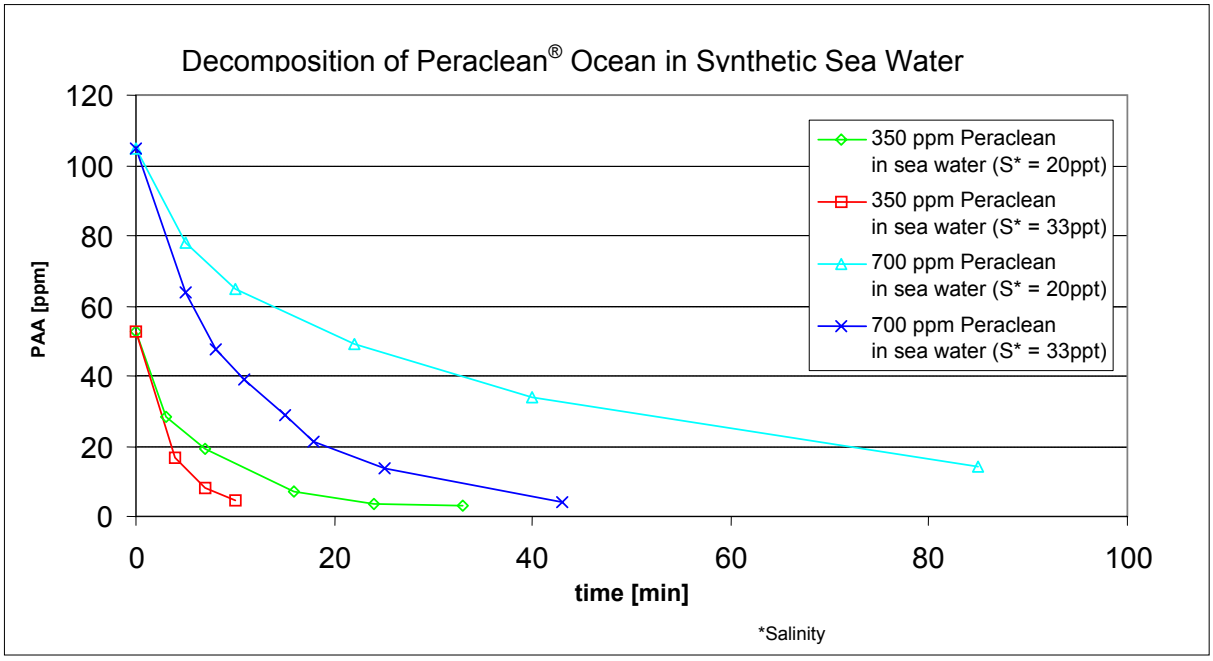

Figure 1: Decomposition of PAA from Peraclean® Ocean in seawater of different salinities.

6. References

Baldry, M.G.C. 1983. The bactericidal, fungicidal and sporicidal properties of hydrogen peroxide and peracetic acid. *J. Appl. Bact.* 54, pp. 417-423.

Block, S.S. 1991. *Disinfection, sterilization, and preservation*, 4th ed., Chapter 9, peroxygen compounds. Lea & Felbinger, Philadelphia PA, 167-181.

Gollasch, S. 1997. *Removal of barriers to the effective implementation of ballast water control and management measures in developing countries*. Desk study carried out for GEF/IMO/UNDP, 187 pp.

See also:

Grenman, D.; Mullen, K.; Parmar S. & Friese C. 1997. *Ballast water treatment systems: A feasibility study*. 61 pp. From the internet: http:/www.ansc.purdue.edu/signis/publicat/papers/.

Schliesser, T.H. & Wiest, J.M. 1979. Catalase-mediated redox reactions. *The Enzymes vol XIII Oxydation-Reduction,* Doyer, P.B. (ed) Part C, 3rd ed, pp. 389-395. Academic Press, New York NY.

Voigt, M. 1999. Treatment Methods for Ballast Water. *2nd annual conference "Managing environmental risks in the maritime industry", London, 30.09.1999-01.10.1999.*

Ballast Water Treatment with Currently Available Biocides

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1. Treatment options being researched

Chemical biocides.

2. Timeframe of the project

To understand the timeline of this project, it is important to understand the context in which it is occurring. The State of Michigan occupies the central geographic location in the Great Lakes system. It borders four of the five Great Lakes and is entirely within the Great Lakes Watershed. Because of this, Michigan has been greatly affected by invasive aquatic species and ships' ballast water is considered a major vector for such species. In early 2000, legislation was introduced in the Michigan Senate to require ballast water sterilization and authorization by permit for discharge in Michigan waters. Shortly thereafter, Michigan's Governor, John Engler, proposed establishing a Ballast Water Task Force, under the auspices of the Council of Great Lakes Governors. Governor Engler was concerned that a Michigan-only approach could not be effective and could lead to a patchwork of individual state regulatory requirements. The purpose of the Task Force is to advise the Governors on the options for inhibiting the further introduction of exotic species from ballast water.

In addition, the regulators were hearing that there was no known method to treat ballast water to remove or kill the foreign species. Therefore, to provide important information to the Council of Great Lakes Governors Task Force, the Director of the Michigan Department of Environmental Quality, Russell J. Harding, established a Ballast Water Work Group (BWWG), with a stated goal of determining "the best way currently available to get ballast water introductions of exotic species stopped in 12 months." Attachment 1 lists the entities represented on the BWWG. The concept of the BWWG is to work cooperatively with the shipping industry to find a practical solution to this problem. The 12-month time frame was established to ensure that the focus would remain on what is currently available – not what might be available in the future. Although the 12 months has passed, the focus is still on what is currently available, and the need to provide answers is intensely felt.

The legislative and executive branches of Michigan's government are absolutely committed to quick action on this problem. Every day that goes by brings the possibility that "another zebra mussel" might be released into the Great Lakes. We are talking about potential billion-dollar losses and potential liability for the vectors of these species. So our "project" is really to establish effective ballast water controls, not just do a research project. Attachment 2 shows a timeline covering the previous year and into the future.

Since its establishment, the BWWG has concluded that the only currently available methods of improving the control of invasive aquatic species in ballast water are improved management practices and biocides. Also, the list of biocides considered to be potentially "currently available" has been narrowed to three – hypochlorite (chlorine), gluteraldehyde, and copper ion. Attachment 3 shows the list of biocides considered to date.

As shown in the timeline on Attachment 2, the BWWG has determined that shipboard testing of the three selected biocides should be carried out. This is needed to demonstrate whether they are practical for general application in foreign ships operating in the Great Lakes. A grant was awarded for the testing of gluteraldehyde and that work is ongoing. For hypochlorite and copper ion, Michigan is now preparing a Request for Proposal (RFP) to carry out the on-board testing. This paper addresses that portion of the overall Michigan "project." The timeframe for that work is the 2001 shipping season. The results are expected to be provided to the Council of Great Lakes Governors Task Force following the shipping season.

3. Aims and objectives of the project

Attachment 4 lists the project objectives which will be incorporated into Michigan's RFP. The RFP is expected to be sent out to prospective contractors in April 2001. As shown in Attachment 4, the objective is to determine if hypochlorite and/or copper ion are practical, effective, and safe biocides for general use in ships' ballast water.

Attachment 5 shows the general criteria for whether these biocides are practical, effective, and safe, along with what we know about them now. Both chlorine and copper are known to be lethal to a broad range of species. Also, both are relatively simple and safe to use, and both are economical and readily available. However, there are some unanswered questions:

1. **What happens when sediment is present in the ballast water?** Simply stated, sediment is bad for biocide effectiveness. It increases the chlorine demand, increasing the cost, and potentially creating unwanted by-products. Copper is readily complexed by organic materials, potentially to the point of ineffectiveness. Questions about the problems associated with sediments need to be answered. The BWWG has recommended, regardless of the biocides used, that ballasting management practices be improved.

2. **Will biocides cause corrosion in ballast tanks?** There has been concern raised that chlorine, in particular, may damage ballast tanks due to corrosion. Michigan believes that corrosion will be minimal at the low concentrations needed. However, this question must be answered before chlorine can be considered for general use. Michigan's RFP will include laboratory testing to determine whether chlorine–induced corrosion is a problem for the various types of tanks and coatings used in the shipping industry.

3. **Is the discharge environmentally acceptable?** Michigan has requested information from all nine Great Lakes jurisdictions in the United States and Canada as to what the regulatory requirements are for these biocides in ballast water discharges. This information will be obtained before field testing begins. The same questions may also need to be answered in other jurisdictions around the world before general use begins.

Chlorine use as a biocide has raised concerns and deserves additional comment. Chlorine has one particular advantage: it is easily neutralized prior to discharge. This prevents acute toxicity in the receiving waters, and is done routinely in the Great Lakes discharges which are disinfected with chlorine.

Another concern is that unwanted chlorinated by-products may cause chronic toxicity. Michigan does not believe that risk is significant in relation to the risks posed by invasive aquatic species. Chlorine is the most widely used biocide for water and wastewater. It is also commonly used to disinfect swimming pools and as a household bleach. Consequently, it is very well understood. Certain chlorinated organic chemicals are toxic, persistent, bioaccumulative, and in some cases carcinogenic. Such compounds can be created in chemical synthesis reactions at elevated temperatures and/or pressures. That has been a problem associated, for example, with pesticide manufacturing and pulp bleaching. Treating ballast water is not expected to create any more significant amounts of these problem compounds than is disinfection of sewage or drinking water. In addition, the amount which would be used for treating ballast water is small in relation to other uses of chlorine. This is

illustrated in Attachment 6. Therefore, chlorine should not be ignored as a possible ballast water biocide.

4. Research methods

Both laboratory and on-board testing will be required by Michigan's RFP, as shown in Attachment 7. The detailed research methods proposed by potential contractors responding to the RFP will be considered as part of the proposal evaluation process. The toxonomic assessments will need to consider a broad range of species, including those which are more resistant to chemical biocides. The chemical analyses will need to be sensitive to the particular forms of copper and chlorine to distinguish between that which is biocidal and that which is complexed and ineffective.

It is possible that some laboratory bioassays will need to be done if the ballast water taken in during the test is lacking in certain aquatic species. This will need to be done on a case-by-case basis.

5. Results

Results of the testing of hypochlorite and copper ion will be available after the testing is completed. This testing will be done during the 2001 shipping season.

6. Conclusions and recommendations

1. Biocides and improved management practices are the only "currently available" methods to minimize invasive aquatic species in ships ballast water.
2. Copper ion, hypochlorite, and gluteraldehyde are biocides which are potentially "currently available."
3. Commercial-scale field testing is needed before these biocides can be recommended for general usage. Some additional complementary laboratory work is also needed.
4. The field testing needs to be done as soon as possible, followed by implementation of ballast water treatment using biocides which are proven to be practical, safe, and effective.
5. As further research is done on ballast water controls, methods which are superior to biocide applications may be found. Thus, use of biocides may be an interim approach which is replaced later. However, the environmental danger of new invasive aquatic species makes interim measures essential.

Attachment 1: Michigan's Ballast Water Work Group

Governmental entities

Michigan Department of Environmental Quality*

Michigan Department of Transportation

Transport Canada

United States Coast Guard*

Associations

Canadian Shipowners Association*

Chamber of Shipping of America

Detroit Port Authority

Lake Carriers' Association*

The Chamber of Maritime Commerce

The Shipping Federation of Canada

Private companies

Algoma Central Marine*

Fednav, Ltd.*

Gresco Ltee

Hasserodt Marine Agency Ltd.

Polsteam USA, Inc.

Scandia Shipping Agencies, Inc.

Stolt -Nielsen Transportation Group Ltd.*

Upper Lakes Group Inc.

Other

University of Michigan, Department of Naval Architecture and Marine Engineering*

*Entities also represented on the Biocides Subgroup

Attachment 2: Timeline for Michigan's ballast water initiative

01/26/00	Legislation introduced in the Michigan Senate to require ballast water sterilization and discharge permits in Michigan waters.
02/18/00	Michigan Governor John Engler proposes establishing a Council of Great Lakes Governors Ballast Water Task Force to develop a regional approach.
03/22/00	DEQ Director Russell Harding establishes a Ballast Water Work Group (BWWG).
04/05/00	BWWG establishes 3 subgroups: 1. Management Practices 2. Biocides 3. Potential New Technologies

05/17/00 Biocides Subgroup recommends:

1. Two candidates for shipboard testing: Gluteraldehyde and Hypochlorite (chlorine)
2. Management Practices to minimize sediment and avoid interference with biocides.

06/07/00 BWWG requests development of biocide shipboard testing plans.

08/31/00 General chlorination shipboard testing plan completed.

02/21/01 Copper Ion added as biocide candidate.

April 2001 Send request for proposals to contractors to carry out the biocide testing.

Summer 2001 Shipboard testing of copper ion and chlorine.

Subsequent Steps: Forward results of shipboard testing to the Council of Great Lakes Governors for implementation of regional approach for the Great Lakes.

Attachment 3: Biocides considered

A. Considered to be "not currently available".

1. Ozone - currently used in wastewater treatment, but must be generated on-site (retrofitting required).
2. Ultra Violet Light - currently used in wastewater treatment; promising, but turbidity must be removed from ballast water. Must generate UV light on-site (retrofitting required).
3. Juglone - needs more research.
4. Peracetic Acid - needs more research.
5. Acrolein - needs more research.
6. Bromine and Iodine - currently used in biocidal applications, but not as toxic as chlorine.
7. Chlorine Dioxide - currently used for bleaching pulp in the papermaking industry, but must be generated on-site (retrofitting required).

B. Considered to be potentially "currently available".

1. Hypochlorite (chlorine) - currently used for disinfecting drinking water, swimming pools, and treated sewage. Also used to treat for zebra mussel control. Extensively used as household bleach.
2. Copper Ion - currently used to control fouling, for example, in heat exchangers.
3. Gluteraldehyde - currently used to disinfect medical instruments. Somewhat more expensive than chlorine or copper ion.

Attachment 4: Michigan biocide testing - project objectives

- To carry out on-board field testing of hypochlorite and copper ion as ballast water biocides. (Some associated laboratory testing will also be done.)

- To answer the following questions about these two biocides in various ballast water matrices:
  - Are they effective in killing a broad range of ballast-borne biota?
  - Can they be safely handled?
  - Are the ultimate discharge concentrations environmentally acceptable to regulatory agencies?
  - Do they damage ballast tanks?
  - Do they work with sediment present?
  - Are they economical and readily available?
  - Are there any other practical considerations to their use?

- The bottom line: can copper ion and/or hypochlorite be recommended for general application as ballast water biocides?

Attachment 5: Comparison with biocide criteria

	CRITERIA	COPPER ION	HYPOCHLORITE
1.	Lethal to a broad range of species.	Yes.	Yes.
2.	Concerns with sediment present.	Readily complexes with organics.	Additional chlorine demand.
3.	Is the discharge environmentally acceptable.	?	Yes.
4.	Simple and safe to use.	Yes.	Yes, but liquid handling required.
5.	Economical and readily available.	Yes.	Yes.
6.	Corrosive to ballast tanks.	No.	?

Attachment 6: Estimated chlorine usage

Sector	U.S. Chlorine Consumption(tons/yr)	Estimated Chlorine Consumption in the Great Lakes Watershed (tons/yr)
Water Intake and Wastewater Treatment	409,000	54,400*
Drinking Water Treatment	146,000	19,400
Household Bleaching and Swimming Pool Treatment	290,000	38,600
Total Consumption (all uses)	13,684,000	1,820,000
Estimated Potential Use for Ballast Water Treatment	- -	34

Notes

1. Amounts shown are expressed as tons/year of chlorine (Cl_2)
2. U.S. chlorine consumption is based on 1997 data provided by the Chlorine Chemical Council.

3. Great Lakes consumption is extrapolated from the U.S. consumption, using the 1991 ratio of total U.S. and Canada population in the Great Lakes Watershed to total U.S. population (ratio = 0.133).

4. Ballast water treatment usage estimate is based on a 5 mg/l chlorine dosage rate, and assumes that all ballast water entering the Great Lakes is treated, including salt water ballast and water remaining the tanks of NOBOB vessels.

*At least 500 tons/year of chlorine are used for zebra mussel control at water intakes.

Attachment 7: Research methods

1. On-board chemical analysis of the biocide residuals over time in dosed ballast water tanks.

2. On-board toxonomic assessment of dosed ballast water over time to assess biocide effectiveness.

3. Laboratory toxicity testing to assess biocide impact on resistant aquatic species, if absent in actual ballast water.

4. Laboratory corrosivity tests to evaluate biocide impact on ballast tank coatings.

The Great Lakes Ballast Technology Demonstration Project: Biological Effectiveness Test Program (including *MV Regal Princess* trials)

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1. Treatment options researched

Mechanical and physical, comprising:

- Cyclonic separation (Hyde-Optimarin).
- Automatic backwash filtration (25, 50, 100, 150, and 200 um), (Ontario Hydro Technologies).
- Ultra violet radiation, (Hyde-Optimarin).
- Combinations of the above physical separation devices and UV.

2. Timeframe of the project

1997-2000

3. Aims and objectives of the project

The experiments reported here were designed to describe and compare the biological effectiveness of commercially-available approaches to mechanical/physical treatment of ballast water: automatic backwash screen filtration (ABSF), cyclonic separation (CS), and ultraviolet radiation (UV), alone and in combination with each other. The tests examine the systems' abilities to kill, remove or impede reproduction of organisms in ballast water. To better describe effectiveness, extensive physical and biological tests were conducted at two scales. All treatments were analyzed on a stationary barge-based experimental platform at 340.8 cubic meters/hour. The CS system was analyzed in the shipboard context in an engine-room installation of an operating passenger vessel – *MV Regal Princess* (Princess Cruise Lines) – at 199.8 cubic meters/hour. The ABSF was analyzed in a shipboard context in a deck installation on an operating bulk cargo carrier – the *MV Algonorth*.

All treatments were analyzed at two time intervals following treatment (0 and 18-24 hours), and several locations with varied physical/chemical source water characteristics (two barge sites in Lake Superior, various *MV Regal Princess* locations along the north Pacific coast of the US and Canada, various *MV Algonorth* locations in the Great Lakes). The barge-based tests illuminated system effectiveness in a high flow, yet controlled experimental context. The ship-board tests provided a real-world assessment of treatment in the context of an operating ballast system. While not all-encompassing, the combination of biological findings reported here provide a strong indication of the overall effectiveness of the systems with respect to bacteria, viruses, phytoplankton and zooplankton. Though the full-scale flow-rate for the passenger ship is low compared to cargo ships, the experiments

are especially informative as to interactions between ballast systems and the biota in treated and untreated water, and the extent to which efficacy results from a barge platform may be translatable to effectiveness in a ship.

4. Research methods

Treatments

Automatic Backwash Screen Filtration System (ABSF) - The ABSF studied was an EvrClear system designed by Ontario Hydro Technologies, Inc. consisting of a 1.45 m long and 0.94 m diameter cylindrical steel housing containing a 0.76 m diameter removable filter element and a backflushing system. Water enters the filter unit and passes from the inside outward through the filter element. The filtered material that builds up on the inside of the filter element causes a pressure drop across the filter element activating the rotation of suction heads within the element. The suction heads remove the filtered material and discharge it overboard with a portion of the raw water. Physical and operational testing in 1998 showed that 50 um ABSF was suitable for shipboard applications for some ships.

Cyclonic Separator (CS) – The Separator is made of 316 stainless steel and has no moving parts. The 340.8 cubic meter/hour installation is 3.3 m long with a maximum diameter of 1 m. It is generally cylindrical with a conical, funnel-shaped head and is mounted at an angle of 65 degrees (non-critical) from horizontal on a steel bedplate and frame. The bedplate is 2 m square. Water enters the Separator at the upstream end (top in the current orientation) through an 0.2 m tangential inlet flanged connection and exits downstream through an in-line 0.2 m outlet flanged connection (bottom in the current orientation). Solids are removed at up to 10% of the total flow rate through a 0.05 m downstream discharge pipe near the bottom. The centrifugal force causes materials heavier than water to move outward to the walls of the Separator and flow downstream past an effluent concentrate orifice where they are removed through a 0.05 m discharge pipe. The clarified water continues along the centerline of the Separator and exits through the downstream discharge. Total pressure drop is estimated at less than ½ bar. The equipment was manufactured by Hyde Marine, Inc.

Ultraviolet Radiation (UV). The MicroKill UV system is also made of stainless steel. The body of the unit is 608 mm in diameter and 1.4 m long. Overall length is 1.72 m. Water flows into the central upstream end of the unit through an 0.2 m flanged connection, passes through the internal exposure chamber, exiting the unit at the opposite downstream end through the top-mounted 0.02 m flanged discharge connection. The 18 radially arranged UV elements are mounted through the downstream end-plate. Each element is contained within a closed quartz tube, with each element-tube assembly extending the full length of the exposure chamber. The UV light intensity is automatically controlled by the power supply and monitored by a sensor inside the unit which delivers a signal to the control panel. The UV unit can be mounted on the same bedplate as the Separator. It is designed to deliver a dose of at least 100 mws/cm2 in water with 90+%/cm UV transmittance at 254 NM.

Platforms

ABSF alone, and ABSF + UV experiments

Filtration experiments were performed aboard the *MV Algonorth* in 1997, and a stationary barge in 1998 and 2000. Both platforms were designed by Parsons et al (1998) and employed the same modular experimental system consisting of two ABSF systems installed in a 6.1 m by 1.8 m container module, and a Godwin 20.3 cm by 15.2 cm HL6 Dri-Prime pump driven by a John Deere 6081T diesel engine to power the water flow through the filtration system.

The *MV Algonorth* is a commercial bulk cargo vessel which operates between the Gulf of St. Lawrence and the western-most Great Lakes ports. Matched #3 Upper Wing Tanks (UWT) with a 220 cu m capacity served as test and control tanks. The matched #3 UWTs were isolated from the lower wing tanks, fitted with spring opened and elevated manholes, and identical trolley systems to suspend plankton nets for uniform sampling hauls. Piping was installed to allow water flow

through the two filter units in series into these tanks, or to bypass one or more of the filters. Water for the biological tests was drawn from the #4 Starboard Ballast Tank (SBT) or directly from the sea, depending upon the operational requirements of the ship. For each trial, the same source of water was used for both the test and control tanks. The control tank only received untreated water, and the test tank only treated water. The control and test tanks were cleaned with high-pressure deck water prior to the overall experiment, and whenever a smaller mesh polishing filter screen was exchanged for a larger screen size. Except in emergencies, no other operations took place in these tanks, and when other ship operations were necessary, the tanks were cleaned prior to reuse for the experiment. Two ABSF were tested in series. The first filter unit in the series contained a 250 μm prefilter, and the second polishing unit contained a 25 μm, 50 μm, 100 μm, or 150 μm screen.

The same diesel powered Godwin HL6 Dri-Prime pump powered the water flow through the ABSF treatment container on the barge-based experimental platform. The UV system was added downstream of the filter units. Flow conditions on the barge platform were nominal 340.8 cubic meters/hour at 70 psi; shutoff head 120 psi. The 20.3 cm pump suction pipe had a 0.08/0.41 m (3/16") perforated screen intake to strain out larger particles that could damage treatment systems. This fixed strainer replaced the prefilter unit employed in the *MV Algonorth* experiment. The suction pipe depth was adjusted to maintain a level of a few feet off the harbor bottom. Nine portable 700 L catchment tanks were installed on the barge to facilitate biological sampling. Each catchment tank had a 10.16 cm drain pipe at the bottom and could be rinsed between uses with filtered tap water. Outflow from the treatment system was subdivided by piping and valves into outlet streams of approximately equivalent flow rate to allow simultaneous filling of three catchment tanks at a time. The flow of water used to fill the catchment tanks can be directed through or by-pass treatment systems. ABSF tests were conducted on 25, 40, and 50 um screens (without a prefilter) on the barge-based platform. UV was tested in combination with the 40 um screen. The barge-based tests took place in Duluth, MN in September 1998, and Duluth, MN and Two Harbors, MN in June and September, 2000, respectively.

CS alone, and CS + UV experiments

CS and UV were tested alone and together on the barge-based platform (described above) in Two Harbors, MN. Shipboard experiments took place on CS in combination with UV at the full-scale for the *MV Regal Princess* (199.8 cubic meter/hour). Three 227 L catchment tanks with 5.1 cm outlets were installed in the engine room of the *MV Regal Princess*. One-half inch internal diameter sample ports were installed before and after the combined treatment system (CS and UV) so that samples can be taken in-line as well as from treated and untreated water which has been stored in a ballast tank. Preliminary tests show that these one-half inch sample ports did not impede the collection of live zooplankton samples. Two identical 90.3 cubic meter ballast tanks (#10 Port and Starboard) were used as matched control and treatment tanks. The PCL agreed to treat all of its ballast water for a period of two months prior to the August tests to minimize concern of leakage of untreated water from other parts of the system into the treated water. The *MV Regal Princess* plied Vancouver, BC to Alaska and back during the May and August testing.

MV Regal Princess experiments, although less comprehensive due to the ship-board context, offered the unique opportunity to measure the influence of the ship-board environment on treatment performance. For each taxonomic grouping, the *MV Regal Princess* tests comprised 1) "Flow-Through" studies, in which the effects of a single pass through the treatment system were measured through in-line pre- and post-treatment sampling (providing a baseline against which to detect ballast tank effects); 2) "Time Zero" studies, which measured the effects of treatment versus no treatment on water pumped into and immediately removed from a ballast tank (to detect effect of physical exposure to a ballast tank and system); and 3) "Time 18-24 Hour" studies, which measured the effects of treatment versus no treatment on water held in a ballast tank for 18-24 hours (to detect the cumulative effects of retention time in a ballast tank on treatment effectiveness).

UV alone experiments

Neither the ABSF nor the CS had a measurable effect on total bacteria, so all ambient bacteria tests involving UV were essentially UV-only tests, including those on the *MV Regal Princess*. UV effects on the MS2 Coliphage spiked into the system and total culturable bacteria were directly compared between the two barge sites to measure effects of UV absorbency on system effectiveness. Relative effects of UV on phytoplankton at the two barge sites were deduced through comparing UV alone effects at Two Harbors with the incremental effectiveness afforded by UV over filtration at the Duluth site.

Assays

Zooplankton

1. Density analysis. Zooplankton samples were concentrated and preserved for microscopic sorting and counting in the laboratory.

2. Live analysis. Live zooplankton samples were analyzed quantitatively using a dissecting and compound microscope for percent live (reactive).

Phytoplankton

1. Density/Acute mortality/removal analysis. Initial concentrations of Chlorophyll *a*.

2. Growth potential analysis. Concentrations of Chlorophyll *a* in incubated samples (barge experiments only).

3. Sorting and sizing analysis. Microscopic analysis of algal densities (ABSF experiments only).

Bacteria and viruses

1. Density of culturable ambient bacteria – Total Plate Count of culturable ambient bacteria.

2. Density of attached bacteria – TPC analysis of samples collected with a 20 um plankton net (ABSF only).

3. Spiked virus density analysis – Spiked Coliphage MS2 Experiments (Barge experiments only).

Particles/water quality

1. Particle removal analysis – Particle count samples were collected and analyzed on-site with a Particle Sizing System (Barge experiments only).

2. Physical/chemical source water analysis – Turbidity, temperature, pH and dissolved oxygen were measured in the catchment tanks using the Datasond 4 Hydrolab.

3. UV absorbency analysis – Whole water samples were collected at the treatment site each test day and filtered to 0.45 um and analyzed with a spectrophotometer for UV transmittance at 254 NM (Barge experiments only).

5. Results

Zooplankton results are expressed primarily in terms of "Percent Reduction in Live Densities" to incorporate both density and mortality effects. Phytoplankton results are expressed in terms of "Percent Reduction in Chlorophyll *a* (or density of specific taxa in the ABSF only tests)". Microbial results are expressed as "Log (or Percent) Reductions in CFU's" (culture forming units). Absolute post-treatment and discharge concentrations of these indicators were also documented. In the barge and *M/V Algonorth* tests, comparisons are made directly between treatment and controls. In the *M/V*

Regal Princess tests, reductions/growth relative to intake in treated water is compared to reductions/growth relative to intake in raw water.

Bioeffectiveness of CS and UV was evaluated at two time intervals following treatment (0 hours and 18-24 hours), two treatment contexts (*MV Regal Princess* installation at 199.8 cu m/hr, and a barge-based platform at 340.8 cu m/hr), and varied physical/chemical water conditions (Pacific Northwest coastal, and two Lake Superior locations). CS and UV effects are compared to ABSF (40 um) and UV based on barge-platform tests using identical protocols. Selected findings follow:

Zooplankton

CS and UV

CS and UV caused a highly significant reduction in live zooplankton on both platforms ($P < .01$). The intake-only treatment on the barge platform (340.8 cu m/hr) decreased live zooplankton by 56 percent over controls (T0). In the shipboard application, which involved treatment at both the intake and discharge, treatment doubled the reduction in live density of zooplankton. The live density of zooplankton in treated ballast water decreased by a mean of 86 percent relative to pre-treatment intake levels, compared to 43 percent in the controls (T0).

In shipboard tests, there were no significant immediate effects of treatment on zooplankton during ballasting, but there were significant delayed effects in both T0 and T18-24 tests**.** During deballasting there was a significant immediate zooplankton mortality, indicating that the intake treatment, storage in a ballast tank, and a slower pump rate upon discharge could contribute to zooplankton susceptibility to the treatment.

Barge tests revealed that both CS and UV contributed to zooplankton mortality, with UV causing a highly significant additional reduction in live density of zooplankton over CS alone ($P < .01$). Delayed (T18) reductions in live densities of zooplankton due to CS alone were observed in the barge tests, with a mean reduction of 30 percent (+/- 14.6) relative to controls.

ABSF and UV

UV in combination with ABSF yielded higher (by nearly twice) reductions in live zooplankton than CS and UV relative to controls. ABSF alone yielded highly significant reductions in zooplankton live densities. ABSF alone consistently reducing macrozooplankton by over 95 percent and microzooplankton (rotifers) by over 90 percent relative to controls (over twice the performance of CS alone.

UV significantly increased the effects of ABSF in the barge tests ($P < .05$), even in both Duluth where the source water transmittance was low. ABSF alone reduced live density by a mean of 96 percent, while ABSF and UV reduced live density by 97 percent.

General

These findings represent a conservative estimate of zooplankton inactivation as latent mortality caused by the discharge treatment and reproductive effects were not measured, and injured individuals were counted as live.

Phytoplankton

CS and UV

The system caused a highly significant ($P < .01$) attenuation of phytoplankton growth and acceleration of die-off relative to controls (measured in barge tests only). Chlorophyll *a* concentrations in incubated samples collected 18 hours following treatment were nearly 60 percent lower than controls.

UV was the only system component causing significant ($P < .01$) reductions in chlorophyll a (phytoplankton).

On both platforms, initial chlorophyll *a* concentrations relative to controls were not significantly altered through acute effects of the system such as removal or bleaching. Storage of the water for 18 hours in a catchment or ballast tank prior to sampling did not alter this finding.

ABSF and UV

ABSF alone significantly reduced phytoplankton concentrations relative to controls while CS alone did not. The ABSF alone caused up to 30 percent (average 20 percent) reduction in initial concentrations of chlorophyll *a,* and much higher reductions in concentrations of specific algal taxa such as dinoflagellates (>95 percent). The ABSF did not cause a significant increase in the number of smaller algal fragments relative to controls due to break-up.

ABSF and UV yielded equivalent reductions to CS and UV, and UV alone, in algal growth in the barge tests suggesting that UV was the operative system component.

Bacteria (ABSF, CS, UV)

Primary treatment did not alter the effects of UV alone at inactivating total culturable bacteria or the MS-2 Coliphage.

The UV system did significantly reduce ambient culturable bacteria concentrations in barge tests (Two Harbors) and in the shipboard tests ($P < 0.01$). MS-2 coliphage concentrations were significantly reduced in all tests ($P < 0.01$) but UV transmittance of source water was highly correlated with system performance. In the barge tests, the mean inactivation due to treatment was approximately one log (90 percent) for bacteria and 1.3 log (95 percent) for coliphage MS-2 at Two Harbors (UV transmittance over 90 percent/cm), while the mean inactivation due to treatment was approximately 0.1 log (25 percent) for bacteria and 0.3 log (50 percent) for MS-2 in Duluth (UV transmittance 30-45 percent).

On the shipboard platform, the reductions in bacteria were of a similar magnitude to those in the Two Harbors barge tests, as would be expected given the generally high optical transmittance quality of the Alaskan waters.

These shipboard treatment effects counteracted increases in bacteria concentration due to exposure and retention in the ballast tank. The mean reduction in culturable bacteria due to one pass through the treatment system in a shipboard context (*MV Regal Princess*) was 0.8 Log (82 percent). Retention for less than two hours in the ballast system raised concentrations of culturable bacteria 1.45 Log higher than levels immediately following treatment. Bacterial regrowth and/or repair during 18 - 24 hour retention in the ballast tank raised bacterial concentrations 2.62 Log. Discharge treatment then reduced bacteria concentrations to a level roughly equivalent to intake concentrations.

Treatment during discharge reduced bacteria twice as effectively than treatment during ballasting, possibly reflecting the slower pump rate during deballasting. While neither CS alone or ABSF alone reduced total culturable bacteria, ABSF alone did reduce attached bacteria concentrations by 50 percent ($P < .05$).

6. Conclusions & recommendations

ABSF alone (40 um) delivers substantial reductions in live zooplankton and some forms of phytoplankton in the ballast water of ships. It does not reduce total culturable bacteria. Cyclonic separation alone does not reduce phytoplankton and bacteria, and only slightly reduces live zooplankton density after a delay period.

