Emerging Ballast Water Management Systems

Proceedings of
the IMO-WMU Research
and Development Forum
26–29 January 2010
Malmö, Sweden

Edited by
Neil Bellefontaine
Fredrik Haag
Olof Lindén
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PROCEEDINGS OF THE
IMO-WMU RESEARCH AND DEVELOPMENT FORUM

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A GLOBALLAST-GLOBAL INDUSTRY ALLIANCE
AND WORLD MARITIME UNIVERSITY INITIATIVE

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Neil Bellefontaine
Fredrik Haag
Olof Lindén
Jose Matheickal

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and the Global Industry Alliance

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Acknowledgements

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Our very special thanks to the WMU President Björn Kjerfve, and Dr. Jose Matheickal, Chief Technical Adviser of the IMO GloBallast Programme for their welcoming addresses; and we are also indebted to Mr. Miguel Palomares, Director of IMO's Marine Environment Division for his closing remarks to the Forum.

In particular, we would like to thank the International Scientific Advisory Committee that aided into selecting topics and papers for the Forum; and of course, thank to all of those twenty-five expert presenters for their addresses, presentations and interventions in the discussions, as well as for their knowledgeable contributions of papers for publication in these proceedings.

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A special acknowledgement must go to the GIA and the GloBallast Partnerships Programme of the IMO for their initiative in recognizing the possibilities for this Forum towards enhancing the momentum of the discussion on ballast water treatment and management systems.

Neil Bellefontaine and Olof Lindén
World Maritime University

April, 2010

Foreword

A jointly sponsored Global International Forum on Research and Development on Ballast Water Management Systems (the R&D Forum) was held at the initiative of the GEF-UNDP-IMO GloBallast Partnerships Programme, the Global Industry Alliance (GIA) and the World Maritime University (WMU). The R&D Forum was held in Malmö, Sweden from January 27 to 29, 2010. In conjunction with the Forum, three different workshops and conferences were held over the course of seven days from January 24 to 30, 2010. The four events were hosted by WMU. The Forum was attended by more than 250 participants representing technology developers, the maritime industry, academia, a number of national governments and international and regional agencies from around the world and was considered a major success by forum participants.

The first ever Global Expert Forum on Ballast Water Test Facility Harmonization was held on January 24–25th, discussing the latest technology-testing approaches and the need for harmonization. The intent of this expert forum was to harmonize the methodology for testing of ballast water treatment systems as required under the Ballast Water Management Convention (the International Convention for the Control and Management of Ship's Ballast Water and Sediments) adopted at IMO in 2004.

The Pre-Conference Workshop on January 26th focussed on issues related to establishing a strong scientific basis for proving equivalency with BW treatment systems under the IMO BWM Convention's Guidelines G8 and G9, in terms of protecting the marine environment, human health, property and natural resources. The Pre-conference Workshop also discussed critical questions relating to testing, monitoring and verification.

The R&D Forum itself covered a breadth of topics that focussed on the various ballast water treatment and management options, innovative technologies for treating ballast water on ships and related issues such as shore reception facilities, sediment management, and the regulatory, technical and environmental challenges facing the ballast water technology manufacturers and the shipping industry.

Twenty-five speakers presented their papers over three plenary sessions that covered – (1) Technical and Regulatory Aspects of Emerging Ballast Water Management Concepts, (2) Progress on Conventional Ballast Water Treatment Systems, and (3) Updates on Testing, Verification and the Monitoring of Ballast Water. There were very informative presentations followed by wide-ranging and active discussions during both the plenary and panel sessions that also addressed such issues as IMO's technology approval process, the challenge to meet the IMO Convention standards and progress made by the Global Industry Alliance (GIA). These sessions also highlighted several of the more than 25 emerging ballast water treatment technologies being developed by manufacturers, the non-ballast ship conceptual developments, risk assessment frameworks, the linkages to hull fouling, invasive species costs and impacts, and finally, the need for capacity building in ballast water management in developing nations.

The Forum noted the progress made thus far, with 7 BWT systems having received their Type Approval certificates from Administrations, and 3 more awaiting certification. Meanwhile, 17 more are already in the approval review pipeline and may be expected to enter the market shortly. Discussions also addressed onshore ballast water treatment and the possible need for a legal brief to IMO's Marine Environmental Protection Committee on the onshore facilities, ship owners/operators legal liability concerns, particularly for the large tanker and LNG fleets. Several key global challenges for the future were also identified and discussed; including the challenge to harmonize the administration of national BW regulatory regimes and their policing and port state control systems to support greater clarity of BW rules for the world's shipping industry. Similarly, the discussion focused on technical issues dealing with the oil tanker fleet (8,000+ ships), BWT system designs for existing engine rooms, and practical technical solutions for several existing and suggested treatments. While recognising and stressing the urgent need for action to prevent the transfer of harmful aquatic organisms and pathogens, the participants also pointed to the fact that ship owners and operators are facing many other challenges including cost increases and other environmental challenges (e.g. air emissions).

The implications of the International Ballast Water Management Convention to the global maritime industry will certainly be profound. The objective of the IMO-GIA-WMU partnership to undertake this Global R&D Forum was to raise awareness of progress made on BWT thus far and to spur greater interest in the further development of emerging technologies. We believe we have successfully accomplished this goal. The presentations and papers presented and enclosed in this publication reflect the international interest in this issue which is of critical importance for the future of our marine environment. The socio-economic and ecological costs of marine aquatic invasions around the world are already very significant, and the need for immediate, precautionary action is apparent.

The challenges ahead are undoubtedly still many, not least due to the cross-sectoral nature of BWM. This is indeed a problem that cannot be solved in isolation. Regulatory frameworks, compliance monitoring and enforcement are all linked to the technical solutions one way or another. There is, therefore, a pressing need for innovative BWM options that are technically and financially feasible, that cater to the various needs of the shipping industry. No solution will fit all situations; different solutions are needed for different ship-types, environmental conditions and voyage types. However, the BWM options must also be in harmony with the evolving regulatory frameworks at the global, regional and national levels.

We believe the maritime industry has come far in recent years towards finding effective solutions to address the ballast water management issue, and it is extremely encouraging to note the open and constructive dialogue that characterised the meetings during the week in Malmö. The main message from the Forum was that technological hurdles should not be an excuse anymore to delay the implementation of the BWM convention as several technologies are currently available and many more are in the pipeline. The technology development community should be congratulated for rising to such a formidable technical challenge posed by the ballast water issues and the signals from the Forum strongly suggest that the pace of innovation will only continue to increase to benefit the maritime community. We are optimistic that this 2010 Global R&D Forum on Emerging Ballast Water Management Systems has made a positive contribution towards maintaining the global momentum to find optimal solutions to diminish the threats from marine invasive species.

Neil Bellefontaine and Olof Lindén
World Maritime University
Malmö, Sweden

Jose Matheickal and Fredrik Haag
International Maritime Organization
London, United Kingdom

IMO-WMU Global R&D Forum on Emerging Ballast Water Management Systems

Björn Kjerfve
PRESIDENT, WORLD MARITIME UNIVERSITY

Ladies and gentlemen, together with the International Maritime Organization, I would like to welcome you to the Global R&D Forum on Ballast Water Management Systems on behalf of the World Maritime University (WMU). I have had the pleasure to serve as the President of WMU for 8 months and have come to recognize the important role that WMU plays globally in maritime post-graduate education and research and in maritime capacity building.

WMU was established by IMO in 1982 to focus on safety and environmental aspects of shipping and to build maritime capacity – now 27 years later, the university collaborates actively with IMO on many contemporary maritime and societal issues. WMU's main focus has been to offer a 14-month program, taught in English, leading to M.Sc. degrees in Marine Affairs in six specializations; WMU also offers an incipient Ph.D. program in Maritime Administration and, together with Swedish and UK partners, in Maritime Law.

The annual M.Sc. student intake is close to 100 in Malmö and up to an additional 80 students annually in Dalian and Shanghai in China. To date, WMU has graduated 2,855 M.Sc. and diploma students and 2 Ph.D. students from 158 countries – the first 2 of many future Ph.D. students graduated this past October.

WMU is supported financially by the Swedish Government, many other governments, the Nippon and Ocean Policy Research foundations of Japan, other non-governmental organizations and industry; WMU is also supported in spirit by the maritime community – governmental and non-governmental – in all the 169 IMO member countries for whom WMU serves as a global resource in maritime capacity building and expertise. As is the case for many institutions of higher learning, sustainable financing remains a challenge and contributions are always welcome.

Management of ship ballast water is a research topic of major maritime and environmental importance. Ballast water management is, in fact, one of the most important environmental issues facing the shipping industry today. Ship ballast water is a culprit in the spread of invasive species. Invasive species in marine and coastal environments are a threat to biodiversity and productivity of the marine ecosystem. Invasive species – even in very remote coastal areas – are now seemingly the norm rather than the exception. As examples, in the North Sea, more than 300 new invasive species have been identified, and in the Baltic Sea, more than 200. Invasive species serve as a major threat to the further expansion of the marine aquaculture industry, and methods to control the spreading of invasive species is, should be, and must be a maritime priority.

Ballast water exchange is the preferred method for effective management to reduce the risk of ballast-mediated invasions. As you are fully aware, ballast water exchange involves replacing coastal water with open-ocean water during a sea voyage. This process reduces the density of coastal organisms in ballast tanks that may be able to invade a recipient port, replacing them with oceanic organisms with a lower probability of survival in nearshore waters. Nevertheless, ballast water exchange is not a guarantee, as ocean currents and wind and wave dispersion may carry unwanted organisms from oceanic to shallow areas, where they may start a new invasion.

WMU is a partner in the EU-supported Ballast Water Opportunity project, and ballast water management systems are indeed one topic of keen research interest at WMU. Other research at WMU is focused on marine piracy, and also on climate change impact on economy, societies, and environment, in both Arctic and tropical environments. Two years ago, we organized a major Climate Change Conference here in Malmö, and next, we are considering organizing a conference on marine/maritime piracy.

In conclusion, the Ballast Water Convention is likely to be adopted, perhaps already this year. I note that our host country, Sweden, has already ratified the Convention, and it is my understanding that a number of other countries are also prepared to sign the Convention. This, of course, puts an extra and not insignificant burden and cost on the shipping industry. The estimate is that at least 50,000 ships worldwide will need to install treatment systems for ballast water management and/or treatment.

I hope this Conference will help to bring some clarification on optimum techniques for ballast water management and point us in the direction of promising future research and development to minimize or eliminate the spread of invasive by maritime shipping.

I wish you welcome to Malmö and a stimulating Conference.

Thank you.

Summary of the 1st Global Expert Workshop on the Harmonization of Methodologies for Test Facilities of Ballast Water Management Systems

24–25 January 2010

There is an urgent need within the shipping industry for the development of cost-effective and environmentally friendly Ballast Water Management Systems (BWMSs). Driven by this need, the technology community has been actively developing various BWMSs to cater to the emerging ballast water technology market. Such systems are required to undergo various testing and approval processes, as per the International Convention on the Management of Ships' Ballast Water and Sediments (BWM Convention, 2004) and its Guidelines, including land-based testing under challenging conditions.

While several BWMSs are currently being developed or approved, testing among ballast water management system test facilities (TFs) around the world tends to be somewhat inconsistent and significant methodological and harmonization gaps remain. This incongruity has contributed to a certain level of confusion and lack of confidence among the technology developers as well as ship owners. It is imperative that end-users of such systems have confidence that reliable and consistent test methodologies are used, as the shipping community expects that a BWMS receiving Type Approval from one Administration will be accepted by all other Administrations at their respective ports irrespective of which facility was used to test the system.

Currently, there are more than 10 established TFs in different stages of development or operation and, therefore, with varied levels of experience in the testing process. Although the Guidelines under the Convention indicate the criteria that BWMSs must meet and do provide general guidance on testing methodologies, there is still no agreed-upon and harmonized view of how certain items required by the G8 Guidelines should be measured. During the 58th session of the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO), an informal meeting was held with representatives of several TFs, who confirmed the need for improved dialogue on technical issues. Indeed, this point was also noted by MEPC itself. Furthermore, during the recent 5th Annual Ballast Water Management Conference, held in London in December 2009, this topic was discussed in detail, and the GEF-UNDP-IMO GloBallast Partnerships Programme Coordination Unit (PCU) was requested to facilitate a dialogue among operators.

The Global Industry Alliance (GIA), being the end-users of BWMSs, identified the value of supporting this process, and took the decision to support the organization of a first Global Expert Workshop on the harmonization of methodologies among the existing TFs. A Correspondence Group including all test facility operators was consequently established, and participants worked together to identify possible outcomes. The intention of the workshop was to provide a neutral platform for discussions, while at the same time encourage an active and results-oriented dialogue. This approach should benefit the community of TF operators as well as the end users of the treatment technologies, by ensuring a reliable testing of treatment systems, and making information about the systems more comparable.

Structure of the Workshop

The workshop was held at World Maritime University (WMU), Malmö, Sweden, and facilitated by Dr. Stephan Gollasch, GoConsult, Hamburg, Germany. In total 29 participants from 9 countries attended the meeting (see Annex 1 for List of Participants). The only facilities absent were the National Institute for Oceanography, India (under development), Resource Ballast Technologies Ltd, South Africa, and the TF operators in China, who unfortunately were unable to attend.

The meeting was opened by Professor Olof Linden, WMU. Mr. Dandu Pughiuc, Head, Biosafety Section, IMO, thereafter addressed the Workshop and provided a background to the meeting, explaining how these efforts fits into the overall efforts of making BWMSs available to ensure a timely implementation of the BWM Convention.

The meeting took the form of a series of plenary sessions with presentations given by representatives from the TFs. Further, the chairman of the GESAMP Ballast Water Working Group and one participant of this GESAMP group were invited to give presentations addressing the Whole Effluent Tests (WET), required by IMO Guideline G9 (IMO, 2008) and implications that such a land-based WET test may have during tests of BWMSs according to Guideline G8 (IMO, 2008).

In the afternoon of Day 1 and on Day 2 breakout groups were formed to discuss urgent harmonization items and how to address them. Results of the discussion were later presented in a final plenary session. Finally, the participants considered the outcomes of all discussions at a concluding session of the workshop.

The Test Facilities

Developing test facilities in Denmark (DHI), India, Japan, Singapore (DHI) and South Africa as well as the facilities with experience in land-based tests of BWMSs, i.e., Korea (KORDI and KOMERI), Norway (NIVA), The Netherlands (NIOZ), and the USA (MERC, GSI, NRL) gave presentations at the workshop addressing the following topics:

- facility organization and funding,
- facility location and physical/biological conditions,
- facility infrastructure and testing team,
- overview of basic testing approaches and methods,
- testing completed to date, and
- key challenges to testing and priority areas for harmonization.

It became clear that the various test facilities considered during the workshop are in different stages of development. In addition to facilities with more experience running tests, other facilities are planning to start their services very soon, i.e., later in 2010. Further, as the description below illustrates, the test facilities operate in very different ways and with very different structures in terms of funding, etc. There are also differences in terms of the administrative process of certification tests and for overseeing of the test facilities.

Possible Harmonization Items

The facility representatives were asked to present a list of potential discussion items with the aim of stimulating a discussion of parameters requiring harmonization. After all presentations were given, the suggested harmonization items were quickly summarized and handed over to the breakout groups as a starting point for their discussions.

During the first session of the breakout discussion groups and subsequently of the plenary discussions, the following items where agreed as of high priority for harmonization:

- QA\QC\GLP
- Documentation
- Manipulation of test water
- Standardization of the sampling approach

All harmonization items identified by the test facility representatives are attached as Appendix 4. Due to time constraints, not all high-priority items could be addressed in the same level of detail, and the following section summarizes the workshop findings based upon further breakout group and plenary discussions.

Results of Discussions on TOP Priority Harmonization Items

QA\QC\GLP

The facilities agreed to make all Quality Assurance and Quality Control (QA\QC) as well Good Laboratory Practice (GLP) plans publicly available with the aim to evaluate practices and compare them among TFs. The QA\QC protocols should address all factors, i.e., water parameters, chemical, physical, biological and toxicological aspects, etc.

Documentation

The reporting format of G8 test results reports, which are written by test facilities for manufacturers to submit to Administrations, should be standardized. This standardization refers in particular to the parameters deemed necessary for inclusion for the non-confidential part of the reports (manufacturer's specifications, etc.). The documentation format may also be used for the submission to the IMO GISIS database, which is required by resolution MEPC.175(58),

Manipulation of test water

The views on manipulation of test water diverge. Facilities add abiotic material or organisms or both to the ambient water at least during some time of the year to meet the requirements set forth in G8, and the manner in which TFs do so differs (e.g., adding naturally occurring sediment vs. commercially purchased sediment). Subject to a manipulation, if necessary, may be physical factors (e.g., salinity, temperature, TSS), chemical factors (e.g., POC, DOC) and biological factors (e.g., organisms).

The group agreed that no manipulation of challenge water would be preferred, but it would be difficult to meet all G8 requirements at all times. It was strongly recommended that the manipulation must be kept to the minimum level possible, e.g., only adding physical, chemical, or biological constituents when the ambient water does not meet the challenge conditions for that parameter. In cases where a manipulation of the test water is essential, this should be done in the same fashion (methods, parameters, etc) during all tests of the treatment system under consideration at this site, i.e., throughout all tests.

Standardization of the sampling approach

Due to time constraints, sampling approach standardization aspects were only briefly discussed and it is hoped that this important harmonization item may be discussed at a future meeting.

Recommendations

During the concluding discussions the following recommendations regarding priority harmonization items were made:

- Compile and share QA\QC protocols of all facilities, in particular for biological aspects.
- Insure the integrity of datasets: TFs should send all test results (including unsuccessful or uncompleted tests) to the relevant Administration, and it will be up to the Administration to decide upon test validity and failure.
- Develop guidance for the evaluation whether or not challenge water conditions need to be manipulated and, if so desired, develop a strategy and methods for such a manipulation of the challenge water conditions to meet all G8 requirements, e.g. the minimum intake organism concentration, TSS content etc.
- Devise standardized reporting of (a) methods used and (b) test results to the Administration. Note that the G8 WET tests have implications also for the required G9 tests.
- Ensure that such a harmonization effort be continued and inform IMO member countries of the harmonization efforts through the IMO/GloBallast Secretariat as appropriate.

To achieve the above, the correspondence group will be continued and workshop participants volunteered to take the lead on specific action points.