UV alone had effectiveness against all biotic groupings tested, and with an improved design and increased dosage, could substantially reduce levels of zooplankton, phytoplankton and bacteria in ships ballast water.

UV significantly enhanced the already substantial and highly consistent effectiveness of ABSF alone against zooplankton and some phytoplankton, and added UV-alone effects on phytoplankton and bacteria to those ABSF effects.

UV highly significantly enhanced the more subtle and variable effects of CS alone on zooplankton live densities, and added the same UV-alone effects on phytoplankton and bacteria.

All of the technologies tested performed approximately as well in the shipboard context as on the barge platform.

UV treatment at the point of discharge in addition to UV treatment at intake is advisable to counteract bacterial regrowth and enhance mortality effects on zooplankton.

7. References

Parsons, M., & Harkins, R. 2000. The Great Lakes Ballast Technology Demonstration Project Mechanical Testing Program. *Marine Technology*, Vol. 37, No. 3, Summer 2000, pp. 129-140.

Parsons, M.G., Harkins, R.W., Mackey, T.P., Munro, D.J. & Cangelosi, A. 1997. Design of the Great Lakes Ballast Technology Demonstrations Project. *Transactions* SNAME 105: 323-348.

Testing of Ballast Water Treatment Technologies at Large Scale

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1. Treatment options being researched

A ballast water treatment test facility was constructed at the Rosensteil School of Marine and Atmospheric Sciences (RSMAS), University of Miami, Florida, USA, to test promising shipboard ballast treatment systems. The current focus is on primary treatment using mechanical methods (self-cleaning strainers and hydrocyclones), followed by secondary treatment using physical methods (UV light).

2. Timeframe of the project

The construction of the Ballast Water Treatment Test Facility started in September 2000, with an operational system for the self-cleaning strainer coupled with the UV unit completed in February 2001. Testing will commence in February 2001, and conclude by June 2001.

3. Aims and objectives of project

The two main aims of this project are to: 1) construct a facility to test treatment options for ballast water at large scale, and 2) conduct experiments to measure and verify efficacy of mechanical treatment followed by physical treatment on killing or removing marine organisms and microorganisms.

The first objective was to construct a pilot test facility at the RSMAS campus, which is located on the shore of Biscayne Bay and Bear Cut. Because of the large demand for water for this project, a separate pumping system was installed to serve the facility. A 1,500 gpm (approximately 5.7 m^3/min) pump at 45 psi (approximately 310 kPa) was installed on one of the RSMAS docks and an intake structure was suspended below the docks in approximately eight feet (2.4 m) of water. This assured a constant water supply to the treatment facility. A flexible pressure discharge line was routed along the bottom, then on shore, and terminated at the pilot plant facility. A separate electrical power service was installed on the dock to supply the large power of the pump.

The treatment test facility is located a short distance onshore from the pump. Holding tanks of 200 gallons (approximately 750 liters) were installed at three sample points within the pilot plant. Specifically, sampling points are located prior to the mechanical treatment operations (self-cleaning strainer or hydrocyclone), after the mechanical treatment operations and before the physical treatment operation (UV), and after the physical treatment operation. These tanks allowed for the collection of samples to evaluate the organisms either retained or passing the representative unit operations. In addition, a 30 gal (approximately 115 liter) tank was installed at the head of the treatment facility, along with a high pressure injection pump to augument turbidity. The ambient water in this location has turbidity values ranging from approximately 2-7 NTU, except in cases of turbulence from severe

weather events. Turbidity will be enhanced by the addition of kaolinite clay which can be added to achieve turbidities to any value. (See Figure 1).

A Hayward Strain-o-Matic® Self-Cleaning Strainer was selected for testing as the first mechanical treatment process in the pilot plant. This particular self-cleaning strainer is a commercially available model and robust for marine applications. A carbon steel and stainless steel unit Model No. 596 was installed, including a 50 µm stainless steel screen. A Krebs Model KSH-20 Desander hydrocyclone was selected for testing as the second mechanical treatment process. This hydrocyclone was selected for demonstration as it has already been tested for the removal of zebra mussel larvae. Preliminary experimentation with this hydrocyclone showed that it was able to separate larvae from Lake Ontario Water.

After the mechanical treatment process, a secondary UV treatment process was tested. A full-scale UV system designed by Wedeco-Ideal Horizons, Inc., included a unit containing 60 low pressure lamps with an estimated dosage of 30,000 µm Ws/cm^2 at 60% service capacity. It was anticipated that this design allowed for the most efficient UV treatment of ballast water possible.
The research goals were to:

1. Conduct experiments to measure and verify efficacy of pump, strainer, and UV treatment on killing or removing marine organisms and microorganisms, including bacteria and other pathogens.
2. Using the same platform and high lift pump used above, similar experiments will be conducted to measure and verify efficacy of pump, hydrocyclonic filtration, and UV treatment on killing or removing marine organisms and microorganisms, including bacteria and other pathogens.

4. Research methods

Samples were collected at the various points noted above. For ATP and zooplankton analyses described below, samples were collected on a 35 µm Nitex mesh net suspended in each of the collection tanks. The samples were analyzed for the following:

Biochemical Analysis for Viability of Organisms: ATP content was used to assess the viability of organisms. ATP is produced by all living organisms and is rapidly degraded by ATPases with cell death. This analysis has wide application in the determination of living biomass in sediments (Karl and LaRock, 1975), sludge (Patterson *et al.,* 1970), marine water columns (Holm-Hansen and Booth, 1966, Maranda and Lacroix, 1983), as well as in phytoplankton (Holm-Hansen 1969, Hitchcock *et al.,* 1987) and bacterial populations (Lundin and Thore, 1975).

Size fractionated samples (>35 µm and <35 µm) were immediately placed in boiling Tris buffer for extraction to avoid ATPase activity (Cheer *et al.,* 1974). Once ATP is released, samples may be frozen with little loss of activity (Patterson *et al.,* 1970). ATP is analyzed with the Luciferin-luciferase assay (Holm Hansen and Booth, 1966) using a Turner TD20/20 luminometer. Carbon from the same Tris extract of each sample is analyzed on a Thermoquest CE NC2000 CN analyzer. Carbon:ATP ratios do vary with season and species (Traganza and Graham, 1977), but for a given area and period they can provide an index of living to dead biomass. These data can then be used to assess the efficacy of UV inactivation.

Microbiological Analysis: Microbiological testing of water for drinking and recreational uses is continually conducted by various local, state and federal agencies. Methods for enumeration and viability of indicator microorganisms are fairly well established, and most agencies follow the protocols stated in *Standard Methods for the Examination of Water and Wastewater* (American Public Health Association, 1998).

Water samples were analyzed for total heterotrophic bacterial counts by the Membrane Filter method (Method 9215D). Water samples were also analysed for total coliform bacteria and *Escherichia coli* by the Enzyme Substrate test (Method 9223). The U.S. EPA (1986) recommended indicator microorganisms for water quality, i.e., enterococci, was also be monitored using an enzyme substrate test.

Phytoplankton Analysis: Phytoplankton pigment analyses provide an index to the biomass of viable phytoplankton through estimates of chlorophyll *a* in living cells. An index to the detrital, or dead, material is provided by the fluorometeric measurement of pheophytin *a*, which is actually composed of a suite of chlorophyll degradation products (Smith *et al.,* 1981). Our method for the analysis of chlorophyll *a* and pheophytin *a* is based on Method 445.0 of the U.S. Environmental Protection Agency (1992). The stated detection limit is 0.05 μg l^{-1} for chlorophyll *a* and 0.06 μg l^{-1} for pheophytin *a* in marine waters. Particulate matter is collected by filtration of three replicates at a vacuum of 5 inches Hg (< 20 kPa) onto Whatman GF/F filters. For typical coastal waters a sample volume of 100 ml is sufficient. If the analyses cannot be conducted immediately, the filters are stored in individual plastic vials in a dessicator at - 20°C. Within three weeks the filters are ground in a tissue grinder in 5 ml of 90% acetone, and the slurry is then transferred to a 15 ml polyethylene test tube. A blank filter is included in the extraction process and analyzed to detect potential contamination of reagents or possible problems with the instrumentation. The capped test tubes are placed the dark at 4°C for 24 h to extract the pigments. This extraction period is sufficient to provide a Relative Standard Deviation of 5.0% on replicate samples (Table 1, USEPA Method 445.0).

The slurry is centrifuged at 1000 g for 5 min to clear the supernatant following the extraction period. The acetone is transferred to a 4 ml glass cuvette and fluorescence is measured before and after acidification (0.1 ml of 0.1 N HCl) on a Turner Designs Model 10 fluorometer. The instrument is equipped with a F4T5 blue lamp, a red-sensitive photomultiplier, a Corning CS-5-60 excitation filter, and a Corning CS-2-64 emission filter in accord with the USEPA Standard Method 445.0. The initial reading reflects the combined contribution of 'total' chlorophyll *a* while the final (acidified) reading is primarily pheophytin *a* (Smith *et al*., 1981). The instrument is calibrated with a Standard Solution made from pure chlorophyll *a* obtained from Sigma Chemical Corp (cf. Section 10.0, Calibration and Standardization, USEPA Method 445.0). The purity and concentration of the Standard Solution is checked by spectrophotometric methods during each bimonthly calibration. Concentrations are reported in triplicate as chlorophyll *a* and phaeopigment *a* as μg l^{-1}.

Zooplankton Analysis: Laboratory analyses of samples for taxonomic enumeration involves splitting each zooplankton sample several times in a Folsom splitter to obtain aliquots containing approximately 200-400 individuals. Three aliquots are counted with the aid of a Leica Wild M10 or Leica MS5 stereomicroscope for numerically dominant mesozooplankton taxa and groups. When an aliquot contains more than 50 specimens of a species or taxon, that taxon is not counted in subsequent aliquots. The composition and number of species present determines the size of the second and third aliquots. For example, if the first aliquot contains 400 organisms of which 300 are small, unidentified copepod nauplii, then a larger aliquot will be utilized for subsequent counts in order to obtain greater numbers of other species or groups. This method has been used in numerous studies conducted previously by Smith and Lane (e.g., Smith *et al.,*1985, Smith and Lane, 1988, Flagg and Smith, 1989, Lane *et al.,* 1993, 1995, 1996, Ashjian *et al.,*1995, 1997) and conforms in general with other recently published zooplankton sample enumeration guidelines (Postel *et al.,* 2000). Previous net samples collected from the dock at the Rosenstiel School have often been dominated numerically by various stages of the small calanoid copepods *Acartia tonsa* and *Paracalanus* spp. , and the small cyclopoid copepod genus *Oithona* (Lane, unpublished data). We anticipate identifying these and any other numerous copepods to the species or genus level and to differentiate adults from copepodites. Other mesozooplanktic groups including chaetognaths; appendicularia; mysiids; and larvae of the decapod, echinoderm and polychaete groups are counted if they are observed in samples. Since the sample collecting mesh will be relatively fine (50 μm), all copepod nauplii are grouped and counted. Eggs and egg clusters are also counted, and if numerous, classified by size.

5. Results

The data presented here must be considered as preliminary in nature, as they represent information collected from start-up runs at the ballast water test facility. In addition, the data here reflect the effects of UV radiation on ambient seawater without any pretreatment. The water coming into the test facility however, is relatively clear with turbidity values less than 3 NTU. The typical UV absorbance of Biscayne Bay water is approximately 0.039 absorbance units and based on this absorption value, the UV system was designed to deliver approximately 50,000 $\mu W/cm^2$ dose. Because no pre-treatment was done, of the seawater before UV radiation, the data presented here only deal with analyses reflecting inactivation of various components of the biota, after being exposed to UV radiation.

Evaluation of zooplankton before and after UV radiation, was undertaken only in a qualitative sense, and only preliminary observations can be reported here. The most abundant group of the zooplankton is the copepod nauplii. Count data suggest an approximate abundance of seven (7) nauplii per liter, followed by foraminifera at two (2) individuals per liter, and the cyclopoid copepod *Oithona sp.* at one (1) individual per liter. Other taxa and groups observed in this preliminary sample, include harpacticoid copepods, calanoid copepods (A*cartia sp.* and P*aracalanus sp.*), gastropod larvae, decopod larvae, and polychaete larvae.

While it is extremely difficult to determine whether components of the zooplankton have been damaged by the UV radiation, utilizing only microscopic observations, some general observations are reported here. Microscopic observations were made immediately following the treatment with UV, and after an 18 hour storage period. In all samples, lively zooplankton specimens, including *Oithona sp*., harpacticoid copepods and copepod nauplii were seen to be lively with a large percentage of the population apparently still viable. The general qualitative observation of samples before and after the UV treatment suggests that a large percentage of the zooplankton remained viable and active after the radiation event.

The organisms most susceptible to UV will be the microorganisms. Figure 2 shows the effects of UV radiation on typical enteric bacteria. Specifically, concentrations of both total coliform organisms as well as *E.coli* are presented. It can be seen that the numbers of these organisms are small in the ambient water, as would be expected in a non-contaminated environment, and also that UV radiation appeared to reduce the numbers at least by one order of magnitude. Concentrations of these organisms are also shown in Figure 2 after an 18 hour storage period. In this case, the water was stored in tanks at the ballast water treatment site. The tanks were polypropylene and did allow sunlight to penetrate. It can be seen that substantial amounts of regrowth occurred with both of the test organisms. It also appears that the regrowth of the irradiated samples was extremely large, and the reason for these large numbers is unknown at this point in time. The phenomenon of regrowth of organisms irradiated by UV has been well understood since the late 1940's. Specifically visible light is capable of repairing damage to the base pairs of DNA (dimarization of thymine) caused by UV radiation.

Figure 3 shows UV irradiation data for the total flora in the seawater as measured by heterotrophic plate counts. Once again, the inactivation of the total plate count by UV irradiation was relatively minor. After 18 hours the ambient bacterial population exhibited a substantial regrowth, while the UV irradiated population did not have a significant regrowth. Also shown in this figure, is ambient water and UV irradiated water kept in the dark and at a cool 4^oC. Here it can be seen that while the ambient water continued to grow, the UV treated water declined in population, under these conditions. This again demonstrates the role of visible light repair of UV damaged base components of DNA.

Figure 4 shows the effect of UV radiation on the total chlorophyll in samples collected before and after UV irradiation. It is expected that organisms containing chlorophyll or other phyto pigments will be more susceptible to UV radiation than the zoo plankton. It can be seen from Figure 4 that after UV irradiation approximately half of the chlorophyll was destroyed by the radiation. It also can be seen that after 18 hours, the concentration of chlorophyll in both the ambient water as well as the

radiated water, continued to decline. Figure 5 shows the same type of data for the phaeophytin a pigment and the same pattern of decline can be seen.

In an effort to quantify the effects of UV radiation on the total biological community in the seawater samples, a bulk measurement of biological activity was made, i.e. the concentrations of Adenosine Tri-Phosphate (ATP). The effects of UV radiation on ATP are shown in Figure 6. As outlined in the methods and materials section, samples were collected by filtration through 35 micron screens, however ATP measurements were run on both samples retained by the 35 micron screen as well as material passing. In each case the amount of ATP was normalized by the amount of protein measured in the sample to give a more reliable basis of biological activity. Figure 6 shows that the relative amount of ATP per mass of protein material is much lower for larger organisms than for smaller organisms. Also, the figure shows that the UV irradiation did very little to decrease enzyme activity for the larger organisms (greater than 35 μ) while some effect was noted on the smaller organisms (less than 35 μ). These observations while preliminary, are consistent with the expected results that smaller organisms will be more effected by UV radiation than larger ones. Also shown in Figure 6, are enzyme activity measurements of the organisms after an 18 hour incubation period (with light available). Again, regrowth is apparent, especially with the smaller microorganisms. It also appears that enzyme activity of irradiated organisms less than 35 μ, had substantial regrowth while standing for 18 hours. These data are consistent with the observations of both bacteria and phytoplankton taken during this experimental phase.

6. Conclusions and recommendations

The preliminary data presented here for UV radiation of raw seawater show that the treatment, even at an estimated dose of 50,000 $\mu W/cm^2$ is unable to substantially reduce the biological activity of the samples. While some effects are obviously occurring, and the process may be optimized by pre-treatment regimes, the results are still less than astounding. Once again, these are preliminary data, and as more data are collected in our system, statistical significance can be applied to the results. However, the results obtained so far are in line with past studies of UV treatment of water for inactivation of microorganisms. Past studies have shown UV to be sensitive to dissolved and suspended materials in the water, and there are only selected applications where UV is a reliable disinfecting process. In order for a process like UV to be successful in treating ballast water, much higher levels of inactivation will need to be recorded to instill reliability in the process. This may be achieved by increasing the UV dose supplied to ballast water, however, our system is delivering a UV dose substantially in excess that normally utilized for microorganism inactivation. It also appears that UV radiation is not going to be particularly effective against the large size components of the zooplankton (greater than 35 μ).

7. References

American Public Health Association, American Water Works Association, Water Environment Federation. 1998. *Standard Methods for the Examination of Water and Wastewater,* 20th ed. American Public Health Assoc., Washington, D.C.

Ashjian, C.J., Smith, S.L., & Lane, P.V.Z. 1995. The Northeast Water Polynya during summer 1992: Distribution and aspects of secondary production of copepods. *J. Geophys. Res*. 100: pp. 4371-4388.

Ashjian, C., Smith, S., Bignami, F., Hopkins, T. & Lane, P. 1997. Distribution of zooplankton in the Northeast Water Polynya during summer 1992. *J. Mar. Sys*. 10: pp. 279-298.

Cheer, S., Gentile, J. & Hegre, C.S. 1974. Improved methods for ATP analysis. *Analyt. Biochem*. 80:pp. 102-114.

Flagg, C.N. & Smith, S.L. 1989. On the use of the acoustic Doppler current profiler to measure zooplankton abundance. *Deep-Sea Res*. 36: pp. 455-474.

Hitchcock, G.L., Langdon, C. & Smayda, T.J. 1987. Short-term changes in the biology of a Gulf Stream warm-core ring: Phytoplankton biomass and productivity. *Limnol. Oceanogr*. 32: pp. 919-928.

Holm-Hansen, O. 1969. Determination of microbial biomass in ocean profiles. *Limnol. Oceanogr*. 14: pp. 740-747.

Holm-Hansen, O. & Booth, C.R. 1966. The measurement of adenosine triphosphate in the ocean and its ecological significance. *Limnol. Oceanogr*. 11: pp. 510-519.

Karl, D.M. & LaRock, P.A. 1975. Adenosine triphosphate measurement in soil and marine sediments. *J. Fish Res. Bd. Can.* 32: pp. 599-607.

Lane, P.V.Z., Smith, S.L. & Schwarting, E.M. 1993. *Zooplankton data report: vertical distributions of zooplankton in the Norwegian and Greenland Seas during summer, 1989*. BNL-49358 Informal Report, Brookhaven National Laboratory, Upton, NY 11973. 158 pp.

Lane, P.V.Z., Smith, S.L. & Ashjian, C.J. 1995. *Zooplankton data report: distribution of zooplankton in the Northeast Water Polynya (NEWP) during summer, 1992*. RSMAS Technical Report 95-002. Div. of Marine Biology and Fisheries, RSMAS, University of Miami, Miami, FL 33149. 139 pp.

Lane, P.V.Z., Smith, S.L. & Ashjian, C.J. 1996. *Zooplankton data report: distribution of zooplankton in the Northeast Water Polynya (NEWP) during summer, 1993*. RSMAS Technical Report 96-007. Div. of Marine Biology and Fisheries, RSMAS, University of Miami, Miami, FL 33149. 96 pp.

Ludin, A. & Thore, A. 1975. Comparison of methods for extraction of bacterial adenosine nucleotides determined by firefly assay. Appl. Microbiol. 30: pp. 713-731.

Patterson, J., Brezonik, P. & Putman, H. 1970. Measurement and significance of adenosine triphosphate in activated sludge. *Environ. Sci. Technol*. 4: pp. 569-575.

Postel, L., Fock, H. & Hagen, W. 2000. Biomass and abundance. *In* Harris, R. P., P. H. Wiebe, J. Lenz, H. R. Skjoldal and M. Huntley, eds. *ICES Zooplankton Methodology Manual*, Academic Press. 684 pp.

Smith, R.C., Baker, K. S. & Dustan, P. 1981. Fluorometric techniques for the measurement of oceanic chlorophyll in the support of remote sensing. SIO Ref. 81-17, *Scripps Institute of Oceanography*, La Jolla, CA, 14 pp.

Smith, S.L., Lane, P.V.Z. & Schwarting E.M. 1985. *Zooplankton data report: shelf-edge exchange processes (SEEP) I*. Technical Report Number BNL 36260, Brookhaven National Laboratory, Upton, NY 11973, 74 pp.

Smith, S.L. & Lane, P.V.Z. 1988. Grazing of the spring diatom bloom in the New York Bight by the calanoid copepods *Calanus finmarchicus, Metridia lucens* and *Centropages typicus*. Cont. Shelf. Res. 8: 485-509.

Traganza, E.D. & Graham, K.J. 1977. Carbon/adenosine triphosphte ratios in marine zooplankton. *Deep-Sea Res*. 24: pp. 1187-1193.

U.S. Environmental Protection Agency. 1986. *Ambient Water Quality for Bacteria – 1986*. EPA-440/5-84-002, U.S. Environmental Protection Agency, Washington, D.C.

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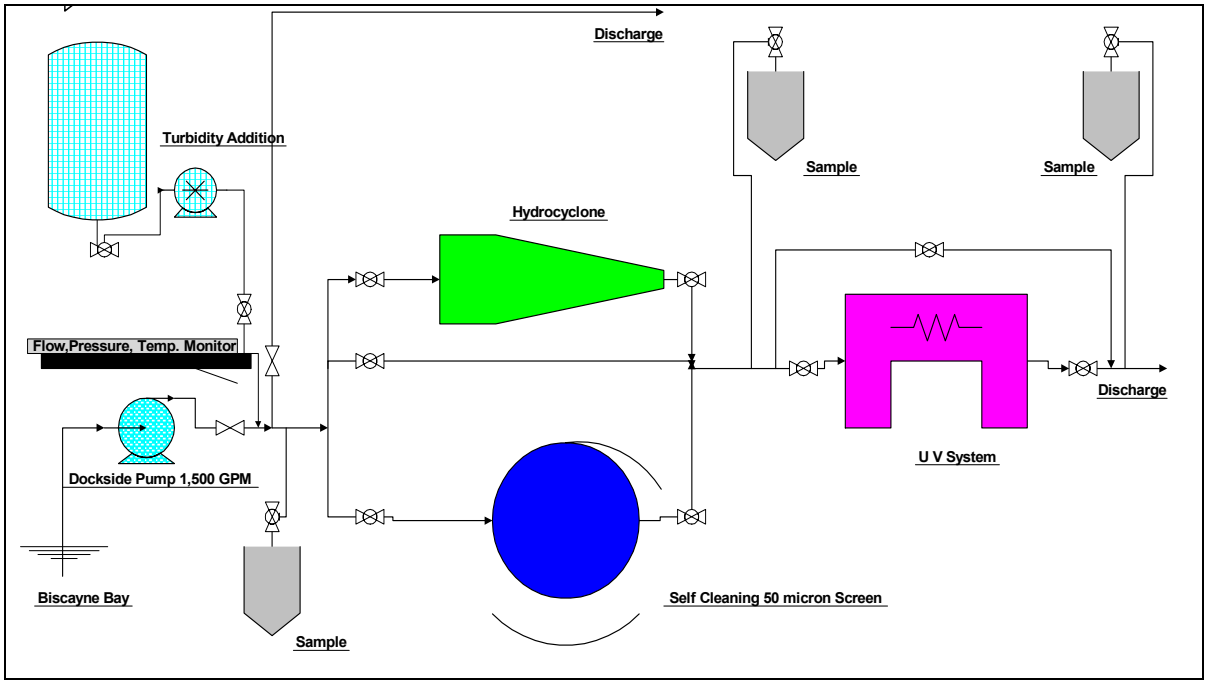

Figure 1: Ballast Water Treatment System

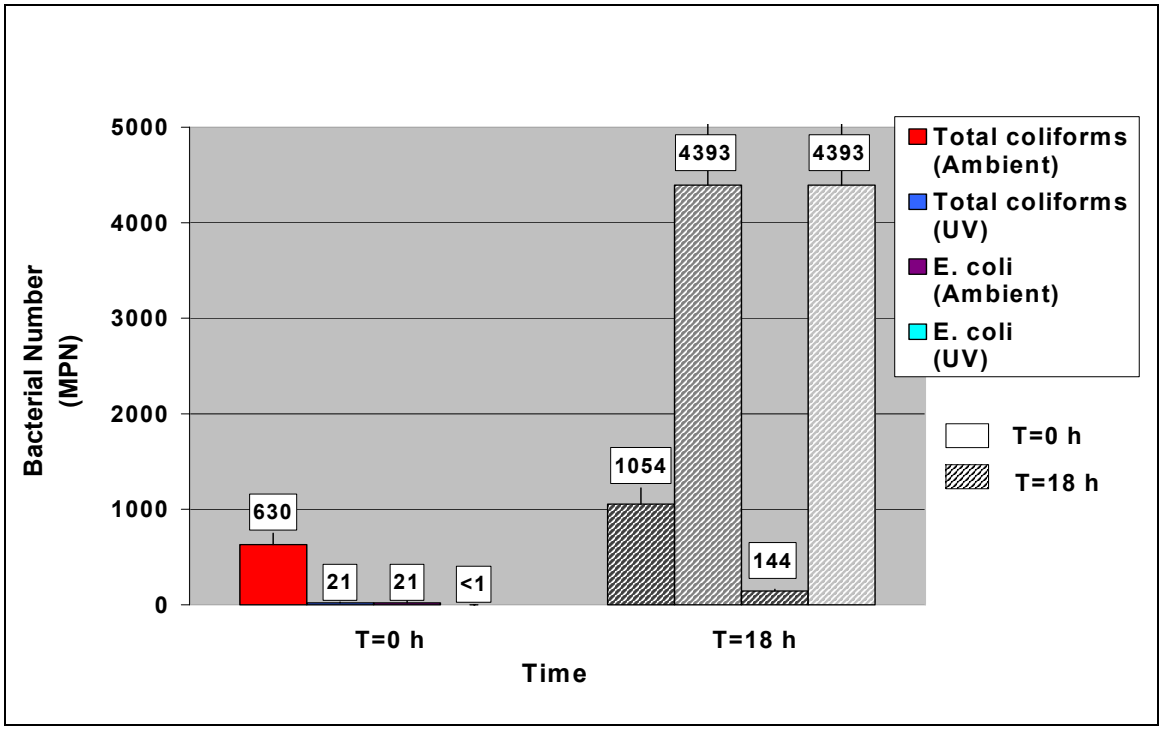

Figure 2: U.V. Irradiation of Ballast Water (Dose = Approx. 50,000 mWatt/cm2)

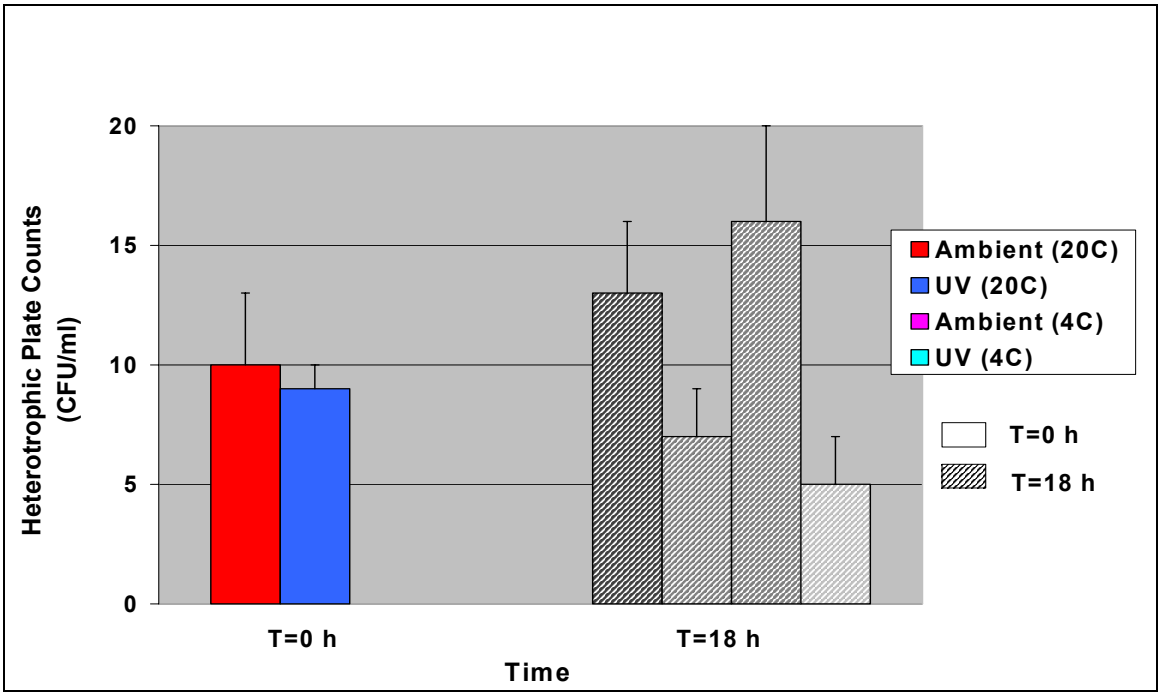

Figure 3: U.V. Irradiation of Ballast Water (Dose = Approx. 50,000 uWatt/cm2)

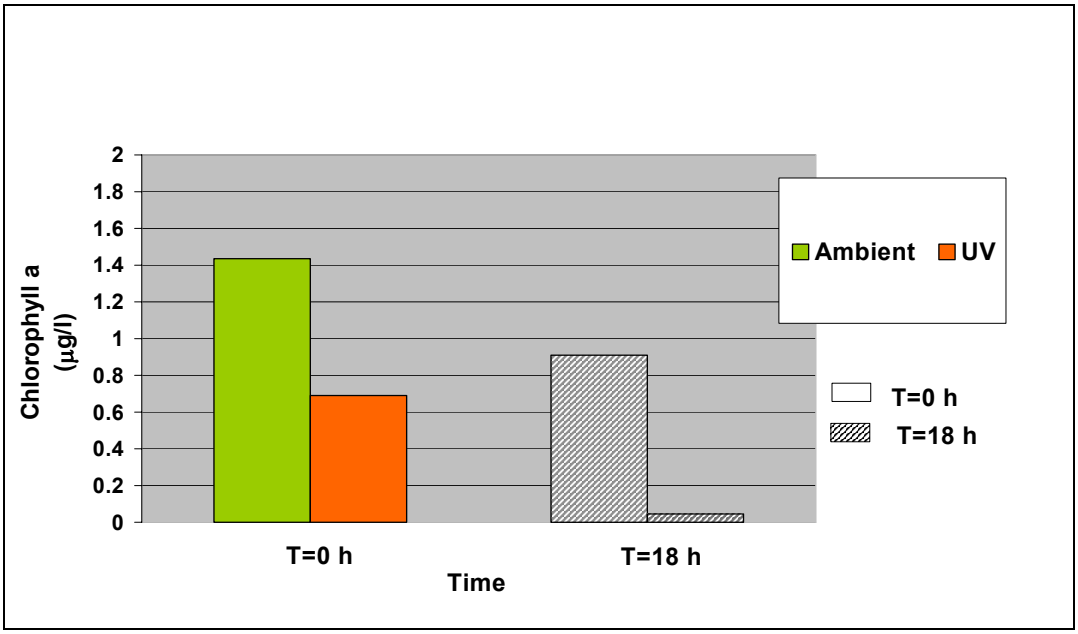

Figure 4: U.V. Irradiation of Ballast Water (Dose = Approx. 50,000 mWatt/cm2)

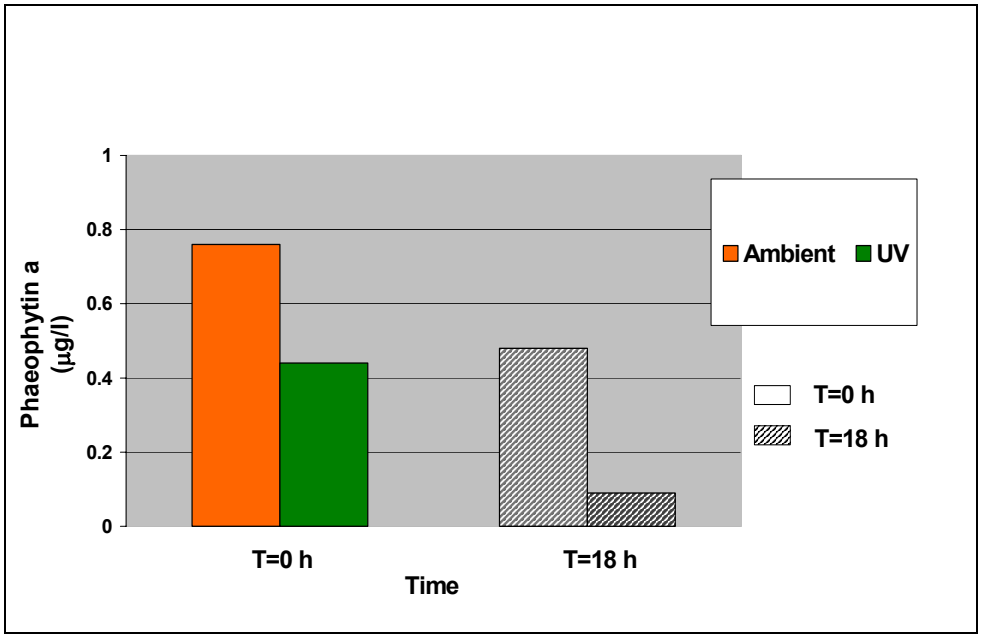

Figure 5: U.V. Irradiation of Ballast Water (Dose = Approx. 50,000 mWatt/cm2)

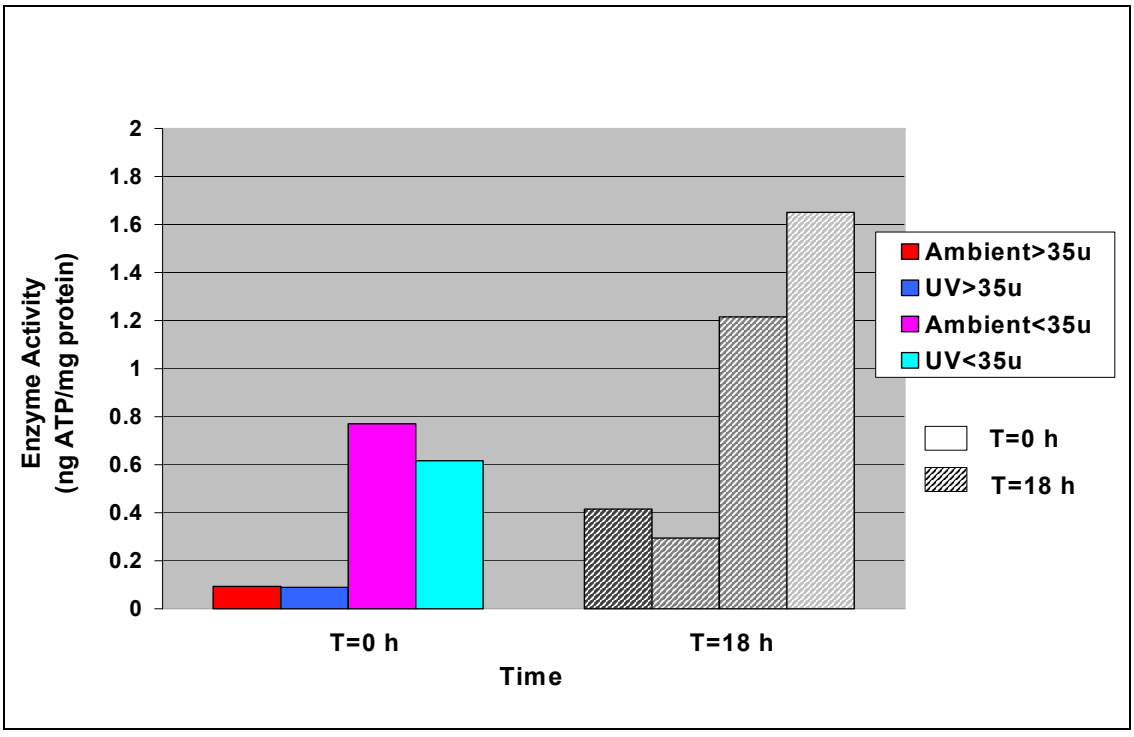

Figure 6: U.V. Irradiation of Ballast Water (Dose = Approx. 50,000 mWatt/cm2)

Shipboard Trials of Ballast Water Treatment Systems by Maritime Solutions

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1. Treatment options being researched

Primary treatment using physical separation and secondary treatment using UV or chemical biocides.