Summary

For the first time, this Workshop brought representatives from almost all TFs of BWMSs together to exchange their approaches and share experience gained during the planning, construction, and operation of the facilities which was already considered as a great success. The need for test facility harmonization has also been expressed by the end-users of ballast water treatment technologies. Workshop participants agreed that such harmonization among TFs would send positive signals to the end-user community and would boost the confidence among this community as they prepare to install treatment technologies onboard ships.

It was clear to all participants that that a two-day workshop cannot result in a harmonized test procedure of all sites, as the work is very complex. It was concluded that the harmonization between TFs is essential and that future events are needed to agree on and address harmonization items. Consequently, an action plan was prepared (see above). The participants felt that the experience gained during tests of BWMSs may lead to proposals to amend, as appropriate, items in Guideline G8. It was therefore suggested that such possible amendments may be considered in the future.

All participants expressed their grateful thanks to the Global Industry Alliance and the GloBallast Partnerships for having made this workshop possible. GloBallast Partnerships will endeavour to support the further development of this harmonization initiative, and to keep the momentum, it will provide secretarial support as appropriate, e.g., continue to facilitate the correspondence group so an active exchange of views continues.

It was agreed by the workshop participants that a series of workshops will be needed to achieve the outstanding harmonization needs. A second ballast water treatment facility harmonization workshop (see action items) is planned to be held back-to-back with the 5th International Conference & Exhibition on Ballast Water Management (ICBWM) 2010 in November 2010 in Singapore.

Note: This is an abbreviated version of the full workshop report, compiled by the workshop facilitator Dr. Stephan Gollasch. The full report is available from the GloBallast Partnerships PCU.

Annex 1

List of Participants

Facility/Organization	Name	Country
Great Ships Initiative/Northeast-Midwest Institute	Allegra Cangelosi	USA
NIOZ	Cato C. Ten Hallers-Tjabbes Etienne Brutel de la Rivière Frank Fuhr Marcel Veldhuis	The Netherlands
DHI	Gitte I. Petersen Claus Jørgensen Kim Gustavson	Denmark
DHI Water & Environment (S) Pte Ltd	Martin Andersen	Singapore
Korea Marine Equipment Research Institute (KOMERI)	Young-Soo Kim	Republic of Korea
NIVA	Helge Liltved Sjur Tveite	Norway
KORDI	Kyoungsoon Shin Eun-Chan Kim	Republic of Korea
Naval Research Laboratory/SAIC	Lisa Drake Mia Steinberg	USA
Maritime Environmental Resource Center	Mario Tamburri	USA
Nippon Hakuyohin Kentei Kyokai	Yasunobu Araki Shinichi Maruta	Japan
Asian Natural Environmental Science Center, University of Tokyo	Yasuwo Fukuyo	Japan
GESAMP BWWG	Jan Linders Shinichi Hanayama Kitae Rhie	
Workshop facilitator/IMO consultant	Stephan Gollasch	
World Maritime University	Olof Linden Mia Hedin	
International Maritime Organization	Dandu Pughiuc Jose Matheickal Fredrik Haag Robert Macciochi	

Summary of the Pre-conference Workshop on Proving Equivalency between G8/G9 Approved Treatment Systems and Alternative Management Options

This summary was compiled by the pre-conference workshop facilitator Mr. Brian Elliott, EMSA, and the GloBallast Partnerships PCU.

Background

In the years following the 2004 adoption of the International Ballast Work Management Convention, various alternatives to the use of 'conventional' ballast water management systems and the consequent need for treatment to ensure tank discharges meet the D2 criteria have been proposed and studied.

These emerging alternatives to 'conventional' BW management include concepts and designs for 'ballast-less' ships; 'ballast-free' ships; 'ballast-thru'/'flow-thru' ships, and 'solid-ballast' ships. Indeed, Regulation B-3, paragraph 7 of the Convention predicts and allows for the development and future use of such alternatives. The workshop highlighted the inherent abilities of these alternatives to exceed or at least meet the Convention's requirements, with particular focus on designs that rely on the continuous flushing or flow-through of seawater to achieve trim and stability.

The expected outcome of the workshop was to identify key issues of concern that can be brought to the attention of the two main International Maritime Organization (IMO) fora, the Sub-committee on Bulk Liquids and Gases (BLG) and the Marine Environment Protection Committee (MEPC), in order to facilitate the implementation, ratification and bringing into force of the BWM Convention.

Objectives and Structure

The key aspects addressed during the workshop were:

- evaluating the emerging alternatives with respect to the present performance testing, type approval and monitoring requirements of the Convention and its G1–G14 Guidelines;

- determining equivalence with the Convention's D-2 performance standard for BW discharges and its sediment management requirements;
- assessing how ship operators and Port States can check that vessels releasing non-compartmentalized ballast are meeting the D2-equivalent performance standard/s during routine operations, cargo loading and in extraordinary circumstances.

The Pre-conference Workshop on proving equivalency between G8/G9 approved treatment systems and alternative management options was attended by approximately 65 participants from administrations, academia, technology developers and the maritime industry. The main focus of the workshop were the key critical questions related to establishing a scientific basis for proving equivalency with systems approved under Guidelines G8 and G9, in terms of providing protection to the environment, human health, property or resources (Regulation B-3, paragraph 7).

The participants were welcomed to meeting by Jose Matheickal, GloBallast Partnerships, IMO, who explained the rationale behind the meeting and why the Global Industry Alliance (GIA) saw the need to fund such an event. Dr. Matheickal's welcome address was followed by a series of technical presentations witch included the following:

Dandu Pughiuc, Biosafety Section, IMO, provided an overview of the BWM Convention and the provision for alternative management systems as per Regulation B-3, Paragraph 7.

Peilin Zhou, Dept. of Naval Architecture and Marine Engineering, University of Strathclyde, presented an overview of the available and emerging alternative systems, including no-ballast systems, flow through systems, partial ballast (increased buoyancy) systems and potable water systems.

Jan Linders, RIVM (National Institute for Public Health and the Environment), Netherlands, summarized the proposed draft procedure for approving other methods of ballast water management in accordance with regulation B-3.7 of the BWM Convention, as submitted to BLG 14 (document BLG 14/5/1).

Rob Hilliard, InterMarine Consulting, reported on the findings of an independent GIA/GloBallast study on options for establishing a scientific basis for equivalency.

The workshop was facilitated by **Brian Elliott**, European Maritime and Safety Agency (EMSA).

Summary of the Discussion

A thorough and in-depth discussion followed the presentations given at the start of the workshop. These ranged from specific issues on the design and equivalence of the specific technologies that were being discussed to the process being proposed in BLG 14/5/1, to generic issues on type approval, proving equivalence and the application of risk assessment.

One major issue in this discussion centered on the definition of the "same level of protection" and how this can be achieved. As the BWM Convention was negotiated a while ago, there was an apparent lack of understanding over how the D-2 Standard was achieved, how the new proposal arose and whether or not the same level of protection can be linked to the D-2 Standard. During the discussion the background to, and the issues raised during the development of these guidelines was outlined. In addition, the following issues were raised, most of which may need clarification in the new guidelines:

- Proving the same level of protection will be difficult because of the variation in technologies being developed.
- In any new guidelines, there will be a need to outline the background to the D-2 Standard and explain how the absolute standard adopted in Regulation D-2 could be compared to a relative measure of risk reduction to prove the same level of protection to the environment, etc.
- Why is there a focus on numbers i.e. 99.99% as an equivalent to the reduction caused by the D-2 Standard? Can other criteria be used?
- The absolute values for standards provided in Regulation D-2 may be convenient for administrations to relate to, in particular in terms of testing, verification and compliance monitoring. However, does this pose a constraint in bringing new concepts and ideas to address ballast water issues?
- If risk assessments are to be used in the approval of BWM systems, how can risk assessments be undertaken with no data? Theoretical versus practical proof – need for a prototype?
- Can the approval of alternative systems be done using a using a two-step process – basic, in-principle approval by MEPC based on theoretical/risk assessment models and final type approval by administrations after prototype trials?
- Should the guidelines provide specific risk assessment guidance for each type of system? The overall consensus of the meeting was that this would introduce a never-ending process where a new risk assessment procedure has to be developed for each new system. Discussions also focused on whether or not this is IMO's role or should it stay with the manufacturer?
- Can invasive species be used as a standard? The meeting agreed that this would undermine the BWM Convention. It would not be possible since there is a lack of information on the distribution of species in most parts of the world, and also

on what constitutes an invasive species. A species may be invasive in one place but not another.
- There is a link to the CO_2 debate that needs to be addressed. Alternative systems – as well as conventional systems – will need to be energy efficient in order not to substitute one environmental impact for another.
- How can consistency be achieved between Type Approvals issued by different administrations?
- Should the developers of each alternative system provide benchmarking for Port State Control and Type Approval/Certification?

Some specific issues that needs to be taken into consideration when discussing specific alternative management methods were also identified by the workshop.

For **flow-through systems**, the following issues were highlighted:

- Are these systems the D-1 standard under a different name?
- Can these be used in coastal waters?
- Would it provide same level of protection as D-2, if the ballast water inside tank is similar to the water outside (ambient)? How can this be verified?
- Would exchange with oceanic “blue water” reach D-2 standards? Does exchanging oceanic “blue water” pose no risks when discharged in coastal waters? Is there a need for data from actual trials to prove this?
- What happens to sedimentation and biofouling? How will the system be maintained?
- What happens to the water in the system when the vessel stops – will it leak and what risks does this pose?
- Is this ballast water? – does the definition of ballast water need to be adapted?

For **potable water systems** the discussion centered on the definition of ballast water and how it applies to potable water systems. Do these systems actually create ballast water? Can potable water tanks be classified as ballast water as they actually provide a ballast function? It should be noted that it only falls under the Convention if the ballast water is discharged to the marine environment.

There are also other issues with ballast water created onboard that may need further investigation, for example the use of active substances (e.g., chlorine and other disinfection by-products), and issues related to maintaining potable water quality onboard.

In summary, the pre-conference workshop served as a useful forum to initiate discussions regarding the applicability of the Convention to those systems that do not fall within the ‘traditional’ framework of BWM systems. The workshop was never intended to solve these issues, but provide a first stepping stone where the regulatory and technical issues and how they are linked together could be openly debated. This is a discussion that will by necessity need to continue in various other fora, but the issues identified in the pre-conference workshop will need attention as a matter of priority, to ensure that BWM solutions that are environmentally sound, technically feasible and financially viable, are available to the industry.

Ballast Water Management – An Overview of the Regulatory Process[1]

Dandu Pughiuc
INTERNATIONAL MARITIME ORGANIZATION

Continuing globalization with ever-increasing travel, trade and transport of goods across borders, has brought tremendous benefits to mankind. It has, however, also facilitated the spread of invasive species with escalating negative impacts. It is, therefore, not surprising that ships' ballast water management has become an issue of the highest priority for a wide group of stakeholders including IMO Member States, the shipping industry, environmentalists, technology developers and technology test facility operators.

Although the problem of invasive species on ships has been known for more than two hundred years, the attempt to regulate this issue on a global basis poses a number of challenges. During the last two decades the IMO has been working constantly to address, meet and respond to the challenges associated with ballast water management, initially through the development of two sets of guidelines and, more recently, by devising a new, legally-binding international instrument. The International Convention for the Control and Management of Ships' Ballast Water and Sediments, adopted in February 2004, has been ratified by 20 countries representing 20.93% of the world's merchant shipping capacity and, together with its associated guidelines, provide the much needed framework for developing an integrated-systems approach to ballast water management. It offers the critically-needed set of management tools through which the maritime industry can be regulated in a manner that is predictable and transparent. The Convention is centred on the precautionary approach principle and gives due consideration to the environmental benefits, technological achievability and, most importantly, to global standardization.

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[1] Views expressed in this paper are those of the author and should not be construed as necessarily reflecting the views of IMO or its Secretariat.

If, in the past, the lack of technologies and management options used to be a matter of concern for those contemplating the ratification of the BWM Convention, the recent surge in the development of groundbreaking ballast water treatment technologies has removed this last barrier in the implementation process. The shipping industry and the international community as a whole need to recognize that ballast water management options are currently available. Out of eight ballast water management systems that have received final approval by IMO, five have been certified for type approval by their national administrations and are readily available for use on board ships, while many more are currently under evaluation by the Organization.

The BWM Convention is a far reaching instrument and leaves the door open to new ideas. Regulation B-3.7 allows for alternatives to the ballast water exchange and treatment and calls for new and bold R&D initiatives, provided that certain conditions are met. This Forum offers an opportunity to discuss such new and creative solutions and agree on global criteria for the emerging alternatives.

The momentum precipitated by technology developers needs to be sustained and the wide ratification of the BWM Convention will provide the necessary guarantee that the effort will be rewarded by the shipping industry which will act decisively to address the issue of aquatic invasive species in ships' ballast waters.

The effectiveness and efficiency of maritime transport and, by extension, IMO's work, can have a major and direct impact on the global economy and environmental sustainability. The Organization remains, therefore, committed to reducing the negative impact of shipping's daily operations on the environment. Further, confirming the importance attached to aquatic invasions, the Marine Environment Protection Committee of IMO has initiated the development of international measures for minimizing the translocation of invasive species through bio-fouling of ships.

IMO will continue, through the Integrated Technical Co-operation Programme, to assist its members in their efforts towards implementation of effective measures to address aquatic invasions, however, all these efforts are futile without the most important ingredient, the determination of Member States. The international community needs vision, foresight, purpose and strength of will. All the stakeholders need to act now, pro-actively, positively and with due sense of responsibility in preserving our planet for the future generations.

BWM Hurdles and the Need for Innovative Approaches: An Industry Perspective

Captain Tey Yoh Huat

CHAIRMAN OF GLOBAL INDUSTRY ALLIANCE TASK FORCE & VP TECHNICAL SERVICES, APL

On behalf of Global Industry Alliance Task Force, I would like to thank World Maritime University and IMO-GloBallast for convening this very timely event. This event is also supported by the IMO-Global Industry Alliance as represented by BP Shipping, Vela Marine International, Daewoo and APL.

The world's growing concerns about greenhouse gas had taken the wind out of the ocean's waters. Lest we forget there is still a lot to be done if we are to prevent the degradation of the oceans and transfer of invasive species.

I am very honored to be given this opportunity to address such a distinguished audience and express the issues facing the marine industry. This I hope will help the developers, scientists and legislators appreciate the shipping community's dilemma in trying to cope with increasing demands imposed upon it.

Shipping is the mainstay of International trade moving almost 80% of the world's total goods. I firmly believe in the saying that without international shipping, half the world would freeze and the other half would starve. Without shipping, intercontinental trade, the bulk transport of raw materials and the import/export of affordable food and manufactured goods would not be possible. Shipping has a major significant impact to the wider global economy and a connection with the lives of just about every person on the planet.

The current financial crisis has clearly shown that recovery and future economic prosperity is dependent on trade which, in turn, is dependent on a safe and secure transport network. Shipping is central to this network, although it is rarely acknowledged as such, and seldom given the recognition that it deserved.

I am sure that the increasing efficiency of the sea transport and the trade liberalization will improve the future prospects of shipping as a mode of transport. Over the past 12 months, shipping has faced perhaps its greatest challenges and sailed into the "The Perfect Storm". The container shipping sector alone recorded losses of around US$20 billion in 2009. While there are some positive indicators, 2010 will remain highly challenging for shipping companies.

No-one can predict when recovery will occur and what form it will take. But if the industry's fortunes are not reversed soon it could negatively impact the investment decisions that shipowners make regarding marine equipment and technologies that can help companies reduce the impact of their operations and for the industry to achieve essential environmental goals. Their primary focus, at the moment, will be only on survival. However, our industry has proved over many years to be incredibly resilient and has a long history of introducing game-changing innovations. Therefore, I'm confident that shipowners along with the maritime equipment sector will ultimately be successful in navigating the treacherous waters we find ourselves in and addressing the great environmental challenges we face.

The current situation also highlights the timeliness and importance of this global forum on emerging ballast water management concepts. Some of these innovations could become cost effective management options to address the ballast water issues. But we must ensure that a number of multiplying factors do not hinder this growth of innovations in the future.

At the outset I would like to reiterate the fact that the shipping industry is committed to doing all it can, as quickly as it can, to address marine biosecurity issues in meaningful ways, which deliver a substantial net environmental benefit. However, even our best efforts will not be enough to achieve absolute protection due to the nature of the ballast water issue.

This leads to my second concern – the presumption that many new technologies could be rapidly introduced to meet legislative requirements – as the cost of non-compliance outweighs that of investment in research and development. History shows that such assumptions may not always work particularly well in shipping. The drivers that may hold true for land-based industries are not present in shipping industry for three main reasons;

1. First, government-sponsored research and development into improving shipping efficiencies is virtually non-existent.
2. Secondly, in the current market condition, investment in new technologies to meet specific environmental benefits for the ships often faces a heavy financial penalty.

3. Thirdly, and in simple terms, shipping may not have a winning formula whereby new technologies can be trialed on a fast track basis on many vessels that were made financially possible by an entirely different set of market conditions.

There is a particularly pertinent comparison here with the movement towards global supply chain security in the past decade. In the rush to comply with new regulations, many "technology solutions" were hastily rolled out before the various supply chain stakeholders could collaborate to try and fully understand the real nature of the challenges they faced.

As in the security arena, we must ensure that industry is not forced to accept expensive solutions that fail to adequately address the problem, and simply add significant friction and cost to the shipowners and their customers. The search and selection for the right solutions should be done in a measured way, by engaging both the public and private sectors through collaborative forums.

Six Key Areas of Focus

Ballast water management has become an issue of great interest to a wide group of stakeholders especially, IMO member States, the maritime industry, scientific community, technology developers, and technology test facility operators.

This Forum brings together experts representing these sectors, so I will focus on certain important needs, with a view that these sectors could continue to address.

1. An urgent need for a fully enforced global regulatory regime and global standards rather than the current patchwork of regulations and varying standards – All efforts are hollow and adds to the confusion among shipping industry without the most important step i.e., a global entry into force of the BWM Convention.
2. There exists a need for the availability of a large number of cost effective and proven technologies that are mature enough for widespread commercialization. The shipping industry needs to recognize that several ballast water management options are currently available, including ballast water exchange. The industry could start embracing these ballast water management options in order to meet the requirements of the BWM Convention in a phased timeframe. Bearing in mind that the first application date for the ballast water performance standards contained in regulation D-2 is fast approaching, and that by 2016 all ships will need to conduct ballast water management to comply with the Convention. The ship building industry also needs to join forces with ballast water technology developers to help shipping to meet these pressing challenges.
3. While there is a high need for sustaining the momentum by the technology development community, in developing ballast water treatment solutions, efforts should be accelerated at all levels to facilitate and encourage alternative or improved ballast water management options.

4. An urgent need for harmonization and cooperation among technology test-facility operators in order to boost the confidence among the shipowners who would potentially invest in these new technologies.
5. States which are dependent on large vessels for their economic growth should also consider providing shore-based ballast water management and treatment systems instead of waiting for implementation by individual vessels. It is in their interest to do so immediately to protect their local ecosystems.
6. An urgent and extremely high need for training of the seafaring community on various aspects of ballast water management.

As I mention earlier, it is not just about meeting legislation, we should bear in mind that with average global trade growth of about 7–8% per year since 1950 as reported by WTO, shipping will continue to grow at about the same rate, which means that it will double in the next 15 years. In 2004 a study had estimated that global shipping uses 3.5 billion tonnes of ballast water a year and by 2019 we will need to manage 7 billion tonnes of ballast water.

The current concept of management of ballast will need to change from that of killing living organisms in ballast water to one that will use radical ship designs that do not require ballast water. We do not want to solve a problem by creating a new problem. Eventually we will be eliminating huge volume of organisms in our oceans to a point where it will impact the biodiversity of our oceans and unwittingly damaging our ecosystem which we sought to protect.

Whilst the ballast water used is not so huge today, researchers and scientists should immediately start to consider alternatives to current solutions to handle the problem of migration of species.

Collaboration is Key

Because of the enormous engineering, technical, scientific, environmental, economic and social implications, the ballast water issue is far more complex than most of the other ship-based pollution threats that shipping industry has faced.

In order to meet these needs, it is crucial to recognize that the ballast water problem requires solutions that integrate biological and engineering aspects. Because these new solutions must integrate the ecosystem, the economy and regulatory aspects, it is no longer possible for biology and engineering disciplines to work independently, or independent of the industry.

What works in the laboratory may not work in the actual marine environment. Therefore, a fully integrated and collaborative approach by all stakeholders is a prerequisite to the development of creative and practical solutions to this issue.

GIA Public-Private Alliances

This leads to my next point – the role of public-private sector partnerships and the important global initiative by IMO and the private sector – namely the Global Industry Alliance for Marine Biosecurity. Such partnerships support the global efforts in meeting the critical areas highlighted before and the industry can also bring tremendous knowledge and expertise to the table.

The idea of establishing this Global Industry Alliance for Marine Biosecurity was first aired in 2005, during the IMO negotiations with the GEF on funding a second phase of the GloBallast Partnerships Project. The result was a pioneering and truly innovative partnership model between IMO and the global shipping industry. It aims to raise awareness of the role and importance of shipping and ports in the global economy; to develop innovative management options and tools to address the severe environmental, economic and public health impacts from invasive marine species; and to act as a catalyst to accelerate the many positive initiatives being carried out by the maritime industry.

Forging such a global alliance was an ambitious target, considering the complexity and technical nature of the issues. Nevertheless, the concept was soon embraced by all the founding partners including APL. The other founding partners are BP Shipping, Daewoo Ship Building & Marine Engineering and Vela Marine International, and I am delighted to see the representatives of these companies here today.

This innovative public-private sector partnership model is the first of its kind, and will assist in creating common solutions for addressing the ballast water issues, including new technologies, along with training and capacity-building activities to benefit the participating private sector companies.

The GIA will also publicize advances in technology development, and provide a global forum to share information and to facilitate communications between technology vendors, technology test facilities and end users of technologies. The GIA will also encourage and facilitate accelerated development and transfer of alternate ballast water management solutions that are cost effective, safe, practical and environmentally friendly.

Launch by IMO Secretary General and the GIA Team

The GIA is advised by a Global Industry Alliance Task Force (GIA-TF), consisting of the GIA partner companies. IMO acts as the fiduciary of the GIA Fund and GloBallast Partnerships PCU acts as the Secretariat for GIA-TF and also as the executing body for the activities supported by the GIA Fund.

Consequently, the GIA was launched by the Secretary General of IMO on 2 March 2009. The Task Force has since met three times to agree on a Terms of Reference, Rules of Procedures as well as the activities to be carried out in the first year of GIA using GIA Fund.

GIA: Initial Priorities

The GIA will initially focus it's activities in the following areas:

- Development of an information clearing-house mechanism for one-stop access by shipping industry; for example GIA is currently supporting an activity to develop a country profile database of the various requirements that any ship master can access to know the specific requirements in that particular port.
- Development of capacity building tools targeted at maritime industry; once again, GIA is currently funding a project that aims to develop an industry specific training package to meet the training needs within the industry.
- Co-organizing global conferences/symposia focusing on technology developments; This Forum is an excellent example how GIA is facilitating such information exchange with a view to encourage the much needed innovations.
- Activities that accelerate technology transfer and technology diffusion within industry.

Join the Global Industry Alliance

Whilst this is a groundbreaking development, it is really only the beginning of a potentially very large global partnership between regulatory bodies such as IMO and the regulated community such as shipping industry.

The GIA encourages any interested shipping industry members to explore joining this partnership as a matter of urgency. Personally, I am excited about this new initiative and the potential for very positive benefits to partners individually and to the global shipping industry in general. You can contact the GIA for at this Forum for more information on joining the alliance.

Treatment Technologies

With respect to treatment technologies there is an industry need to look for solutions without carrying the baggage and legacy that has plagued the maritime industry. There is no one solution to the problem that we face to meet the needs of all stakeholders.

While the challenges involved in finding appropriate engineering solutions for ballast water issues appeared to be very high, I would like to congratulate the technology development and scientific community gathered here today for rising to these challenges and making an impressive progress over the last few years.

A review by the IMO's MEPC aimed at assessing the status of technology developments had concluded in 2006 and 2007 that the variety of systems being tested on board ships have the potential to meet the criteria of safety, environmental accessibility and practicality and that it is reasonable to expect that ballast water management technologies and type-approved systems will be available by end of 2008.

I am extremely glad to note that you have proved this prediction true and we have six systems that have been type approved by their respective Administrations and four additional systems that have been granted Final Approval by the IMO and are likely to become available in 2010.While there is an impressive momentum gathered in technology developments, it should however be noted that an accurate comparison of these technologies is still difficult, especially from a ship owner point of view, due to the varying range of testing methodologies and procedures used by the technology developers.

Lack of an international guideline for approval of ballast water management systems was a major barrier to the development and commercialization of ballast water management technologies until two years ago. However, the IMO's Guidelines (G8 and G9) for approval of ballast water management systems are already proving to be a useful tool for removing this barrier. But wide-scale availability of the physical infrastructure to test such treatment technologies and to evaluate and approve the new ballast water treatment systems consistent with the international guidelines remains a major challenge.

While there are promising signals from pioneering initiatives in USA, Europe and Asia, more cooperative action among these initiatives is to be encouraged to ensure a common level of quality assurance and control. Also, inter-calibration procedures for test protocols should be encouraged to boost the confidence by the technology investors/users, such as the ship owners.

I am pleased to note that the GloBallast Partnerships with the support of GIA has facilitated a forum here a few days back that brought all the major test facility operators around the world to initiate an active dialogue with a view to establish such common protocols. Furthermore, I am confident that this will certainly boost the confidence level among the ship owner community and I would like to congratulate the IMO GloBallast PCU in catalyzing this dialogue.

Shipping is Crucial to Global Economy

Technology development efforts must take into account the absence of and need for standardized test data regarding the efficacy of ballast water treatment technologies applied to different geographic regions, the operational realities of maritime transportation, and the critical role that the maritime transportation industry plays in the world's economic prosperity. In our minds, we must also be clear of our intentions and goals that is to protect the marine environment and not just to satisfy the legal requirements.

In this context, the development of appropriate technologies to address this complex issue will continue to pose some challenges. I am confident that, as has already proven by the industry and the technology and R&D community, human ingenuity will overcome these technological challenges very soon, and the increasing number of shipboard installations of approved technologies is a clear indication of progress.

Looking at the agenda of this Forum it is exciting to see the new concepts that are emerging and I am very hopeful that several will mature fast and move to the application side very soon. Also GloBallast's private sector alliances such as the GIA and the expected outcomes from such alliances clearly send an optimistic message to the global community that, while the environmental challenges appear to be significant, they are not insurmountable. With the effective and intelligent use of resources and through an integrated and collaborative approach, answers to these challenges will be found, so that the industry can work in better harmony with the environment.

Conferences such as this provide a wonderful platform to bring the industry, technology developers and scientists together so that they can share and build on information, knowledge and new ideas for the greater good of all.

I would like to congratulate GloBallast and WMU for organizing this forum and on behalf of GIA I feel proud to be part of this global partnership in supporting this forum.

I wish you all a very fruitful discussion and dialogue in the coming two days.

Thank you.

Ballast Water Treatment Systems: "Old" and "New" Ones

Marcel Veldhuis*, Cato ten Hallers, Etienne Brutel de la Rivière, Frank Fuhr, Jan Finke, Peter Paul Steehouwer, Isabel van de Star and Cees van Sloote

Abstract
This paper offers an overview of the currently available Ballast Water Treatment systems, their efficacy in reducing the number of organisms in relation with the IMO and other, future standards, and explores potentially new and promising technologies and current gaps.

Key words: Ballast Water Treatment (BWT), Alien Invasive Organisms, IMO D2-Standard, Active Substances, UV-radiation

Introduction

Aquatic bioinvasion refers to the introduction of non indigenous organism(s) into another ecosystem. Once established in the new environment, introduced species can turn out to be a threat, resulting in an undesirable imbalances in the ecosystem. The Aquatic Invasive Species (AIS) are therefore serious threats to global biodiversity, resulting in habitat loss, economical damage and even threatening (human) health.

Shipping is the backbone of global economy and facilitates transportation of over 80% of the worlds commodities. The total amount of ballast water shipped across the globe is vast, 2–3 billion tonnes on an annuals basis, and the total number of ships is increasing as well as their size and speed. Translocation of aquatic organisms through ships is one of the main vectors in the exponential increase in the number of AIS since the 1800s, and invasive marine species are one of the greatest threats to the world's oceans.

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* Dr., Royal Netherlands Institute for Sea Research, Den Burg, TEXEL, the Netherlands.

In an attempt to reduce the spread of AIS by ships the International Maritime Organization (IMO), the United Nations Agency for shipping, is responsible for the international regulation of ship safety and the prevention of marine pollution, adopted the International Convention for the Control and Management of Ships Ballast Water and Sediments in 2004[1].

Despite the fact that as of 2010, the Convention has not yet been sufficiently ratified to enter into force, considerable effort is made by several administrations, industry stakeholders and research laboratories of joining forces in the development and testing of promising Ballast Water Treatment (BWT) technologies. One of such initiatives is the Ballast Water Opportunity programme, an ERDF programme of the seven countries bordering the North Sea (see www.NorthSeaBallast.eu for details).

From the start of the discussion on the ballast water issue it was clear that not all ships can or should meet the criteria as stated in the Convention. Moreover, are current BWT technologies, a universal solution for all ships or are there other promising technologies emerging offering a better solution of preventing the spread of AIS? This paper provides an overview of the present knowledge and practical experience the research team of the Royal Netherlands Institute for Sea has gained during the past six years during its collaboration with over 35 different companies and developers in the field of BWT technologies, but also with a variety of stake-holders (ship owners and port authorities). Based on the outcome of current research and discussions on future needs the following aspects will be addressed in this paper:

- Efficacy and availability of the current generation of certified BWT systems; do they meet the need or are they already old and outdated?
- Emerging BWT technologies; our hope for the future?
- Vessels with exceptional BW requirements; latest generation container carriers, tankers, bulk carriers, heavy-lift ships, floating docks, semi-submersible barges, dredging material such as trailing suction hopper dredgers, split hopper barges etc.

The Current Generation of BWT Systems

As of July 2009, eight BWT systems have been given IMO Final Approval for the use of active substances in the BWT system, six of those also received Type Approval by a national administration. In recent years a total of five full-scale BWT systems were tested at NIOZ for land-based performance and efficacy according to the IMO guidelines (G8 guidelines), using the turbid Wadden Sea inlet as the challenging water. The five tested BWT systems included three using active substances (AS), two of them based on a chlorine-related AS[1], one system using and organic

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[1] The Ecochlor system of the company Ecochlor (US), with in-line chlorine-dioxide production as active substance and the BalPure system of Severn Trent de Nora (US) with in-line made hypochlorite solution.

acid/H_2O_2 mixture[2] (PERACLEAN® Ocean) as active substance, and two systems equipped with a UV-reactor[3]. The D2-Standard of the IMO Ballast Water Management Convention is only defining a maximum number of viable organisms during discharge of the larger (i.e. > 50 micron in cell diameter) and smaller plankton in the 10 to 50 micron cell diameter size class, but entirely ignores the plankton smaller than 10 micron. The only exception made is for some indicator human pathogens. In a similar way, the Phase-2 standard of the USCG (which is a 1,000 fold stricter than the D2-Standard), is including standards for bacteria and viruses, but does also not define maximum allowed number for the phytoplankton component with a cell diameter of less than 10 micron. The ultimate aim of the Ballast Water Management Convention is to reduce the risk of new invasions of (all sorts) of non indigenous aquatic organisms. Current inventories demonstrate that potentially every species can become invasive and/or a nuisance, irrespective of size or its taxonomic group (bacteria, phytoplankton, zooplankton) in a new environment. If this happens, when, where and what the magnitude will be of its caused damage is entirely unpredictable and remains often a complete mystery. Therefore, to ensure maximum safety and a complete as possible insight in the performance of the different BWT systems all organisms will be included in studies conducted at the NIOZ land-based test site, irrespective of their size. This results in an evaluation ranging from virus to whales.

All five fully land-based tested BWT systems were equipped with a filter which reduces the number of all larger sized organisms, and to some extent also sediment (on average 30%). This primary physical step turned out to be crucial in the reduction of a whole series of extremely tough and hard to kill organisms (e.g. barnacle larvae, see also Fuhr et al this issue). Also the secondary treatment, either physical-based on UV-radiation or with the use of different active substances (AS), is a non-selective method since it affected all organisms passing the primary filtration step.

In general, it was observed that the efficacy of all five BWT systems was better than the IMO D2-Standard. The numerical abundance of the viable organisms as indicated in the BWM Convention but also the number of other (phyto)plankton declined substantially, often to nearly undectable values. One of the main challenges for the research team was to develop suitable methods for counting and addressing the cell viability of the biological component. As a result for the biological parameters multiple tools and methods were necessary to gain a legally sound and, therefore, accurate as possible estimate of the remaining number of organisms and their viability status. This was necessary because of the diversity of organisms present and

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[2] SEDNA system of the company Hamann (Germany), using PERACLEAN® Ocean as active substance.

[3] Hyde-Guardian system of Hyde Marine/Lamor (US and Finland), with a medium-pressure UV-reactor and OPS (Ocean Protection System) of Mahle NFV (Germany), with a low-pressure UV-reactor.

typical characteristics associated with the different life stages such as; eggs, cysts, resting stages, larvae and adults.

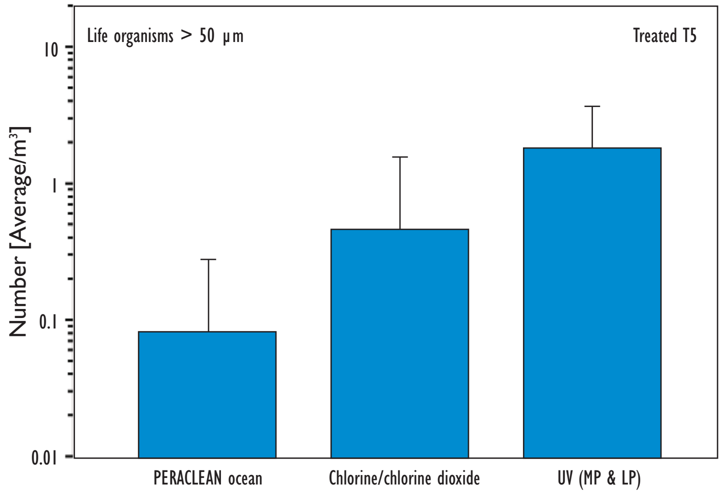

Figure 1. Average number of larger organisms (>50 micron in cell diameter) at discharge of 3 different types of BWT technologies during land-based testing

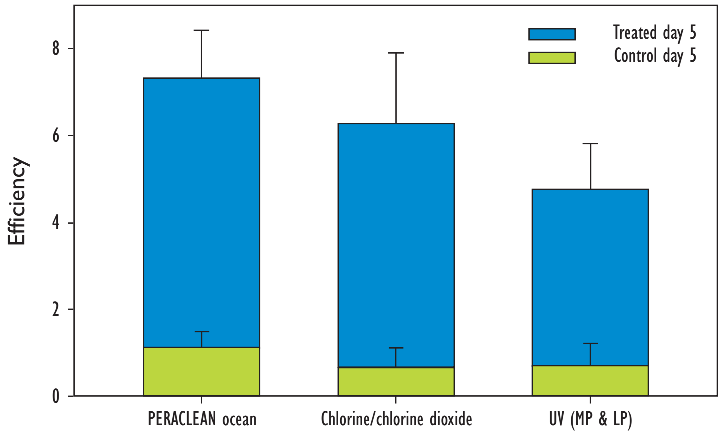

Figure 2. Efficiency of 3 different types of BWT technologies to remove larger sized organisms (> 50 micron in cell diameter) during land-based testing. Control and treated water sampled after 5 days during discharge

Using the larger than 50 micron in cell diameter organisms as a bench mark for inter comparison the remaining number of organisms at discharge was one order of magnitude lower than the D2-Standard of the IMO (see Figure 1). Also the efficiency, expressed as -log (intake/discharge), was very high (see Figure 2). Compared to the control (only pumping water in and out the holding tank, resembling a ballast water tank) the five BWT technologies were capable of reducing the number of organisms by 4 to 6 orders of magnitude. Moreover, the environmental impact of the discharged water was non-detectable and, therefore, all systems can be considered as environmentally friendly BWT technologies.