Current IMO prescribed ballast water management practices, voluntary for the most part now but expected to become mandatory in the near future, are largely based upon the seriously troubled practice of ballast exchange with open ocean water. Ballast water exchange at sea puts many ships, their cargoes and, most importantly, the lives of their crews at risk due to the possible changes in transverse stability and/or longitudinal hull-girder loading. Beyond this, ballast water exchange has been variously determined to achieve a level of only 65 % to 90 % effectiveness in the exchange of the original ballast water; the actual result being dependent on ship type (tanker, bulk carrier, containership, etc.), the specific design of a particular vessel, and its trade route or voyage pattern. In fact, the level of effectiveness of ballast water exchange is 0 % when it is not practiced (i.e., whenever the Master determines that 'conditions' do not allow it to be performed). At the same time, only a fraction of the sediment contained in the original ballast water is eliminated, leaving a refuge and an active breeding ground for many marine organisms. It is, as a result, abundantly clear that higher-level technology needs to be employed to assure shipboard safety, to reduce sediment loading in ballast water, and to provide for a higher level of effectiveness in the mitigation of biological invasions.

In the interest of offering a viable shipboard alternative to ballast water exchange, Maritime Solutions, Inc. has lead the development of a two-stage system as recommended by The Shipping Study (Carlton et al. 1995), wherein it was clearly predicted that a multi-stage system would be necessary to effectively mitigate against sediment and organism introduction by ballast waters. The approach taken by Maritime Solutions also conforms with the conclusions reported by the National Research Council (1996) in that it couples state-of-the-art separator technology with advanced UV or, alternatively, chemical biocide technology resulting in what is expected to be a safe, effective, practical, and cost effective solution to the ballast water problem.

The resulting 'Maritime Solutions Ballast Water Treatment System' (MSI System), patent pending, is based upon the separation technology of Enviro Voraxial Technology, Inc. (EVTN), serving as the first stage (Figure 1) and the UV technology of Aquionics, Inc. (Figure 2) or, alternatively, the chemical biocide technology of Degussa AG and/or Vitamar, Inc. providing second stage treatment (Figure 3). The two-stage MSI System offers the promise of superior organism elimination, increased silt and sediment reduction (> 90%), and flow rates to meet shipboard requirements (e.g., 300 - 20,000 $m^3 \cdot h^{-1}$); all within a compact, crew friendly and energy efficient installation. Maritime Solutions is currently involved in a rigorous program of system engineering and independent shipboard system testing with oversight provided by the U.S. Coast Guard.

The MSI System testing is supported by grants made by the State of Maryland Port Administration (MPA) and the National Oceanic and Atmospheric Administration (NOAA). Working in cooperation with the Center for Environmental Science, part of the University of Maryland, Maritime Solutions has additionally won the support of the U.S. Maritime Administration (MARAD) that will allow the

testing to take place aboard the "CAPE MAY", a ship of the U.S. Ready Reserve Force. The former Lykes Lines SEABEE vessel of 39,000 tons dead weight (DWT), now berthed in the Port of Baltimore, Maryland and managed by Interocean Ugland Management, will allow for realistic shipboard testing of the MSI System in treating water taken from Baltimore Harbor and the Chesapeake Bay. Additionally, the U.S. Coast Guard, with support from the Volpe National Transportation Center, will observe the test program. The Center for Environmental Science serves as the independent testing body and, as a result, is providing the principal investigators to oversee the testing program. The Chamber of Shipping of America is providing for 'peer review' via a committee of maritime industry experts.

The MPA and NOAA grants coupled with the financial support and in-kind contributions of the other program participants and MSI System component suppliers have made for a public/private sector initiative that has a total value approaching One Million ($1,000,000) U.S. Dollars.

The MSI System will utilize the EVTN Voraxial Separator to separate the components of influent ballast water in the primary treatment stage. As a primary treatment, the Voraxial Separator is intended to remove silt and sediments and certain large organisms from the influent ballast water and then immediately return these materials back to the source waters in a small fraction of the water stream. The remaining 'clean' water stream is then to be treated by UV or, alternatively, by chemical biocide in a secondary system stage. The primary treatment stage will be assessed as to its value in removing sediments from ballast-bound water, as well as its effect on the efficacy of the secondary treatments. Following treatment, the 'cleaned' and disinfected ballast water will be transferred via the vessel's ballast pump to the ballast tanks.

EVTN Voraxial Separator

The EVTN Voraxial Separator is a patented, continuous flow turbo machine that generates a strong 'voraxial flow' or vortex and high centrifugal forces (i.e., estimated at 1,200g for operating conditions in this test, Sigma Design Company, L.L.C.) capable of separating liquids of different specific gravities, or any other combination of liquids and solids, all at extremely high flow rates per unit size of separator. As the fluid passes through the EVTN Voraxial Separator, separation is accomplished by a single rotating impeller contained within a stationary housing that is coupled to a static separation chamber (Figure 1). In liquid/liquid and liquid/solid mixture separation, the separator's 'voraxial flow' and centrifugal forces cause the denser components to gravitate to the outside of the liquid stream and the less dense elements to move to the center where an inner core is formed. The liquid stream is divided into separate fractions as a function of relative density as it passes through the static separation chamber. The various liquid and solid fractions are ultimately separated at the discharge end of the chamber where they pass through separate collection ports with the 'clean' water passing on to secondary treatment.

Aquionics – In-Line UV Treatment System

The Aquionics In-Line UV treatment system has been selected for incorporation in the MSI System because of its superior design, quality of construction and proven ability to provide proper disinfection, even to poor quality liquid streams. In order to properly disinfect, UV germicidal energy must pass through all of the fluid that requires treatment. If even 1% of the liquid stream goes untreated there will be a dramatic reduction in overall effectiveness. A standard design UV chamber will not be effective in treating water with poor UV transmission because of the hydrodynamic complexities affecting the application of uniform UV treatment. The Aquionics In-Line chamber, with its unique design, was developed to address just this problem (Figure 2).

The Aquionics In-Line chamber system contains multiple lamps (specific number determined by treatment and flow rate requirements) installed perpendicular to the liquid flow. The lamps are situated in such an arrangement that all of the liquid (in this case influent ballast water) is forced to pass within close tolerances to the surface of the high intensity, medium pressure UV arc tube lamps thereby eliminating untreated 'dead legs' of water. The Aquionics In-Line UV systems are self-cleaning and monitoring and can treat flows ranging from 50-13,000 gpm (i.e., 11- 2,955 $m^3 \cdot h^{-1}$). The

In-Line cleaning system is designed to glide over the lamp sheaves and remove deposits that might otherwise block the light. Minimal annual maintenance is required.

Degussa AG – PERACLEAN® OCEAN

PERACLEAN® OCEAN is a special biocide formulation based on peroxy acetic acid for ballast water treatment. It has excellent biocidal, virucidal and fungicidal properties at very low concentrations (5-100 ppm) as well as good effectiveness on phytoplankton, zooplankton and other species found in the ballast water of ships. PERACLEAN® OCEAN is effective over a wide range of pH and temperatures. It is also readily biodegradable according to OECD test guidelines. Residual PERACLEAN® OCEAN in ballast water decomposes to water, acetic acid (e.g., vinegar) and oxygen. The half-life is in the range from 10 minutes to 24hrs depending on pH, salinity and temperature.

PERACLEAN® OCEAN is commercially available in 220 l drums, 1 m^3 IBCs or in bulk containers (Figure 3). PERACLEAN® OCEAN itself has a shelf life of > 1 year (< 10% loss in activity). Analytical methods to determine PERACLEAN® OCEAN concentration in ballast water have been developed. Test strips for quick semi-quantitative analysis of residual PERACLEAN® OCEAN in ballast water are also available.

Vitamar, Inc. – SEAKLEEN®

SEAKLEEN® represents another of a new class of environmentally friendly natural product biocides. It is a non-halogenated nutricide of mammalian/microbial origin.

Fluid Imaging Technologies, Inc. – FlowCAM®

On board monitoring of the MSI System is to be performed by Fluid Imaging Technologies, Inc.'s FlowCAM®; an imaging flow cytometer that monitors liquids for the presence of particles from 5 µm to 1000 µm in discrete samples or from continuous sources. Continuous sources such as ballast water can be monitored for extended periods of time with only a limited weekly maintenance requirement. The FlowCAM® measures in-vitro or discrete samples with a flow rate of 10 $ml \cdot min^{-1}$. Each particle is automatically imaged and measured and the data directly stored to disk. FlowCAM®'s image recognition software processes all particle images to determine particle types present. The instrument measures several particle properties, including fluorescence, light scatter, size and time of particle passage. These measurements and the image recognition software make it possible to determine how many of the different organisms are present at any given time. The FlowCAM®'s CPU can also accommodate additional sensors to simultaneously monitor ballast water treatment equipment and water properties such as turbidity, temperature, salinity and fluorescence. Because the FlowCAM® provides continuous, real-time particle data, it will be useful for assuring proper operation of the particle separator. It will also monitor the effectiveness of these treatments as the water-borne organisms die off in the ballast tanks.

Program management, participation and support

Maritime Solutions is managing this ballast water treatment system program and has provided for project planning as well as specialized personnel services in order to assure program success. In addition to its own staff, Maritime Solutions has the benefit of the active involvement of Unitor AS, Oslo, Norway; Enviro Voraxial Technology, Inc., Deerfield Beach, Florida; Aquionics, Inc., a Halma Group Company, Erlanger, Kentucky; Degussa-Hüls Aktiengesellschaft, Frankfort, Germany; Vitamar, Inc., Memphis, Tennessee; and Fluid Imaging Technologies, East Boothbay, Maine. Beyond this, Maritime Solutions has the benefit of the involvement of a number of leading marine and equipment system consultants and subject matter experts who have committed to participate in this development program. These include Sigma Design Company, L.L.C., Springfield, New Jersey; Martin, Ottaway, van Hemmen & Dolan, Inc., Red Bank, New Jersey; and Environmental Research Services, Solomons, Maryland.

2. Timeframe of the project

Northern winter 2000-2001:

- Computer fluid dynamics modeling completed by Sigma Design Company, L.L.C. to confirm the optimal design characteristics for the EVTN Voraxial Separator
- Complete engineering design to integrate the test system with the ballast system on board the "CAPE MAY"
- Develop dosing systems for the chemical biocides Peraclean Ocean® and Seakleen®
- Contract for the fabrication/assembly of the complete MSI System
- Establish locations on board the "CAPE MAY" or locally to process samples and conduct latent effects analysis.

Northern spring 2001:

- Complete installation of the MSI System aboard the "CAPE MAY"
- Conduct preliminary testing of each system component
- Conduct intensive system test and sampling

Northern summer 2001:

- Data analysis and report completion
- Submit reports to NOAA, MPA, MARAD, U.S. Coast Guard and IMO

Northern fall 2001:

- Obtain the required governmental (i.e., U.S. Coast Guard and/or IMO) approval of the MSI System as an alternative to 'ballast water exchange'.
- Install MSI Systems aboard trading merchant vessels

3. Aims and objectives of the project

The prototype MSI System consists of an EVTN 8000 Voraxial Separator working in series with an Aquionics UV treatment system capable of delivering 100 $mWs \cdot cm^{-2}$ or, alternatively, in series with two independent chemical biocide dosing units. The entire system will be mounted in the machinery space of the "CAPE MAY" and connected to the ship's ballast water system (Figure 4). The installation will be made in such manner that collection of physical and biological samples can be made before and after all treatment combinations (Figure 5).

Given the above, important sampling design and procedural issues include:

- Development of an installation design and sample collection process that provides for unbiased estimates of effectiveness, sufficient information to assess effectiveness over a range of conditions, and a standardized manner that can be repeated in subsequent tests.
- Determination of what and how many specific primary and secondary treatments should be applied during the testing program. That is, what will be the operating parameters for the primary treatment in terms of flow rate, characteristics of UV light (intensity and special composition) and, alternatively, concentration of chemical biocide as a secondary treatment.

- Determination of the environmental variables to be tested in the on board assessment. That is, how many and what experimental combinations of environmental (and biological) conditions are to be tested in the experiment?

- Selection of the environmental variables to be quantified, organisms to be assessed (and how this will be conducted) for effectiveness of each ballast water treatment combination, as well as procedures for sampling, processing and statistically analyzing the samples taken during the testing process. Provision to be made for determination of latent effects.

Sampling design

Treatment Combinations (Total = 12):

- Control (by-pass all treatments) Sample at Ports A and C.
- Separation Only: Sample at Ports A, B1, B2 and C.
- Separation + UV: Sample at Ports A and C.
- Separation + PERACLEAN® OCEAN (2): Sample at Ports A and C.
- Separation + SEAKLEEN® (2): Sample at Ports A and C.
- UV alone: Sample at Ports A and C.
- PERACLEAN® OCEAN alone (2): Sample at Ports A and C.
- SEAKLEEN® alone (2): Sample at Ports A and C.

There are a total of twelve treatments owing to the fact that two concentrations of each of PERACLEAN® OCEAN and SEAKLEEN® will be tested.

Sample collection

During each trial, water will be collected simultaneously at each of the sampling ports (Figure 5) needed for the specific treatment using identical taps (to prevent different effects of tap aperture design on organism survivorship, especially zooplankton) and collecting similar volumes of water (~400 liters = ~100 gallons) over the duration of at least one minute. The value of this long collection time is to maximize the likelihood that the same body of water is sampled at all ports even though there is travel time between ports. That is, integrated samples will be taken over sufficient time that differences in water masses sampled due to travel time will be minimized. These water samples will be collected in ~600-liter polyethylene tanks. In addition, the installation design calls for samples to be collected in both polyethylene tanks and in the ship's ballast water tanks. While taking samples from ballast tanks has its challenges, it is deemed necessary for this test program. Finally, provision will be made that all control and treated water passes through the same ballast pump.

Sampling effort

An extensive sampling effort consisting of the following treatments and trials:

- 12 treatment combinations.

- 3 trials per treatment.

- 36 total trials.

The purpose of sampling ports B_1 and B_2 off of the EVTN Voraxial Separator is the collection of samples of the water stream that will be discharged back into the Chesapeake Bay. Some organisms will be entrained in this discharged water, as will a majority of the sediment. The sediment load and organism abundance in these effluent waters will then be sampled and analyzed. Alternatively, determination of the fraction of these variables removed by the primary treatment could be made when samples are collected from Ports A and C (i.e., by subtraction). The disadvantage in the

alternative approach is that there will be no explicit determination that the sum of the discharge concentrations equals the intake concentration of any variable. The advantage is a reduction in the sampling effort per trial and thus an opportunity to increase the number of trials (replicates). The approach to be taken is a series of pilot trials to quantify the sediment load and organism abundance from all ports (i.e., A, B_1, B_2 and C) and confirm that all material entering the intake can be accounted for. If, as expected, this approach is confirmed to be appropriate, samples will be taken only from Ports A and C reducing the sampling effort per trial and allowing for an increase in the number of trials per treatment.

Each of the single or combination treatments is to be repeated three times. Although these trials can not be called true replicates (which would be impossible in a field trial of this nature) they will provide an estimate of the degree of repeatability of the tests under conditions that may differ from day to day or from week to week (depending on the periodicity of the repeated tests). Each test or group of tests will be accompanied by a 'control' in which ballasting will proceed without any of the treatments referred to above. An effort will be made to conduct a control test as close in time as possible to the respective treatment. Ideally, this will best be performed at the ballast water intake as part of a single ballasting operation, with the equipment turned off (immediately before or after a treatment phase). The aim will also be to sample different parts of the ballast water system of the vessel following a treatment cycle. While this may not be possible to do for all of the aforementioned treatments, an attempt will be made to sample as many ballast access areas as possible.

Replication

Three trials will be conducted for each treatment alternative. For example, if a comparison is being made of chlorophyll *a* concentration in samples between sampling ports and three trials are made, three estimates of the proportional decline in chlorophyll *a* will result. These three estimates can be compared with estimates from other treatments using ANOVA (or the nonparametric equivalent, Kruskal-Wallace test).

4. Research methods

For all of the treatments and sampling described above, a suite of physical and biological observations designed to specifically test the effectiveness of each treatment will be made.

Environmental conditions

Most of the environmental variables in this shipboard test cannot, of course, be controlled. However an effort will be made to minimize the variability of these variables within the testing period, as well as to determine the effectiveness of the treatments across a range of sediment loading conditions. Thus, in each trial, when applicable, the following will be quantified:

- Temperature
- Salinity
- pH
- Sediment load (total, organic and inorganic fraction, and particle size distribution)
- Flow rate (specifically at the intake and the three outlets of the EVTN Voraxial Separator)
- Light transmission (absorbance, to quantify exposure rates for UV testing)
- Concentration of chemical biocides applied and at 24 and 48 hours after application.

Suspended sediments

For treatments involving the EVTN Voraxial Separator, it will be important to determine performance in removing a range of suspended sediments and, when the separator is not being used, it will be important to know the sediment-loading rate to assess the impact on the secondary treatment systems. The sediment loading of estuarine waters is expected to range from an ambient mid-water level of

<0.1 $g \cdot l^{-1}$ to as much as 50 $g \cdot l^{-1}$ in heavily loaded (turbidity maxima) regions (Li 1999). Separatory performance will be determined by making a series of measurements of ballast-bound water from the intake and exit streams of the separator. These measurements will include determination of (1) total sediment mass at the sampling ports, (2) light transmission characteristics (3) particle size fractions, and (4) of ash-free dry mass.

Total solids per unit volume will be determined by collecting two depth-integrated sub-samples from the collection tanks, and then passing each through oven-dried and pre-weighed 0.4 µm Nucleopore filters. The volume of each sub-sample processed will depend upon the sediment load. Sub-samples will be dried at 60C for 24 hours, cooled in a dessicator and then weighed to estimate total sediment load. An alternative approach when sediment loads are high will be to place volumes of the sub-sample into pre-weighed ceramic crucibles, evaporate contained water in drying ovens (60C) and then reweigh the crucibles. Ash-free dry mass (AFDM, i.e., the inorganic fraction of the sediment) will be estimated by ashing the dried sub-samples at 550C for 24 hours and then reweighing the residue. For sub-samples processed through membrane filters, appropriate standards (blank filters) will be processed in order to remove the contribution of the filters to the residue mass. This process will provide data on percent organic matter in samples.

Particle size distribution will be quantified from at least 500 particles in samples taken from each sampling port under the two sediment loads (i.e., ambient mid-water, and mechanically elevated condition). Samples will be filtered through blank 0.4 µm Nucleopore filters and then later dispersed by ultrasonic treatment for 2 minutes (Eisma 1986; Li et al. 1999). Particular profiles from these samples will be generated using a Model IIA flow cytometer. This will produce comparative size data that can be calibrated with the addition of particles of known size. Profiles will be checked with a 'Multisizer' particle counter that will supply a frequency distribution over the whole particulate size range.

It is anticipated that organisms will form part of the fraction 'filtered' by the EVTN Voraxial Separator. As indicated above, this fractional removal will be quantified in preliminary trails with the expectation that the numbers in the trials can be determined through density differences from Ports A and C (Figure 5).

Bacteria

Bacterial viability will be assessed using the two-color fluorescence assay, namely the live/dead Bac Light TM bacterial viability kit for microscopy (Molecular Probes, Eugene Oregon). The live/dead assay uses a Syto green fluorescence nucleic acid stain and the red fluorescence nucleic acid stain propidium iodide. These strains differ both in their spectral characteristics and their ability to penetrate healthy cells. Samples of the ballast water pre- and post-treatments will be filtered onto black, 0.2-µm micron Nucleopore filters stained with the two-component mixture and the red vs. green fluorescence of bacterial cells counted by epifluorescence microscopy using appropriate wavelength filters.

From the 36 trials planned for this study we will be collecting at two ports per trial and analyzing certain viability initially and a 24 and at 48 hours post-test to determine the latent mortality effects of treatment. Thus we will be collecting a total of 216 samples. During incubation periods, samples will be aerated in the dark at ambient ballast water temperature.

Phytoplankton

Phytoplankton biomass and viability are important components in the assessment of both primary and secondary treatments. As most phytoplankton species expected to be seen in Baltimore Harbor waters are <10 µm and have specific gravity near that of ambient water the separatory ability of the EVTN Voraxial Separator is uncertain in this regard and secondary treatment will be an important component of the overall treatment strategy. Measurements will, therefore, be directed towards the assessment of both phytoplankton biomass (chlorophyll *a*) and the capacity for regrowth after treatment.

Extractable chlorophyll *a* fluorescence determination will be made on all treated and untreated ballast water samples. Whole water samples will be taken from the collection tanks and particulates extracted using glass fiber filters which will be used to determine concentrations of chlorophyll *a* over time in pre- and post-treatment samples (sampling ports A and C, Figure 5). The standard operating procedures to be followed will be those outlined in Standard Methods for the Examination of Water and Wastewater, 20th Edition (1998) under sections 10-20 and 10-21, Biological Examination.

The testing instrument employed will consist of a Hitachi F4500 scanning spectrofluorimeter with a dedicated computer controller. Excitation will be set at 430nm with a slit width of 10nm. Emission wavelength will be fixed at 633nm with a 10nm slit width. For extractable chlorophyll *a*, standard operating procedures outlined in Standard Methods for the Examination of Water and Wastewater, 20th Edition (1998) under sections 10-20 and 10-21, "Biological Examination" will be followed with the exception that the extraction solvent will be ethanol, which has proven to be more efficient in extracting chlorophyll *a* from glass fiber filters at room temperature in the dark for 3 hours. A total of 216 samples will be processed with each technique.

Latent Effects: Water samples will be aerated and illuminated under fluorescent lights on site for a 48-hour period to examine the capacity for cell doubling based on repeated measurement of chlorophyll *a* fluorescence. This capacity for regrowth will be the unit of measure to determine latent effects of each treatment and follows the standard operating procedures as outlined in Standard Methods for the Examination of Water and Wastewater (1998). After exposure to light for 24 and 48 hours, under aerated conditions and ambient temperature, each sample of phytoplankton will be resampled to estimate chlorophyll *a* concentration.

Cell Counts: To quantify phytoplankton abundance (cell counts) in order to compare with chlorophyll *a* concentration, subsamples of collected water will be taken and examined under the microscope (i.e., Olympus BH2) for cell counts and taxonomic identification. Chlorophyll *a* concentration is species and time dependent, as well as being dependent upon cell biovolume. Taxonomic identification and cell counts of phytoplankton will be made on the following subset of samples:

- Separation plus UV, PERACLEAN® OCEAN or SEAKLEEN® (5 treatments)
- Ports A and C
- Replication: 3
- Timed samples: initial, 24 and 48 hour
- Total samples to be processed: 90

Zooplankton

Four to six of the most common zooplankton taxa will be identified in the local water at the time of the trials, and abundance and survivorship of these taxa will be quantified. At least one rotifer, two crustaceans (an adult copepod (*Eurytemora affinis*) and a naupliar stage), and hopefully a mollusk larva (oyster).

To assure the proper collection of samples from the collection tanks, the water in the tanks will be mixed thoroughly immediately after collection and three or more depth integrated samples (using a 10-cm diameter clear polycarbonate cylinder) will be taken from the center tank, pooled (total volume recorded) and then concentrated through a 20-µm mesh Nitex filter chamber that is submerged in water to minimize handling damage to zooplankton. The sample will be transferred into 2- 4 liter holding chambers of known volume. Subsamples of organisms in the holding chamber will be collected with small depth-integrated samplers. Density, as well as numbers alive, will be determined until at least 50 of each taxon are counted. Organisms in holding chambers will be exposed to aerated water at ambient temperature and will be kept in total darkness until it is time to quantify survivorship

through the latency periods. As with the phytoplankton and bacteria sampling a total of 216 samples will be collected.

Latent Effects: Data for SEAKLEEN® from Vitamar through Drs. Wright and Dawson (University of Maryland Chesapeake Environmental Laboratory) and for PERACLEAN® OCEAN from Degussa AG suggest that 24 hours should be sufficient time for mortality to approach 100% and for the biocides likely be degraded at the concentrations to be used. However, because the sediment loading will reduce chemical biocide and UV effectiveness to some extent, survivorship of zooplankton will be determined at both 24 hours and 48 hours after each trial.

Counting: As indicated above, the volume of water collected in the sample tanks, the subsampled water volume, and the concentrated holding chamber volume will be recorded, along with the volume sampled in the holding chamber in order to back calculate the density of zooplankton taxon in the water from the sampling ports. Each time counts and survivorship are determined an attempt will be made to locate at least 50 organisms of each taxon. Because density and survivorship will be recorded, any decline in the density (i.e., decomposition of dead organisms) in any holding tank can be determined.

Data analysis

Data will be analyzed using desktop software such as Microsoft Excel, QuatroPro and system software such as Statistics and Analysis System (SAS). Efficiency of treatments will be determined first using a paired t-test to determine the statistical difference ($p<0.05$) between treatments and controls for each trial. Where there is a statistical difference, the average percent efficiency for each treatment (relative to the control) will be determined for that trial. These average efficiencies will be used to determine a mean efficiency and standard deviations across trials.

Oversight

The U.S. Coast Guard will be invited to conduct a review of the test protocol before it is finalized. Beyond this, the U.S. Coast Guard has already engaged the Volpe National Transportation Laboratory to monitor the testing program, including matters of sampling and data analysis, with support from the engineering firm, Camp, Dresser and McKee. It is anticipated that this oversight will include both independent sample collection and analysis.

5. Results

Testing aboard the "CAPE MAY" will occur during the spring of 2001 (see Time Table). Data will be analyzed and reports written for presentation before September 2001.

6. Conclusions and recommendations:

Maritime Solutions believes that the MSI System, patent pending, represents the best available technology to effectively mitigate ballast water transfer of aquatic nuisance species. Furthermore, after independent testing and reporting on performance has been completed, Maritime Solutions believes that the MSI System will be recognized as being superior to any other alternative to ballast exchange proposed to date for the following reasons:

- The MSI System is completely scaleable and can, as a result, produce ballast water flow rates equal to the loading rates required by all merchant and naval vessels.
- The MSI System provides an economic benefit to ship owners/operators due to its removal of silt and sediment from the ballast water intake stream, obviating the need for periodic and expensive tank clean-out and insuring, all the while, the maximum cargo carrying capacity of the vessel.

- The MSI System's 'secondary' treatment stage, UV or chemical biocide subject to throughput capacity requirement, is extremely effective and safe for both the crew and the environment. Ballast water 'residence' time associated with effective 'secondary' treatment is significantly reduced due to the system's removal of entrained silt and sediments and does not, as a result, hinder the ballasting process and the vessel's time schedule.

- The compact size and energy efficiency of the complete two-stage MSI System allows for easy, cost effective, retrofit or installation and operation aboard both existing vessels and new building tonnage.

- The environmental benefits accruing from the ship's ability to utilize the MSI System at the time of every ballasting, with no subsequent impact or slowdown on other vessel activities or operations.

- The MSI System has no crew, vessel, or cargo related safety (stability and trim, longitudinal hull strength, etc.) issues as are associated with the current practice of ballast water exchange.

- The MSI System will be virtually automatic, requiring minimal crew training and operating instructions. Owing to its design simplicity and quality of construction, the system is virtually clog-free and requires limited maintenance.

7. References

Clesceri, L.S., Greenberg, A.E. & Eaton, A.D. eds. 1998. *Standard Methods for the Examination of Water and Wastewater* (20th ed.). American Public Health Association (APHA), American Water Works Association, Water Environment Federation, Washington, D.C.

Chamber of Shipping of America 2000. *Environmental Reference Handbook*. Washington, D.C.

Eisma, D. 1986. Flocculation and deflocculation of suspended sediments in estuaries. *Netherlands Journal of Sea Research* 36: pp. 16-29.

Khan, S.U. & Dupont, S. 1987. Bound pesticide residues and their bioavailability. *Proceedings 6th International Congress Pesticide Chemistry (I.U.P.C.) Ottawa, Canada, 10-15 August 198,* R. Greenhalgh & Roberts, T.R., editors. London. UK.. pp. 417-420

Li, B.G., Eisma, D., Xie, Q., Kalf, J., Li, Y. & Xia, X. 1999. Concentration, clay mineral composition Coulter counter size distribution of suspended sediment in the turbidity maximum of the Jiaojang River estuary, Zhejiang, China. *Journal of Sea Research* 42: pp. 105-116.

Morillo, E., Unadeytia, T., & Maqueda, C. 1997. Adsorption of glyphosate on clay mineral montmorillonite: effect of Cu(II) in solution and adsorbed on the mineral. *Environmental Science and Technology* 31: pp. 3588-3592.

National Research Council, 1996. *Stemming the Tide – Controlling Introductions of Nonindigenous Species by Ships' Ballast Water*. National Academy Press, Washington, D.C.

Parsons, M. G., Moll, R., Mackey, T.P. & Farley, R.B. 1997. *Great Lakes Demonstration Project-Phase 1. Final Report*. Cooperative Center for Limnology and Ecosystem Research (CILER) University of Michigan, Ann Arbor, MI, USA.

Piccolo, A., Conte, P., Scheunert, I. & Paci, M. 1998. Atrazine interactions with soil humic substances of different molecular structure. *Journal of Environmental Quality* 27: pp. 1324-1333.

Undabeytia, T., Nir, S. & Rubin, B. 2000. Organo-clay formulations of the hydrophobic herbicide Norflurazon yield reduced leaching. *Journal of Agriculture and Food Chemistry* 48: pp. 4767-4773.

Voigt, M. & Gollasch, S. 2000. *Ballast Water: The Latest Research and Methods of Treatment*. 3rd Annual conference "Managing Environmental Risk in the Maritime Industry", October 25th-26th, 2000, London, UK

Wright, D.A., Magee, J.A., Setzler-Hamilton, E.M., Chalker-Scott, L. & Morgan, G.L. 1997. Use of high energy monochromatic UV light to kill dreissenid larvae. In: *Zebra Mussels and Aquatic Nuisance Species,* F. D'Itri (ed.). Ann Arbor Press, Ann Arbor, MI, USA.

Wright, D.A., Dawson, R. & Wildgust, M. 2000. *Excimer UV light as a potential treatment for ballast water.* Presentation at the 10th Annual Aquatic Nuisance Species and Zebra Mussel Conference, Toronto, Canada. February 13-17, 2000.