Although the discharge water tended to be devoid of organisms regrowth of bacteria and phytoplankton (mainly species smaller than 10 micron in cell diameter) was observed within a time span of 7 to 20 days[2]. In nearly all test series the numerical decline of viable organisms was accompanied by a reduction in total numbers as well, as the treatments often resulted in a full disintegration of the organisms.

Emerging BWT Technologies

The above indicated BWT technologies are all interpreting the reduction in risk of invasive species in eliminating the presence of ***all*** organisms (with exception of bacteria) to an acceptable but extremely low level. It should be noted that only full sterilization and sealing of the ballast water tanks will result in a 100% safe and organism-free ballast water. A single organism can, in potentially, cause a breakout of an unwanted non-indigenous population.

Essentially, the current D2-Standard of the IMO can be defined as:

1. Reduction of ***all*** *organisms present to an acceptable level of risk*

However, the original aim of the Ballast Water Convention is to eliminate only those organisms with a potential risk of becoming an invasive population damaging to the ecosystem to a certain degree. In principle this approach would be far more environmentally friendly than the current methods and should be the ultimate goal of safe and environmental-friendly shipping.

The D2-Standard would than be reformulated as:

2. Reduction of ***potentially*** *invasive organisms to an acceptable level of risk*

The second definition is ambitious but a far more difficult goal to achieve as, despite our currently vast and still increasing knowledge of aquatic biodiversity, it is almost impossible to identify the potential risk of each individual species for a specific environment, if only as so many species have not yet been identified or even found before at all. Rephrasing the second definition slightly it will then read as:

> *the biodiversity (i.e. number of different species) in the ballast water tanks should be equal or less than the biodiversity of the surrounding aquatic environment and all species should match.*

This approach is essentially what currently would be the outcome of ballast water exchange (D1-Standard) in the ideal situation. Unfortunately, for a correct and complete comparison of the biodiversity inside the ballast water tanks as well as from the surrounding aquatic environment a full scan of the organisms present is required. With over at least 4,000 known and unknown different species present in a single tank[3] only real-time modern molecular technologies would offer a sufficiently detailed analysis of the biodiversity. Despite the great potential of molecular biology, the limited time available prior to discharge, exceeds the abilities of most advanced molecular technologies presently available. In addition the current costs of such detailed molecular analyses are astronomical.

Besides the above indicated solutions there are nevertheless several promising ideas which may offer interesting alternatives or additions now or in the future to the current in-line treatments described in section 2 of this paper, these include;

- Ballastless ship (NOBOB or ships with a reduced ballast water volume that remains inside the vessel).
- Flush through BW tanks (different concepts of flushing).
- In-tank treatments (physical, chemical and biological).
- Reception facilities (recycling BW and treatment in land facilities).

In the following section the pros and cons of each alternative will be discussed in view of their ability to reduce total numbers of potentially invasive species and how to assess the efficacy of this technology.

Ballastless Ship

In principle, this would be the ideal solution. As no water containing organisms would be loaded and discharged, there automatically would be no global distribution of alien invasive species using this approach This would require, however, a complete new design of ships in terms of length and width and would for sure result in a revolution in the maritime sector. It also requires new design constraints, which allows a deviation from existing IMO conventions. As shipping is rather conservative and is also linked to many other sectors, such as ports, industries and supply chains, this type of innovation may take considerable time before it would be globally accepted and implemented. Alternatively, as in the old days, other modes of ballast could be used such as stones, barrels, etc as ballast. Given the global unbalance in import/export of commodities this is also not a very valid option.

Flush through Systems

Based on this principle, there are several solutions varying from simple concepts of pumping water in and out of the ballast water tanks at appreciable speed to more complex solutions including ones that also aim on flushing out (residual) sediment. Despite the fact that even pumps result in a considerable mortality of organisms, on average 90%, the abundance of remaining organisms is still well above the IMO D2-Standard for residual numbers. The basic concept of this approach would therefore be to achieve an identical biodiversity in and outside the BW tanks. This requires real-time measurement and comparison of bio-diversity at both sides.

Several tests showed that the overall efficacy would be equal to that of exchange or the filling and emptying the ballast water tank three times in a row. Besides the problems associated with assessing a full scale biodiversity analysis (see above) the flushing rate is also important. Assuming a flush rate of 1,000 m^3/h and a ballast volume of 10,000 m^3 this will require 10 hours for a single replacement of the volume. To be completely safe this should be done at least three times, over 30 hours. A ship sailing at 14 knots will move 420 miles before the operation is completed. A vessel doing 25 knots sails 750 nautical miles in the same period. The efficiency is always a combination of three factors, i.e. ballast volume, actual pumping rate and speed of the vessel. The latter are variables, the first depends on constraints of the vessel, stowage of the cargo and required trim, list and draft.

A ship entering the Strait of Dover will not be finished with its exchange before it enters the port of Hamburg. As many shipping routes are on a longitudinal line a ship equipped with this kind of flush through system will pass different biogeographical provinces within this time span. Whereas the approach would be acceptable within a single biogeographical province it is certainly not acceptable when it would include multiple bioprovinces. The challenges for such systems when passing land-barriers between different oceans or seas by connecting waters, such as the Panama and Suez Canal, so far remain without any potential solution.

In-tank Treatment

In-tank treatments can be separated in three different types (physical, chemical and biological), but in all cases the main advantage is that they are not immediately linked to an active treatment during intake or discharge of ballast water but can switch on at any convenient moment during a ships voyage. Further, since there are no major changes in the water volume or flow, the stability of the ship will also not be affected.

The physical separation is based on the addition of flocculating detergents resulting in an enhanced sedimentation rate of particles (inorganic as well organisms) by increasing their size and therefore their weight. Some of these mineral flocculation agents can even be used for particles as small as bacteria. This treatment results in a clear water phase and a sediment layer at the bottom of the tank rapidly increasing in thickness. In principle the water would become devoid of organisms, but the remaining life would be concentrated in the sediment layer. On discharge great care should be taken to prevent a disturbance of the sediment layer. Over time with a substantial higher sedimentation rate the accumulation of sediments will require a more frequent cleaning of the ballast water tanks. The accumulation of sediment may become a disadvantage for a ship's operation, as more sediment means less cargo hold.

With respect to a chemical in-tank treatment, there are in principle two options possible. The first one includes active substances with a refractive nature (e.g. based on or including non degradable components like metals, which bear an environment risk upon discharge due to accumulation), the second class ASs are labile substances (including biodegradable organics, e.g. PERACLEAN® Ocean). Both types of biocides result in a complete elimination of all organisms rather than selectively killing the potentially invasive species. Irrespective of their nature such chemically active substances should possess a high initial biocide activity when added, but have a half-life time in relation to the ships operation (short-sea traffic or long distance). The decomposition would be due to autolysis (in the dark or rapidly after discharge in the light) or due to microbial activity (mineralization). The nature and frequency of administering chemical additives during a voyage needs to be in line with the cruising scheme of the vessel.

A third and so far poorly exploited method of in-tank treatment would be based on biological control. Biological control is increasing in importance in particular in terrestrial ecology as it is usually very specific but is only rarely exploited for aquatic purposes. Potential bio-controlling candidates are viruses, bacteria and parasites. An example of a case study is the well studied phytoplankter *Phaeocystis globosa* and its bloom controlling virus. This Harmful Alga Bloom-forming species is annually dominating the coastal waters of the North Sea and responsible for considerable ecological and economic damage[4]. The bloom is very often entirely terminated in only a few days as a result of viral infection[5]. Using this virus as an active bio-controlling agent is, however, far away from reality. Because of the high degree of specificity associated with this type of biological control, treatment should be conducted at the port of intake rather than at the port of discharge.

Another type of biological treatment approach is to use the mineralization capacity of bacteria; essentially identical to what is happening in a sewage treatment plant. This would require a suitable set of bacteria, probably multiple sets as salinity can be highly variable, and bacteria differ largely in their tolerance to salinity. In addition, considerable quantities of growth stimulating substances such as organic carbon, vitamins, trace elements, etc will be required. This concept is based on altering the water environment in such a way that it will become a lethal environment for all other organisms. There is however, a whole suite of organisms living in a heavily sheltered environment (shellfish), but also cysts and eggs which may well survive such treatment. Finally, after discharge the ballast water thus treated should be without residual effects to the natural environment.

Reception Facilities

Ballast water reception facilities would be an elegant solution for small harbours with only a limited amount of (short sea) traffic. A closed and well controlled system of water recycling assures a safe water quality. The water quality is actually not crucial as long as it is not mixed with harbour water.

A second advantage is that there will be no accumulation of sediment in the ballast water tanks in such a closed cycle. A small land-based treatment unit in the harbour would be sufficient to clean the ballast water and to guarantee the water quality in terms of organism. In areas with sufficient drinking water also standard tap-water could be used to supplement the pool of ballast water. This water is already free from organisms and sediment. As the standards for the chemical water quality are nearly as strict as those for drinking water, this water source should at least be acceptable. In some regions drinking water contains active substance (chlorine) exceeding the discharge standard for ballast water.

One of the things to bear in mind is that ballast water operations do not only take place while moored at the jetty. Before entering the shallow waters of a port, ships will be deballasted to pass barriers such as sills or ballasted to reduce air-draught. Moreover, reception facilities require a completely new logistic service in ports.

Exceptional Ballasting

In line with the D2-Standard, our current attempt to minimize the inflow of invasive alien organisms is to achieve a reduction of all organisms and ensure the water quality almost equals that of drinking water. In this respect, the environmental awareness and consequences are clearly defined. The water quality in many harbours has improved in recent years but the majority of ports are still far from being a pristine environment. The water quality in the harbours, ignoring the fact that seawater is unsuitable as drinking water, is far from the universal standards for drinking water. In fact, the discharge of ballast water might actually improve the harbour quality as it does not contain organisms or human pathogens and is depleted of toxic substances. Ballast water is in fact industrial water and should, therefore, not be compared to drinking water. Alternatively, criteria with respect to residual toxicity or the presence of active substances (e.g. chlorine) should, therefore, be in line with those for the discharge of industrial water and not that of drinking water.

The current generation of BWT systems meets the criteria of the IMO and several systems can also meet the even the stricter California standard. Although such BWT systems can handle high flow rates they are not actually designed for handling large ballast water volumes. In particular, the presence of filters limits high flow rates. For flow rates higher than 2,000 m^3/h and large water volumes, these modular BWT systems will be bulky and complex to operate. Large VLCCs but also dredgers, hopper barges, heavy-lift ships, floating docks and barges will have serious problems considering their ballast management and operational procedures. These types of vessels may require a different BW management capable of handling extremely large volumes mainly based on a single treatment with active substances. As current results show that, in particular, hard shelled organisms can only be eliminated by filtration, a single chemical treatment will be less effective. Subsequently, on discharge the number of organisms may (incidentally) exceed the D2-Standard. To reduce such risk the ambient concentration of the active substance could be increased or the choice could be for chemicals with a longer half-life time. This will reduce the residual number of organisms but a negative effect might be an increased residual chemical load upon discharge. As these vessels are responsible for a substantial volume of the total ballast water transport an adequate solution to this problem receives a high priority.

Summary or Conclusion

In conclusion, as ballast water management is currently manageable and is increasing in importance on all levels depending on ships design, operation and investment in suitable BWT systems. The present generation of BWT systems, based on in-line treatment, performs above expectation certainly in view of the fact that they are in principle based on technologies 'adapted' from drinking- and sewage water treatment. In the upcoming decade this industry will develop and be a mature water treatment branch of its own, adopting new technologies and applications such as in-tank treatment. Nevertheless, in view of gaps still to be covered, the economical gains, both as to losses to the environmental as well as to market potential for BWT systems, there remains an ample challenge for creative and innovative ideas.

Endnotes

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The Variable Buoyancy Ship: A Road to the Elimination of Ballast

*Michael G. Parsons**

Abstract

The development of the Variable Buoyancy Ship concept is described in this paper. This was conceived as a way to eliminate the transport of ballast water across the globe. Instead of using weight in conventional ballast tanks to submerge the vessel to safe drafts in the ballast condition, the Variable Buoyancy Ship floods open longitudinal trunks that extend the length of the ship below the "ballast waterline" to reduce the buoyancy of the ship and allow it to achieve safe drafts. When the ship is at speed, the natural pressure difference between the ship's bow and the stern induces a slow flow through these open trunks resulting in their always being filled with local seawater. The overall concept, required structural arrangement, propulsion impacts, damage survivability, and order of magnitude economics of a Variable Buoyancy Seaway-sized bulk carrier are described.

Key words: Ballast Water Exchange Variable Buoyancy Ship, Ballast–Free Ships, Ballast Water Treatment

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1 Background

The author has been involved in ballast water management research over the past 18 years including participation in the U.S. National Research Council's Ship's Ballast Water Operations Committee (NRC 1996) and the Great Lakes Ballast Water Demonstration Project (Parsons et al. 1997; Mackey et al. 2000). Investigations have included operational issues involved in ballast water exchange (Woodward et al. 1994), testing and design of full-scale ballast water filtration systems (Parsons and Harkins 2000; Parsons and Harkins 2002; Parsons 2003), numerical simulation of flow-through ballast water exchange (Parsons 1998; Kent and Parsons 2004), and the use of glutaraldehyde for ballast water treatment (Jennings et al.1999; Lubomudrov et al. 2001).

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[*] Arthur: F. Thurnau Professor Emeritus, Professor Emeritus of Naval Architecture and Marine Engineering.

[**] University of Michigan, Ann Arbor, MI, USA.

As an eventual result of questions posed to the author by environmentalists on the Ship's Ballast Water Operations Committee (NRC 1996), who asked the simple question "why not just get rid of ballast?", the Variable Buoyancy or Ballast-Free Ship concept was invented at the University of Michigan (U.S. Patent 2004). This concept has been developed and researched over the past years and this work has been presented in industry publications (e.g. *Ballast Water News* 2004; Parsons 2008), a dissertation (Kotinis 2005), and professional society literature (Kotinis et al. 2004; Kotinis and Parsons 2007a; Kotinis and Parsons 2007b; Kotinis and Parsons 2008). This concept will be described in this paper.

2 Concept Overview

The Variable Buoyancy Ship concept represents a fundamental, paradigm shift in thinking about surface ship design. Since the introduction of steam machinery in the 1800's, ships have added ballast water weight in the no-cargo, ballast condition in order to achieve safe operating drafts (Figure 1). Unfortunately, this has proved to be the primary vector for the movement of non-indigenous aquatic species around the globe (Mills et al. 1993; Carlton et al. 1995). The Variable Buoyancy Ship approaches the situation somewhat like a submarine. Instead of adding weight, it uses reduced buoyancy to get the ship down to safe operating drafts in the no-cargo condition. This is achieved by arranging the ship to have structural trunks of sufficient volume that extend most of the length of the ship below the "ballast waterline" and then opening these trunks to the sea in the no-cargo condition (Figure 2). When the ship is at speed, the natural pressure difference between the bow and the stern of the ship induces a slow flow through these open trunks resulting in their always being filled with local seawater that is exchanged about once per hour. The vessel also uses a closed trim system using the fore peak tank and the aft peak tank so that all traditional ballast is eliminated.

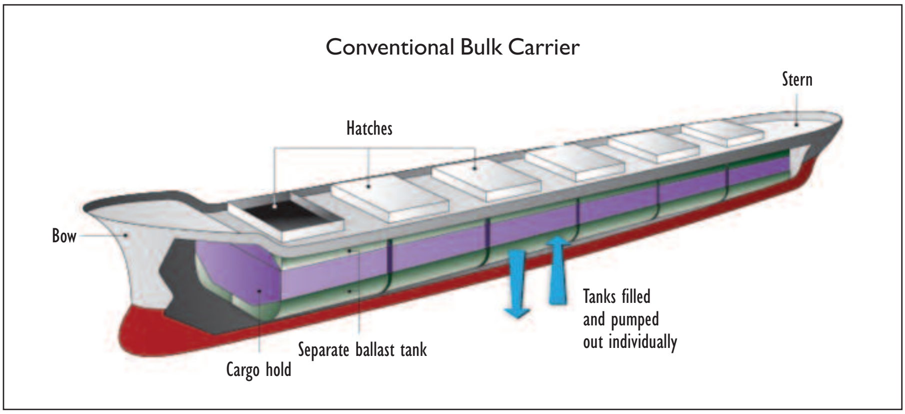

Figure 1. Conventional Single Hull Seaway-sized or Handy Bulk Carrier

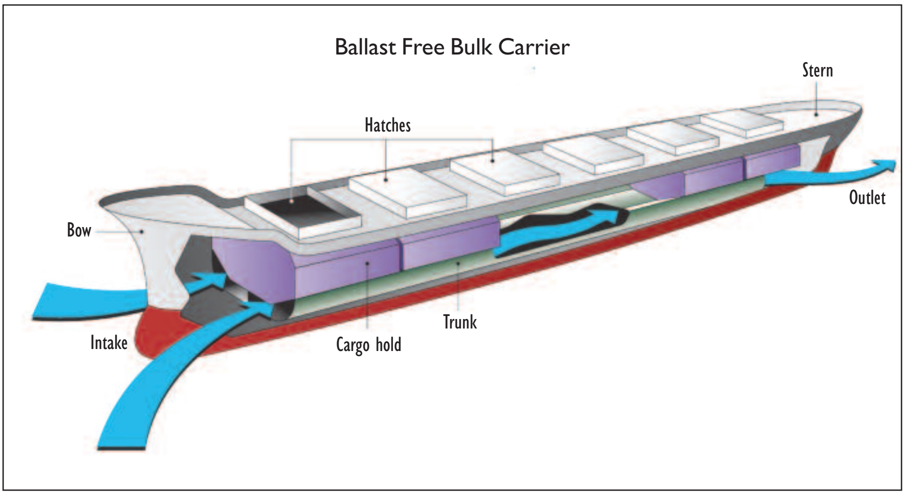

Figure 2. Variable Buoyancy Handy-Sized Bulk Carrier

The trunks are connected to an inlet plenum at the bow and an outlet plenum at the stern. The trunks are equipped with motor-operated butterfly isolation valves at the bulkheads at the ends of the cargo region. When the vessel is ready to reload cargo these valves are closed and the ducts are pumped dry using conventional ballast pumps. This design essentially eliminates the transport of ballast water. The problem of transport of sediments in the trunks remains and the trunks will still have to be periodically cleaned of any sediment (IMO 2004).