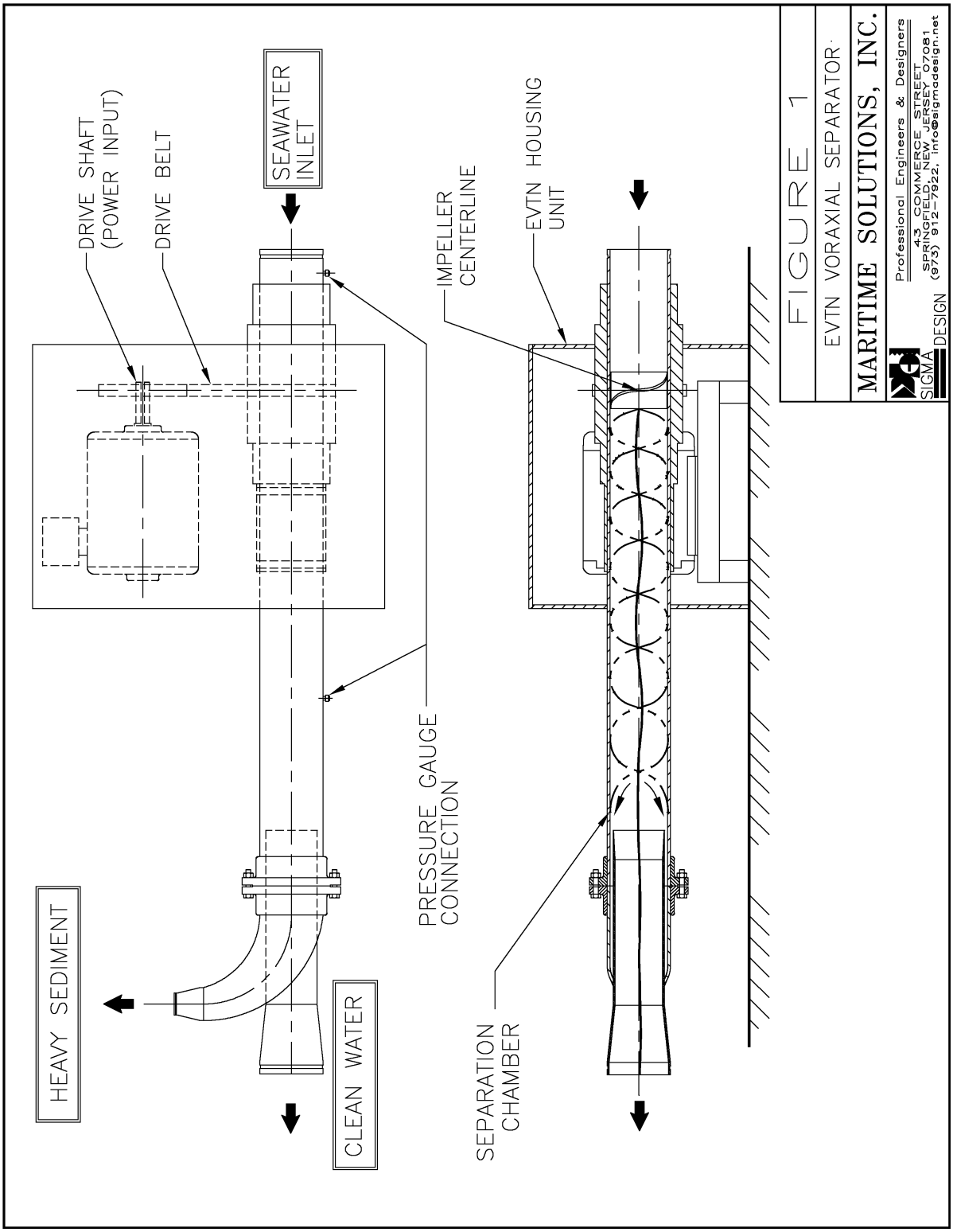

Figure 1: EVTN Voraxial Seperator

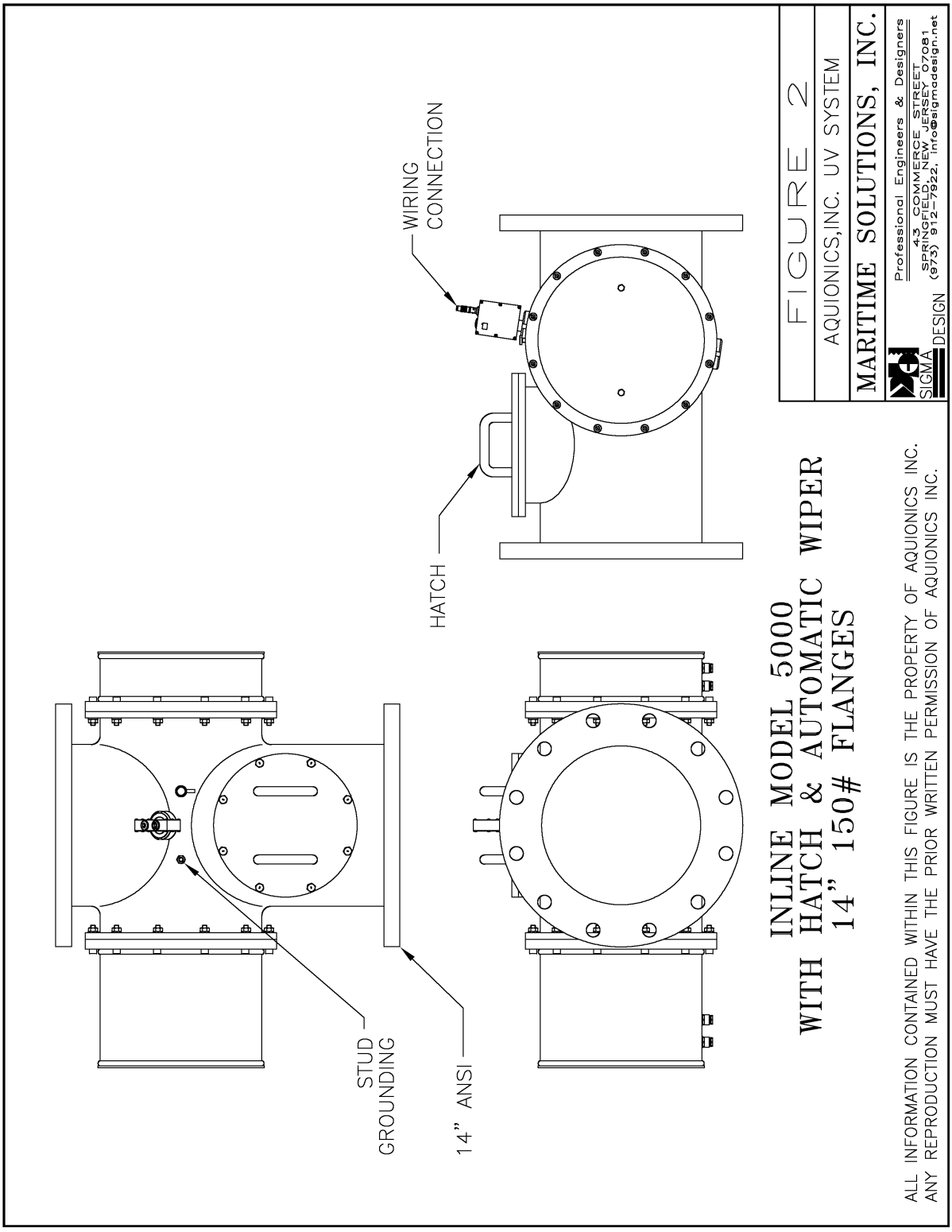

Figure 2: Aquionics, Inc. UV System

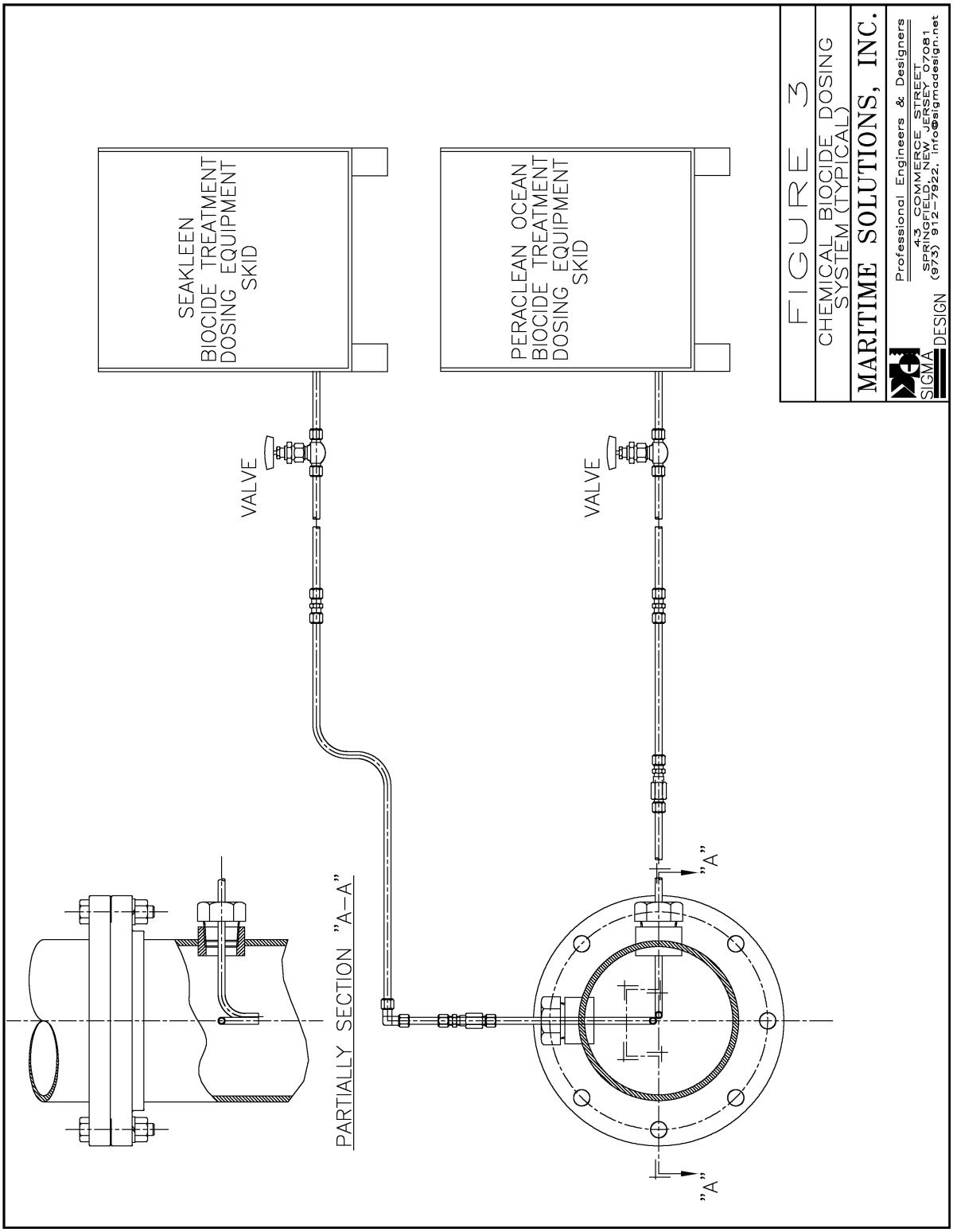

Figure 3: Chemical Biocide Dosing System (typical)

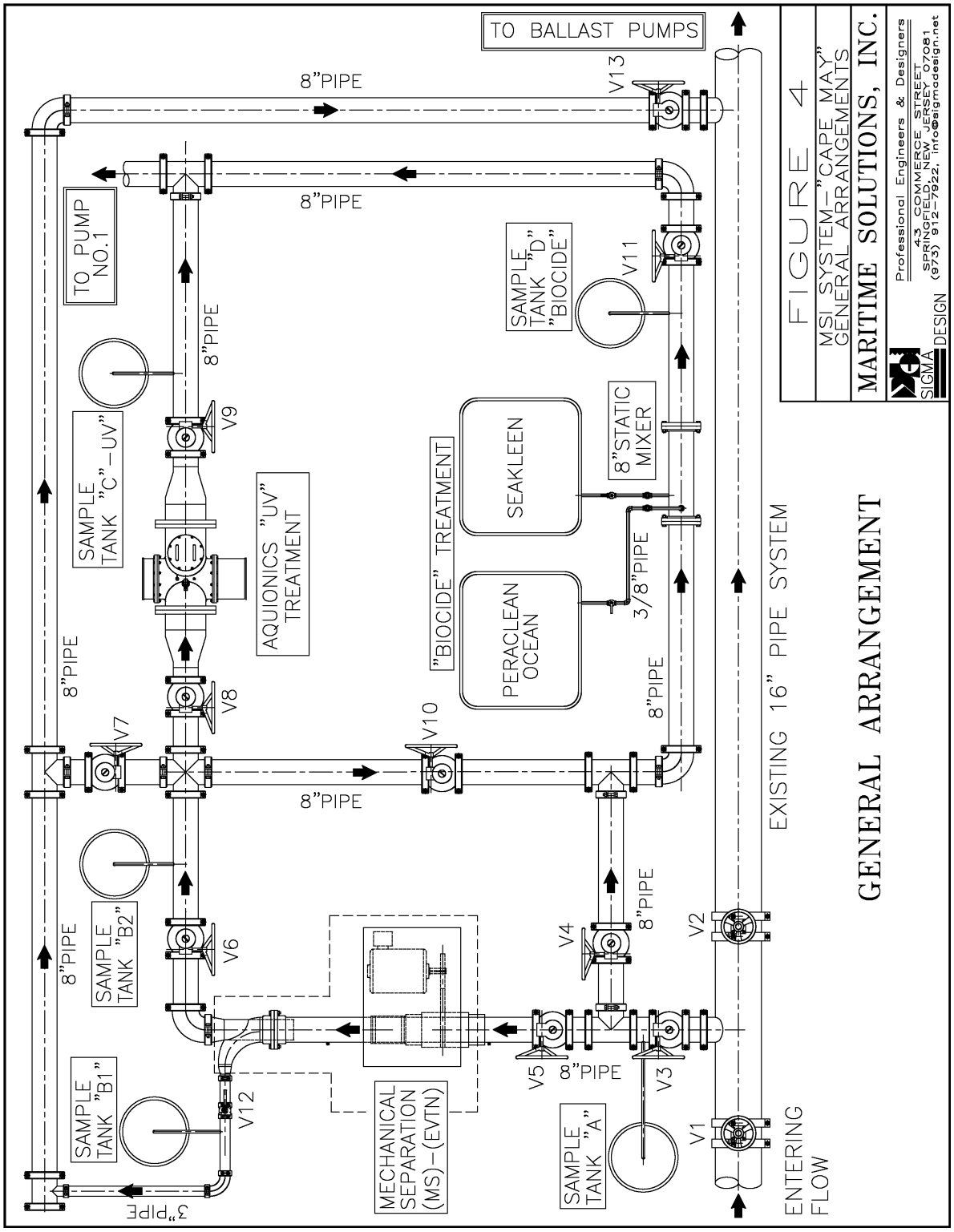

Figure 4: MSI System – "Cape May"

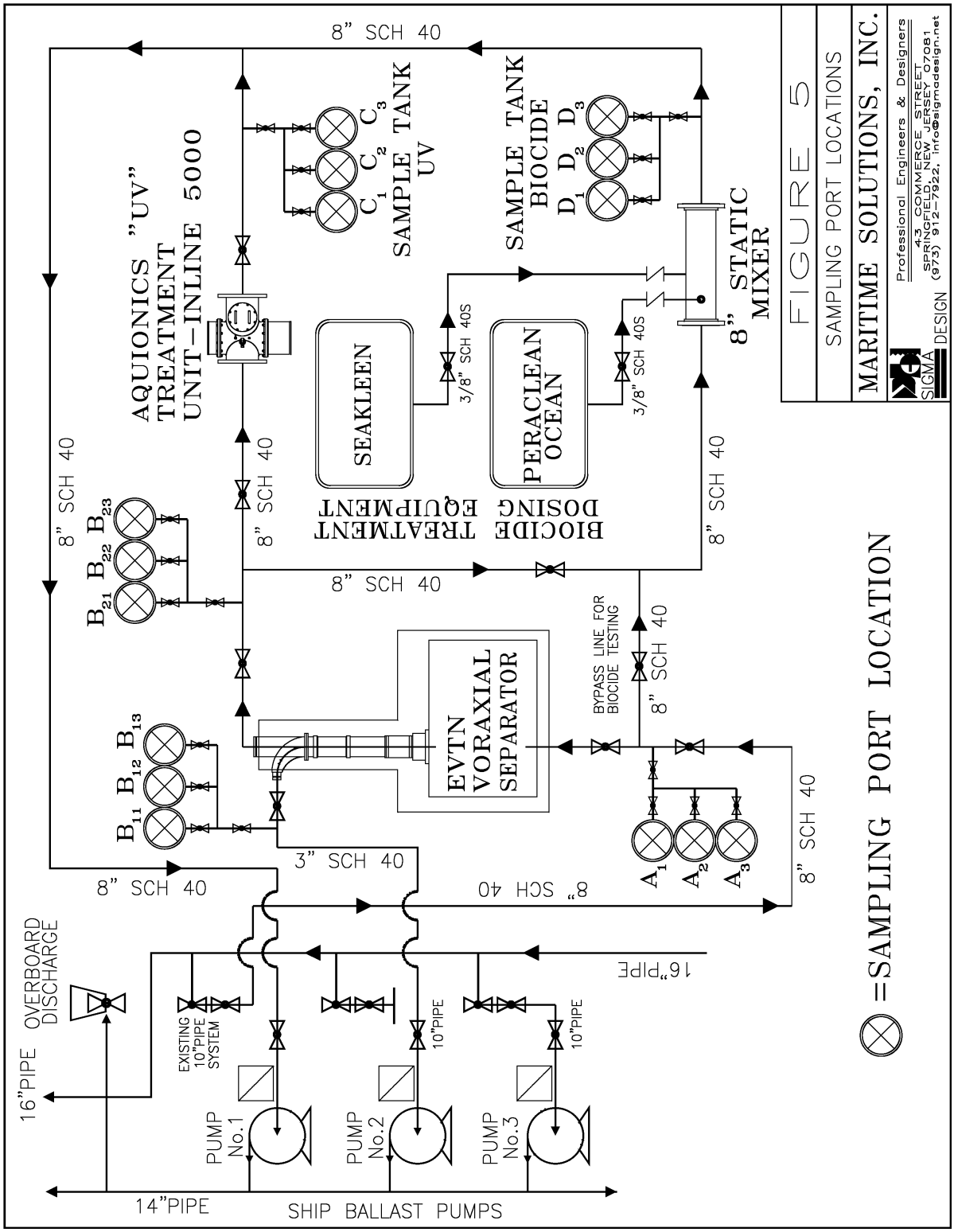

Figure 5: Sampling Port Locations

The Influence of Cyclonic Separation and UV Treatment on the Mortality of Marine Plankton

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1. Treatment options being researched

The Integrated Cyclone-UV Treatment System (ITS) was designed by Velox Technology Inc. as a prototype test apparatus to simulate treatment of ballast water (Figure 1). The ITS contains two separate treatment phases: 1) cyclonic pre-treatment and 2) ultraviolet radiation (UV) treatment. The cyclonic separation phase consists of a single housing, which contains 3 parallel cyclone tube apparatii (patent-pending). Each cyclone tube immediately generates high centrifugal forces and imparts a gravitational force on suspended particulates as water passes through each tube. The centrifugal force is derived from the conversion of potential energy of the process stream to kinetic energy at the separator's feed inlet. The gravitational force (G) imparted on suspended particulates varies depending upon the mass and kinetic strength of each particle. Since variations in the size, mass, and exoskeleton structure existed for the targeted species, differences in the kinetic strength of each species would differ along with mortality estimates. The pre-treatment cyclonic apparatus utilized for this study was designed to operate at a pressure drop of 7 to 10 PSIG.

Because higher-density and usually larger-sized particles have significantly higher centrifugal forces imparted upon them, "heavier particles" tend to migrate to the outer wall while travelling down the length of each tube before exiting out the post-solids outlet (PS). Thus, two distinct size fractions are discharged through separate outlets located at the distal ends of the cyclonic housing. After cyclonic pre-treatment, the post-cyclone (PC) pre-treated water flows to the secondary treatment stage through to the ultraviolet (UV) chamber which may contain up to 8 UV-C lamps. The UV test chamber provided allowed for the experiments to be conducted utilizing two different UV-C lamp sizes and (nominal) wattages. For this study, combinations of 39W and 120W lamps were used to generate the UV dosages necessary for the experiments.

2. Timeframe of the project

Treatment experiments were carried out between October, 1999, and January, 2000, at the West Vancouver Laboratory, British Columbia, Canada (Fisheries and Oceans

3. Aims and objectives of the project

The objective of this study was to: 1) develop an assay technique to assess the efficiencies of two treatment technologies when used as primary/secondary phases in a ballast water treatment system and 2) determine the effect of this combined treatment system on the survivorship of invertebrate larvae and plankton.

4. Research methods

The Integrated Cyclone-UV Treatment System designed and provided by Velox Technology Inc. for this study was installed and mobilized within the Outdoor Aquarium facility at West Vancouver Laboratory and connected to a piping system that allowed for controlled access to seawater source and discharge tanks. Treatment experiments were carried out on cultures of invertebrate larvae and a natural population of zooplankton over a range of 6 different ultraviolet radiation (UV) dosages (Sutherland et al. in review). A description of the treatment system is outlined above.

Invertebrate larvae cultures

Larvae of *Mytilus trossulus* (blue mussel), *Crassostrea gigas* (Pacific oyster), and *Venerupis phillipinarum* (Manilla clam) were obtained from Innovative Aquaculture Products Limited. The larvae size ranged between 160 and 180 microns in diameter and the ages of the bivalve larvae ranged between 1 (clam) to 2 (oyster, mussel) weeks old consisting of the post D-stage of larval development. The inoculation concentration for each larval species was standardized to 400,000 mussel larvae, 300,000 oyster larvae, and 350,000 clam larvae. Experiments were also carried out on *Artemia franciscana* (brine shrimp) and natural populations of zooplankton. Brine shrimp were hatched from cysts obtained from Argent Chemical Laboratories (Argentemia; Grade 3). One-day old brine shrimp were used in the treatment experiments. Injection concentrations consisted of approximately 1000 individuals L^{-1}. The concentrations of the various organisms in the treatment discharge samples ranged from 50 to 150 organisms per litre.

Natural zooplankton population

Zooplankton were collected from Nitinat Lake, a permanently-stratified fjord (28 psu) located on Vancouver Island, British Columbia and transported quickly to the laboratory to maintain ambient conditions. The natural zooplankton population consisted of adult calanoid copepods and barnacle nauplii. Injection concentrations were standardized to 4000 individuals L^{-1} in total. It was thought that the mussel, clam, and copepod species used in this study would serve as proxies for species (Zebra mussel, Asian clam, Asian copepod) that have been introduced to the Great Lakes (Johnston and Carlton, 1996) and Californian estuaries (Fleminger and Kramer, 1988; Carlton et al. 1990).

Treatment experiments

Seawater used in the treatment experiments was filtered to 10 microns using sand filtration on the seawater intake system at the West Vancouver Laboratory. Approximately 3000 litres of filtered seawater were placed in an aquarium tank. A submersible heater (CLEPCO Model DRG 160) was placed in the aquarium tank in order to heat the seawater to the appropriate temperature which varied depending on the test organism. A Pumpex Model P2001 (575V/20A/60Hz) Electric Submersible Pump (ESP) with a rated flow capacity of 200 L min^{-1} (125ft. NPSH) was placed within the aquarium tank and attached to the treatment piping system to supply seawater to the treatment system. Filtered seawater was flushed through the treatment system for several minutes prior to each experiment. In general, flow through the system equilibrated at approximately 288 m^3 day^{-1} (200 L min^{-1}) during each experimental trial. Samples were collected simultaneously from the post-solids (PS), post-cyclone (PC), and post-UV (PUV) ports for mortality estimates (Figure 1).

A series of 6 experiments, each consisting of a different UV dosage, was carried out for mussel, oyster and brine shrimp larvae. The UV dosages consisted of the following values: 0.0, 49.5, 79.5, 98.9, 178.4, and 257.9 mW sec cm^{-2}. Three replicate trials (n=3) were carried out for each UV dosage. Replicate experiments were carried out on clam larvae and a zooplankton population at UV dosages of 178.4 and 257.9 mW sec cm^{-2}, respectively. The inoculate concentration of organisms was gravity fed into the treatment system at the port located upstream of the cyclone at the initiation of each experiment. The treatment system pump was turned on and samples were collected simultaneously from the PS, PC, and PUV ports for a period of 30 seconds.

The seawater samples were processed within 30 minutes of each experimental trial after being transported to the laboratory. The organisms in each sample were concentrated using a filtration system and transferred to petri dishes for examination under a Leitz dissecting microscope at 25 x magnification. A poker was used to prod the organisms to assess their survivorship based on an activity response to physical stimulus. Survivorship was defined when the organism was capable of swimming (Chalker-Scott et al. 1992) or exhibited a heartbeat or evidence of an internal circulation process. The time-dependent survivorship estimates of the natural zooplankton population were carried out once a day for approximately 4 days. Mortality estimates of stock cultures were determined prior to each experiment.

5. Results

Mortality estimates were calculated and mean values plotted for both cumulative and incremental mortality estimates. Total System Mortality (TSM) is defined as the cumulative mortality of organisms observed following exposure to both treatment phases (cyclonic pre-treatment and UV radiation), while Incremental System Mortality (ISM) represents the mortality of organisms estimated at each treatment level. Incremental system mortality is reported to represent the removal or inactivation of target species at each treatment phase. Statistical comparisons carried out are described in each section below.

Total System Mortality (TSM)

Figure 2 shows the TSM curves for mussel, oyster, and brine shrimp larvae following exposure to the ITS over a range of UV dosages. In general, the percent mortality of each species tends to increase with increasing UV dosage. Statistical results reveal that the ITS had a significant effect on TSM for mussel ($p < 0.001$), oyster ($p < 0.001$), brine shrimp ($p = 0.011$) larvae. TSM for clam larvae (97 percent) was assessed at only one UV dosage (178.4 mW sec cm^{-2}) of the integrated treatment system.

Incremental System Mortality (ISM)

Incremental System Mortality (ISM) of mussel, oyster, and brine shrimp larvae was examined at the two treatment stages (cyclonic pre-treatment and UV radiation) of the treatment system. A significant difference was observed between percent mortality estimates of the cyclonic pre-treatment stage (Post-cyclone) and the stock culture for mussel ($p < 0.001$), oyster ($p < 0.001$), and brine shrimp ($p < 0.001$), suggesting that the cyclonic pre-treatment affected invertebrate larval survivorship. Clam mortality was also observed to be 81 % following the cyclonic pre-treatment stage. Although mortality of brine shrimp nauplii was observed during the experiment with the highest UV dosage, no significant difference was observed in mortality across the 3 experiments.

A comparison was made between mean mortality values of the cyclone (PC) and solids fractions (PS) of the cyclonic pre-treatment stage for the mussel, oyster, brine shrimp, and clam experiments. No significant difference was observed in mussel ($p = 0.162$), oyster ($p = 0.854$), brine shrimp ($p = 0.337$), and clam ($p = 0.869$) larval mortality between the cyclone and solids fraction of the cyclonic pre-treatment phase.

Time-dependent mortality estimates of zooplankton

Immediately folllowing treatment, TSM of zooplankton was highest (40.2 %) in the UV treated samples, relative to the ISM observed in the cyclone, solids, and control fractions (Figure 3). A statistical test (Post-hoc Tukey test) revealed that the mortality estimates of the UV-treated zooplankton population was significantly greater than those estimates observed for the post-cyclone, post solids, and stock culture samples ($p = 0.031$). On day four of the incubation period following the exposure to the ITS, 99.3 % mortality was observed in the UV-treated samples, while approximately 74.2 % and 25.8 % mortality was observed in the cyclone and control samples, respectively. The carapaces of zooplankton exposed to UV treatment turned opaque, while those exposed to the

cyclonic treatment remained translucent. In addition, the morphology of the UV-treated zooplankton was altered with appendages hanging loosely from the main body parts.

In summary, the zooplankton population showed the highest tolerance to the ITS at the highest UV dosage, while the clam, mussel and oyster larvae showed the lowest tolerance (Figure 4). A statistical test (Post-hoc Tukey test) revealed a significant difference between the mortality values of three groups of organisms: 1) zooplankton, 2) brine shrimp nauplii, and 3) clam, mussel, and oyster larvae ($p < 0.001$).

Practicability, cost, and safety implications of technology researched

Velox Corporation offers ballast water treatment systems for use as either mobile systems, on-board (ship-based) systems or stationary (on-shore) systems. Velox Ballast Water Systems are automatic and modular in operation and design. These systems can be fitted into existing or newbuild installations utilizing existing ballast pumps and piping systems. Mobile systems incorporate integrated pumping and recovered integrated solids handling facilities to ensure safety and handling of incoming untreated ballast water. The economics of ballast water treatment with Velox Ballast Water systems will vary with application, equipment financing options, ship size and required ballast water treatment rates. Velox offers ballast water treatment systems ranging in capacities from 500 tonnes/hr. – 12,000 tonnes/hr. Custom systems are also available.

The Velox™ Ballast Water Management System is relatively easy to operate and maintain. Because Velox Ballast Water treatment equipment has no moving parts, operator safety is not compromised and maintenance is also minimal. Velox electrical and mechanical designs meet or exceed required standards and incorporate high standards of quality control and design to further facilitate ease of operation and maintenance. Typical maintenance procedures include; periodic cleaning, changing or replacement of lamps and general system upkeep.

6. Conclusions and recommendations

This study examined the influence of an Integrated Cyclone-UV Treatment System on the survivorship of zooplankton and invertebrate larvae. In general, an increase in the mortality of mussel, oyster, and brine shrimp larvae was observed immediately following exposure to the ITS over a range of UV-treatment dosages (Figure 2). In addition, the mortality of clam larvae and a natural zooplankton population also increased upon exposure to the ITS at a single UV dosage.

Figure 3 shows the survivorship results of the natural zooplankton population exposed to the ITS at a single UV dosage. The UV-treated zooplankton fraction exposed to the combined treatment system reached 100 % mortality sooner than the zooplankton fraction exposed to the cyclonic pre-treatment phase only. The opaque colouration and degradation of the structural configuration of the calanoid copepods and barnacle nauplii following UV exposure was notable. These observations were consistent with those made by Jelmert (1999) who noted the opaque appearance of brine shrimp nauplii representing the denaturation of proteins and destruction of exoskeleton after UV-C exposure.

The natural zooplankton population which consisted of adult copepods and barnacle larvae appeared to be the most tolerant taxa, while the mussel, oyster, and clam larvae appeared to be the most vulnerable taxa to the exposure of the integrated treatment phases of the ITS (Figure 4). Brine shrimp nauplii were observed to be intermediate in their vulnerability. However, similarities in the outer tissues as well as photoprotective and photoreactivation mechanisms may explain the grouping of the mussel, clam, and oyster larvae (soft-shelled) according to their mortality estimates. The different pigment and cuticular exoskeleton (hard-shelled) of the brine shrimp larvae and zooplankton may be responsible for the increased survivorship of these organisms. It should also be noted that determining mortality in bivalve larvae is more difficult than that of zooplankton and brine shrimp nauplii.

Taxa-specific responses to ultraviolet radiation may result from two mechanisms evolved by organisms to cope with harmful levels of solar ultraviolet radiation: photoprotection and

photoreactivation (Damkaer and Day, 1983; Siebeck and Bohm, 1994; Zagarese et al. 1997). Photoprotection results from the production of photoprotective compounds that filter out harmful doses of UV radiation before reaching vital genetic or membrane structures. In addition, the protection of vital structures (proteins and nucleic acids) of organisms also depends on the reflection, refraction, or absorption of harmful wavelengths by exterior tissues capable of shading sensitive structures (Cheng et al. 1978). Both the quantity and quality of the external tissues of various organisms may aid in enhancing survival following exposure to UV radiation. Thus, the larger size and cuticular exoskeleton of the brine shrimp nauplii may have assisted in protecting UV-sensitive structures and decrease mortality relative to that of the mussel, oyster, and clam larvae. The small size (160 µm) and soft-shelled nature of the mussel, oyster, and clam larvae may have lead to an increase in larval mortality relative to that of the brine shrimp nauplii and the natural zooplankton.

Photoreactivation is a photoenzymatic system that uses longer-wavelength light to repair UV-induced damage to organismal structures (Cook, 1970; Rupert, 1964). It is likely that some form of photoreactivation mechanisms took place in this study, since the photorepair processes relying on recovery radiation appears to be a common phenomenon in a wide variety of organisms (Karentz et al. 1991; Siebeck and Bohm, 1994; Zagarese et al. 1997). In summary, the differences in the mortality responses of each taxa exposed to the ITS may be a combination of the individual photoprotection and photoreactivation potentials and nutritional status. In addition, structural damage to the outer tissues/cuticles or photoprotective pigments of the taxa exposed to the cyclonic pre-treatment may have enhanced their vulnerability to UV.

Dark experiments are a requirement for future investigations assessing the overall efficiency of ballast water treatment systems (Sutherland et al. 2001), since in a ship the treated water would be held in a darkened tank. In addition, the ability of an organism to reproduce should be assessed when dealing with UV-tolerant organisms or sublethal treatment dosages of UV-C. Reproductive impairment due to UV-B exposure has been shown to be a more sensitive indicator of UV-B stress than survival (Karanas et al. 1981). The results of this study also demonstrate that biological assays designed to assess the efficiencies of ballast water treatment systems should incorporate time-dependent mortality estimates to accurately determine UV-C radiation effects on marine plankton.

7. References

Carlton, J.T., Thompson, J.K., Schemel, L.E. & Nichols, F.H. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. I. Introduction and dispersal. *Marine Ecology Progress Series*, 66: pp. 81-94.

Chalker-Scott, L., Scott, J.D., Dunning, C. & Smith, K. 1992. Effect of ultraviolet-B radiation (280-320 nm) on survivorship of zebra mussel larvae (*Dreissena polymorpha*): a potential control strategy. *Journal of Shellfish Research*, Vol 11 (1), p.221.

Cheng, L., Douek, M. & Goring, D. 1978. UV absorption by gerrid cuticles. *Limnology and Oceanography*, 23: pp. l554-556.

Cook, J.S. 1970. Photoreactivation in animal cells. *Photophysiology*, 5: pp. 191-232.

Damkaer, D.M. & Dey, D.B. 1983. UV damage and photoreactivation potentials of larval shrimp, *Pandalus platyceros*, and adult euphausiids, *Thysanoessa rashcii*. *Oecologia*, 60: pp. 169-175.

Fleminger, A. & Hendrix Kramer, S. 1988. Recent introduction of an Asian estuarine copepod, *Pseudodiaptomus marinus* (Copepoda: Calanoida), into southern California embayments. *Marine Biology*, 98: pp. 535-541.

Jelmers, A. 1999. Testing the effectiveness of an integrated hydrocyclone/UV-treatment system for ballast water. *Consultancy report, Institute of Marine Research, Austevoll Aquaculture Research Station*, pp. 1-22.

Johnston, L.E. & Carlton, J.T. 1996. Post-establishment spread in large-scale invasions: Dispersal mechanisms of the zebra mussel *Dreissena polymorpha*. *Ecology*, 77 (6): pp. 1686-1690.

Karentz, D., McEuen, F.S., Land, M.C. & Dunlap, W.C. 1991. Survey of mycosporine-like amino acid compounds in Antarctic marine organisms: potential protection from ultraviolet exposure. *Marine Biology*, 108: pp. 157-166.

Rupert, C.S. 1964. Photoreactivation of ultraviolet damage. *Photophysiology*, 2: pp. 283-327.

Siebeck, O. & Bohm, U. 1994. Challenges for an appraisal of UV-B effects upon planktonic crustaceans under natural radiation conditions with a non-migrating *(Daphnia pulex obtusa*) and a migrating cladoceran (*Daphnia galeata*). *Arch. Hydrobiol. Beih*, 43: pp. 197-206.

Sutherland, T.F., Levings, C.D., Elliott, C.C. & Hesse, W.W. 2001. Effect of ballast water treatment system on survivorship of natural populations of marine plankton. *Marine Ecology Progress Series*, 210: pp. 139-148.

Sutherland, T.F., Levings, C.D., Petersen, S. & Hesse, W.W. Mortality of zooplankton and invertebrate larvae exposed to cyclonic pre-treatment and ultraviolet radiation. Submitted to *Marine Ecology Progress Series*.

Zagarese, H.E., Feldman, M. & Williamson, C.E. 1997. UV-B-induced damage and photoreactivation in three species of *Boeckella* (Copepoda, Calanoida). *Journal of Plankton Research*, 19 (3): pp. 357–367.

The OptiMar Ballast System

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1. Treatment options researched

The OptiMar Ballast System is based on solids separation, filtration and UV irradiation and uses the existing ballast pumps, pipelines and ballast control system aboard the vessel. The system can handle flow rates from 100 m3/h up to 3000 m^3/h per ballast pump.

The MicroKill Separator removes larger suspended solids. The MicroKill Filter removes all solids down to a desired micron size including organisms. The components can be used together with the MicroKill Separator in front or separately depending on the expected conditions or the level of treatment desired. For smaller ballast systems the Filter is relatively economical and practical and is recommended. The Separator is recommended for higher flow systems.

The MicroKill UV destroys or inactivates biological organisms including zooplankton, algae, bacteria and pathogens from ballast water without affecting the normal operation of the ship. Ballast water is also treated during de-ballasting to ensure the maximum effect.

OptiMar ballast systems capacities

MicroKill Separator

Capacity: 100 - 3000 m^3/h

Materials: Stainless Steel 316 L/ CuNi 90/10

Ballast water enters the inlet chamber in a circular flow, sets up a centrifugal action through the venturi shaped passage between the chamber and the separation chamber. The helical centrifugal action propels the particles to the wall and moves them into the sludge chamber. The clean water flows to the outlet pipe. The sludge is continuously bled through the sludge pipe back to the harbor. Simple controls regulate the balance of flow between clean water and sludge and measure the ship's draft and system pressure to ensure sludge discharge overboard. Pressure drop is minimal and only 5% or less of the ballast water flow is discharged with the sludge.

MicroKill Filter

Capacity: 100 - 700 m^3/h

Materials: Stainless Steel 316 L/ CuNi 90/10

MicroKill Filters use special stacked filter disks. The disks are color-coded by micron size, and are assembled according to the specific filtration requirements. The disk assembly has a spring compression unit and an internal piston, which operate during alternate filtering or back flushing modes.

The disk and spine assembly is specially designed to compress the micron-grooved discs inside a corrosion and pressure resistant housing. The MicroKill Filter can be designed in any orientation and fitted into existing available space. The MicroKill Filter has a very low pressure drop and requires only about 0.25% of the flow for backflushing.

MicroKill UV

Capacity:	100 - 3000 m^3/h
UV Dose:	120 mWs/cm2
Materials:	Stainless Steel 316 L/ CuNi 90/10 90/10
Power:	1,2 - 58 kW

The UV is designed for efficient kill or inactivation of organisms, bacteria and pathogens in ballast water and is based on 20 years experience in water injection on offshore platforms and water treatment for fish farming and drinking water plants in Norway. The system has a very low-pressure drop to minimize its effect on ballast pump capacity. The MicroKill UV is a minimum maintenance system and has low power consumption compared to capacity.

Each microorganism must absorb a specific UV dose to be destroyed; the UV penetrates the bacteria wall and is absorbed by the DNA consequently destroying life and preventing reproduction. The MicroKill UV is designed for efficient inactivation of organisms with a very low-pressure drop to meet the requirements of ballast systems and pumps.

UV light, when used in the wavelength ranging from 215 - 315 nm (nano-meter) the UV-C spectrum will cause irreparable damages to the DNA in bacteria & microorganisms. The most potent and effective wavelength for the damage of the DNA is 253,7 nm.

Both low pressure and medium pressure UV lamp systems are available. The choice depends on system capacity and the most efficient and cost effective design for the particular ship is offered.

UV Control Panel

The MicroKill UV is delivered with power and control panels. The control panel monitors and logs the performance of the UV system and has a continuous performance log. The control system also ensures that all water passing through the UV chamber receives at least the minimum prescribed UV dose.

The control panel is also equipped with a self-diagnostic system and will alarm if the performance is below the specified intensity due to unclean quartz tubes, reduced water quality or if a UV lamp needs to be replaced.

2. Timeframe of the project

The OptiMar Ballast System was developed based on 20 years experience in the offshore and the fish farming industries and from the supply of drinking water plants in Norway.

The idea for the 'OptiMar Ballast Systems'' was first conceived, after an inquiry from the Norwegian Department of Shipping in 1995. The concept of ''OptiMar Ballast Systems'' was developed and presented to the Department of Shipping in May 1997.

The development of the MicroKill UV, a UV system for fish farming and ships was started in early 1998, based on previous experience in manufacturing and application of UV systems. The prototype was sold to the fish farming industry on the day it was completed. In the fall of 1998 another 5 systems were delivered, each with flow rate capacity of 1000 m^3/h.

Testing 1998

The OptiMar Ballast System was tested for the first time at the Institute of Marine Research, Austevoll Aquaculture Research Station. The results were promising and were presented in the report "Testing ballast water treatment by low G-force vortex separation and UV-Radiation". By Anders Jelmert, Institute of Marine Research, Norway 1998. The report was also presented at the IMO meeting MEPC 42.

Testing 1999

In March 1999 another test funded by OptiMarin AS was conducted at the Institute of Marine Research, Austevoll Aquaculture Research Station, with a different separator. The result was similar to the tests conducted in 1998. The test results are available at www.optimarin.com

In April 1999 OptiMarin AS participated in a test in Vancouver, Canada, together with Terri Sutherland, Research Scientist, Marine Environment and Habitat Science Division, West Vancouver Laboratory, Fisheries and Oceans Canada. The result was similar to the test at Austevoll. The test report was published in volume 210 of the Marine Ecology Progress Series Journal.

The separators used in the Vancouver tests had a pressure drop that made them unsuitable for use in ballast water systems without changing the ballast pumps and the size of the equipment would make installation on a ship very difficult.

Between May and September 1999 OptiMarin AS, therefore, conducted tests with several different hydro cyclone separators. After numerous tests we found a model that separated sand from water without a major pressure drop. This resulted in the MicroKill Separator, patent pending 12.11.1999. Further development is taking place in Norway and at research institutions in England and Jordan.

Princess Cruises

In April 2000 the OptiMar Ballast System was installed aboard the Princess Cruises "Regal Princess", by OptiMarin and our US partner Hyde Marine, is the first ballast water treatment system aboard an operating vessel.

The "Regal Princess" takes on and discharges ballast water at a rate of 200 m^3/h (880 US GPM) as fuel and other consumables are used. The OptiMar Ballast System was installed aboard the "Regal Princess" during a regular scheduled two-week cruise from Southern California along the Mexican West Coast in late March 2000. There were no interruptions to the ship's normal operations. The system is compact enough to be located in the ship's pump room. The ship's existing ballast piping system, ballast pump(s), and control valves and systems were used as much as possible to minimize the total installation cost.

The OptiMar Ballast System has operated continuously since mid May 2000 during every ballasting and de-ballasting operation. The ship has reported no problems and no down time on the system. Preliminary onboard testing has indicated significant reductions in organisms, bacteria and pathogens as a result of treatment with the OptiMar system.

We have the following statement from Princess Cruises dated 10/10/2000

> *I confirm that to date we have not had any down time and it is being used for all ballast operations on and off the vessel.*
>
> Lars Nordin, VP Technical Services

George Wright, Director of Compliance & Security, Princess Cruises confirmed that is still the case, in a California State Lands meeting on January 31st 2001.

Testing 2000

Allegra Cangelosi from the Northeast-Midwest Institute in Washington, DC together with an international group of scientists conducted initial biological tests aboard the Regal Princess in May. The tests are conducted on a 4-day voyage between Vancouver and Alaska. The same team conducted more extensive tests aboard the Regal Princess on a 2-week voyage in August.

OptiMarin AS and Hyde Marine, Inc. also supplied the OptiMar Ballast System for "The Great Lakes Ballast Technology Demonstration Program" during the late summer of 2000. A report combining the findings on the Regal Princess and "The Great Lakes Ballast Water Demonstration Project will be

published in early 2001 and the findings and conclusions of the tests will be presented at this symposium.

New developments OptiMarin R & D

Our involvement in test projects mentioned above and the experiences from the shipboard installation on Regal Princess and the participation in the Great Lakes Project barge testing have given us invaluable feedback to be able to improve the performance of the OptiMar Ballast System.

MicroKill Separator

- Increase separation performance and minimize the pressure drop to avoid increased ballasting time or problems topping up wing or side tanks.
- Project with University of Herefordshire, Hatfield, UK and University of Amman, Jordan, for modelling of flow and Computational Fluid Dynamics within the MicroKill Separator.
- Utilizing new materials to avoid corrosion by seawater in the separator.
- Ongoing performance testing of the Separator to improve separation and minimize pressure drop and the volume of the sludge water slurry.

MicroKill Filter

OptiMarin AS has been evaluating various types of filters in addition to or instead of the separator where applicable. New back-flushing systems have been developed to meet the requirements on ships. The ''MicroKill Filters'' can be delivered in almost any orientation and construction to adapt the filter to the space available on a particular ship.

Due to the corrosive atmosphere in seawater OptiMarin AS selects the best materials for seawater applications. It is very important to select filters with minimum pressure drop to avoid significant reductions in ballast pump capacity.

MicroKill UV

The objective of our new developments has been to reduce the size to flow ratio and to use new materials to meet the corrosion problems in seawater. This will be a continuous effort and challenge.

We have designed a new UV system using medium pressure multi UV lamp systems with the new Multi Wave Technology. The new UV system uses power from 1 kW UV-C to 58 kW UV-C per unit. The UV doses are 147 Mws/cm2 for capacities up to 3000 m3/t per pump and 90% transmission. The new system will be certified to Explosion Proof installation in gas area Class Zone II or Cargo Pump Room.

3. Aims and objectives of the project

The objective in developing the OptiMar Ballast system was to be able to offer an effective and practical solution for the treatment of ballast water on ships and also to be able to retrofit to existing seagoing vessels and to participate in new buildings.

Designing a ballast water treatment process with solids separation & UV irradiation

1. Establish the dose required for treatment
   a) IMO, Harbor Authorities, Water Analyses
2. Determine flow rates required
   a) Ballast pump capacity
3. Establish UV transmission values
   a) Harbor Authorities, water analyses

4. Consider re-circulation if applicable
    a) Use stripping or main pumps
5. Treat water during de-ballasting

Installation

One of the objectives of the OptiMar Ballast System is to be able to retrofit the system into existing vessels, and the installation on the M/S Regal Princess has confirmed that we can do that, and that the installation can be done under operating conditions.

The installation aboard the Regal Princess was carried out "on the run" during two cruises in March 2000. Two fitters completed the job in about two weeks. The ship's ballast piping was cut in only two places and no other modifications to the machinery space were required. The total installation cost was less than $15,000 with no loss in operating time. Only two connections into the ship's existing ballast system piping were required, as shown in the diagram below. No fixed equipment had to be moved and nothing had to be rerouted to accommodate the installation.

Where to install

- In pump room shaft
- In pump room if space
- In engine room
- Void spaces

How to install

In a By-Pass line after ballast pumps

4. Research methods

The research that has been done with the OptiMar Ballast System and its components has been done in cooperation with researchers from all over the world. We have participated in several test projects and the findings are referred to in this paper and is also available on our web site www.ballastwater.com .

The test protocol and testing methods used for the full scale testing of the treatment system aboard the Regal Princess are described in Allegra Cangelosi presentation at this Symposium.

5. Results

We have included a summary of the different tests we have participated in and the most important finding is referred to below.

Organism removal

- Consistently reduce culture-forming units of bacteria on a marine agar more than 90%
- Consistently reduce the MS-2 coliphage virus by over 90%
- Significantly reduce the concentration of live zooplankton relative to controls
- Significantly reduced phytoplankton growth potential relative to controls

Practicability

The shipboard installation aboard the Regal Princes has been very successful and confirmed that the OptiMar Ballast System is suitable for on-board installations.

Cost effectiveness

The OptiMar system was designed from the beginning to be both efficient and cost effective. The modular design and the availability of optional methods for solids separation and the most suitable UV design help to minimize both the system's first cost and the cost of installation and operation.

Safety implications

There are no crew or ship safety concerns with the OptiMar Ballast System. We are in the process of certifying the system to Explosion Proof - for installation in gas area Class Zone II or Cargo Pump Room.

Tests results

1998 Tests at Institute of Marine Research, Austevoll Aquaculture Research Station, Norway.

Test Method

Water was pumped from the sea at a rate of 50 m^3/h. A low G-force separator was installed after the pump for pre-treatment, for removing suspended solids, sand, seaweed and uni- and multicellular organisms.

A medium pressure single chamber UV unit was used for secondary treatment. The single UV lamp had a UV power of 5,8 kW nominal and a UV-C power of 850 W. Applied dose at 254 nm was 93 mWs/cm^2Calculated from the flow and UV transmission. Sample injection was 0,8 l/min and purge 15 l/min, or about 2% of the flow.

Summary of Results

- Mortality of the model zooplankton (Artemia sp.) was 100% after UV-treatment.
- Removal of Cysts of model zooplankton: 81%
- The algae Isochrysis galbana and Pavlova sp. had a mortality of 100% and 85%, respectively. No signs of photorepair observed.
- The 2 bacterial strains were killed with an efficacy greater then 99.9995%.

Conclusions

The mortality of several aquatic organisms was 100%, or in the 99% range

The mortality of UV-adapted organisms was 85% (one Algae) and 81% (Artemia cysts)

Particles <40 µm was not effectively removed in the separator

The method can be expected to reduce transfer success significantly.

See details of the report on our web site www.ballastwater.com .

1999 Tests at Institute of Marine Research, Austevoll Aquaculture Research Station, Norway.

Executive summary.

This report describes the results obtained in a semi-scale laboratory test of an integrated hydro cyclone-UV unit, designed for removal of exotic species in ballast water.

The scope of the treatment was to remove as much as possible suspended solids and uni- and multi cellular organisms in a hydro cyclone, and to kill the remaining biota by UV irradiation, which has maximal biocidal activity at 254nm.

The applied dose is dependent of flow and the transmissivity of the water. To ensure a good «signal to noise» ratio in the test, dense cultures of Artemia sp, naupleii, Artemia cysts, the dinoflagellate Prorocentrum minimum, the green algae Tetraselmis sp., and two isolates of marine bacteria was injected into the water flow.

Except for the extremely UV-resistant Atremia-cysts, the tested equipment (Hydro cyclone + UV irradiation chamber) did remove model zooplankton, two species of marine alga, and a community of marine bacteria to a higher percentage than practical trials with ballast water exchange have accomplished.

The hydro cyclone utilized was not found suitable as a singular treatment option, but hydrocyclones may function as a suitable pre-treatment for UV irradiation.

Abstract from the report.

The removal of particles, and mortality of the various biota at four consecutive stages through the treatment system was recorded.

Cysts of the brine shrimp Artemia sp. were removed at an efficiency of 13.7% in the hydro cyclone, and the naupilus-larva of Artemia were removed by an efficiency of 8.3%.

Through the UV-unit, the naupleii showed a mortality of 99.5% and the numbers of hatching of cysts was 26 % lower than the numbers before the unit.

The microalga were removed with an efficacy in the 10 - 30 % range in the hydro cyclone, and showed a mortality in the UV-unit of 84.7% and 87.6 %, respectively for P. minimum and Tetraselmis sp.

The removal of bacteria in the hydro cyclone was negligible; while the bacterial numbers were reduced corresponding to a -2.3 log and -1.9 log elimination respectively, in two separate trials.

The complete report can be downloaded from our web site www.ballastwater.com or ask for a paper copy.

1999 Tests by Fisheries and Oceans Canada, Vancouver, Canada

A field test was carried out in the port of Vancouver in April 1999. The treatment system consisted of the same type of separator, Velox, and MicroKill UV as in the previous test at Institute of Marine Research only designed to a higher capacity. The Cyclone and UV used at IMR were designed at 120 m^3/h while the actual flow during testing was 75 m^3/h average. At the Vancouver test the equipment used were for 1000 m^3/h, but the actual flow average was 330 m^3/h during testing.

Abstract from the Report

A field experiment was carried out to determine the influence of a 2-stage ballast water treatment system on the survivorship of natural populations of plankton. This Integrated Cyclone-UV Treatment System (ITS) was designed and constructed by Velox Technology Inc. and consisted of 2 treatment phases: (1) the cyclonic pre-treatment phase, (2) the ultraviolet-radiation phase (UV-C). The ITS was deployed on the Vancouver Port Authority dock, British Columbia on April 11, 1999. Seawater samples were collected from ports located along the treatment stages of the ITS and analyzed for plankton survivorship. The sampling stages were defined as Pre-Intake, Pre-Cyclone, Post-Cyclone, Post-Solids, and Post-UV-on and Post-UV-off. The survivorship of planktonic invertebrates was assessed immediately through direct observations, while phytoplankton survivorship was assessed through incubation grow-out experiments. With respect to zooplankton, live copepods were observed in the Pre-Intake and Pre-Cyclone samples, while dead or moribund copepods were observed in samples collected from both early and late stages of the ITS. Statistical comparisons were carried out on phytoplankton growth parameters such as starting concentration, lag phase, growth rate, and relative abundance generated during the incubation experiment. *Chaetoceros gracile* appeared to be the most sensitive organism to the ITS as it exhibited a 4 d lag phase prior to growth. The starting concentration, growth rate, and relative abundance of this species observed in the Post UV-on samples were significantly lower than those

observed in the Pre-Intake samples (control). In addition, the auxospores formed by *Skeletonema costatum* during the incubation experiment were observed in all treatment samples with the exception of those exposed to the Post-UV-on stage of the ITS. A second phytoplankton incubation experiment was carried out using the original samples following a 3 mo storage period in dark, cold conditions (4°C). The results of this experiment revealed that the phytoplankton population in the UV-treated samples was not capable of growth, while those in the remaining treatments exhibited growth. Thus, future studies assessing the effect of the ITS on phytoplankton survivorship should incorporate increases in the intensity and exposure period of ultraviolet radiation followed by a dark, cold-storage period, thereby reducing the chance of photorepair.

2000 Tests on Regal Princes and the Great Lakes Ballast Technology Demonstration Program by Allegra Cangelosi, Northeast-Midwest Institute and collaborators

The experiments reported here were designed to describe the biological effectiveness of the OptiMar Ballast Treatment System at killing, removing, or impeding reproduction of organisms in ballast water (operational findings will be reported elsewhere). Extensive physical and biological tests were conducted on the system on both a stationary barge-based experimental platform at 1500 USGPM, and in an engine-room installation of an operating passenger vessel (*MV Regal Princess*) at 880 USGPM. The barge-based tests illuminated system effectiveness in a high flow, yet controlled experimental context. The ship-board tests provided a real-world assessment of the treatment in the context of an operating ballast system. While not all-encompassing, the combination of biological findings reported here provide a strong indication of overall system effectiveness with respect to bacteria, viruses, phytoplankton and zooplankton. Though the full-scale flow-rate for the passenger ship is low compared to cargo ships, the experiments were also informative as to interactions between ballast systems and the biota in treated and untreated water, and the extent to which efficacy results from a barge platform may be translatable to effectiveness in a ship.

System performance

1. Performance evaluations at two time intervals following treatment (0 hours and 18-24 hours), in two treatment contexts (actual ship ballast system, and a barge-based platform), and varied locations with diverse physical/chemical water conditions (Pacific Northwest coastal, and two Lake Superior locations) revealed system effectiveness at elevating zooplankton and phytoplankton mortality, and inhibiting phytoplankton and microbial growth.

2. Both CS and UV contributed to zooplankton mortality, while the UV system alone caused phytoplankton and bacteria inactivation.

3. The shipboard system, which treated water on uptake and discharge, elevated zooplankton mortality two and a half fold relative to controls. Treatment upon intake caused no immediate zooplankton mortality, but did cause latent mortality. Immediate zooplankton mortality was evident upon treatment of the discharge stream in both T0 and T18-24 studies, indicating that the intake treatment, short or long-term storage in a ballast tank, and/or a slower pump rate upon discharge may contribute to zooplankton susceptibility to the treatment. The overall decrease in live density of zooplankton in T-18-24 treated water following discharge treatment was over 90% relative to intake levels in the shipboard application (compared to a 55% decrease in the controls). The intake-only treatment on the barge platform elevated zooplankton mortality 51% relative to controls. These findings represent a conservative estimate of zooplankton inactivation as latent zooplankton mortality caused by the discharge treatment and reproductive effects in general were not measured. In addition, moribund individuals were counted as live.

4. The system did not alter absolute chlorophyll *a* concentrations relative to controls through acute effects such as removal or bleaching on either platform. Storage of the water for 18 hours in a catchment or ballast tank prior to sampling did not alter this finding. The system did reduce algal growth and accelerated die-off relative to controls in incubated samples.

Chlorophyll *a* concentrations in incubated samples collected 18 hours following treatment by UV alone and CS and UV decreased by nearly 60% relative to controls, while CS alone did not affect algal growth.

5. The system significantly reduced microbial concentrations at all test sites. The mean reduction due to one pass through the treatment system on the *MV Regal Princess* was 82%. Retention for less than two hours in the ballast system raised concentrations of culturable bacteria 1.45 Log higher than levels immediately following treatment. Bacterial regrowth and/or repair during 18-24 hour retention in the ballast tank raised bacterial concentrations 2.62 Log, over twice as effectively as during intake.

6. The UV transmittance of source water, especially resulting from dissolved compounds, which cannot be removed with physical separation devices, strongly influences system performance. Treatment performance characterizations must therefore be qualified by this information, and treatment systems designed for effectiveness for the range of UV transmittance characteristics that the ship is likely to encounter in harbor waters.

7. The effectiveness of the system on bacteria and phytoplankton, while measurable and statistically significant on one or both experimental platforms, might not be biologically significant in terms of the receiving system due to the high capacity of these organisms to regrow. The system may have selectively reduced some types of bacteria and phytoplankton to adequately low levels to be biologically significant. However, it may also have the effect of selecting for organisms that are resistant to UV effects. These tests do show, however, that the technology can be effective against these organisms in field conditions, and with design modifications a greater level of effectiveness these organisms can be achieved.

6. Conclusions and recommendations

The OptiMar Ballast System is the first and only full-scale shipboard system in successful operation on any ship. The system has proven to be reliable and effective and is running during every ballasting and de-ballasting operation aboard the Regal Princess

We believe that a full-scale shipboard installation is the only way to verify if a treatment solution is a viable option and practical for the every day operation of the ship. The Regal Princess shipboard installation and the experience gathered from the daily operation of the system and the tests we have participated in have given us invaluable feedback. These have resulted in further improvements to the OptiMar System making it even more efficient and easier to operate for our customers. OptiMarin and Hyde Marine are committed to continuous improvement of the OptiMar treatment technologies.

7. References

Jelmert, A. & Nilsen, H, 1998. *Testing ballast water treatment by low G-force vortex separation and UV-Radiation*. Optimar Marketing M/S, Stavanger, Norway.

Jelmert, A 1999. *Testing The Effectiveness Of An Integrated Hydro cyclone/UV treatment system for Ballast Water Treatment.* Optimar Marketing M/S, Stavanger, Norway.

Sutherland, T.F., Levings, C.D., & Elliot, C.C. 2001. Effect of a ballast water treatment system on survivorship of natural populations of marine plankton. *Marine Ecology Progress Series Journal* volume 210 pp. 139-148

Cangelosi, A. et al. 2000. *The Great Lakes Ballast Technology Demonstration Project: Biological Effectiveness Test Program (including MV Regal Princess trials).* Paper presented at this conference.

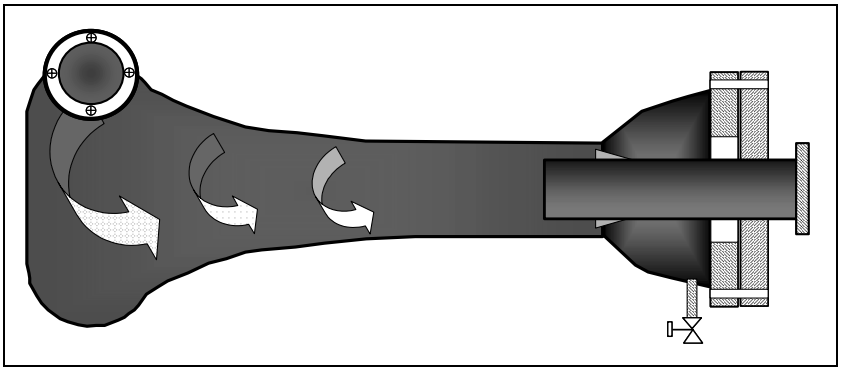


Figure 1: MicroKill seperator.

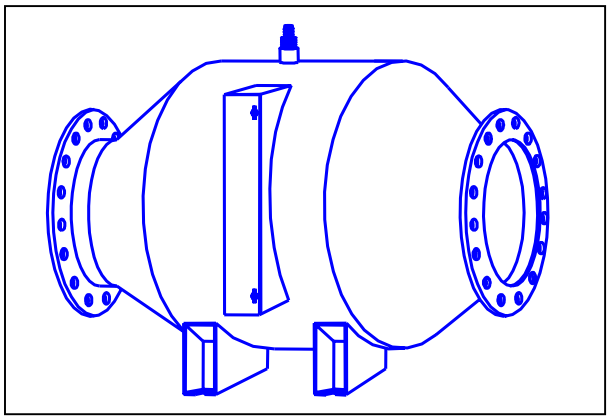


Figure 2: Multi Wave UV Technology. The new design is an in-line chamber with a high capacity and improved and simplified replacement of UV lamps and general service.

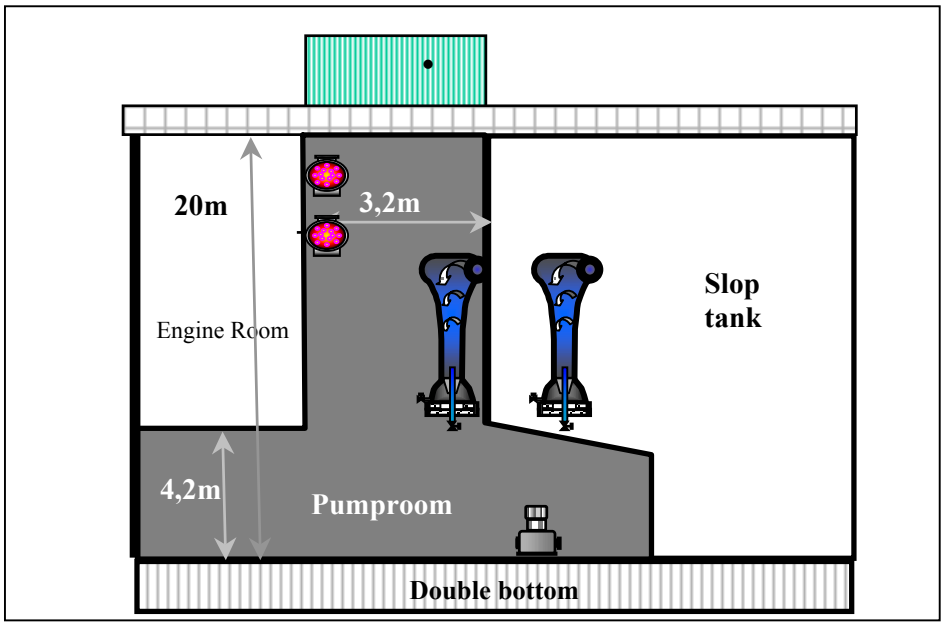
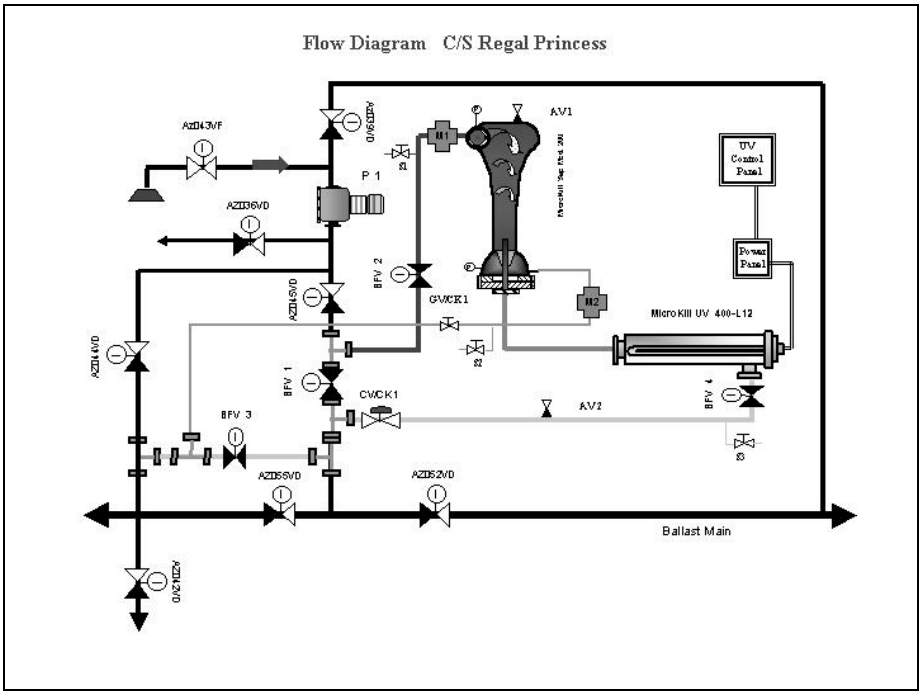


Figure 3: Possible installation on a Tanker



Figures 4- 6: The OptiMar system installed on the CS Regal Princess

Ballast Water Treatment R&D Activities on North American Pacific Coast

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1. Timeframe of the project

Numerous international, national, regional and local groups are discussing ways to minimize the spread of invasive species from ballast water. Everyone is hampered by the same set of problems. Creating a practical and effective ballast water discharge standard is complicated by the vast diversity of organisms found in ballast water. Ballast water treatment is new and rapidly evolving with many promising technologies, but none that have been widely proven in the varied world of shipboard operations. Ballast water treatment testing facilities have not been available for long-term standardized testing of technology effectiveness. The production and installation of new treatment technologies is hampered by the lack of a standard. The National Invasive Species Act states that any form of treatment must be as good or better than ballast exchange, which unintentionally complicates the establishment of a standard because of the difficulty in defining the varying effectiveness of exchange. Salinity testing is the current method of evaluating exchange and is regarded as ineffective. All of these interrelated problems need to be addressed in a manner that promotes consensus for a unified state, national, and international ballast water management program.

The Pacific Ballast Water Treatment Pilot Project was established to cooperatively conduct ballast water research of common interest to the International Maritime Organization, U.S. Coast Guard, British Columbia, and the Pacific states of California, Oregon, Washington and Alaska. Researching new methods to stop invasive species introductions from ballast water unites the project partners in a common goal. The ambitious efforts undertaken in this project are beyond the ability of any single member. By combining resources, we increase our ability to solve problems that impede the development of a comprehensive and effective ballast water management program.