3 Available Pressure Differential

The initial issue for proof of concept was to determine if sufficient pressure differential will exist between the bow and stern at speed to provide the slow internal flow desired. Early predictions using a plug flow assumption and marine engineering pipe flow pressure drop methods indicated that exchange could be achieved once per hour with a pressure differential of about $\Delta C_P = 0.033$.

Early external flow Computational Fluid Dynamics (CFD) studies of a Seaway-sized bulk carrier in the ballast condition were performed using FLUENT® as shown in Figure 3. These results show that intakes on the side of bulb and discharge at about Station 18 (as shown by the red squares in Figure 3) would provide about $\Delta C_p = -0.05 - (-0.15) = 0.10$ or about 3 times that needed (see Kotinis et al. 2004, Kotinis and Parsons 2007b for details). Most recent external flow CFD studies have been performed in Star-CCM+® (Kotinis and Parsons 2008).

4 Ship Internal Arrangement

The Variable Buoyancy Ship would require new construction. A typical midship section of a conventional single hull Seaway-sized bulk carrier is shown on the left in Figure 4. These ships are the greatest risk for the introduction of nonindigenous aquatic species to the Great Lakes of the United States and Canada, Ballast is carried in the upper wing (topside) tanks, most of the double bottom and the hopper side tanks. One cargo hold is typically also used to achieve the required winter storm ballast volume.

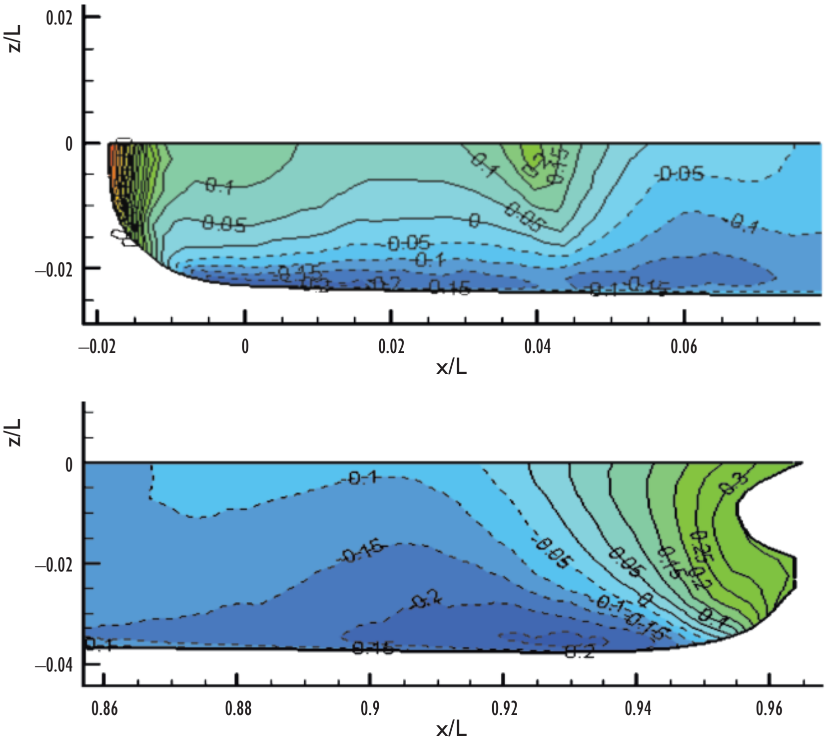

Figure 3. Typical Pressure Distributions at Bow and Stern at Ballast Draft

A midship section of a Variable Buoyancy or Ballast-Free bulk carrier is shown at the right in Figure 4. To provide full storm ballast volume below the ballast draft the inner bottom is raised from 1.6 m to 2.4 m. To maintain full grain capacity with the higher inner bottom, the hull depth is increased from 15 m to 16 m. There are three longitudinal trunks per side of the ship: two in the double bottom and one consisting of the hopper side region. The deeper double bottom will facilitate trunk cleaning with its full head room. To further aid the cleaning of the trunks, most of the floor plating is cutaway at the bottom plating so that the trunks could be more easily hosed clean below each cargo hold. The resulting hull steel weight increases from 5,553 t to 5,767 t (+3.85%) when designed to the ABS pre-Common Structural Rules (CSR) Bulk Carrier rules (ABS 2002). The cutaway floors were permitted by these rules because once the aspect ratio of a panel reaches about 3 it is essentially an infinitely long, two-dimensional problem. The hull has to be slightly fuller (increased block coefficient) to accommodate the water left in the bow and stern plena at full load and the greater hull steel weight at constant Seaway draft. The resulting midship section has less work content primarily due to the elimination of much of the floor welding to the bottom shell.

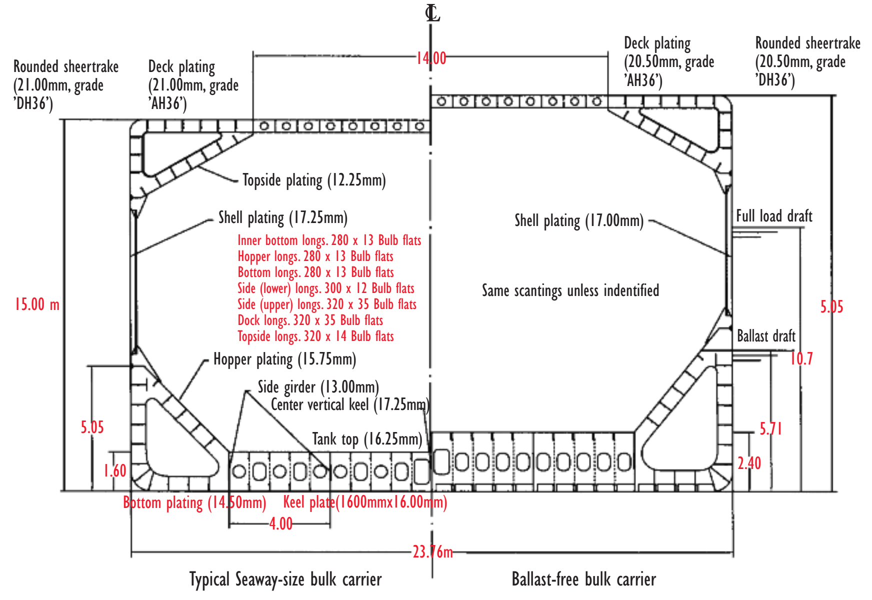

Figure 4. Midship Sections of Conventional and Variable Buoyancy Bulk Carriers

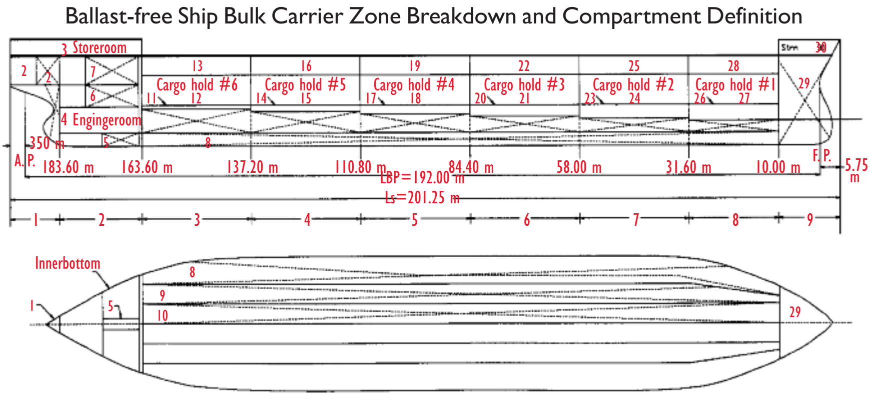

Figure 5. Longitudinal Arrangement of Variable Buoyancy Bulk Carrier

The inboard profile of a typical Variable Buoyancy bulk carrier is shown in Figure 5 assuming storm ballast drafts of 40% of full load draft forward and 70% aft. To keep all of the trunks below the ballast waterline, the hopper side tanks become gradually deeper in steps as they move aft. Butterfly isolation valves would be installed near the bulkheads at the fore and aft ends of the cargo region to provide the needed trunk isolation for pump out using conventional ballast pumps.

5 Flow Initiation

With adequate pressure differential available, it remains to verify that the flow in the trunks will begin when the trunks are opened to the sea and the ship is at operating speed. Internal flow CFD studies were conducted to verify that the flow would perform as expected. Figure 6 shows the 705,915 cell half-ship internal trunk flow model analyzed in FLUENT®. The pressures predicted in the external flow CFD studies were imposed on this model as boundary conditions with a step change to simulate the opening of the isolation valves when the vessel is at a “ballast condition” speed.

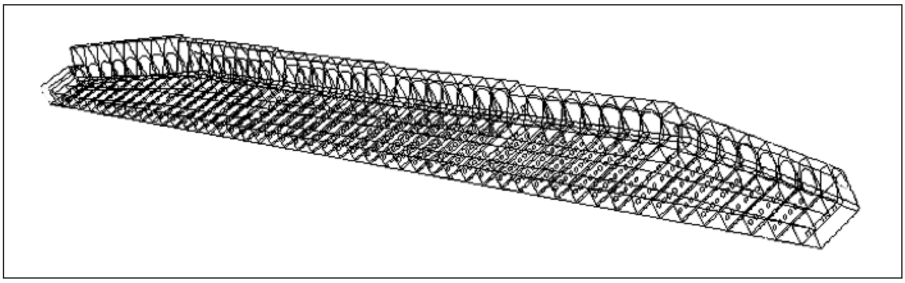

Figure 6. Internal Trunk Flow Analyzed in FLUENT®

A typical result from these simulations is shown in Figure 7, which depicts the concentration of new water in the trunks at 3,000 seconds after flow initiation. The colors show the concentrations of the mixtures of new and old water and the clear on the right shows 100% new water has entered the trunks. The trunks contain 100% new water by about 6,000 seconds after the opening of the trunks. These results show that the trunk flow will initiate as expected. These studies also confirmed the theoretically derived scaling law for the internal flow used in the subsequent ship model testing.

6 Propulsion Effects

The introduction of inlet and discharge openings in the hull and the discharge of trunk flow into the hull boundary layer aft can cause an increase or decrease in the ship resistance and required propulsion power. The initial work unfortunately showed that this might increase the required ship power by as much as 7.4%, which would seriously jeopardize the economics of the concept (Kotinis et al. 2004). Further design refinement and research has subsequently shown that with optimized design of the intake and discharge location and details that a modest required power reduction of 1.7% can actually be achieved (Kotinis and Parsons 2008).

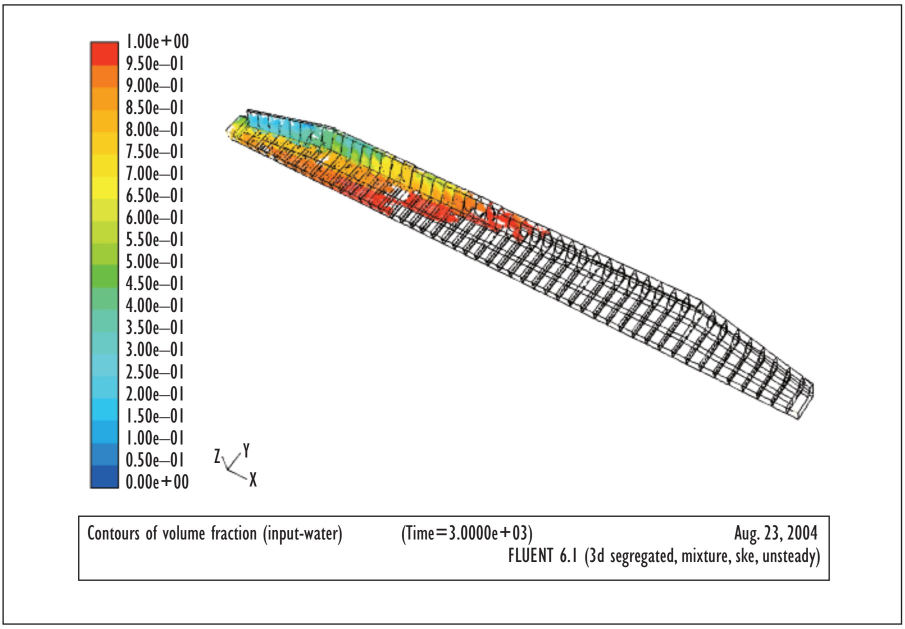

Figure 7. Internal Trunk Concentration of New Water 3,000s after Flow Initiation

To undertake these studies, a Seaway-sized handy bulk carrier was designed based primarily on the Polsteam *Isa* that currently trades into the Great Lakes. This design has a 195.5 m load waterline, 23.76 m Seaway beam, and Variable Buoyancy design 16 m depth. The ballast speed was assumed to be 15.5 knots. A 5 m model of this hull was built as shown in Figure 8. This model was tested in the University of Michigan Marine Hydrodynamics Laboratory (MHL) for both bare hull resistance and self propulsion with and without flow through an internal trunk system. Since the modeling and scaling of the internal flow would be questionable at this scale, a precision controlled, Froude-scaled internal flow was pumped through internal tubing to simulate the operation of the internal trunks (Kotinis and Parsons 2007b and 2008).

To maximize the pressure differential across the trunks, the intake was placed at the tip of the bulbous bow at about 25% of the design waterline as shown in Figure 9. Two different stern discharge locations as shown in Figure 10 were tested. One pair was placed at about the 45% design waterline near Station 17, roughly the forward engine room bulkhead, with the other pair at about the 30% design waterline near Station 19, roughly the after engine room bulkhead. One meter diameter inlet and discharges were used with the discharges oriented at 10 degrees to the local surface tangent.

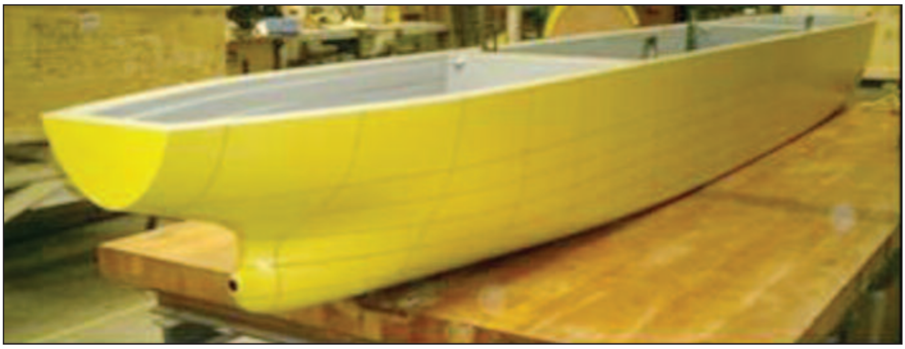

Figure 8. Five Meter Propulsion Model of Variable Buoyancy Bulk Carrier

Figure 9. Bow Location of Trunk Inlet

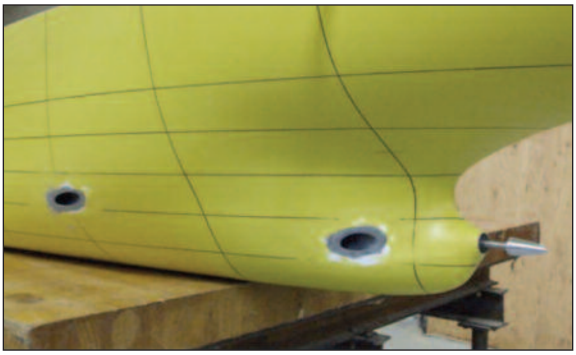

Figure 10. Alternative Stern Locations of Trunk Discharge Tested

The bare hull resistance of the model (without a propeller) was established using standard model testing techniques and then scaled to predict the ship resistance. Tests were conducted at the ballast drafts without the trunk flow and with the scaled trunk flow discharging at either the location near Station 17 or that near Station 19. The full-scale ship resistance is shown in Figure 11. The resistance increases 4.17% over the no trunk flow case when the discharge is near Station 17, which is preferred since it would not be necessary to continue the trunks underneath the engine room with the forward discharge.

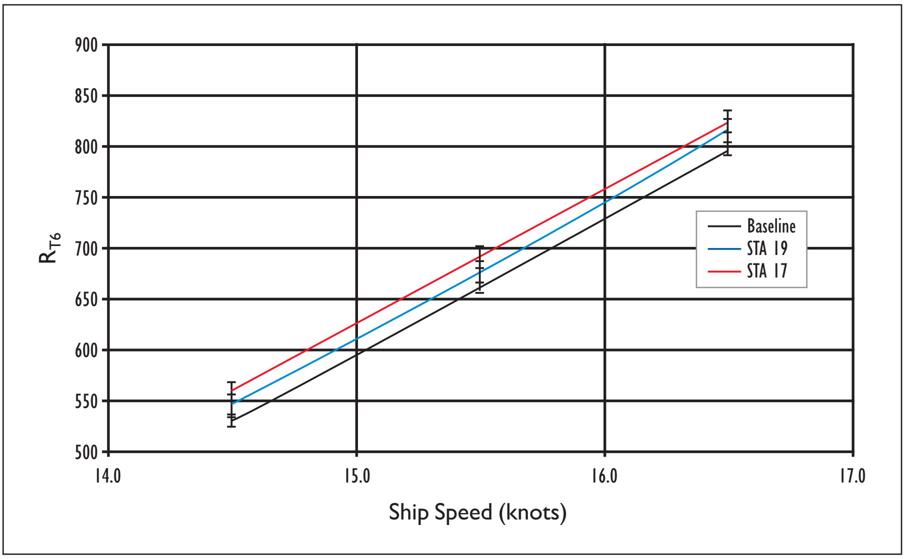

Figure 11. Predicted Full-scale Ship Resistance with and without Trunk Flow

While a bare hull resistance increase is of concern, the real question is what happens to the required ship power when the model is propelled by a propeller? Self propulsion tests were conducted using a stock propeller from the MHL to answer this critical economic question. The required power is related to the bare hull resistance when it is expressed as the effective power by the following:

Required power P_D = Effective power P_E/propulsive efficiency

where the propulsive efficiency is given by $\eta_D = \eta_O \times \eta_R \times \eta_H$ and η_O is the open water propeller efficiency obtained without a hull in front of the propeller, η_R is the relative rotative efficiency that relates how this efficiency changes when behind the hull, and η_H is the hull efficiency that reflects the effect of the hull on the flow field that enters the propeller and the effect of the propeller operation on the bare hull resistance of the hull. Even though the bare hull resistance increases as shown in Figure 11, it is still possible to have a reduction in the required power if the propulsive efficiency increases by a greater amount. The results of the self propulsion test with the trunk flow discharging near Station 17 at the ballast condition speed of 15.5 knots is summarized in Table 1. The components of η_D change with the trunk flow such that the propulsive efficiency increases and the required propulsion power is reduced a modest, but important, 1.7%.