A research team has been formed to cooperatively conduct the research undertaken in this project with guidance from advisory teams. Each team member focuses on a specific project, yet each adds their expertise to the development of all project components. The team members are from diverse backgrounds providing a balance of scientific, professional and political perspectives. The diversity of team members is intended to insure that our results will be scientifically defensible, practical and widely accepted.

The Project objectives include the building of a ballast water research facility for pilot scale testing, shipboard installations for full-scale testing, establishment of standardized testing protocols, a recommended interim standard for ballast discharges, and a recommended monitoring protocol to verify the effectiveness of ballast water exchange. Individual project results will be submitted to various journals for publication and combined together into one comprehensive project report.

Stopping new invasive species introductions from ballast water is an enormously complex undertaking. Thousands of vessels move billions of gallons of ballast water around the globe daily. Trade through shipping improves the economies of every country on earth, yet invasive species introductions continue to cause economic and environmental problems. The members of this project are dedicated to discovering innovative ways to prevent new invasive species introductions, while

minimizing impact to the maritime industry. Our efforts are intended to provide a positive step towards a global solution.

Project partners and funding

The following table is intended to provide a general overview of the project. Team members will cooperatively exchange ideas and provide advice. However, the lead organization for each project component retains complete authority for the implementation of their respective research. A detailed description of each project component can be found in section 5.0.

Table 1: Project partners and funding

Project Components	Lead Organization	Funding Source	Dedicated Funds
Laboratory Testing of Ballast Water Treatment Technologies	USGS Biological Resources	USGS Biological Resources Prince William Sound Regional Advisory Council	$500,000 (Annual Appropriation) $30,000
West Coast Regional Applied Ballast Water Management Research and Demonstration Project	California State Lands Commission	U.S. Fish and Wildlife Service Port of Oakland California State Water Resources Control Board	$150,000 $150,000 To be determined
Verifying the Efficiency of Ballast Exchange	University of Washington	U.S. Fish and Wildlife Service	$150,000
Mobile Ballast Water Treatment Demonstration Project	To be determined	Under Consideration by the Port of Seattle	To be determined
Project Coordination	Washington Department of Fish and Wildlife	Washington Department of Fish and Wildlife	Staff time

2. Project organization

Scott Smith from the Washington Department of Fish and Wildlife serves as the projects coordinator.

The following teams have been formed to conduct the pilot project research, provide advice and ballast treatment technologies for evaluation. The team members may change as the project proceeds. New members are welcomed as appropriate (see figure 1).

Research Team

Consists of scientists that are actively conducting research within the project.

Allegra Cangelosi, Ecosystems Projects Northeast-Midwest Institute

Jeffery Cordell, University of Washington

Dr. Russell Herwig, University of Washington

Dr. Colin D. Levings, Fisheries and Oceans Canada, Science Branch

Dr. Frank Shipley, U.S. Geological Services Biological Resources

Dr. Terry Sutherland, Fisheries and Oceans Canada, Science Branch

Dr. Jim Winton, U.S. Geological ServicesBiological Resources

Science Advisory Team

Consists of representatives from agencies, academia and interested researchers. This team provides a diversity of scientific perspectives and knowledge to the research team.

Dr. Richard Everett, U.S. Coast Guard

Dr. Robert Hiltabrand, U.S. Coast Guard

Dr. Henry Lee, U.S. Environmental Protection Agency

Anna-Louise Reysenbach, Portland State University

Dr. Greg Ruiz, Smithsonian Environmental Research Center

Dr. Mark Sytsma, Portland State University

Dr. Jan Thompson, U.S. Geological Services- Menlo Park Center

Dr. Tom Waite, University of Miami

Barnaby Watten, U.S. Geological Services-Leetown Science Center

Maritime Advisory Team

Consists of representatives from marine trade associations, shipping associations, ports marine engineers and other interested parties.

David Cook, Inchcape Shipping Services

Sebastian Degans, Port of Portland

Richard Harkins, Lake Carriers' Association

William Hurley, Jr. P.E., Glosten Assoc. Inc.

Harry Hutchins, Puget Sound Steamship Operators Association

Marilyn Leland, Prince Williams Sound Regional Citizens' Advisory Council

Carl Loehr, Port of Vancouver, USA

David G. Schneidler, Port of Seattle

Jim Townley, Columbia River Steamship Operators Association

Regulatory Agency Team

Will provide guidance to insure that our research contributes to the creation of an effective, verifiable and consistent regulatory program.

Dorn Carlson, U.S. Environmental Protection Agency

Captain Michael Cormier, Adjoint au Capitaine de Port of Vancouver

Jeff Fishel, Washington Department of Ecology

Mary Mahaffy, U.S. Fish and Wildlife

Pam Meacham, WA Dept of Fish and Wildlife

Daryla Montgomery, U.S. Navy

Scott Smith, WA Dept of Fish and Wildlife

Linda Sturgis, U.S. Coast Guard

Chris Woodley, U.S. Coast Guard

Technology manufacturers

The following corporations have offered to provide their ballast water treatment technologies for evaluation by the research team. These manufacturers will be encouraged to provide information and support to the teams listed above as necessary. The acceptance of a specific manufacturer into the projects verification program does not constitute an endorsement of their technology. The research team is currently defining new requirements that additional technology manufacturers must meet prior to acceptance into the verification program.

Wayne Hesse, Velox Technologies, Inc.

Ken Hughes, Delta Marine International, Inc.

Tomas Mackey, Hyde Marine, Inc.

3. Synthesizing existing research and interim standard proposal

Existing ballast water treatment research

Table 4.1.1: Summary of Ballast Water Treatment Trials

Year	Author(s)	Treatment type	Vessel Type	Taxa	Study Type	No. Ships	No. Tanks per Ship	No. Trips	Treatment effectiveness (%)
1996	Aquatic Sciences Inc.	Exchange	Great Lakes ships	FW	Comparison of ships that did or did not exchange	105			? Live organisms present in most samples, even tanks with high salinity levels
	Armstrong	Exchange	Tanker Dry bulk carrier Container ship Pass						95% (?) water exchanged
1993	Bolch & Hallegraeff	Salinity Copper sulfate Chlorine Hydrogen peroxide Heat		Dinoflag.	Lab trials				100 ppt salinities prevented germination; 68% germination with copper sulfate; successful germination with free chlorine <500 ppm; hydrogen peroxide killed cysts at >10,000ppm; no germination above 45 deg.C.
1995-1997	Cawthron	Exchange	Container ship Bulk carrier Break bulk carrier	Phytopl. Zoopl.	Comparison of ship and tank types	75	161 total ballast tanks		83% of all tanks sampled contained live invertebrates. Approx. half of the tanks had reportedly been exchanged in mid-ocean. Many of the exchanged tanks had coastal marine life mixed with mid-ocean species. Zoopl. Also found to be persistent residents of tank sediments.
1996-1998	Cawthron	Oxygen removal Heat		All	Lab and vessel trial				A heat treatment facility designed to kill target species was trailed based on lab experiments. Encouraging results were obtained at temperatures as low as 40 deg. C. for a range of organisms under different temperature and times
1999	Dickman & Zhang	Exchange	Container ship	Diatoms Dinoflag.	Comparison of ships that did or did not exchange	3	1	9	48% diatoms and dinoflag. killed 39% harmful biota killed 95% water exchanged
1996-2000	Great Lakes Ballast Technology Demons-tration Project	CS, UV, Filter							

Year	Author(s)	Treatment type	Vessel Type	Taxa	Study Type	No. Ships	No. Tanks per Ship	No. Trips	Treatment effectiveness (%)
1995	Japanese Shipowners' Association	Heat	Ore Carrier	Phytopl.		1			None of the phytoplankton in the original ballast tank survived the journey from Japan to Australia, but there was still the possibility of cysts surviving in bottom sediments Ballast water heated to 43 deg. C. at the inlet but only reached 35 deg. C. at the point of the tank furthermost from the inlet.
1991	Locke et al.	Exchange	Great Lake ships	Macrozoo	Comparison of ships that did or did not exchange	12	1?	12	67-86% effectiveness as 14-33% of the ships that exchanged FW ballast in mid-ocean carried living FW tolerant zoopl. At time of entry to seaway
1998-1999	OptiMar	CS+UV			Semi-scale lab				CS removed 13.7% of Brine shrimp cysts, 8.3% of brine shrimp nauplius larva, 10-30% of microalga, and was negligible for bacteria. UV removed killed 99.5% of nauplii, reduced hatching cysts by 26%, killed 84.7-87.6% of alga, and reduced bacterial numbers by 1.9-2.3 logs.
1998	Petrobras	Exchange	Oil tanker	All		1			The amount of original water that remained after exchanging 3 volumes (21 hours) depended on the parameter analyzed: Chlorophyll a (14%), methylene blue (10%), phytoplankton abundance (4%). Only oceanic zooplankton groups with the dominance of oceanic copepods were found and microalgae cysts/resting spores were close to non-detected in the water column. Visual observation of sediment indicated that thick layers previously present had been washed. Cysts/resting spores that remained in tank (1-2 x 105 cysts-spores/L).
1993	Rigby & Hallegraeff	Exchange	Dry bulk carrier	Diatoms Dinoflag. Copepods	Comparison of before and after in one ship	1	1	1	Using methylene blue dye as a tracer, under sea going conditions, approximately 4% of the original water and 5% of the original dead plankton material remained after exchanging 3 tank volumes of water. The proportion of living organisms surviving ocean exchange was only a small fraction of the above.
1997	Rigby, Hallegraeff & Sutton	Heat	Bulk carrier	All	Two ship board tests	1		2	Earlier lab experiments indicated that toxic dinoflagellate cysts were killed after 4.5 hours at 38 deg.C. The shipboard trial showed that all water in the ballast tank exceeded 38 deg. C. after 30 hours of heating. 0% zooplankton and only limited phytoplankton survived the heat treatment
1997-1999	Ruiz et al.	Exchange	Tankers	All	Comparison of ships that did or did not exchange	126			Ballast exchange expts suggest that tankers arriving to Port Valdez from foreign ports have reduced resident coastal organisms by >90%. Abundance of coastal organisms was 10-100 fold lower for oil tankers that were foreign arrivals than domestic arrivals (not required to undergo BWE)
1997-2000	Ruiz et al.	Exchange	Multiple ship types	All					Preliminary results based on salinity and Rhodamine dye tracers indicate significant water mass exchange (>80%) for both flow-through and empty refill methods, with the later being more efficient
2001	Sutherland et al.	CS + UV							
1988	Williams et al.	Exchange	Dry bulk carrier	Copepods Macrozoo	Comparison of ships that did or did not exchange	23(?)	?	23	100% Japanese copepods killed 84% copepods killed

Year	Author(s)	Treatment type	Vessel Type	Taxa	Study Type	No. Ships	No. Tanks per Ship	No. Trips	Treatment effectiveness (%)
1996	Wonham et al.	Exchange	Dry bulk carrier	Diatoms Dinoflag. Macrozoo	Paired exchanged and unexchanged tanks	1	3 pairs		99% water exchanged using known salinities of ballast and ocean water
1999	Zhang & Dickman	Exchange	Container ship.	Diatoms Dinoflag.	Comparison of ships that did or did not exchange	5	1	34	95-99% water exchange; 87% harmful biota killed

Interim standard proposal

To be completed after being presented and discussed at the International Ballast Water Treatment R&D Workshop sponsored by the International Maritime Organization in London (March 28-30).

4. Research components

Laboratory testing of ballast water treatment technologies

Laboratory testing of various technologies will be accomplished at the U.S. Geological Services Marrowstone Island Field Station. This field station is located on Marrowstone Island at the northern entrance to Puget Sound, where the currents from the Strait of Juan de Fuca enter from the Pacific to the west and turn south to feed the Sound itself. The station is a former U.S. Coast Guard lighthouse, acquired by the BRD (then FWS) in 1974. Besides the classic old lighthouse keeper's residence (a three-story house now used for office, library, and dorm space), the station maintains a laboratory/office building, two wetlabs with constant seawater flow, a semi-enclosed halibut tank facility, and support structures such as the pumphouse and shop. Approximately $4.0 million dollars was invested in construction and remodeling in the early 1990s

Exceptionally high seawater quality is the station's primary asset, and most research at Marrowstone consists of experiments which depend upon laboratory rearing of salt water organisms. Due to limited staffing, most research at the Marrowstone Island Field Station is cooperative in nature. The facility is the Biological Resources Division's only seawater laboratory, and a critical research asset nationwide. However, the high scientific potential of this institution is not fully realized. Little modification is needed to create a premier ballast water treatment technology testing facility on the site.

Suggested modifications include the installation of three 10,000 gallon tanks with removable dividers that have the potential to make one 30,000 gallon tank that mimics a ballast tank that could be seeded with organisms to study grow-out, etc. The water would be piped through a test pad area where treatment technologies could be installed, and then into a set of holding tanks. The design would permit triplicate testing. Provisions are also made for chemical treatment of the water before returning it to the Sound if hazardous pathogens are present. Preliminary engineering drawings and design estimates have been created by Glosten and Associates (figure 2). Site evaluation and civil engineering is tentatively planned for early summer.

West Coast Regional Applied Ballast Water Management Research and Demonstration Project (West Coast Demonstration Project)

Maurya B. Falkner - Principle Investigator
California State Lands Commission

Introduction

In August 2000, California State Lands Commission (CSLC) was awarded a grant from the US Fish and Wildlife Service (USFWS), for $150,000.00 for our West Coast Demonstration Project. The proposal originally called for the CSLC to identify a "volunteer" vessel, contract with a

marine engineering firm to conduct full scale engineering designs for the retrofit of an on-board, flow-through ballast water treatment system, financially assist the vessel owner with portion of the installation cost of the ballast water treatment system, and in conjunction with the California State Water Resources Control Board (SWRCB) and the University of Washington (UW), evaluate the effectiveness of the particular system under operational conditions.

Subsequent to the submittal of the West Coast Demonstration Project proposal, it was discovered that key portions of the proposal were being conducted by engineering firms funded by the Great Lakes Ballast Technology Demonstration Project (GLBTDP). In particular, the GLBTDP, which is co-led by the Northeast-Midwest Institute and the Lake Carriers' Association, is conducting full-scale engineering designs on two vessels operating in US waters. The engineering firms are in the process of evaluating the ship particulars and vessel routes to determine the most appropriate ballast water treatment system for installation. No funding was secured to actually implement the recommended ballast water treatment system installation on the vessels. Therefore, in order to maximize the benefits of the two projects, it was decided that partnering of these two grants was appropriate. CSLC initiated a conversation with our funding agent, Sharon Gross, USFWS, seeking approval to modify our proposal. Approval was granted, verbally, on October 31, 2000.

Revised Project

The revised CSLC proposal will utilize the engineering feasibility analyses currently funded by the GLBTDP and assist in the installation of the ballast water treatment system on one or both of the vessels. Briefly, the two vessels currently included in the NEMW funded project are *R. J. Pfeiffer* and *Polar Endeavor*. The *R.J. Pfeiffer* is a 31573-ton; US flagged container vessel, built in 1992. She has 26 ballast water tanks with a total capacity of 14620m^3. Her two ballast water pumps have a maximum pump rate of 350m^3/hour/pump (1540 gallons/minute/pump). This vessel operates between Hawaii, California, and Washington ports. She enters CA ports (Los Angeles or Oakland) every 14 days.

Current engineering designs for the *R. J. Pfeiffer* recommend a two-stage treatment system. The first stage includes a multiple filtration system to remove large organisms and reduce turbidity; this is followed by a secondary treatment with UV light. The engineering plans also include a back-up chemical treatment system. CSLC is discussing the next phase, actual installation of the treatment system and subsequent evaluation, with the vessel owner. Current concerns about the recommended system include operational constraints because of the multi-filtration system. Preliminary testing of the filtration system to evaluate its performance and maintenance requirements on a dockside barge facility, prior to the actual retrofit, are being discussed.

The second vessel is the *Polar Endeavor*, a tank vessel currently under construction, is expected to begin operate along the West Coast of North America, carrying crude oil from Alaska to West Coast ports in late summer or early fall of 2001. The engineering designs for the *Polar Endeavor* recommend a two-stage treatment system, with the first stage utilizing a hydrocyclonic filtration system, followed by UV light treatment. A backup chemical treatment system is also included in the designs. CSLC has had preliminary discussions with the owners of this vessel. Due to concerns about the intrinsic safety of this system aboard a petroleum tank vessel, additional engineering designs are being evaluated.

Matching funds

In December 2000, the Port of Oakland (POO) agreed to match the USFWS funds, doubling the funds available for this project. The Port of Oakland (POO) funds will be used to bring an additional vessel into the West Coast Demonstration Project, assist in the evaluation of the effectiveness of the treatment system on board the vessel, and the subsequent development of standards for ballast water treatment technology. CSLC, working through the two California maritime associations and various ship owners is attempting to identify additional "volunteer" vessels interested participating in the expanded Demonstration Project.

Additionally, the California State Water Resources Control Board (SWRCB) is proposing to partner with CSLC to evaluate the effectiveness of ballast water treatment systems installed on Demonstration Project vessels. Using sampling protocols and analyses developed by Allegra Cangellosi, NEMW Institute, (see Attachment A), SWRCB will be contracting with various local experts to collect and analyze ballast water samples from Demonstration Project vessels to determine the effectiveness of a ballast water treatment system under operational conditions.

Finally, CSLC has begun discussing, with Dr. Greg Ruiz, at the Smithsonian Environmental Research Center (SERC), coordination between our evaluation of treatment systems, with his ballast water exchange efficacy study underway at POO. We hope to combine forces and collect data on these two important areas to ultimately assist in the development of standards for ballast water treatment systems.

Sample collection to evaluate the effectiveness of ballast water treatment systems.

Samples should be collected pre-treatment (Control = C), post-treatment (Time zero = T_1) and post-treatment (Time X = T_x). Additionally, a "holding time" sample will be collected ~36 hours after the final treatment.

If possible use Particle Sizing Analyzer (PSS) to quantify effectiveness of mechanical filtration systems (filters & hydrocyclone).

Collect pre-treatment samples and post-treatment (filtered) samples.

In systems that utilize multiple treatment regimes, for example filtration with UV-C, samples should be collected pre-treatment, post-treatment1, post-treatment2, and holding samples (~36 hours post-treatment2).

Analyze all samples for salinity, pH, temperature, turbidity, zooplankton (density, live/dead), phytoplankton (ChlorA), bacteria (culture).

For zooplankton, it is recommended that both counting and sorting be conducted, as well as sizing if possible. Zooplankton should be sorted by broad taxonomic categories that represent large morphological distinctions. For example Copepods, Nauplii, Worms, Cladocerans, rotifers, etc. Analysis of live/dead and any bacterial culturing must be done on the vessel.

Initial sample collection and analysis will be done while the vessel is underway. The sampling regime will require up to four individuals to accompany the vessel over one leg of its voyage (Hawaii to CA, Japan to CA, etc.). Individual expertise required includes a microbiologist to collect set-up and evaluate bacterial cultures, a zooplankton specialist to collect and analyze samples for density and live/dead/, and a phytoplankton specialist. An additional person to help organize all the sampling and deal with problems that arise is also recommended.

Overall cost is estimated at $35,000.00/sampling exercise (up to 2 week voyage) - of this ~$5000.00 is for supplies. This assumes the vessel covers food, etc. while on the vessel.

Verifying the efficiency of ballast exchange

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Introduction

In August 2000, the University of Washington (UW) was awarded a $150,000 grant from U.S. Fish and Wildlife Service for a proposal that was entitled "Ballast Water Monitoring and Treatment". The proposed research was extremely ambitious and involved both an examination

of ballast water treatment technologies and ballast water exchange. The UW also proposed to work on the development of assays to assess the effectiveness of ballast water treatment and ballast water exchange. At the time of the grant award, the U.S. Fish and Wildlife Service encouraged the UW to focus its research effort on a portion of the work that was proposed. Shortly thereafter, the USGS received appropriations ($500,000 per year) to initiate a research at the Marrowstone Marine Field Station related to the treatment of ballast water. The UW decided to direct its research efforts to scientific and development issues related to ballast water exchange. Monitoring methods that evaluate the efficiency of ballast water exchange in reducing the chance of exotic species introduction need to be developed and tested. We anticipate that several of these monitoring protocols will also be useful to determine the efficiency of ballast water treatment. For the UW research, samples of ballast water will be collected primarily from commercial ships that enter Puget Sound, Washington. We will also make a smaller effort to collect ballast water from ships that enter the Columbia River.

Initial efforts during for the UW project involved the formation of a research team and developing contacts in state and federal agencies, and with representatives of the Puget Sound shipping industry. Presently, the UW research team consists of the following people: Dr. Russell Herwig (Principal Investigator, Research Assistant Professor), Mr. Jeffery Cordell (Co-Principal Investigator, Fisheries Biologist), Dr. Marcia House (Postdoctoral Research Associate), Mr. Jason Toft (Fisheries Biologist), and Ms. Christine Nguyen (Undergraduate Student). Our primary contacts in Washington state agencies include: Mr. Scott Smith and Ms. Pamela Meacham (Washington Department of Fish and Wildlife); Mr. Jeff Fishel, Mr. Norm Davis, Mr. Guy Grayson, and Mr. Dodge Kenyon (Washington Department of Ecology). We have discussed our research plans and begun to coordinate research activities with Ms. Allegra Cangelosi (Northeast-Midwest Institute), Dr. Greg Ruiz (Smithsonian Environmental Research Center), Mr. Greg Ma (King County Environmental Laboratory), Mr. Harry Hutchins (Puget Sound Steamship Owners Association), and Mr. Robert Bohlman (Puget Sound Marine Exchange).

Project Plan

Our long-term goal is to perform scientific research that will aid in the development of ballast water monitoring protocols that can be used to determine if ballast water has been adequately exchanged with mid-ocean water thereby decreasing the risk of exotic species introductions. Most environmental scientists would agree that ballast water that is exchanged in the open seas presents less of an ecological threat or risk to the receiving waters than ballast water taken up at near shore locations, for example, the last port of call. The question is whether the threat has been reduced to an acceptable level. As presently engineered and practiced, reballasting does not exchange 100% of the ballast water or remove all of the sediments that are found in ballast water tanks. The amount of the exchange also varies from ship to ship.

The UW research team will begin their effort by sampling ballast water from vessels that arrive in Puget Sound. Sampling will primarily focus on (1) the composition and viability of zooplankton and microorganisms, (2) biochemical methods that can be used to measure living biomass, (3) geochemical signatures of nearshore and midocean water, and (4) development of methods for "fingerprinting" ballast water samples. We expect to sample approximately 60 ships during the first year of our project. Sampling will be biased toward ships that have ports of origin in Southeast Asia and along the west coast of the United States, or toward ships that routinely transport large amounts of ballast water into Puget Sound.

Summary of Research Protocols and Development

Characterization of Representative Zooplankton Taxa

One method for evaluating the effectiveness of ballast exchange is to quantify zooplankton before and after the exchange event. Specifically, exchange efficiency can be estimated by enumerating the number of coastal/estuarine taxa taken on during ballasting and comparing them with oceanic taxa typical of those taken on during open-ocean exchange. The decrease in proportion of coastal taxa after exchange and at the end of the journey is a measure of exchange effectiveness. We will

sample zooplankton from ships as follows: zooplankton sampling will consist of three replicate vertical plankton hauls taken at each sampling period with a 0.3 m diameter, 80 µm mesh plankton net. The net will be lowered to within 0.5 m of the bottom, and after 30 s have elapsed to allow net disturbance to dissipate, the net will be hauled slowly to the surface. In order to quantify organisms affiliated with the bottom sediment, we will sample zooplankton with a pump. Outflow from the pump will be collected on an 80-µm screen. All zooplankton samples will be fixed in 5% buffered formaldehyde solution.

In the laboratory, zooplankton samples will be filtered through an 80-µm screen to remove fixative and retain most copepod stages. Sub-samples will be taken until the total count for the most numerous species and stage exceeds 100. If a sample is dominated by small stages such that larger stages are eliminated by sub-sampling, the sample will be separated into several size fractions that will be analyzed separately. Adults of particularly abundant copepod taxa and those deemed to be useful in identifying coastal and oceanic waters will be identified to species. We also plan to evaluate the possibility of using image-analysis software to identify specific groups of zooplankton. The Cordell laboratory has extensive experience and accumulated expertise in identifying West Coast, oceanic, and ballast water copepods.

Enumeration of Culturable and Total Numbers of Bacteria

The number of bacteria can be enumerated by examining a filtered and stained sample under a microscope or by inoculating a variety of bacteriological media. For determining the total number of microorganisms, samples will be preserved using formaldehyde and concentrated by passing it through a membrane filter. The nucleic acid within the cells will be stained and the cells can be observed using an epifluorescent microscope.

For our ballast water research, culturable microorganisms will be enumerated on a media developed in our laboratory, called Marine R2A Agar. Aliquots of ballast water will be diluted and inoculated on the agar surface by the spread-plate method. After a 10-day incubation period at room temperature, colony-forming units will be counted. The advantage of this procedure is that it is easy to perform and it yields information about the number of microorganisms that are viable.

Enumeration of Representative Indicator Organisms and Pathogenic Bacteria

A large number of potentially pathogenic bacteria and viruses could be transported and contained in ballast water, including microorganisms that are associated with human fecal pollution. Fortunately, many of the potentially pathogenic bacteria and human viruses show a pattern of "die-off" when introduced in marine or estuarine waters. In our investigation, we will identify and enumerate representative indicator microorganisms, and marine or estuarine human pathogenic bacteria in ballast water. If ships exchange their ballast with mid-ocean water then these organisms should be at extremely low or undetectable concentrations in ballast water samples.

We will enumerate microbial groups that are indicator organisms for fecal contamination. These include fecal coliforms and enterococci. Ballast water samples will be concentrated on membrane filters and placed on standard bacteriological media that is routinely used by public health agencies. Human pathogens that could survive and proliferate in Puget Sound include *Vibrio cholerae* and *Vibrio parahaemolyticus*. *Vibrio parahaemolyticus* is a species that is already present in Puget Sound, and it is primarily associated with nearshore sites in southern Puget Sound during the warmer times of the year. The Herwig laboratory has conducted a study of the distribution of this organism in Puget Sound water, sediments, and oysters. *Vibrio parahaemolyticus* may cause problems for people who consume raw oysters that are harvested during the late summer. Only certain types of *V. cholerae* and *V. parahaemolyticus* cause disease, so we not only need to monitor for the presence of the species in ballast water, but also need to identify whether or not specific types or strains of the species are present. For example, it had been previously established that there was an endemic Gulf Coast strain of *V. cholerae* in the Gulf of Mexico. In the early 1990's, a new and more pathogenic strain of the organism was discovered, and there was evidence that it may have been introduced in ballast water.

Chemical and Physical Measures of Seawater Samples

The following chemical and physical parameters will be determined in samples collected from ship ballast: salinity, temperature, pH, oxygen, ammonia, nitrate, nitrite, phosphate, and dissolved organic carbon. Measurement of these components is relatively easy using portable equipment in some cases, or by collecting samples for those that require for analysis by a chemistry laboratory. The School of Oceanography at the University of Washington has a Chemistry Laboratory that provides routine service for the determination of these compounds.

Biochemical Measures of Living Biomass

Several different biochemical techniques have been developed in biological oceanography and microbial ecology to determine the biomass in an aquatic sample. For rapidly determining the effectiveness of ballast water treatment or the amounts of living biomass present in a particular ballast tank, a chemical method for analysis desirable. A biochemical marker that is present only in living organisms and that rapidly disappears or degrades in dead organisms would be ideal. Adenosine triphosphate (ATP) is the high-energy compound that is found in living microorganisms and higher organisms. The analysis of this compound has been performed by biologists for many years to determine living biomass. Upon the death of microorganisms and other organisms, ATP is converted to other phosphorylated compounds over time.

The analytical procedures to measure ATP begin with extracting the compound from the biological sample. For untreated and treated ballast water, aliquots of will be passed through a filter, and the ATP from the organisms that are collected on the filter will be extracted. Different sized filters can be used so the various biota within the sample can be fractionated by size or by its association with particulates.

Photosynthetic organisms will be monitored by measuring chlorophyll *a*. Filtered samples will be extracted with methanol and the quantity of chlorophyll *a* will be determined by measuring the fluorescence in the samples. We are requesting funds to purchase a fluorometer that can be used to measure chlorophyll.

In addition to the protocols described above, the Herwig laboratory is also evaluating other molecular or chemical based protocols that could be used to rapidly examine the composition of microbial communities in seawater samples. Table 1 outlines the protocols that we will use for evaluating ballast water exchange and for examining the contents of ballast water on ships that enter the state of Washington.

Table 5.3.1. Monitoring methods used to evaluate the composition of ballast water.

Chemical and physical methods	*Selected macrofaunal identification*
Temperature	Copepods
Salinity	
Nutrients	*Microbiological Methods*
Oxygen	Total direct count of bacteria
	Total culturable bacteria
Measures of living biomass	Indicator organisms
ATP	Selected pathogenic bacteria
Chlorophyll	
	Microbial Fingerprint
	T-RFLP analysis
	Fatty acid analysis

Mobile ballast water treatment demonstration project

The Port of Seattle is currently exploring the possibility of creating a mobile ballast water treatment prototype for testing. A portable treatment facility will make it possible for vessels without an on-board ballast water treatment system to have access to treatment as needed. The portability of the treatment facility will also make it available to small, outlying port areas at a reasonable cost. This will serve to meet the Washington State legislative mandate to develop methods of ballast water treatment that equalize the cost among large and small ports.

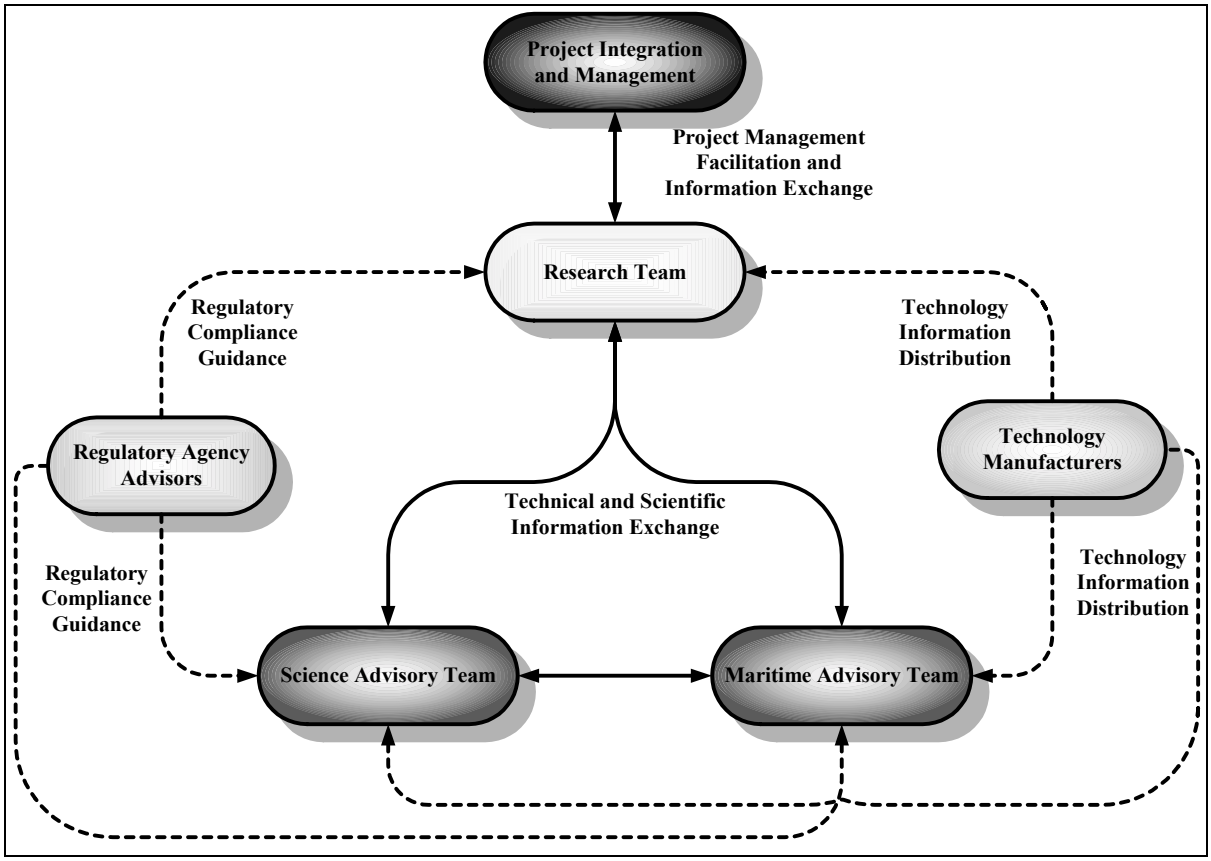

Figure 1: Project organization

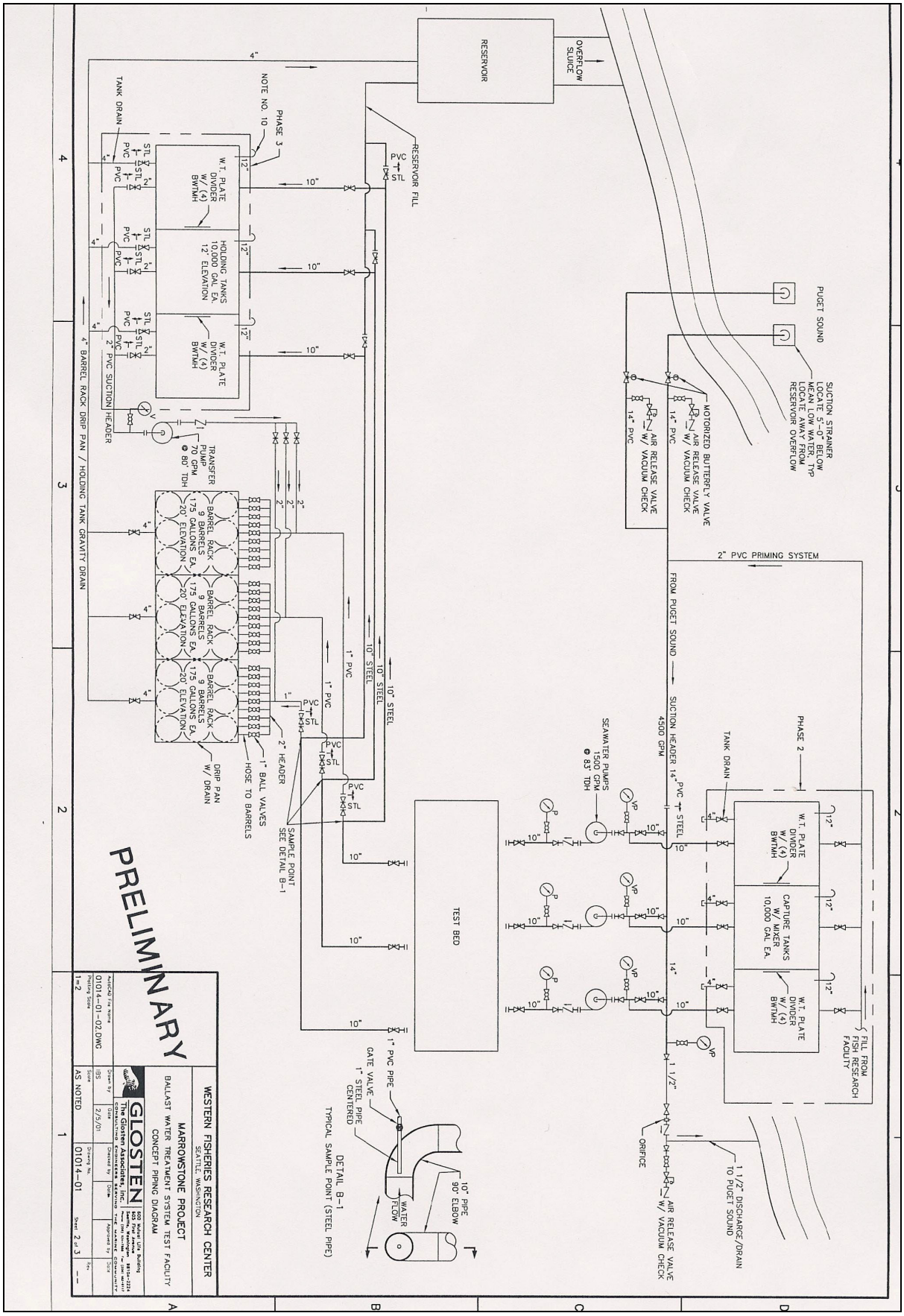

Figure 2: Preliminary Engineering Drawings for Marrowstone Facility

Simulations of Ballast Water Treatment

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1. Introduction

The transport of potentially harmful organisms in ballast water from country to country is undesirable and regulations (both statutory and voluntary) and guidelines have been produced to prevent this.

One of the most practical method of preventing carriage of these organisms is to exchange ballast water while in open ocean away from territorial waters. Ballast exchange is the most effective means of minimising the spread of unwanted organisms [1]. Indeed, current guidelines and legislation in its present form specify ballast exchange or quote it as a yardstick by which other methods are to be judged. Ballast exchange by emptying and refilling may however simple not be safe for reasons of stability and/or structural strength under certain conditions. Earlier published work from the University of Hertfordshire has focused on the modelling of Ballast water exchange [2,3].

Whilst ballast water exchange is an accepted method, there are conditions where other methods can be more appropriate. The additional methods considered were UV radiation and the use of separators.

If any method is to be used onboard a ship which must fulfill criteria as well as guidelines, then it must be proven that the design will be adequate. A system that works onboard one type or design of ship may not work as well onboard another ship design. A further question is how a system can be tuned to enhance or optimize its performance both in terms of installation cost, maintainance and operation. To solve such issues a traditional approach has been to use model tests. Such tests are however both time consuming and very costly an can not readily be used in conjunction with todays rapid design and building of modern ships. The modern alternative is the application of Computational Fluid Dynamics (CFD) to Ballast water treatment and exchange methods which is the subject of the present paper.

To indicate the type of savings that can be achieved, the provision of flow-through exchange in bulk carriers is relatively straightforward, although over 50% of the capital costs of ballast system modifications arise from the distribution pipe-work within the tank. Previous work suggests that this can be optimized from CFD studies [2].

The objective of this work is to demonstrate the efficacy of CFD as a design and analytical tool and also as a first step to establishing a general system design method.

2. Regulatory framework and guidelines

In the guidelines adopted by IMO member countries in 1997 as Assembly Resolution A868(20) each ship which carries ballast water should be provided with a Ballast Water Management Plan. This plan should address, inter alia, the relevant parts of the guidelines, approval documentation relating to any treatment equipment, an indication or records required, and the location of sampling points. The

records will include details of ballast uptake and discharge including date and time, geographical location, quantities, salinity and specific gravity.

The guidelines also include requirements for port States concerning reception facilities for sediments and the provision of information on the uptake of ballast water in their area.

Operationally; uptake, treatment and discharge of ballast water and sediments is to be in accordance with the guidelines, although enforcement and monitoring procedures by port States are required to recognise the overall effect of ballast water and sediment discharge on the safety of ships. Port States should not, of course, require any action of the Master that imperils ship safety.

In November 1996 the United States passed the National Invasive Species Act, which requires that vessels entering US waters from outside the 200 mile Exclusive Economic Zone must exchange their ballast water before entering the EEZ. The procedure is initially voluntary, but would become mandatory after two years if compliance were deemed to be insufficient.

In addition to the present international guidelines contained in M 1533, MCA has issued M Notices 1532 and 1662 which reproduce the guidelines promulgated by Australia, New Zealand and Israel concerning the control of ballast water discharges destined for their ports. The requirements of M 1532 in respect of Australia and New Zealand are similar to the international guidelines in M 1533, and Israel requires that a ship must exchange any ballast water not taken on board in open ocean. Ships visiting Eilat must exchange outside the Red Sea and those visiting Mediterranean ports must exchange in the Atlantic.

Several of the options described in the new Resolution A868(20) guidelines are straightforward statements of good practice but in many circumstances the choices available to an operator may be very restricted depending on technical and scientific advances.

Problem analysis and choice of simulation method

The main task of the design is to ensure that contaminated ballast water is flushed out during the voyage so that when the vessel arrives at the next port of call the level of contaminants is significantly below any level of concern or to have a system that separates or kills before entrance to ballast tanks. The contamination of a ballast water tank can be of two main types:

- Biological (particulate)
- Chemical

Provided that the particles are small with a density close to ballast water and that the chemical density in suspension is also close to water, then both cases can be considered as modelled by species transport. With diatoms considered as a representative contaminant these conditions are met.

The purpose of the present simulation work was to demonstrate the feasibility of the design. Despite this aim, it is important do ensure that the governing parameters are correctly modelled.

An examination of the problem and the scaling laws reveals that the governing equations are the general Conservation Laws (Conservation of Mass, Momentum and Energy).

In terms of the experimental modelling technique rapid dilution of the inlet stream means that the diffusion equation regarding the concentration of species may be considered de-coupled from the other governing equations. It can also be demonstrated that the kinetic energy term and the viscous dissipation terms in the energy equation can be neglected for typical flows of this type. If the Boussinesque approximation to the buoyancy term of the momentum equation is employed, it can be shown that for flow similarity between model and full scale it is necessary to have the identical Reynolds, Richardson and Prandtl numbers in both model and full scale. The Reynolds (Re) number is of course the ratio of inertia to viscous forces;

$$\mathrm{Re} = \frac{\rho U d}{\mu}$$

whilst the Richardson (Ri) number is the Buoyancy to Momentum ratio:

$$\mathrm{Ri} = \frac{g\frac{\Delta\rho}{\rho}d}{U^2}$$

and the Prandtl number (Pr), Schmidt number (Sc) and Lewis number (Le) are the ratios of viscous diffusion rate to thermal diffusion rate, viscous diffusion rate to mass diffusion rate and mass diffusion rate to thermal diffusion rate respectively;

$$\mathrm{Pr} = \frac{\nu}{\alpha} \quad ; \; \mathrm{Sc} = \frac{\nu}{D} \quad ; \quad \mathrm{Le} = \frac{D}{\alpha}$$

Furthermore, if the Prandtl and Schmidt numbers are identical the equations for energy conservation and diffusion becomes identical. Other significant dimensionless parameters can be shown to be the velocity ratio between the inlet and outlet as well as the momentum ratio.

In turbulent flows the Prandtl number may be interpreted as a ratio between diffusivities or eddy viscosities for mass and heat. Similarly the Schmidt number can be understood as a ratio between the diffusivities for matter and viscosity.

Due to the intense mixing in turbulent flows all these diffusivities are likely to depend on the eddy size of the turbulent motion or more specifically on the turbulent eddy structure. Therefore in turbulent flows the Prandtl number is equal to the Schmidt number and this gives identical equations for diffusion and energy conservation. The above fact permits many types of model flow simulation to be performed, but due to the scales involved in the present study there may be considerable problems as outlined below.

For ballast exchange the total volumetric flow rates due to pumping are small compared with the overall volume of the ballast tanks, the velocity in the tanks will be low and typically of a range between 0.025 and 0.05 m/s. Assuming water as the operating fluid and channel dimensions within the tanks of 2m this gives a characteristic Reynolds number of 50 to 100 000. Given that model scale the of a 52 m long tank is likely to be 1/50 it is clearly seen that the model Reynolds number based on the tank channels can easily fall below 1000. This means that even with roughened internal walls the flow is likely to become laminar. If the model flow is laminar or the possibility of re-laminarisation exists it is very difficult to use such results for full scale predictions. First of all the full scale flow is clearly going to be turbulent and this in itself means that the results from physical models can not be readily used. Furthermore due to the scaling considerations thermal or buoyancy effects can not readily be studied.

It is apparent that when conducting experiments under these conditions misleading interpretation of results can easily occur and it was therefore decided to employ the use of Computational Fluid Dynamics (CFD).

If modeling of separators are carried out, then another dimensionless parameter, the Dean number, should also be considered. The Dean number expresses the effect of curvature of a pipe and is usually given as:

$$Dn = \mathrm{Re}\sqrt{D/(2R)}$$

It is known that turbulence models are very sensitive to the Dean number. In the present work the so-called k-ε RNG turbulence model as well as the LVEL turbulence model due to Spalding were used. The first model is based on additional transport equations for turbulent kinetic energy and length scale

whilst the second model is algebraic and based around the concept of several turbulent mixing lengths. Both models are well documented and have been extensively tested by the CFD community.

Basic CFD theory

Computational Fluid Dynamics (CFD) is the numerical solutions to the governing equations of Heat and Mass transport using the Finite Difference, Finite Volume or Finite Element Method. The foundation of fluid dynamics is the governing equations of fluid flow. They are the mathematical expressions of the physical principles which fluid dynamics is based. Computational Fluid Dynamics is also based on these equations so it is important that the equations are clearly understood before CFD is applied to a problem. The physical principles are as follows:

- Conservation of mass.
- Conservation of momentum.
- Conservation of energy.

The resulting equations are a set of non-linear partial differential equations which have no analytical solution and consequently iterative numerical methods have to be used to solve the equations. The methods used have all their limitations and it is thus necessary to exercise caution when using these methods. However, the limitations and preferred application of certain methods are now well documented.

For many practical purposes the flow is turbulent as in the present case and a turbulence model has to be used. The turbulence models do not mimic the turbulent motions, but they model the effect of turbulence on the mean flow. Most practical models are based on time averaging on the Navier Stokes equations and there are a variety of models with a certain range of applicability.

CFD model designs

The ballast tank selected for this analysis is illustrated in Figure 1 and the separator is shown in Figure 2.

The ballast tank model was constructed using the CFD program PHOENICS and is shown on Figure 3. The model has all the dimensions of the full scale ballast tank, and all the partitions have been modelled as per the design drawings. The only exceptions are circular apertures which have been modelled as rectangular openings with total areas being the same in model and full scale. The surface of the model is assumed to have a surface roughness of 5mm which may not be an unreasonable value based on observations of such ballast tanks. The model is terminated at the 0.45m x 0.45m outlet duct. The total number of mesh points was 162 000 and the mesh density distribution was even apart from near surfaces where the mesh density was higher.

The second model, the model based on the separator was identical in all respects to the real separator. The total number of mesh points was 500 000, significantly larger than for the tank model due to the much larger velocity gradients and accelerations present in a separator (Figure 4).

3. Results

Separator results

The present results from the separator simulation are shown in terms of streamlines in Figures 6 and 7. Locations of inflow and outflow can be seen. It is also clearly shown that the highest ratio between radial and axial velocity is present in the upper part of the separator. Figure 7 shows that the speed of the fluid is higher near the bottom of the separator.

The results are based on a single fluid simulation. This type of simulations and corresponding results can be used for cases where the particles are comparatively small and follows the fluid motion. When the particles are larger then it may well be favorable to use two-phase modeling in order to track the larger particles. The results are in overall agreement with global experiments carried out on the separator.

Figure 8 shows the core physics behind this type of separator which is the vortex.

Ballast tank results

All models were used with the RNG based turbulence model. Since the purpose of the tests was to investigate the feasibility of the design, it was decided to first carry out the simulations using a steady state simulation method. This is equivalent to study what the flow would be as time becomes very large indeed, but it is a good way of studying feasibility of designs. If the flow and concentration levels are unsuitable at a very large time, then clearly the concept will not work for a low number of water exchanges and the method is thus a very good screening process. The simulations used the "hybrid" numerical scheme available in PHOENICS and convergence was assumed to take place at three decades.

A small part of the results are shown below:

Model No	Description	RNG Concentration %
1	Full size, distributed inlet, two outlets	9.8
2	Full size, distributed inlet and outlet	2.1

Model 2 had a distributed inlet and the maximum concentration level was near the top of the tank closer to the outlet, but the concentration level at this location is reduced to 2.1 %. Everywhere else the concentration level is reduced to close to zero. The result is shown in Figure 9.

A time dependent simulation was also carried out and it shows that it is necessary to carry out exchange of water for a considerable time and that in some instances the present proposals may be insufficient as far as number of exchanges is concerned.

UV ducting

Work has also been carried out in order to optimize the design of ducts around the UV sources so that the radiation to the water could be optimized and thereby decreasing outlet of contaminants.

4. Discussion

The results of the simulations illustrates quite clearly that the proposed methods are very good and will give acceptable concentration values. However, the use of CFD can be used with advantage to improve the designs.

An example is the ballast water steady state study which indicated that two inlets gave optimum results. This is a single result and may need further investigation and confirmation. However, on the assumption that it is representative, this finding shows the cost effectiveness of CFD analysis. Armstrong gave a total cost of £528,000 for the ballast exchange system for a 190,000 dwt bulk carrier of which £260,000 was for the distribution piping in the tanks. This suggests that a saving in excess of £200,000 may be achievable by relatively cheap CFD modelling. Against this one may have to consider the need to introduce scouring of tank surfaces to disturb sediment. Observations on *Ormond* and *Iron Whyalla* suggest that sedimentation is unlikely to be a problem on bulk carriers using deep-water ports.

Overall the objective of this and any future work is to produce a simple and cost effective design method for ballast exchange, separators and UV treatment. The work reported here shows this to be readily achievable

5. Conclusions

- CFD has been shown to be an effective analytical tool for the investigation of flow regimes during ballast exchange and the potential for the using CFD as a design tool has been established.
- The results obtained by analysis are broadly in line with full scale trials, giving confidence in CFD as a design tool.
- Steady state results indicate that previously proposed complex distribution pipe-work may not be necessary. This suggests potential cost savings in the region of £200,000 for a typical bulk carrier installation.

6. References

Armstrong, G., Rose, A. & Holdø, A.E. 1999. Institute of Marine Engineers, London

Armstrong, G. 1998. *Bulk Carrier Ballast System Design for Flow Through Exchange of Ballast Water*. RINA Conference May 1998.

International Maritime Organization 1999. *Harmful Organisms in Ballast Water.* IMO Publication MEPC 42/INF. 14

McLean, R.C. & Ivimey-Cook, W.R. 1951. *Text Book of Theoretical Botany.* Longmans, Green and Co.

Rigby, G. & Hallegraph, G. 1994. The transfer and control of marine organisms in shipping ballast water: behaviour of marine plankton and ballast water exchange trials on the M.V. *Iron Whyalla*. *J. Marine Env. Engg.*, Vol. 1, pp. 91-110.

Spalding, D.B. 1994, *Poster Session, International Heat Transfer Conference*, Institute of Chemical Engineers, London.

Spalding, D.B. 1996, *The Phoenics Encyclopedia*, Concentration, Heat and Momentum Ltd., London.

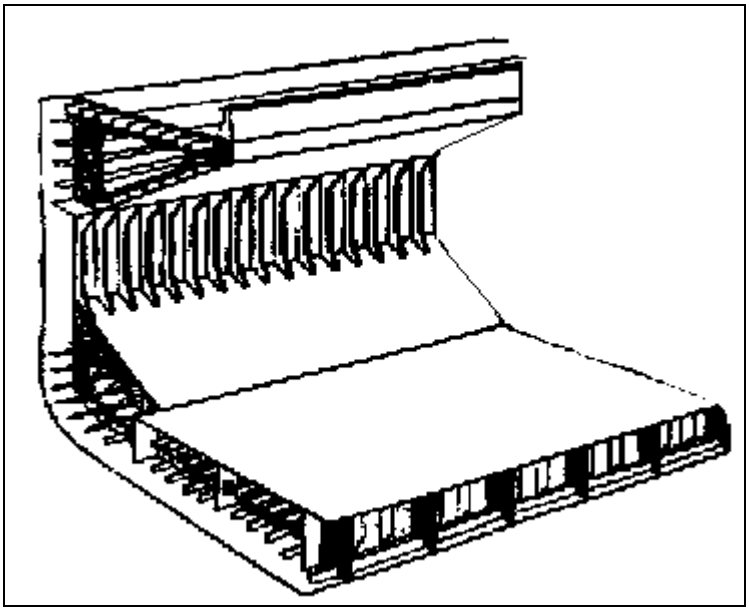

Figure 1: Typical Ballast Tank used for study.

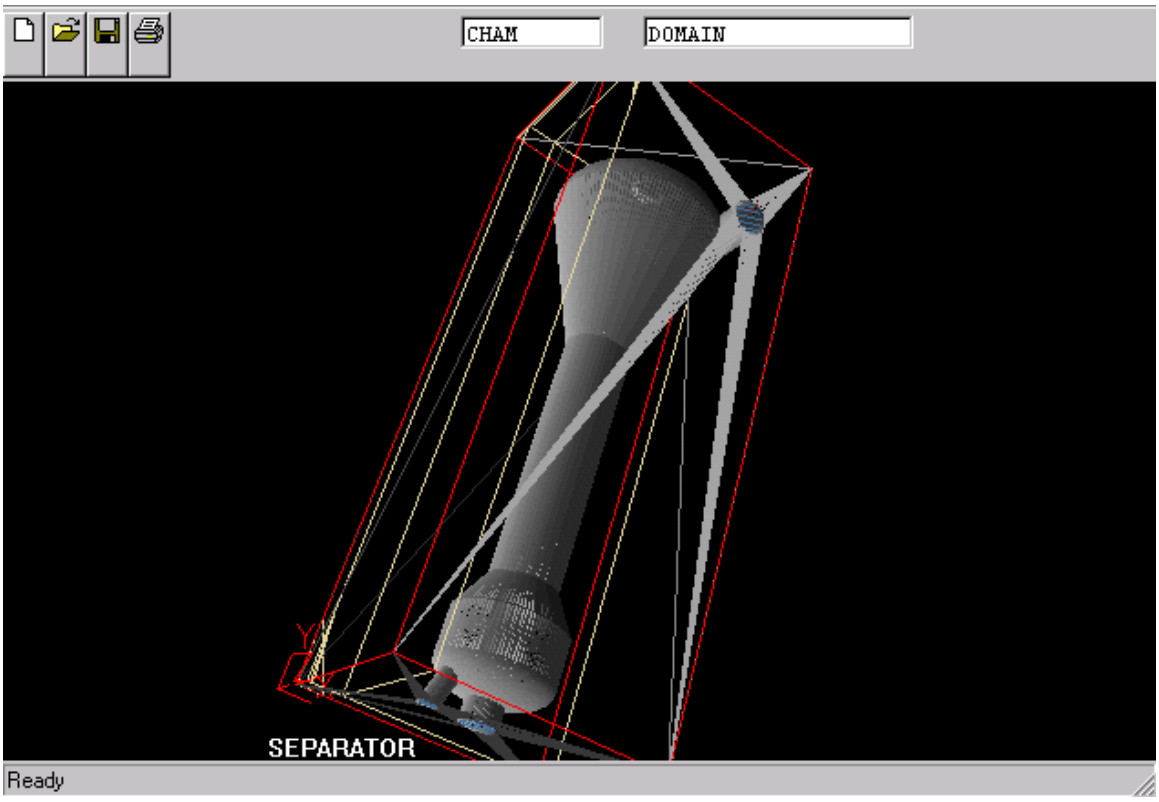

Figure 2: The Separator as a CFD model

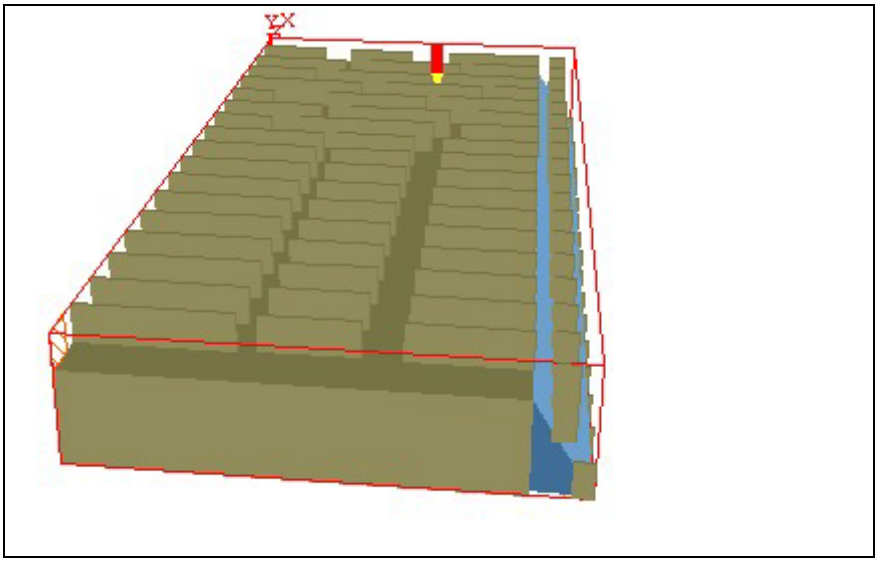

Figure 3: Model of Ballast tank

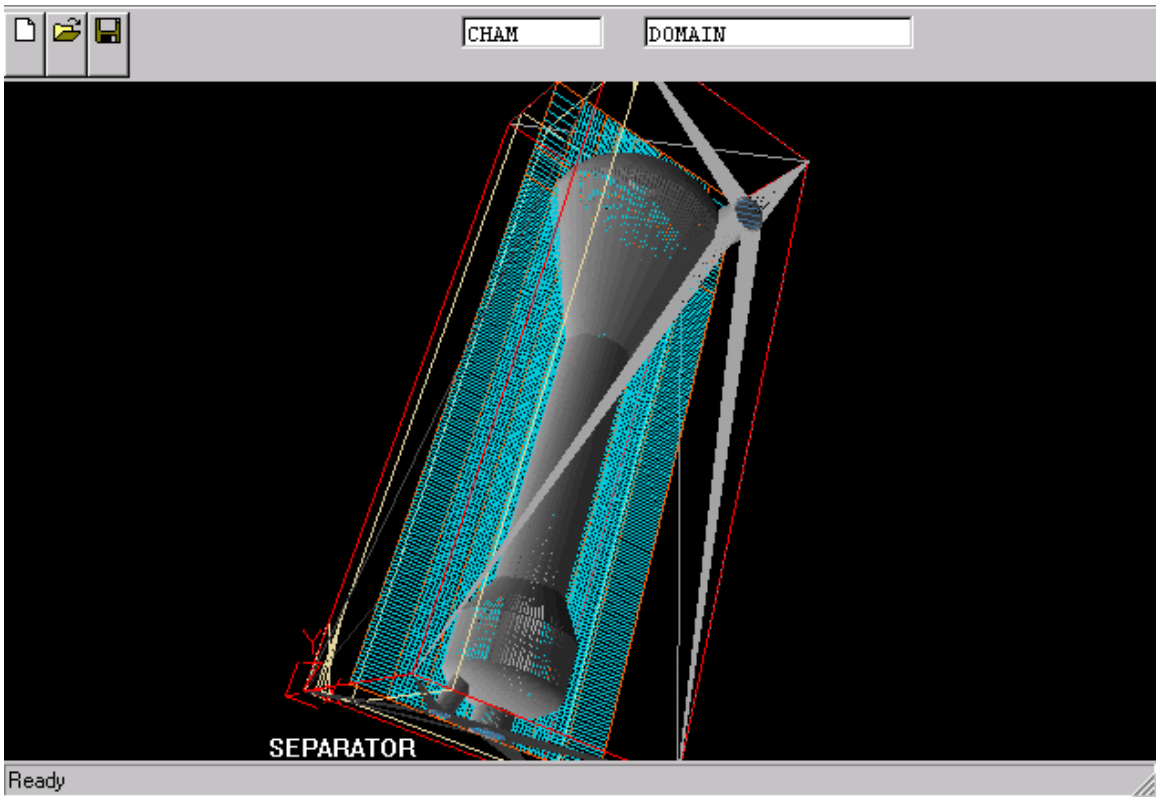

Figure 4: Mesh density and separator

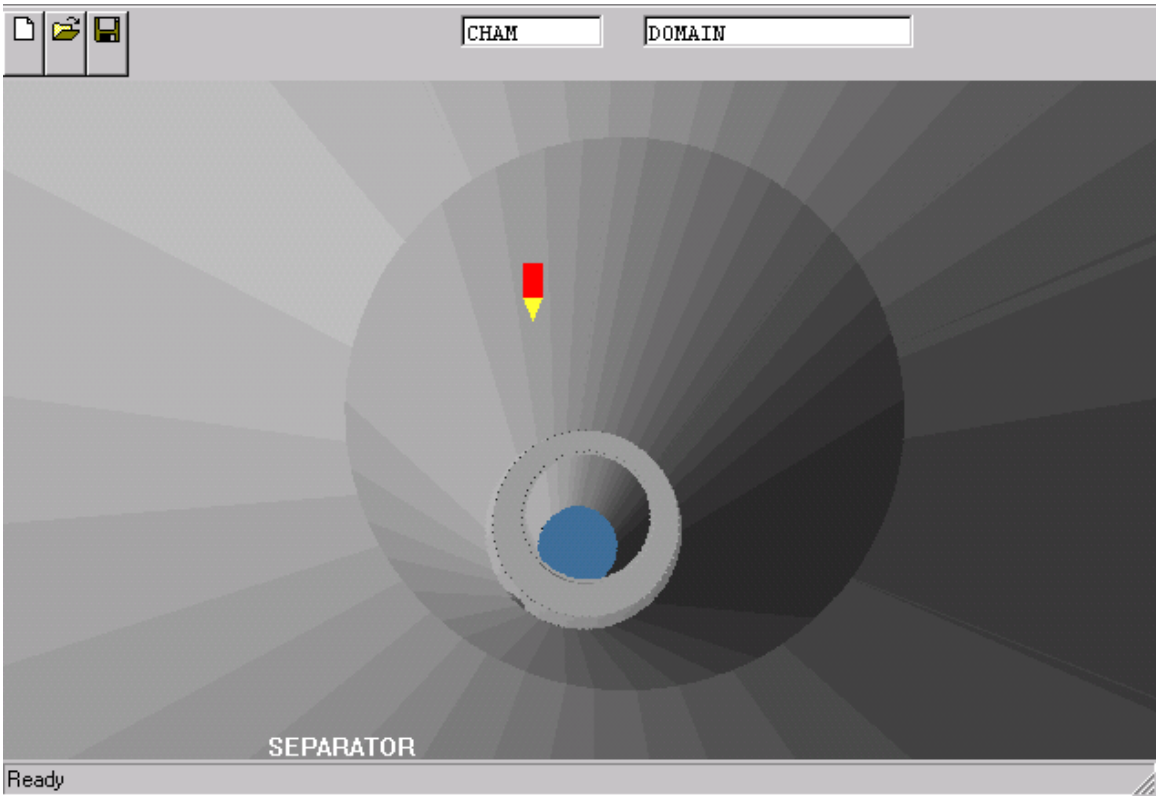

Figure 5: Inside view of separator.

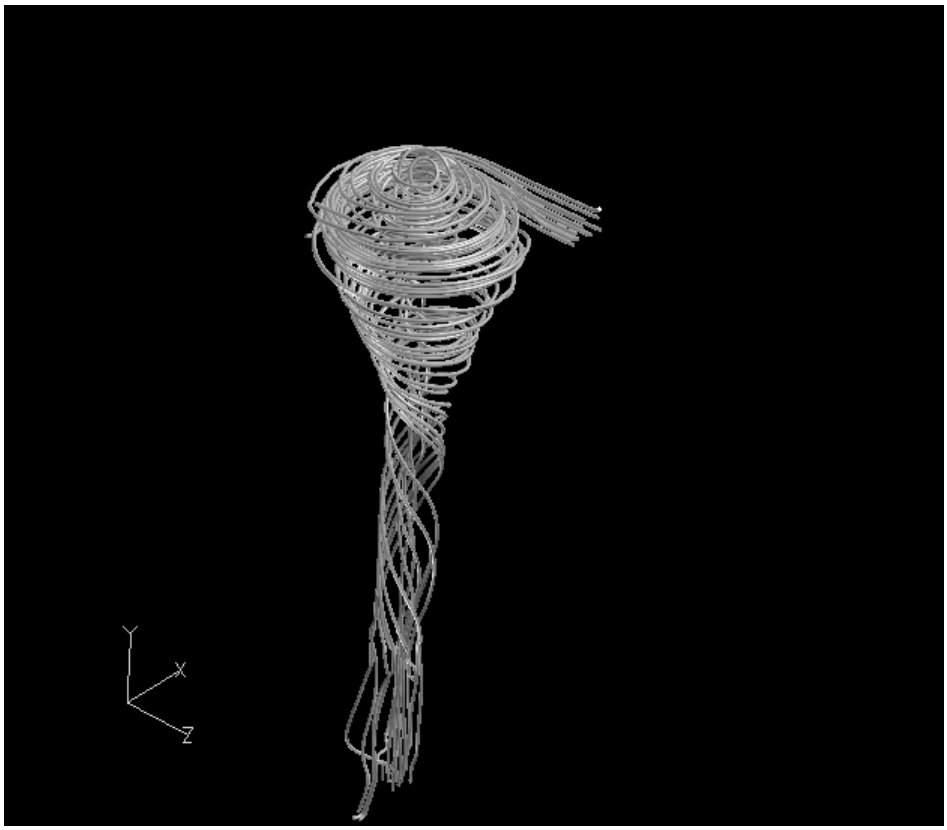

Figure 6: Flow in separator illustrated by streamlines.

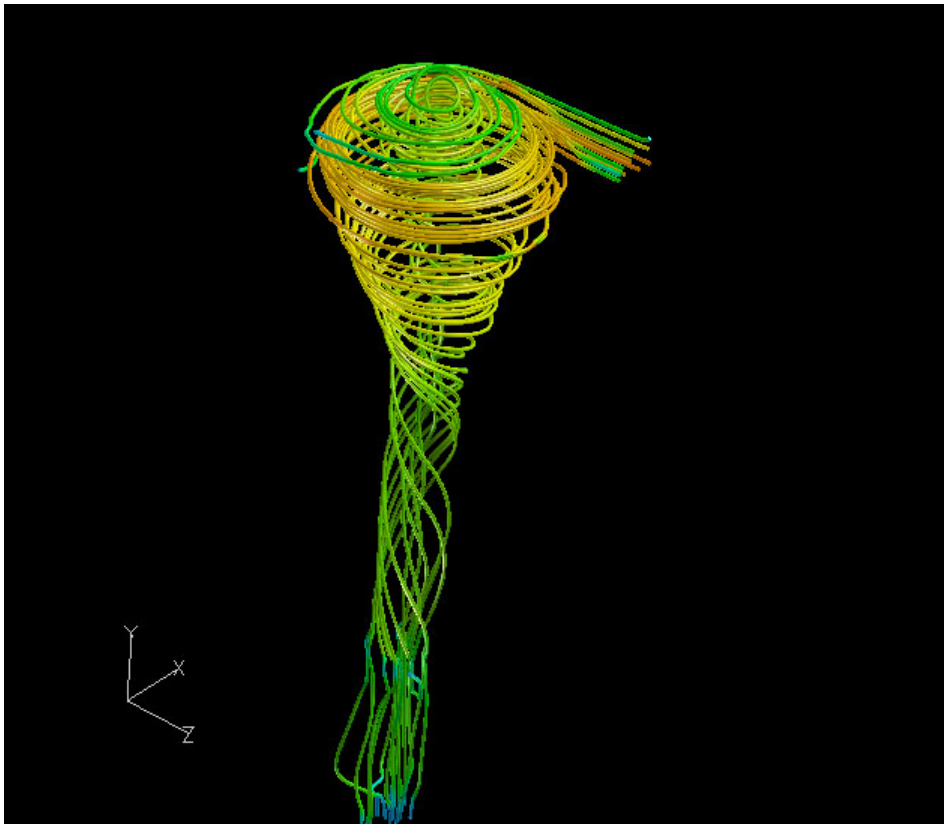

Figure 7: Streamlines coloured by peripheral speed.