Table 1. Results of Self Propulsion Tests with and without Trunk Flow

Case	**No Trunk Flow**	**Trunk Flow with Discharge at Station 17**
Effective power P_E	Baseline	Plus 4.51%
Open water efficiency eta_O	0.487	0.522
Relative rotative efficiency eta_R	1.0126	0.9593
Hull efficiency eta_H	1.0876	1.1380
Propulsive efficiency eta_D	0.5363	0.5699
Required Propulsion Power P_D	Baseline	Minus 1.67%

7 Damage Survivability

With continuous trunks extending most of the length of the ship, there is concern about the damage survivability of the Variable Buoyancy Ship when it is fully loaded and the trunks are empty. Any bottom flooding could extend the full length of the cargo hold without additional isolation valves within the trunks. The Variable Buoyancy bulk carrier was analyzed using the requirements of SOLAS Chapter II-1, Part B-1 (IMO 1974 and 1993) and Society of Naval Architecture and Marine Engineers guidelines (SNAME 2001). The required subdivision index for these vessels was R = 0.568. A conventional design using typical ballast tanks had an attained index of A = 0.887 > R.

The Variable Buoyancy bulk carrier was analyzed initially with trunk isolation valves only at the ends of the cargo region. The partial load condition assumed that there was no cargo and the trunks were in operation. The goal of this design was to have both the full load and partial load (trunks in use) conditions meet the required subdivision index even though the rules only require that their expected value (average) meet that value. Three additional cases were analyzed: one set of isolation valves was added at the bulkhead between holds 3 and 4; two sets of isolation valves were added at the bulkheads between holds 2 and 3 and between holds 4 and 5; and additional isolation valves were added at each internal cargo region bulkhead. In view of the probabilistic distribution assumption of the rules for depth of penetration, these additional valves were *only added to the two outboard trunks on each side*. The results are summarized in Table 2. To achieve the design goal, five sets of additional isolation valves would be used.

Table 2. Probabilistic Damage Assessment with Various Internal Trunk Isolation in the Two Outboard Trunks on Each Side

Attained Subdivision Index	$A_{\text{full load}}$	$A_{\text{partial load}}$	**A**
No internal isolation valves	0.1209	0.9998	0.5603
One set of isolation valves	0.2606	0.9998	0.6302
Two sets of isolation valves	0.4662	0.9998	0.733
Five sets of isolation valves	0.5846	0.9998	0.7931

8 Economics

An order of magnitude economics comparison was made between a Variable Buoyancy Seaway-sized bulk carrier and a typical conventional design that has a ballast water filtration and UV treatment system installed to meet IMO requirements (IMO 2004). The results of this study are summarized in Table 3 (for more details see Kotinis and Parsons 2008). The greater hull depth, fullness, and hull steel weight are included. The trade is assumed to be a ballast voyage from Rotterdam to Duluth, MN at the head of the Great Lakes to load grain for an 8 m Seaway draft return voyage. The net annual change in capital cost for the added hull steel, reduced structural work content, elimination of filtration and UV equipment, and reduced ballast piping, etc. would be US$476,400 assuming a Capital Recovery Factor based upon 20 years and a return of 10%. The net annual change in operating cost, primarily for the reduced fuel requirement in the ballast condition, would be US$116,920 assuming heavy fuel use. This would increase when reduced sulfur fuel requirements come into force. The net result would be a reduction in the Required Freight Rate of about $1 US per tonne of grain.

Table 3. Order of Magnitude Economics Summary

	Typical Bulk Carrier	Ballast-free Bulk Carrier
Installed engine nominal MCR (kW)	8,580	
Block coefficient	0.835	0.841
Required service MCR in ballast (kW)	7,700	7,575
Hull steel weight (tonnes)	5,553	5,767
CRF (i = 10%, 20 yrs.)	0.1175	
Case: Roundtrip Rotterdam; Seaway draft; discharge at Station 17 compared with filtration and UV treatment **when** ballast exchange is no longer allowed		
Net capital cost change ($)	–476,400 Lowered	
Net operating cost change per annum ($)	–116,920 Fuel savings	
Change in RFR ($/tonne)	**–1.03**	

9 Conclusions

The Variable Buoyancy Ship concept offers a way to eliminate the use of ballast and provide a cost savings compared to the use of ballast water treatment systems when ballast water exchange is no longer available. With proper design optimization, the use of the trunks can save fuel in the ballast condition. A predicted savings of 1.7% was found in the Seaway-sized bulk carrier investigated to date. Unfortunately, the full validation of these ideas will likely require its application in detailed design and full-scale, new construction. Work underway in the current year will further clarify the propulsion requirements and assess and refine the ability of the Variable Buoyancy Ship to handle all required draft and trim variations.

10 Acknowledgements

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Ballast Water Replacement with Fresh Water – Why Not?

Valter Suban[*], Peter Vidmar and Marko Perkovič

Abstract

G8 and G9 recommended ballast water treatments consume a lot of energy. This has the consequential environmental impact of additional greenhouse gas pollution as well as an economic impact due to the increase of daily consumption of diesel or fuel oil. At the same time a lot of heat from exhaust gases is released inefficiently into the atmosphere. These deleterious effects can be reduced during the voyage by producing fresh water in the evaporators. The existing capacity on ships can produce daily only a limited quantity of fresh (drinkable) water for her needs. But if additional evaporators are supplied on board to produce industrial (non-drinkable) water, the production rate could be increased several times. As there are many ballast income ports located in the places where fresh water resources are limited, the ship may sell produced fresh water to the terminal. Preliminary research of fresh water prices in ports world wide shows that the average price is 3 €per metric ton. If ships sell fresh water produced during the voyage for a single 1€on average, the yearly income could be significant. Fresh water production would also eliminate some other problems such as the negative effects of BWT using chemical additives and preventing accumulation of sediments in ballast tanks. Of course, further detailed studies will be necessary to research the following: existing structure and possible changes of ship tanks in correlation with free surface moments which have great impact on stability, the optimum of efficient sizes of evaporators due to reduced space in the engine room, the environmental contribution due to reduction of greenhouse and other pollutant gases while not wasting energy using BWT systems and economic impact in general. Also potential heat energy should be examined in detail. The paper will explain an idea as to how to establish the necessary equipment on board and the advantages and disvantages of such equipment. The paper is not a result of extensive research, rather proposes to represent their initiation

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[*] University of Ljubljana, Faculty of Maritime Studies and Transport, Slovenia.

Key words: Ballast Water Exchange, Treatment, Marine Propulsion Thermal Efficiency, Fresh Water Generation

Introduction

It has been known for decades that discharged ballast water transferred from distance ports could be a significant vector to introduce non-indigenous invasive organisms. Recognizing this problem, the International Maritime Organization (IMO) in November 2004 introduced the International Convention for the Control and Management of Ships' Ballast Water and Sediments (hereafter referred to as BWM Convention; IMO 2004) to reduce the consequences. According to the convention, after a defined period, depending on construction date and ballast capacity, ships shall meet the Ballast Water Performance Standard (Regulation D-2) which stipulates that discharged ballast water shall contain fewer organisms than defined. In the meantime Ballast Water Exchange (BWE) remains a valuable interim option and improvements to ships' designs may increase the efficiency of BWE. The operating cost of BWE is approximately US $0.01–0.02 per ton of ballast water, but higher costs result when a ship requires additional piping for safe or effective exchange (Taylor et al. 2002).

Current Ballast Water Treatment (BWT) Methods

There are several known BWT methods. They vary in efficiency of cleaning and energy consumption, and hence vary in emission levels and price efficiency. All data in this chapter have been taken from the most recent available review of technologies used for BWT, analyzed by Gregg et al. (2009) The cleaning effect is of course very important for satisfying the BWM Convention requirements, but this text will concentrate on energy.

Filtration

Filtration is an environmentally sound technique for the control of ballast water organisms that works by capturing organisms and particles as water passes through a porous screen, filtration medium or stacks of special grooved disks. Filtration is relatively expensive, costing an estimated $0.06–0.19 per ton of ballast water (including capital cost) (Taylor et al. 2002; Perakis and Yang 2003). There is no data about the increasing rate of energy due to increased pressure needed to pass the filter. Net lost flow due to backwash (%) depends on the size of filters. Using filters with nominal pore size (μm) 25 net lost flows is 10.6–21.2%, pore size (μm) 50 net lost flow is 6.8–13.5, while with pore size (μm) 100 net lost flow is 4.9–6.8% (Gregg et al. 2009).

Cyclonic Separation

Cyclonic separators, or hydrocyclones, are simple mechanical devices that operate by centrifugal action causing heavier particles to move to the outside where they are captured by a weir-like feature near the discharge point (Parsons and Harkins

2002). The estimated cost of cyclonic separation is \$0.05–0.26 per ton of water (including capital cost) (Taylor et al. 2002; Perakis and Yang 2003). There is no data about the increased rate of energy needed for the separator's work. There is also 10% of net lost flow due to the discharge path (Jelmert 1999, Sutherland et al. 2001)

Heat Treatment

The use of heat for treating indigenous organisms in ballast water is potentially cost effective. Several different heat treatment processes have been suggested as potential shipboard ballast water treatment options (Table 1) (Gregg et al. 2009). One proposed method uses waste heat from the ships engine cooling system and exhaust to treat ballast water, which significantly reduces costs (Hallegraeff et al. 1997; Perkovič and David 2001, Rigby et al. 2004).

The amount of heat needed to heat a medium (ballast water) from one temperature level to another can be expressed as: $Q = cp\ m\ dT$

where

Q = amount of heat (kJ)
cp = specific heat capacity (kJ/kg.K)
m = mass (kg)
dT = temperature difference between hot and cold side (K)
Heating energy;

Time for dt heating of ballast without losses:

$$t = \frac{Q}{P}\ [\mathrm{sec}]$$

where

P = heating power (kJ/s)

Much more expensive, but more efficient, is the method combining Microwave heating and an additional heat exchanger. The estimated capital costs of this high temperature treatment system are between US \$350,000 and 400,000 for ballast flow rates of 1,000 to 3,500 m^3/h and estimated operational costs (based on increased fuel consumption) range from over \$100 for 1,000 m^3/h to over \$600 for 3,500 m^3/h (Mesbahi et al. 2007).

UV Radiation

Three wavelength bands are of interest for the control of organisms, but gamma ray and microwave technology requires high energy together with high capital and operational costs (Gregg et al. 2009). So, only ultra-violet (UV) rays are suitable for use as a BWT method.

Table 1. Comparison of achievable temperature, biological efficacy and estimated cost of different potential shipboard ballast water heat treatment options (Source: listed in the table)

Treatment Process	**Attainable Temperature**	**Biological Efficacy**	**Estimated Cost ($ per ton)**	**Reference**
Engine waste heat	35–38°C after 24-30 h 37–38.4°C after 24–30 h	100% of zooplankton and phytoplankton, 100% of zooplankton and most phytoplankton	0.056 (including capital costs)	Rigby and Hallegraeff (1993) Rigby et al. (1998) Rigby et al. (2004)
Heat exchangers	55–80°C for 1–2 sec	95% of zooplankton, 63–90% of phytoplankton, 95% of bacteria	0.10–0.17 (excluding capital costs)	Quilez-Badia et al. (2008) Mesbahi et al. (2007)
Microwave heating	69–89°C in 100–200 sec	100% of Artemia salina adults, Artemia salina nauplii, Crassostrea virginica larvae and Nannochloropsis aculata	2.55 (including capital costs)	Boldor et al. (2008)
Microwave heating and additional heat exchanger	73–>100°C in several mins	100% of Artemia salina cysts	1.09 (including capital costs)	Boldor et al. (2008) Balasubramanian et al. (2008)

The estimated capital cost for an UV ballast water treatment system ranges from US $300,000 to $400,000 depending on the manufacturer with operational costs of approximately US $0.065–0.26 per ton of ballast water (Perakis and Yang 2003; Sassi et al. 2005; Lloyd's Register 2007).

Cavitations (Ultra-sound)

The mechanical effects of ultra-sound on biological systems in a liquid medium are mainly thought to be due to cavitation, although pressure wave deflections and possibly the degassing effect may also contribute to the mortality of aquatic organisms (Mason et al. 2003; Rigby and Taylor 2001). The cavitation systems for ballast water treatment may prove problematic on flow rates higher than 5,000m^3/h of a single ballast pump. (Gregg et al. 2009).

Sassi et al. (2005) estimate the cost of an ultrasound ballast water treatment system for a ship with a ballast capacity of around 50,000 tons is in the vicinity of $6 million with an operational cost of approximately $0.56 per ton of ballast water, but Environmental Technologies Inc. claim to be developing a system costing only $500,000 with an operational cost of $0.005 (Lloyd's Register 2007). Apart from costs, other aspects that require consideration include health and safety issues, which may arise from noise generated by the ultrasound treatment unit, high energy requirements, and hull integrity problems due to repeated exposure to cavitation. (Gregg et al. 2009).

Electrocution

Electrocution has been considered as a potential treatment of ballast water organisms during ballasting and deballasting and was first proposed by Montani et al. (1995). The de-activation of bacteria by generating pulsed electric fields has been demonstrated by Blatchley and Isaac (1992) and Aronsson et al. (2001). The authors have not found any data about energy requirements and costs.

Mechanical Damage

The use of high velocity pumps during ballast water intake and discharge may cause lethal damage to some organisms by mechanical abrasion. (Gregg et al. 2009). Taylor et al. (2002) suggest that these systems are hard to install and the cost for installing additional infrastructure to create high velocity jets of water in ballast tanks or pipelines would be prohibitively expensive.

Magnetic Treatment

Magnetic treatment has been utilized for the elimination of bacterial growth in diesel fuel. In this process, a magnetic field is pulsed along fuel lines generating very low frequency, de-ionising electromagnetic radiation. No installation or operational costs are available at the current stage of development (Gregg et al. 2009).

Active Substances

As the focus point of the paper is efficiency of using energy and its coherence costs, the active substances will not be covered in detail. Only the costs and needed energy will be covered –

- *Chlorine concentrations* required for the effective treatment of ballast water are likely to be prohibitively expensive. Bolch and Hallegraeff (1993) indicate that the costs required for adequate chlorination of 50,000 tons of ballast water would be in the vicinity of $160,000.
- *Chlorine dioxide (ClO2)* is not used widely in wastewater disinfection due to the high cost involved compared with chlorination. According to Carney et al. (2008), the capital cost of the system is between $260,000 and $400,000 for flow capacities of 200 m^3/h and 2,000 m^3/h, respectively, with an operating cost of $0.06 per ton of ballast water.
- *Ozone* is a powerful oxidant used to control microorganisms in a variety of applications. Projected costs of an ozone treatment system are in the vicinity of $800,000 to $1.6 million with an operational cost of $0.28–0.32 per ton of ballast water (Sassi et al. 2005; Carney et al. 2008).
- *Hydrogen peroxide* is an oxidative biocide considered attractive for the treatment of ballast water as it is known to be of limited risk to humans and decomposes

rapidly, resulting in harmless by-products of oxygen and water (Gregg et al. 2009). Efficacy and cost data are not available to the authors.

- *Glutaraldehyde* is an organic biocide which has been proposed, either on its own or in combination with surfactant, for the treatment of vessels carrying little or no ballast to control organisms present in ballast tank residues and sediment (Lubomudrov Sano et al. 2003, 2004). Lubomudrov Sano et al. (2003) suggest the cost of glutaraldehyde treatment would be $25 per ton of ballast water, thus limiting the treatment to vessels with small quantities of ballast water and sediment.
- *Peracetic acid* is another organic biocide suggested as a potential ballast water treatment due to its broad-spectrum activity and lack of undesirable by-products (Gregg et al. 2009). The cost for this type of treatment is suggested to be in the vicinity of $0.20–0.30 per ton of ballast water (Rigby and Taylor 2001).
- *SeaKleen®* is a patented biocide developed by Garnett, Inc. Atlanta and manufactured by Vitamar Inc. Memphis. The estimated cost of SeaKleen® is approximately $0.20 per ton when applied at a concentration of 2 ppm, which may limit the use of this biocide to vessels with small or moderate ballast capacities.
- *Acrolein®* is a broad-spectrum biocide produced by the Baker Petrolite Corporation. The current estimated cost of Acrolein® for treating ballast water is between $0.16 and 0.19 per ton.
- One of the more recent treatment options proposed for the control of ballast water organisms involves the onboard generation of *hydroxyl- and oxygen radicals*. The equipment is small in size, operationally simple and cost effective (Gregg et al. 2009). Bai et al. (2005) imply that the running cost of hydroxyl radical treatment is 1/30th the cost of ballast water exchange; however the initial cost and power requirements would be expected to be considerable.
- *De-oxygenation* has been suggested to be a cost effective technique to prevent aquatic introductions while reducing ship corrosion (Gregg et al. 2009). Cost estimates for this type of treatment system range from $135,000 to in excess of $3 million depending on ballast capacity and operating costs are approximately $0.06 per ton of ballast water (Lloyd's Register 2007). The cost of the Venturi Oxygen Stripping™ system ranges from $150,000 to $400,000 depending on the flow capacity of the ship and operating costs are approximately $0.05 per ton of ballast water (Lloyd's Register 2007). Although a number of authors indicate that using de-oxygenation techniques may provide ship owners with a significant economic saving (approximately $80,000–100,000 per year) due to a reduction in ballast tank corrosion (Deacutis and Ribb 2002; Browning Jr. et al. 2004), it is suggested that alternating back and forth from anoxic conditions to air as well as the stimulation of anaerobic bacteria may act to enhance corrosion rates (Oemcke 1999; Tamburri et al. 2004).
- Many organisms cannot survive large *variations in pH* (Muntisov et al. 1993). Raising or lowering pH level in ballast tanks can be achieved by the addition of alkali or basic chemicals and may effectively kill many organisms. The authors have not found data about required energy and cost.

- *Salinity adjustment* is aimed to de-activate or osmotically destroy marine organisms present in ballast water by increasing or decreasing the salinity of the water (Gregg et al. 2009). No data about the cost and energy is needed.

Multi-component Treatment Systems

Many ballast water treatment systems use a combination of treatment options. A selected number of such systems that are currently under commercial development and in various stages of testing and/or IMO approval are discussed below. The BWM Convention requires that systems used to comply with the convention must be approved by the Administration and need to be tested in a land-based facility and on board ships to prove that they meet the performance standard D-2 of the BWM Convention. Successful fulfilment of the provisions should lead to the issuance of a Type Approval Certificate. Systems which make use of Active Substances to comply with the convention shall be approved by the IMO in a two-tier process – to ensure that the ballast water management system does not pose unreasonable risk to the environment, human health, property or resources. (Gregg et al. 2009). In the rest of this section there is a recapitulation of some BWT systems concentrated on cost and energy efficiency where available –

- Mitsui Engineering and Shipbuilding Co., Ltd, in conjunction with the Japanese Association of Marine Safety (JAMS) have developed the *Special Pipe Ballast Water Management System* (combined with ozone treatment). The system costs approximately $1 million for installation on an existing container ship with an estimated operating cost of $0.15 per ton of ballast water (MEPC 2006).
- The Oceansaver® is a Norwegian-made *multicomponent treatment system* consisting of a mechanical filtration unit, a hydrodynamic cavitation chamber, an electrochemical disinfection unit and a nitrogen super-saturation generator. The technology is expected to cost approximately $800,000 per unit with an operating cost of $0.06 per ton of ballast water (Lloyd's Register 2007).
- Hamann AG and Degussa AG of Germany have produced the SEDNA® (Safe, Effective Deactivation of Non-indigenous Aliens) – a *modular ballast water treatment* system which consists of a two-step physical separation and a secondary biocide treatment that operates during ballast intake only. Potential disadvantages of the system include the cost effectiveness of Peraclean® Ocean (approximately $0.30 per tonne of ballast water), possible increased corrosion due to the use of an oxidative biocide, the reduced effectiveness of Peraclean® Ocean against resistant organisms and in the presence of sediments, health and safety issues and space requirements relating to the need to store large amounts of noxious chemicals onboard and possible residual toxicity of treated ballast water (Gregg and Hallegraeff 2007; de Lafontaine et al. 2008a). SEDNA® ballast water treatment system using Peraclean® Ocean was the first operational system that has received both Basic and Final Approval by the IMO for its use of an active substance as well as for the whole system and Type Approval by the relevant national

regulatory authority, the Federal Maritime and Hydrographic Agency, Hamburg (MEPC 2007).

- Environmental Technologies Inc. and Qwater Corporation of the United States are developing treatment systems that *combine filtration and cavitation*. At the current stage of development, however, ultrasound technologies would not be considered appropriate for the shipboard treatment of ballast water due to high capital and operating costs and high power requirements (Rigby and Taylor 2001).
- Several companies have produced two-stage ballast water treatment systems that *combine primary separation devices followed by disinfection by electrochlorination*. The estimated cost for full installation of Greenship's Ballast Water Management System is $2,300,000 for a system capable of treating a flow of 2,000 m^3/h (Carney et al. 2008). This system achieved basic approval from IMO in 2008. Severn Trent De Nora builds a similar treatment system, the BalPure® Ballast Water Treatment System, but this differs in that filtration is used prior to electrochlorination. The capital cost of this system is considerably less than the Greenship system ($US500,000 for 2,000 m^3/h flow capacity) and has an operational cost of $0.02 per tonne of ballast water (Lloyd's Register 2007).
- RWO GmbH Marine Water Technology and Veolia Water Solutions and Technologies have developed 'CleanBallast!' – a *two-stage ballast water treatment* system that consists of a mechanical separation step and an electrochemical treatment step. The operational cost of the system is approximately $0.06 per tons of ballast water (MEPC 2006).
- Another technology that could reduce the ballast mediated transfer of non-indigenous organisms is the *'ballast-free ship' concept*. It involves redesigning the ballast system of ships so that a constant flow of water runs through the entire length of the ship essentially eliminating the transport of ballast water (Parsons and Kotonis 2007). If successful, this design would eliminate the need for costly ballast water treatment equipment or active substances and is even suggested to result in as much as a 7.3% reduction in the power needed to propel the ship (Erickson 2008). The researchers suggest that the new design would result in a net capital-cost saving of around $540,000 per ship and combined with the expected fuel savings, total transport costs would be cut by $US2.55 per ton of cargo (Erickson 2008).

Using Fresh Water

When marine diesel engines run, only part of the energy from the fuel is converted into useful work. In the most efficient engines this percentage could be a bit more than 50% (MAN Diesel 2005), but usually this output energy is around 40–50%. The remainder of the energy is mainly lost in the cooling systems and exhaust gas. A heat balance diagram for a large diesel engine is shown in Figure 1.

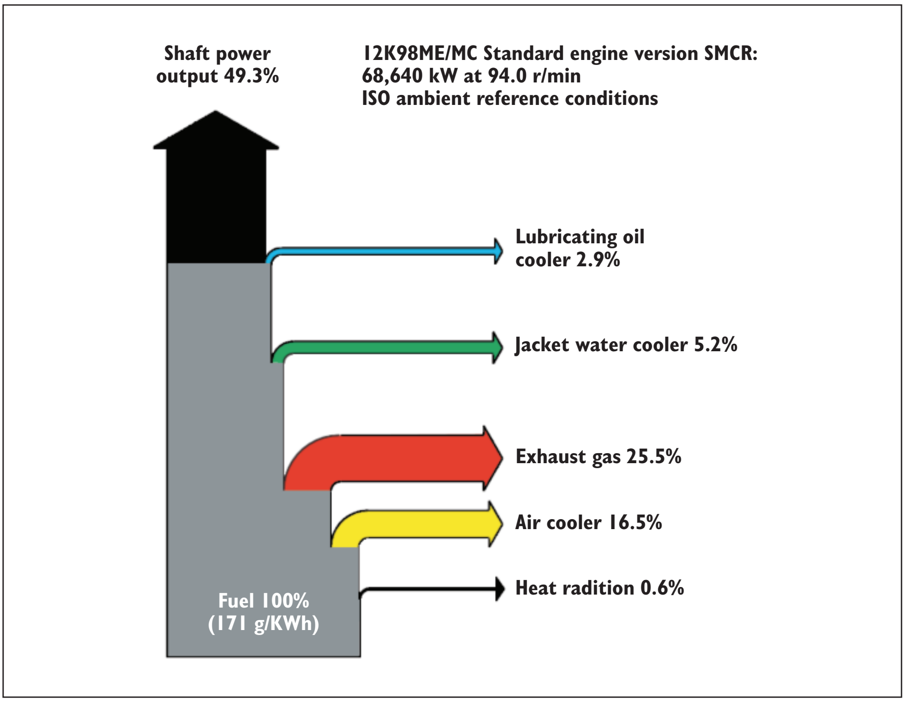

Figure 1. Heat balance diagram of the nominally rated 12K98ME/MC engine of the standard engine version operating at ISO ambient reference conditions and at 100% SMCR (Source: MAN Diesel Technical Paper 2005)

The two stroke diesel engine is unrivalled as the most fuel efficient prime mover whether compared with medium speed engines, steam turbines or single-cycle or combined cycle gas turbines. Furthermore, considering typical part load efficiencies of prime movers the efficiency of diesel engines, and especially of two stroke low speed diesel engines, is almost independent of load over a wide load range Figure 2 (lower diagram) which provide the possibility to use engine waste heat at the same rate when running engine at low power. (MAN Diesel Technical Paper 2009).

Some exhaust gases energy could be recovered, but this depends on a number of factors, such as the amount of available energy, the time available and the capital cost of a recovery plant. Modern vessels partly use this energy in scavenge air cooling water as a heating source for bunker fuel tanks. Also the jacket cooling water heat can be recovered, usually to produce freshwater. Additional energy but in smaller quantities could also be taken from the auxiliary engines for electricity production. The number and sizes depends on a ship's needs.

The authors have made a survey of average installed shaft power as the prime mover. The normal running condition of 85% load on the main engine in normal operation, called CSO (continuous service output) or NCR (normal continuous rating) has been taken. The data were acquired from the ship's particulars of over 200 ships of different types that called in the port of Koper in the last year (Table 2). Sizes and values are rounded.

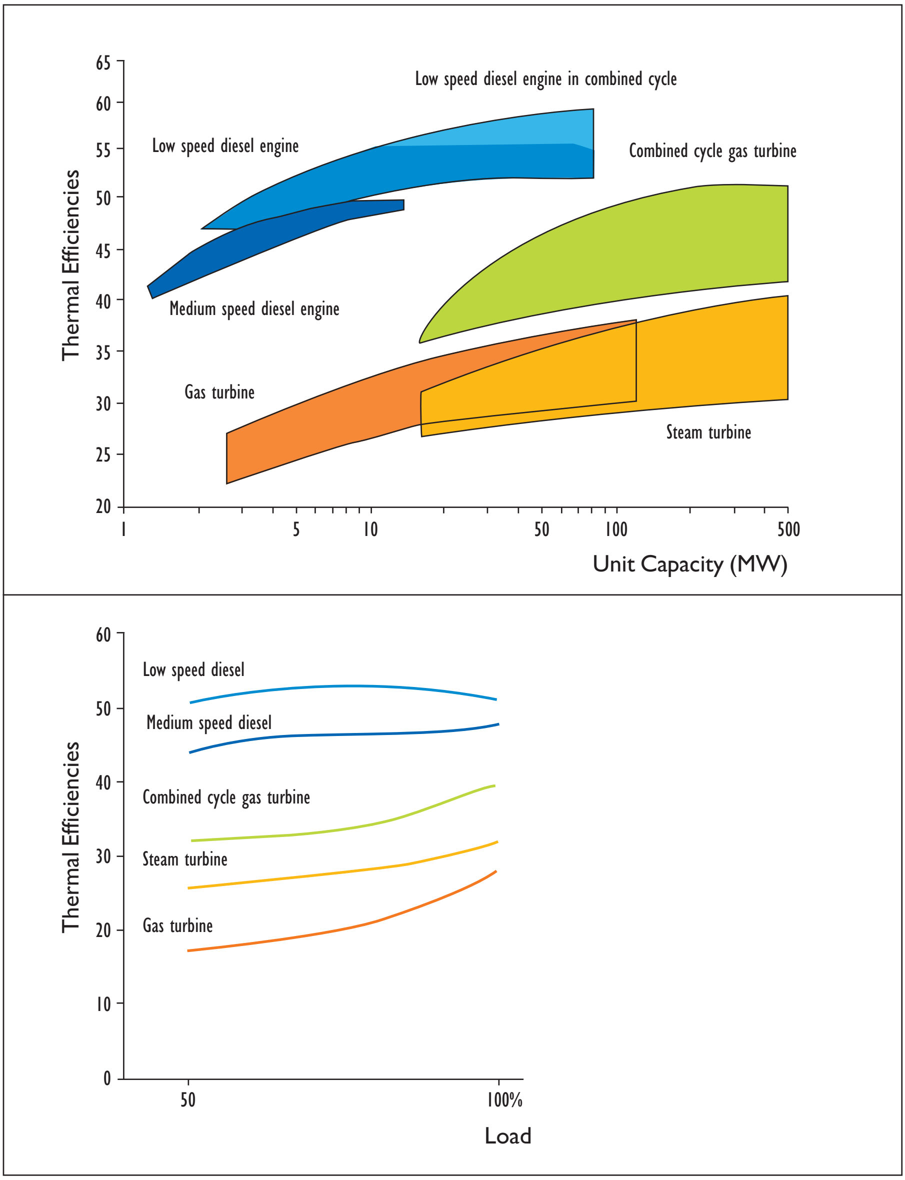

Figure 2. Power efficiency comparison and typical part load efficiencies of prime movers at ISO 3046 (Source: MAN Diesel Technical Paper 2009)

The thermal efficiency of MSF evaporators is rated at less than 150 kWh per ton of distillate to 190 kWh per ton. (Hamworthy 2010a). According to the calculation for the thermal efficiency of the evaporator on a cruise ship, energy for FW production of a 30,000 kW engine is around 1,200 tons per day. (Greffrath R. 2010a). The results of a linear comparison, which can provide only a rough estimation of quantities, is shown in Table 2. Comparison with the largest cruise ship "Oasis of the Sea" confirms that the approximation is accurate. This ship has an installed power of 96 MW kilowatts (Wartsila 2010), which could be converted to CSO of 81,600 kW and have evaporators capacity of 3,300 tons per day (Hamworthy 2010a).

Table 2. Thermal Energy Calculations for different ships

Ship Type and Size	Average CSO in kW	Possible FW Production (tons per day)	Normal Ballast Voyage Length	Total Light Ballast (tons)	Is Ship Usual in Ballast Condition
Cape size bulk carrier	14–15,000	560–600	Long	65,000	Y
Panamax bulk carrier	8-9,000	360	Long	25,000	Y
50000 dwt bulk carrier	7,800	300	Long	17,000	Y
Handy bulk carrier 30,000 dwt	7,500	290	Long	10,000	Y
19000 dwt/150m bulk carrier	3,700	140	Long	6,500	Y
9000 dwt/ 110 m bulk carrier bulk	2,500	100	Medium	3,000	Y
Container vessel 100 TEU	900	35	Very short	500	N
Container vessel 350 TEU	3,000	120	Short	1,500	N
Container vessel 450 TEU	4,000	160	Short	2,000	N
Container vessel 1,500 TEU	9500	370	Medium	6,500	N
Container vessel 2,000 TEU	15,000	600	Medium	9,000	N
Container vessel 2,500 TEU	30,000	1,200	Medium	11,000	N
Postpanamax Container vessel 4,000 TEU	37,000	1,400	Long	17,000	N
Postpanamax Container vessel 5,300 TEU	50,000	2,000	Long	24,000	N
Car carrier 175m	9,000	470	Long	30,000	Y
Car carrier 200m	13,000	400	Long	17,000	Y
Tanker aframax 100,000 dwt	12,000	270	Long	13,000	Y
Tanker handy 50,000 dwt	9-10,000	180	Medium	7,000	Y
Tanker handy 40,000 dwt	7,000	40	Short	1,200	N
Tanker 20,000 dwt	4,500	100	Medium	2,300	N
General cargo 3,500 DWT	1,000	160	Medium	3,000	N
General cargo 7,000 DWT	2,000–2,500	560–600	Long	65,000	Y
General cargo 10,000 DWT	4,000	360	Long	25,000	Y

Distillation

Distillation is the oldest and most commonly used method of desalination. Distillation is a phase separation method whereby saline water is heated using engine jacket cooling water or steam heat from exhaust gas fired boilers to evaporate sea water, which is then condensed freshwater. Normally water is boiled at 100 degree Celsius, but in a freshwater generator it is done at a lower temperature. Reducing chamber pressure water starts boiling at a temperature lower than normal. For this purpose, eductors or air ejectors are used.

The various distillation processes are used to produce potable water on ships. The most common processes are Single Stage (SS), Multi Stage Flash (MSF), Multi Effect (ME), Vapor Compression VC, and Membrane Treatment (MT), known as Reverse Osmosis (RO). Aside from MT, they all operate on the principle of reducing the vapor pressure of water within the unit to permit boiling to occur at lower temperatures without the use of additional heat. Distillation units routinely use designs that conserve as much thermal energy as possible by interchanging the heat of condensation and the heat of vaporization within the units. The major energy requirement in the distillation process thus becomes providing the heat for vaporization to the feed water.

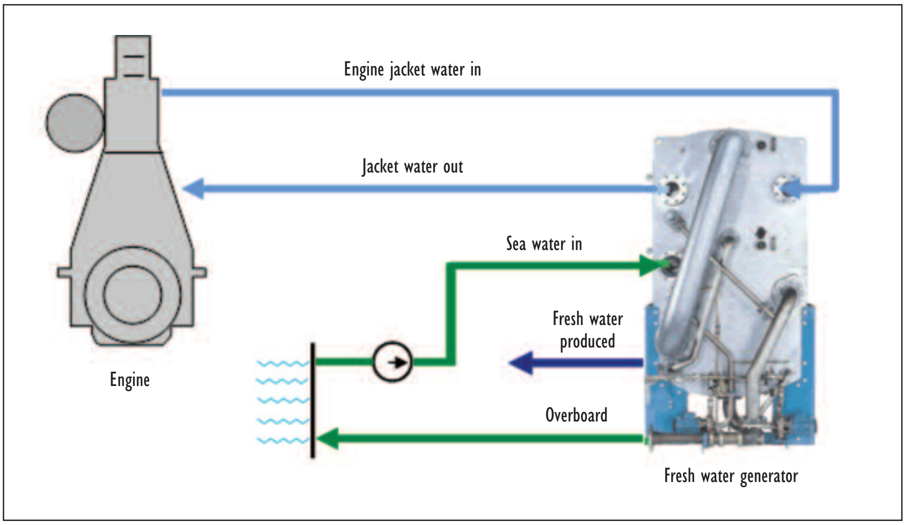

Figure 3. Typical FWG Installation Layout (Source: Lynks 2010)

Single Stage Fresh Water Generator

The hot jacket water from the diesel engine is passed through the evaporator's heated nest. The sea water enters the evaporator through the flow meter and due to the low pressure of the chamber it boils and is converted to steam. Generally the feed of the seawater is half the stated quantity to facilitate adequate boiling of sea water. The steam then passes through a steam separator, in which the water particles in the steam are separated and collected.

The steam then enters the condenser, where it cools down to form fresh water. It is then removed from the condenser with the help of a distillate pump. The remainder of sea water particles or the brine which gets collected at the bottom is drawn out with the help of an ejector pump. (Raunekk 2010), Taylor D.A (1996).