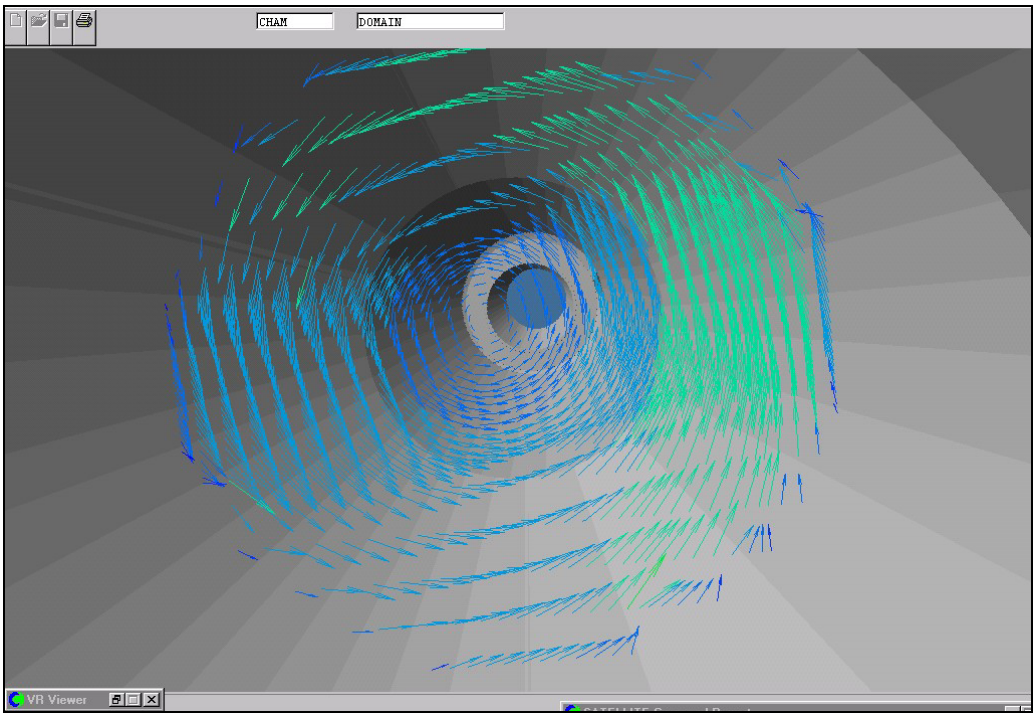

Figure 8: Vortex inside the separator illustrated using velocity vectors from CFD simulation.

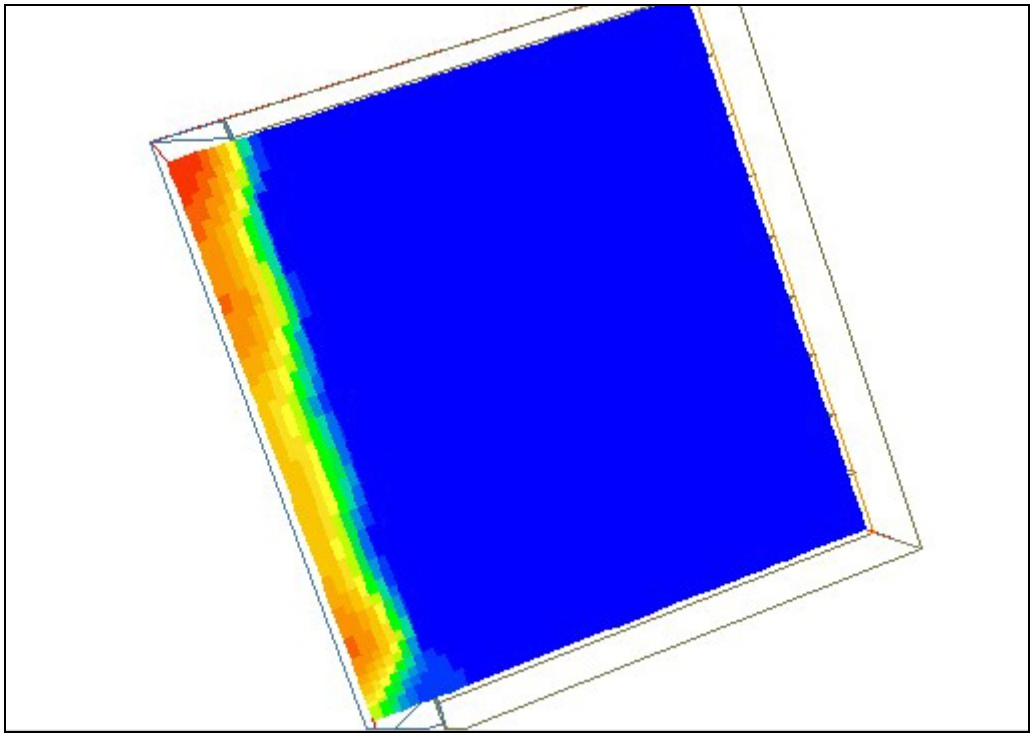

Figure 9: Concentration levels within tank.

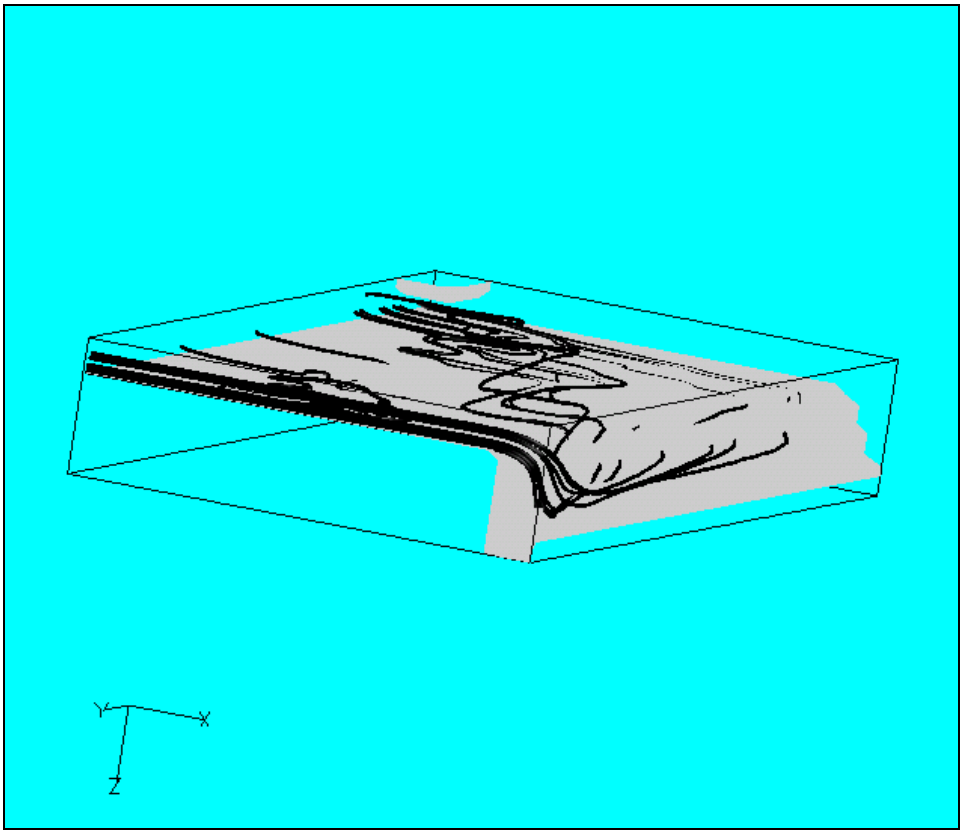

Figure 10: Particle traces inside tanks during second water exhange. Walls removed for better view.

Ballast System Design for Flow Through Exchange of Ballast Water

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1. Treatment options researched

Improved ballast water pumping and piping system to facilitate ballast water exchange by the flow-through method.

2. Conclusions and recommendations

Ballast water exchange and tank flushing

Ballast water exchange is the standard defined in the US National Invasive Species Act even though its effectiveness is not finally resolved. At present it is the best available treatment. Exchange by means of emptying and refilling tanks would be preferred but the guidelines recognise that this may not always be achievable due to considerations of stability, longitudinal stress limits, and the possibility of damage due to sloshing in partially filled tanks.

Rigby and Hallegraeff [1] examined the effects of ballast water exchange by emptying and refilling tanks on the hull structural shear forces and longitudinal bending moments of the 140,000 tonnes dwt bulk carrier *Iron Whyalla*. Under conditions in which one set of tanks (port and starboard double bottom and topside) are empty with all others full it is shown, for example, that the still water bending moment applied to the ship's structure can be as high as 163% of the maximum allowable. Peak structural stresses in rough weather would of course be greater. Additionally, as tanks further aft are emptied propeller immersion is reduced to a degree which is unacceptable.

This leads to consideration of the alternative of flushing the tanks with at least three times the tank volume, following the experimental results [1] on *Iron Whyalla*.

One of the series of trials conducted on *Iron Whyalla* was to examine the process of ballast water exchange. Methylene blue dye was added directly to the tank through three sampling tubes and a period of 20 hours allowed for dispersion. Samples were taken from the three points in the tank (see Fig 1): one inboard in the double bottom adjacent to the pipe tunnel (although the longitudinal position of this sampling point relative to the suction/discharge is not stated); a second in the double bottom outboard; and a third in the topside tank. For the purpose of the trials the tanks overflowed through a manhole access on deck.

The theoretical concentration of the dye in the tank during flushing was calculated assuming perfectly mixed conditions. No modifications were made to ballast tank internal pipework to improve water distribution and a comparison between the theoretical concentration and the concentration measured at the inboard point in the double bottom after the exchange of one double bottom tank volume (ie one residence time) showed a substantial 'short circuit' component (where less than ideal mixing takes place between the original ballast water and the incoming water). However, at the overflow the measured concentration was close to that predicted by the theory, assuming perfect mixing after one

residence time. However, without distribution pipework in the double bottom to promote mixing or details of the position of the sample tube in relation to the filling point there must have remained unflushed areas in the double bottom, although flushing of other areas of the tank appears to have been thorough.

Assuming perfectly mixed conditions, the efficiency of the exchange would be as shown in Table 1.

Table 1. Efficiency of Exchange due to Flushing

No. of tank volumes exchanged	Proportion of original ballast exchanged, %
0.5	39.3
1.0	63.2
2.0	86.5
3.0	95.0
4.0	98.2

Table 1 shows that after an exchange of three tank volumes 95% of the original ballast water has been exchanged, and this is the justification behind the requirement of 3 x tank volume in the IMO guidelines.

Ballast system design for flow-through exchange

A detailed design of a ballast system to permit continuous flow exchange of balllast water was investigated for the 190,000 dwt P&O bulk carrier *Ormond*, which trades between Europe, Brazil, Japan and Australia. The voyages from Europe to Brazil (14 days) and Japan to Australia (11-12 days) are ballast voyages.

Ballast tank capacities are given in Table 2.

Table 2. Ormond Ballast Tank Capacities

Tank	*Capacity*
F Peak	5376 m^3
No 1 P	2444 m^3
No 1 S	2444 m^3
No 2 P	6430 m^3
No 2 S	6430 m^3
No 3 P	6478 m^3
No 3 S	6478 m^3
No 4 P	6465 m^3
No 4 S	6465 m^3
No 5 P	4695 m^3
No 5 S	4693 m^3
Aft Peak	1170 m^3
TOTAL	59568 m^3

In additional to the ballast tank capacity in Table 2, No. 6 cargo hold, of capacity 21,811 m^3, is always filled when the ship is in ballast, giving a total ballast capacity of 81,379 m^3.

Exchange duration and cost

There are two ballast pumps, each with a capacity of 2.500 m^3/hr, and hence with one pump running, the duration of flushing to achieve 3 x tank volume is approx 4 days.This can be achieved within the 14 day Europe to Brazil and 11-12 day Japan to Australia ballast voyages.

The fuel cost arising from running the ballast pumps for this period of time is approximately $470, equivalent to 0.58 cents per tonne of ballast water.

System design

The port and starboard double bottom and upper hopper ballast tanks are shown schematically in Figure 1. The upper hopper tanks are permanently connected to the double bottom tanks by trunks at each end. *Ormond* is not fitted with a duct keel: the ballast main runs through the ballast tanks as shown. For continuous flushing purposes and to promote distribution in the double bottom it is proposed to fit an internal arrangement of pipework in order to provide a point of discharge between each solid floor. The diameter of this pipework has been calculated so that approximately equal flow rates are achieved at each discharge point. Such an arrangement merely minimises the risk of areas of stagnation in the tanks and the risk of sediment deposition. There is no intention to scour the tank surfaces with any impingement equivalent to crude oil washing. Bulk carriers which ballast in deep water ports are less likely to take on large quantities of harbour sediment, and the tanks of *Ormond* after ten years service were seen to be remarkably clear. A similar observation was made with respect to *Iron Whyalla*, [1], although P&O report that *Ormond* is not necessarily typical and ballast tank sediment is a significant problem in some ports.

From each distribution point flow is outboard and up into the hopper tanks, from where it is discharged overboard above the ballast water line through dedicated overboard connections. The height of the entry point to the discharge pipes within the tank is calculated so that the tank remains full with the flowrate of one ballast pump. Water is not discharged onto deck through the tank vent pipes. Lloyds Register have raised no objection in principle to the proposals, and confirmed that the overboard discharge valves would not be required to be non-return. The Rule-sized air pipes remain unchanged.

Discharge overboard and the supply to the internal distribution pipework in the double bottoms are controlled by remotely operated valves.

The arrangements for Number 6 cargo hold are different as no internal pipework can be fitted in a cargo hold, but there is of course no solid flooring to impede mixing as there is in a double bottom tank. This is shown in Figure 2. The water level is to be maintained just under the hatch, but the presence of steel structure inhibits access for pipework directly to the hatch coaming. Instead, the connection to the hold is taken into the adjacent hopper tanks, with the height of the right angle bend in the tank designed so that the water level in the cargo tank is maintained under the flow from one ballast pump. The highest part of the bend is fitted with a flushing connection in case of ingress of cargo.

The fore peak tank at 5376 m^3 contains a large proportion of the ballast total, and it is therefore proposed to fit internal pipework to facilitate mixing (Figure 3). Discharge pipework port and starboard is fitted in a similar arrangement to the ballast tanks.

In the after peak tank, which contains only 1170 m^3, the supply and discharge can be well spaced longitudinally and hence internal pipework to promote mixing would not be required (Figure 4).

The total additional weight of pipes and valves is estimated to be 42 tonnes if GRP is used for tank internal pipework, and 85 tonnes in the case of steel.

Ballast system additional costs

For ballast exchange on this vessel a GRP piping distribution system would be proposed in each tank, supplied through a 350 mm bore valve. Overboard discharges from each tank are through two 350 mm bore ship side valves with galvanised steel piping. All valves are remotely operated from a central control panel. Pipes are sized on the basis of the flowrate from one ballast pump.

1.	GRP distribution pipework in FP tank and ballast tanks, including installation	£260,000
2.	Overboard discharge pipework, including installation	£154,000
3.	23 shipside flanged butterfly valves	£80,500
4.	11 tank distribution wafer butterfly valves	£33,500
	Total, including valve actuation and remote operation	£528,000

These costs were calculated on the basis of retrofitting the system at European rates. The additional costs involved for the system when incorporated in a new build in the Far East are of course difficult to quantify, but would probably be less than £200,000.

Flow modelling

Half of the additional costs of a ballast system designed for flow-through exchange arises from the distribution pipework in the tank. Currently CFD studies are in progress [2] to examine in greater detail the flow regime in the tank, in order to optimise the amount and layout of the internal pipework.

Sandwich plate construction

A significant impediment to achieving adequate exchange and removal of sediment is of course the structural stiffening in the ballast tank itself. It would therefore be very beneficial if the structure could be simplified to provide an uninterrupted surface. Fortunately this possibility now exists due to the development of a sandwich plate construction by the Canadian Company Intelligent Engineering, in which a stiffened plate is formed by a metal-elastomer-metal sandwich. The use of this construction method in shipbuilding is approved by Lloyds Register [3], [4] and its application to ballast tanks looks very promising.

3. References

Holdø, A.E., Rose, A., Armstrong, G. 1999. An Analysis of Flow-Through Ballast Water Exchange, *Trans IMarE* Vol 111 Pt 2.

Lloyd's Register 2000. *A New Concept For a New Age – The Sandwich Plate System (SPS) for Shipbuilding*. Marine Bulletin Special Report.

Rigby, G. & Hallegraeff, G. 1994. The Transfer and Control of Harmful Marine Organisms in Shipping Ballast Water: Behaviour of Marine Plankton and Ballast Water Exchange Trials on the MV *Iron Whyalla. J. Marine Env. Engg.,* Vol 1, pp. 91-110.

www.ie-sps.com.

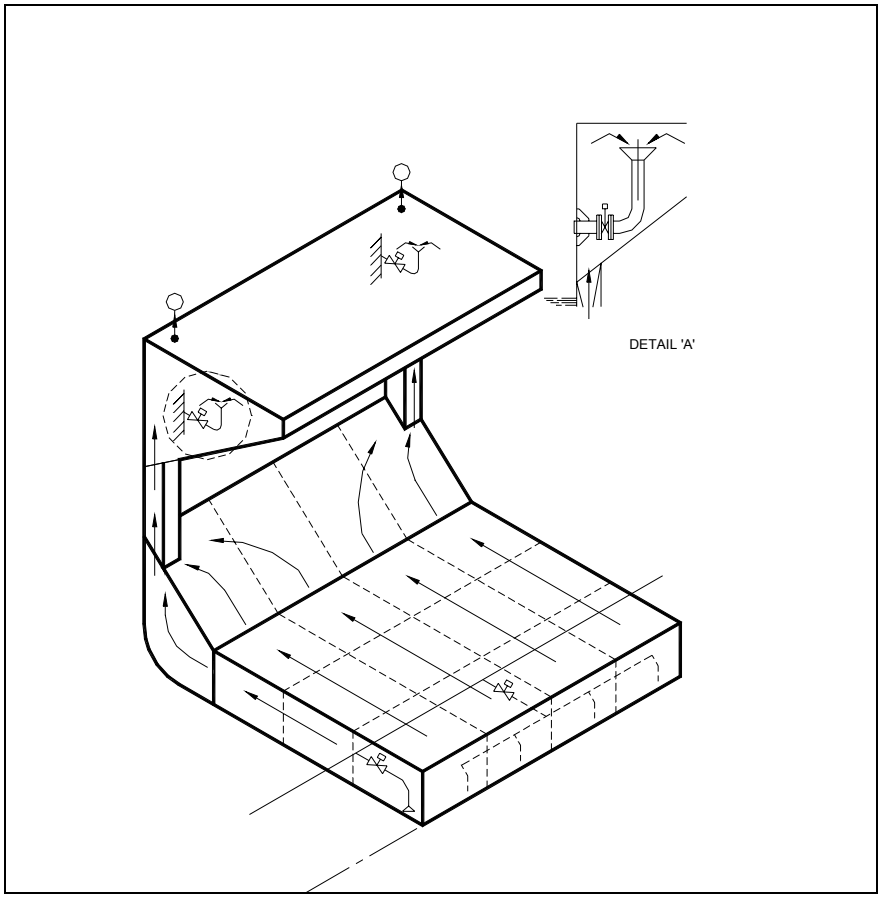

Fig. 1: Bulk carrier ballast system modifications

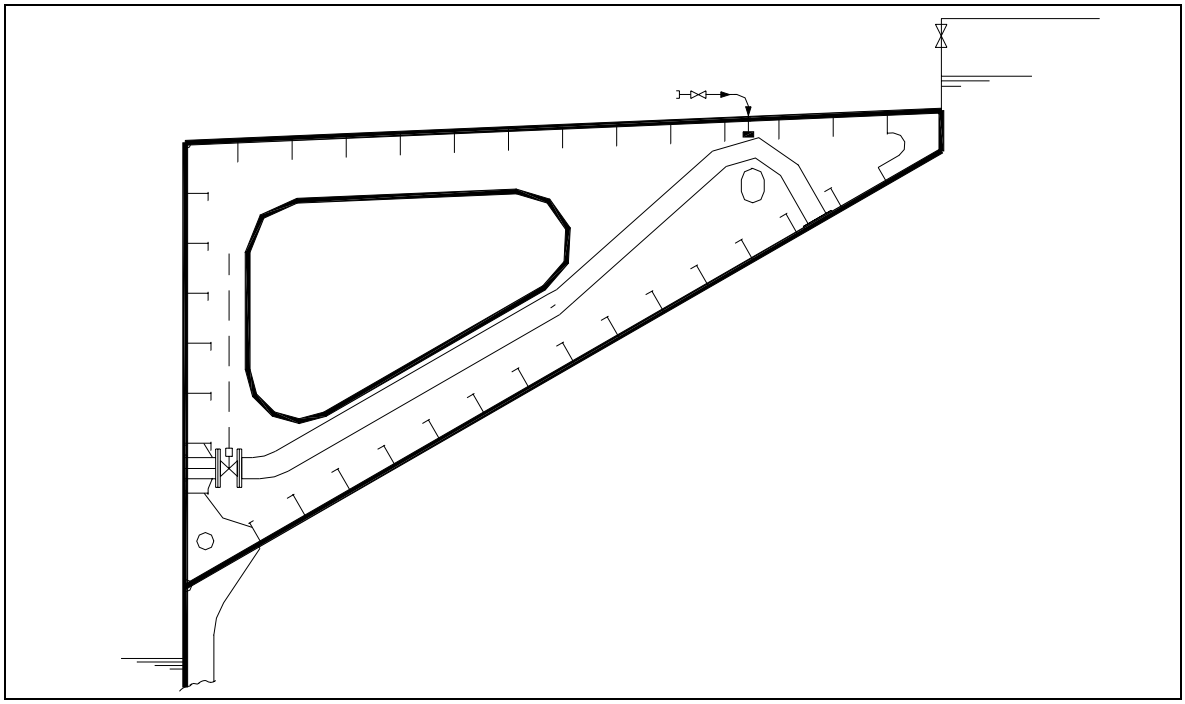

Figure 2: Cargo Hold Discharge

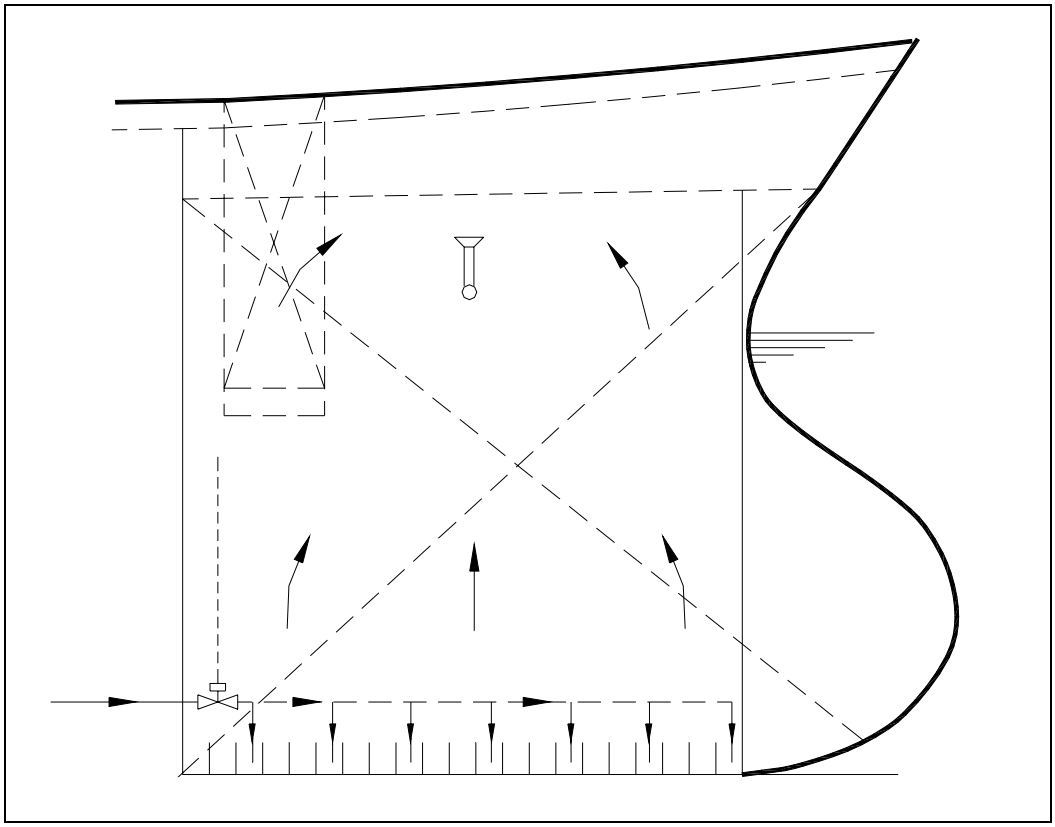

Fig. 3: Fore peak tank

Suggested Designs to Facilitate Improved Management and Treatment of Ballast Water on New and Existing Ships

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1. Treatment options researched

This review covers the use of all current published ballast water treatment options and looks at design enhancement to facilitate the minimisation of the risk of the introduction of harmful aquatic organisms and pathogens in ship's ballast water and sediment discharges.

2. Timeframe of project

The review covers work carried out by the current authors over many years that includes operational, repair, design and research work as well as recent work reported by other workers.

3. Aims and objectives of the project

The main objective of this work has been to suggest design, operational and maintenance procedures that can be considered by shipbuilders, owners and operators of ships that will facilitate improved management and treatment of ballast water on new and existing ships.

4. Research methods

The method employed was to look at the existing design of ships using best practice design aspects and operational experience related to sea chests, ballast tanks (especially strength, stability, water flow and minimisation of sediment accumulation), ballast pumps and pipework and chain lockers in relation to sediments. This in conjunction with a review of the precautionary practices, current treatment options relating to ballast water management and combined management strategies were used to develop the suggested designs, operational and maintenance procedures.

5. Results

(The results are summarised below and complete details are included in the published report, which will be available at the Symposium).

The adoption of many of the treatment and/or management options proposed as part of the new International Maritime Organisation ***International Instrument*** will require the retrofitting or

modification of existing pipework and/or equipment on existing ships to permit the new procedures to be put into practice in a safe, technically effective, environmentally acceptable, practical and cost effective way.

The background and design aspects of suggested management and treatment techniques as well as many of the ballast water and related design and operational concepts have been developed from ship design and experience over many years. Suggested designs to be considered in the design phase of new ships to minimise the build up of sediments and to allow the range of management and treatment options to be designed and utilised at the highest level of efficiencies have been presented.

Particular emphasis has been given to the significance and importance of the development of the Ballast Water Management Plan and the representative sampling of ballast water and sediments.

Ocean exchange of original ballast water forms the basis of ballast water control measures being utilised by several countries at present and is likely to continue as a preferred option for the near future. A review of the various options as well as a number of design suggestions aimed at providing flexibility and safety and making provision for use of one or more options has been presented. It is important to note that although ocean exchange is currently the most widely accepted treatment option, the generally accepted efficiency of water exchange (typically specified as 95%) means that substantial numbers of organisms may still be present in the water discharged in the receiving port and could constitute a significant threat to the receiving environment. The further development and adoption of new technologies that are capable of achieving higher efficiencies of removing or killing organisms will form an essential part of future ballast water management guidelines and practices.

Heating of ballast water using waste heat from the main engine cooling water system to kill or inactivate a range of harmful organisms has been demonstrated to be both environmentally attractive and cost effective in some cases. Relatively simple modifications to pipework as well as changes to the heating circuit involving some additional heat exchangers offers the potential of extending this technique to a wide range of ships and voyages. The potential for a high level of biological effectiveness of this option means that it may well become one of the preferable long term treatment technologies.

Although various chemicals can be quite effective in killing some organisms, it is likely that costs, practical and safety considerations and undesirable environmental effects will limit extensive use in ballast water treatment. However, there may be some special circumstances where chemicals might need to be used and appropriate design procedures to handle chemicals in a shipboard environment have been suggested.

Several other treatment options, including filtration, hydrocyclones, ultraviolet irradiation, oxygen deprivation and electrical shock have been suggested and are being demonstrated in some cases at practical capacities. However, at the current stage of development, only preliminary performance data is available and equipment design criteria is somewhat limited. Some typical design guidelines for filtration, hydrocyclones and ultraviolet irradiation have been included as a basis for preliminary designs.

The potential for use of fresh or recirculated process water, as well as the discharge of ballast water to shore based or a dedicated treatment ship facilities has been considered and design aspects to facilitate the provision of shipboard infrastructure to facilitate the handling and transfer of water has been discussed.

Best practice design aspects related to sea chests, ballast tanks (especially strength, water flow and minimisation of sediment accumulation), ballast pumps and pipework and chain lockers in relation to sediments have been reviewed and discussed in some detail to allow these concepts to be considered and implemented at the design phase, where appropriate.

6. Conclusions and recommendations

Although ballast water exchange together with a number of other management and treatment options currently under development have been suggested to miminse the translocation on nonindigenous organisms around the world, implementation of some of these on existing ships will be limited due to current operational and design limitations.

It will be possible to install and implement these new technologies and practices on new ships much more readily than existing ships since the appropriate modifications and new equipment can be considered at the design phase. Provisions for the modification/installation of new and improved treatment technologies as they are developed in the future can also be accommodated at the design phase by addressing the specific operating requirements and allowing space within the engine room or other suitable areas. In addition the costs involved will represent a minor additional cost of the new ship.

An essential part of any effective system will be the Ballast Water Management Plan. It is important that the BWMP be considered as part of the new ship design and that attention be given to ensure that appropriate communication and compliance systems are installed to facilitate the management requirements. When developing the BWMP ship owners and designers should consider the range of options available and make use of the most appropriate option(s) for the particular ship, based on voyage schedules and duration, ship operational requirements and country/port requirements.

Sampling of ballast water and/or sediments from ships is an important part of ongoing research, monitoring and compliance programmes. A range of design suggestions has been included to facilitate more effective sampling. In particular the need to obtain a representative sample of all the ballast water present on the ship (often from several sources) is addressed and a new sampling approach to facilitate this sampling has been suggested.

To improve the widespread use of the various forms of water exchange a number of design and management suggestions related to ease of operation and crew and ships' safety have been made. Specific design details for additional air pipes, tanker hatches, internal overflow pipes as well as suggested best design practices for pumps, valves, sea chests, strainers and ballast tank construction to improve flexibility, safety and effectiveness of water exchange have been included.

Heating of ballast water has been identified as one of the more promising treatment options for the future (especially for voyages involving approximately 10 days or more), based on both cost and effectiveness for killing removing/organisms. A number of suggestions involving flushing with hot water from the ship's main engine as well as alternative designs utilising additional heat exchangers, steam injection and optimisation of engine cooling circuits to facilitate more widespread applicability have been examined. Application of heating to inactivate organisms contained in sediments is also addressed.

Although widespread use of chemicals is expected to be very limited, however safety and operational requirements for their use is discussed for instances where such treatment may be appropriate.

Some typical design guidelines for filtration, hydrocyclones and ultraviolet irradiation have been included as a basis for preliminary designs, although specific requirements will need to be developed for these technologies as performance data and equipment components are identified from current and future demonstration trials.

Several design aspects related to the use of fresh or recirculated process water, as well as the discharge of ballast water to shore based or a dedicated treatment ship facilities have been included.

There are many design aspects associated with new ships that will enhance the ability to carry out appropriate ballast water management and treatment. As an aid to identifying the most practical and cost effective system(s) and developing the BWMP for a particular ship, it is recommended that a New Ship Design Check List be developed as a basis for reviewing the various options at the design phase. This List would contain suggested design features to be considered for each aspect of

management and treatment and would be best developed after review of the design criteria suggested in this report.

7. References

(A detailed list of other references is included in the full report, which will be available at the Symposium)

Rigby, G.R. and A.H. Taylor. 2000. *Suggested Designs to Facilitate Improved Management and Treatment of Ballast Water on New and Existing Ships*. AQIS Ballast Water Research Series Report.

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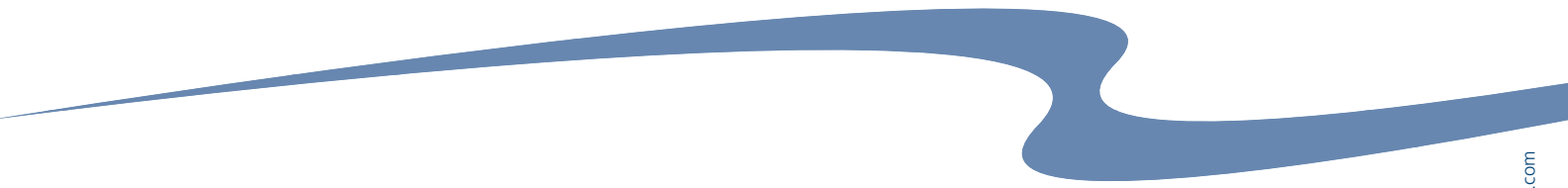

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