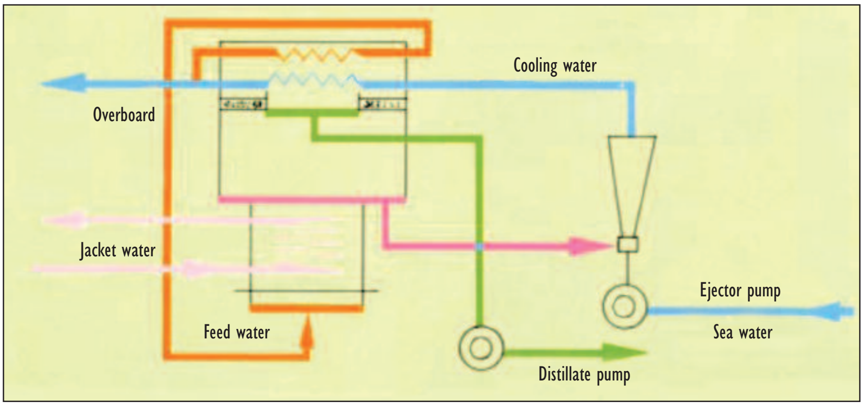

Figure 4. Single stage fresh water generator (Source: Ki-Won 2010)

Multi Stage Fresh Water Generator

A multi-stage FWG is similar to the single stage FWG, the only difference being that the whole single stage process is repeated several times. On the one hand, many stages increase the overall efficiency of heat recovery in the plant and decrease its operating costs. On the other hand, more stages increase the capital cost of the unit.

The flash process increases the efficiency. A liquid which is already relatively hot when introduced into a pressurized chamber, immediately gets converted to steam – i.e., in a flash – without the boiling process. Thus, the phenomena can be used to acquire higher levels of efficiency by controlling the exact pressure and temperature of the water, which will lead to higher energy efficiency.

The producing process is explained by one of the manufacturers in the following way (Hamworthy 2010). The sea water (feed) flows under positive pressure through the tubes of a number of condensers from the last stage to the first stage, heated gradually by the vapor condensing in the various stages. After leaving the first stage condenser, the sea water flows through the brine heater where the heat input to the plant (steam or engine jacket water) causes a further temperature increase. The sea water leaves the brine heater at the Brine Top Temperature (BTT = approx.

80°C). Up to this point, the pressure of the sea water is above the atmospheric pressure and therefore below boiling pressure. The sea water is then directed into the first stage of the plant which is at a pressure below boiling pressure. In order to return to a state of equilibrium, part of the sea water flashes off such that the saturation temperature corresponds to the pressure in the stage. This process is repeated from stage to stage whereby the pressure and the temperature in each stage is less than that of the preceding stage. The brine is then discharged from the last stage by the brine pump. The distillate is drawn through from the first to the last stage condenser, where it is discharged by the distillate pump. The non-condensable gases released in the various stages are discharged by the ejectors. (Hamworthy 2010a)

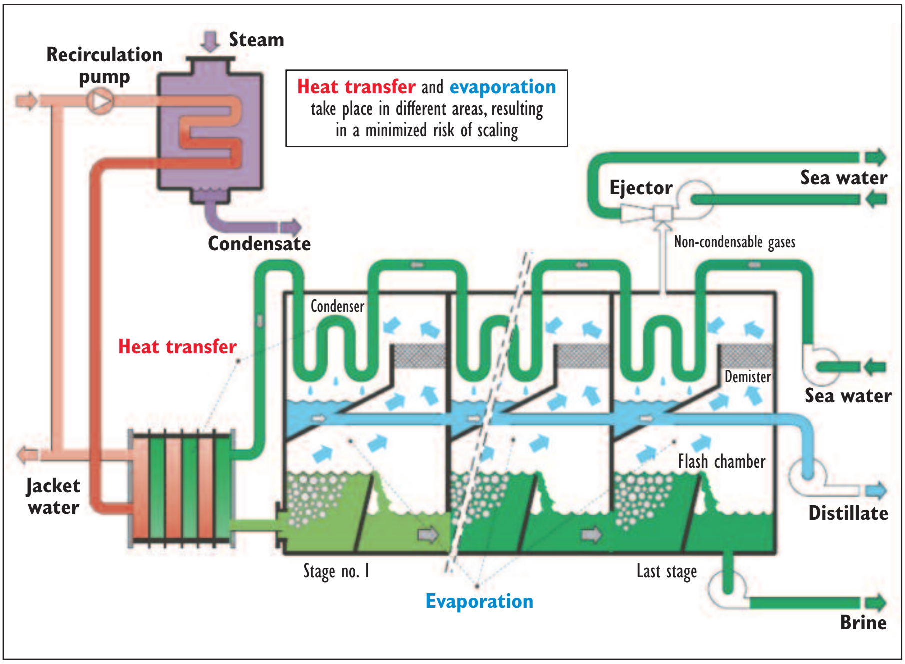

Figure 5. Multi stage fresh water generator (Source: Hamworthy 2010b)

Multi Effect Evaporator

The first stage evaporator is heated by jacket water from the diesel engine or other sources, utilizing waste heat. The heating medium flows over the tubes and sea water is passed through the tubes. Evaporation takes place inside vacuum chambers. The vapor produced is not passed through the brine in the upper casing. Drops of brine which are still contained in the vapor are separated by the mesh type demister fitted in the upper part of the evaporating chamber. The vapor from the first stage is then passed to the second stage evaporator where it condenses on the outside of the evaporator tubes, transferring its latent heat to the sea water inside the tubes. The vapor produced in the second stage is led in the same manner to the third stage. After passing through the demister, the vapor produced in the third stage is led into the condenser. The condenser cooling water flows through the tubes and the vapor is condensed on the outside of the tubes. Part of the preheated sea cooling water is used as feed water. For better thermal efficiency, the hot brine of stage 1 is transferred to the feed water inlet of stage 2. The brine of stage 2 is then passed to stage 3. The cumulated brine of all stages, the air and other noncondensable gases are discharged overboard by a sea water operated combined brine/air ejector. The cumulated distillate of all stages is discharged by a centrifugal single stage distillate pump. Depending on the ship's sea water cooling system, the motive sea water flow from the ejector is delivered either by a separate sea water booster pump with suction from the condenser outlet, or sea water outlet flow is used directly if pressure is sufficient. The evaporator can be designed for manual or fully automatic operation.

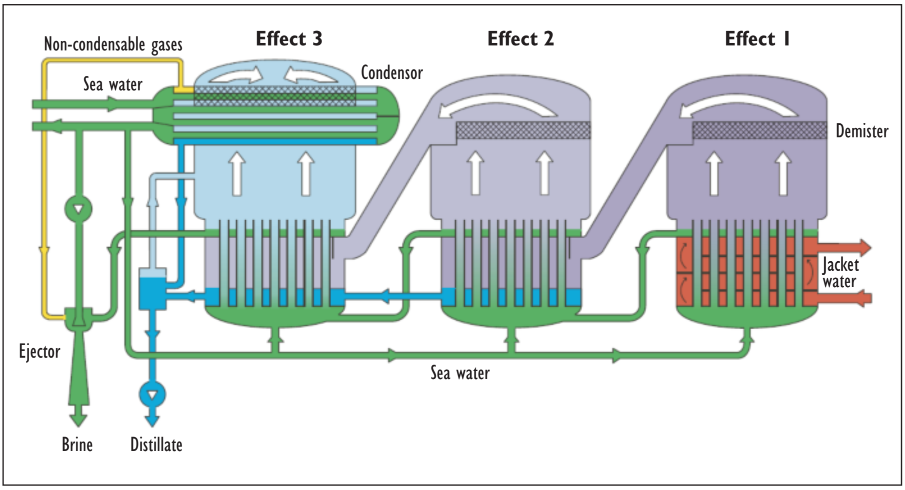

Figure 6. Multi stage fresh water generator (Source: Hamworthy 2010b)

Other FWG

Other FWG, like Vapor Compression (VC) and Reverse Osmosis (RO), do not use only waste heat energy; they require an additional energy source. We mention these processes, but they are outside the scope of our concern.

The VC uses mechanical energy rather than direct heat as a source of thermal energy. Water vapor is drawn from the evaporation chamber by a compressor and except in the first stage is condensed on the outsides of tubes in the same chambers. The heat of condensation is used to evaporate a film of saline water applied to the insides of the tubes within the evaporation chambers. These units are usually used at resorts and industrial sites (IETC UNEP 1997) (Buros O.K. et al. 1982), but the US navy has also tested it in detail (Rose C., Heck J., Pergande W. 2009).

RO involves seawater being pushed through a semi-permeable membrane that traps the salt and other impurities on one side and allows water to be filtered through a microscopic strainer. RO is very useful for fresh water production on ships where there is not enough space and waste energy (yachts, small vessels…). The US navy has also tested this process (Pizzino J. F., Adamson W. L., Smith W. L. 2009).

Further Discussion

The existing evaporators produce different quantities of fresh water. This mostly depends on the ship's needs for fresh water. In the world fleet, the largest evaporators are installed on cruising vessels where demand for water is great. For example, according to the web site of the largest cruise ship "Oasis of the Sea", expected fresh water consumption is 2,350 metric tons daily. To satisfy this demand they have installed four fresh water generators, as each has eight evaporator stages and is rated at 825 tonnes/day of distillate, or a total of 3,300 tons a day. With the other ship types the water producing quantity is only a few tons per day, but this quantity is sufficient for their needs.

According to manufacturer declarations they could make MSF evaporators of very high capacities. For example, Hamworthy declares production up to 1,000 tons/day (Hamwothy 2010 b), DongHwa Entec declares production up to 1,500 tons/day (DongHwa Entec 2010). But as mentioned, the real problem is available heat energy onboard. Therefore, we must know how long the voyage will be and how much ballast is required.

There are several methods of estimating ballast quantities to be discharged in port (Perkovič et al. 2004). For these purposes, the authors use their own method, based on cargo to be loaded (Suban V. 2005) (Suban et al. 2006). Large tankers and bulk carriers normally have on board full ballast capacity, which is around 30% of DWT that must be exchanged/or treated. Smaller coastal tankers (parcel tankers), which do not discharge all cargo in the port, could have less ballast. Container ships, general cargo ships, reefers, ferry boats and cruise ships are usually not empty and they have on average around 10–20% of DWT ballast on board. The estimations are shown in Table 2.

The typical length of the voyage of different ship types is estimated by the authors (Table 2). For the purpose of this paper, the typical voyages are categorised as very short (one day or two), short (up to one week), medium (up to two weeks) and long (more than two weeks). Given this and the available waste heat energy, an estimation regarding the best strategy of FW production on board to replace ballast can be made.

The strategy of FW production using waste heat energy will be very cheap per unit. In this case, the production price of the fresh water depends on the installation cost. The authors could find no information in this regard, but other costs, like support pumps energy costs, are practically negligible. So the running cost depends only on the cost of maintenance. Due to the very simple structure of FWG, the authors estimated this cost to be very low.

In many parts of the world where there is a lack of fresh water a great deal of ballast water is discharged at their ports (Arabic countries, Australia…). On board FW produced water could be freely delivered or sold at such ports. Where fresh water is abundant FW ballast at least may be discharged without any damage to the environment.

In current technology, the brine from the evaporator is directly discharged into the sea. But if this brine, which is also already thermally treated, could be discharged into the ballast water tanks the salinity in tanks will increase and destroy marine organisms to some extent. Some studies have confirmed this notion (Xu et al. 1982; Huq et al. 1984; Munro and Cowell 1996; Bolch and Hallegraeff 1993). Salinities in this extreme range are not considered economically or practically achievable in onboard situations, (Gregg et al. 2009) but in the case of fresh water production in great quantities the salt from the brine is a secondary product and the cost is not a consideration.

As ballast is central to a vessel's stability, obviously any new methods employed should take into account the effect on calculations in this regard, especially considering that ballast water is 2.5% heavier than fresh water. Potential problems that should be taken into account are changes to the center of gravity and possible instability during ballast exchange. However, these are matters easily solved, for instance by installation of additional tanks or dividing extant tanks. The cost involved for ships already in use would not be prohibitive and would be practically negligible for newly constructed vessels.

Conclusion

Fresh water production onboard ship is a well known application used for engines, cargo and human needs. In most applications the energy consumed for FWG is taken from the waste energy of the main engine, particularly from the jacket cooling cycle. Although the exhaust gases are used for steam production a large part of steam is then condensed and the water cooled down using sea water. Of the energy lost about one third may be utilized for FWG. The idea that therefore occurred to the authors is that a lot of wasted or lost energy might be used for more fresh water production, with the intention of improving the ballast water situation and perhaps even producing fresh water for trade. Vessels could be equipped with efficient evaporators that are able to use the maximum available waste heat energy from the engine system. Certainly for some vessels this could only be a part of the ballast management system; and, of course, before adopting this method every eventual stability problem should be considered.

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A Study of Ballast Water Treatment Applied on Iron Ore Ports in Brazil Using Discrete Simulation

[*]Newton Narciso Pereira, Rui Carlos Botter, Hernani Luiz Brinati
and Edson Felipe Trevis

Abstract

An onshore treatment station is a very relevant alternative to eliminate invasive species contained in ballast water. However, few studies about the advantages and disadvantages of this important alternative have been carried out so far. The concern over the impact of an on-land station on the operation performance is due to ballast water collection and storage processes, which could cause additional queuing time and port congestion. Thus, this study was undertaken in order to evaluate the impact of an on-land treatment station of ballast water on the port operation, and a discrete event simulation model was developed as an important tool in analysis of results. The results reveal that it is possible to collect, store and treat ballast water on land, without compromising the port operation.

Key words: Ballast Water, Onshore Treatment Facility, Iron Ore Ports

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Introduction

Men have been using water as a means of transportation for thousands of years. For locomotion and transportation of goods, several kinds of vessels were developed, some handmade and others built industrially, being rafts and canoes the first ever known. Rafts were built with the junction of tree trunks and canoes, with a single trunk. Over the years, with the ever-growing necessity to transport more people and loads, men started to develop new vessels, making use of several kinds of material. Initially, wood was the most used material in the construction of load and passengers vessels, having been used until today, mainly in the construction of small vessels; nevertheless, with the technological development, new materials appeared and steel started to be, from the end of the 19th century, used in the construction of small, medium and large ships.

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[*] Polytechnic School of University of Sao Paulo, SP, Brazil.

With the emergence of steel-hulled vessels, a new challenge had to be faced by designers and shipowners: what is the most efficient way to put ballast in the ship with safety and practicality? Someday, someone must have thought: "*why not put seawater inside the ship's holds to increase its weight, once we do not use wooden hulls, and, consequently, the water will not flow off through the hull's gaps?*" From the point of view of the operation engineering, it was a wise thought because, as the steel hull started to be completely airtight, the water placed in its interior could be retained, increasing the weight of the ship; besides that, whenever it became necessary to load the ship again, the water would simply have to be returned to the sea, and the problem would be solved. From this moment on, it was decided that ballast water would be used in substitution to solid ballast.

Thus, Ballast Water can be defined as "water collected in the sea or river which, stored inside the ballast tanks, has the objective of ensuring that vessels operate in safe conditions regarding stability, maneuvering (propeller immersion), guidance (direction) and distribution of tensions (action of internal and external forces) on the ship's hull."

- Stability: ballast water aims to guarantee that the ship maintains its condition of equilibrium defined in the project during the trip, minimizing the risks of the ship's swaying from side to side. When the ship has no load, its gravity center rises considerably, which affects its stability, i.e. The ships "grows" because part of the hull stays out of water, the external action of the wind and the waves may make it start swaying from side to side, and, if these movements become faster and faster and more intense, the ship may not be able to return to its equilibrium condition, running the risk of keeling or capsizing.Another problem refers to the trim condition, i.e. The longitudinal equilibrium of the ship, as the injection of ballast water in the tanks ensures that the ship remains longitudinally stable;
- Maneuvering: for the ship to perform an efficient maneuver, whether at the port or in the sea, the propeller needs to be totally immersed in water, as only this way it can render a better performance to the ship; when the propeller is out of water, the ship loses efficiency during the maneuvers. As ballast water increases the ship's weight, the hull submerges in the water, having as a consequence the propeller immersion;
- Guidance: besides maneuvering, the ship must try to remain at the route destined for it; thus, ballast water also favors this process because, if the propeller is immersed and it is stable, the ship will tend to follow the predetermined route to reach its destination;
- Distribution of stress on the hull: during loading and unloading, it is necessary to control the efforts to which the structure of the ship is submitted. When the ship is operating on the sea, it suffers the action of the forces of nature, such as waves and the wind, besides internal forces, such as the load in its interior acting on the structure. In this context, ballast water plays an important role, as it ensures

that, when the ship has no load, it does not suffer excessively from external agents, which may jeopardize its structure, causing, in some cases, the ship's rupture and loss. Especially during the loading operations, ballast water has the essential role of guaranteeing that the structure of the ship does not suffer an accentuated stress in only a single place.

There are situations that the ballast tanks can contain a mixture of water from different ports and countries. International maritime enterprises estimate that, approximately, 65,000 transoceanic ships are operating, nowadays. This means that, there is a transportation of, approximately, 5 billions m^3 of ballast water per year, and, that 3,000 species of micro organisms can be transported in the ships' ballast water (A.C. Leal Neto 2007).Furthermore, many species contained in ballast tanks can be potentially invasive. The treatment of ballast water to diminish the risk of potential invasive species is a major challenge that has yet to be equated. A single preventive treatment may not be effective. Therefore, in many cases it may be necessary two or more methods in order to exterminate most of organisms at once.

Currently, all treatment options for ballast water are targeted to be installed on board vessels, such as filtration, ultraviolet radiation, heating, hydrocyclones, electrical pulse and so on. Some of these technologies have already been approved by the IMO and are already available for the maritime community. However, none of them can eliminate all the species contained in ballast water.

Since ships travel great distances between ports and visit many ports throughout the course of a journey, substantial limitations of space in ships, as well as the security concerns for the vessel and its crew, make treatment options on board complex. Specially capacity is a critical issue in most of ships, being a serious constrain when additional systems are required, even more when this systems have to be installed in already built ships. Furthermore, the fleet age can directly affect the development of treatment alternatives. On the other hand, stations on land may be an efficient solution. The ballast water treatment on land starts as soon as the ship berths, when ducts are connected to the ship and the ballast water is pumped towards the on-land station, stored and treated with convenient techniques. There are few studies and references about this kind of alternative, as well as studies that prove its efficiency and the feasibility.

Thus, this paper aims to present the application of treatment of ballast water on land and study the impact of this alternative on a Brazilian terminal of iron ore.

1 Onshore Ballast Water Treatment Facility

The on-land treatment of ballast water demands a complex facility. When the ship berths, ducts are connected to the tanks in order to remove ballast water and store it in tanks, where the treatment happens. On-land stations were originally proposed by AQIS (1993) and Carlton et al. (1995). AQIS (1993) shows the layout of hypothetical on-land treatment facility, as shown in Figure 1.

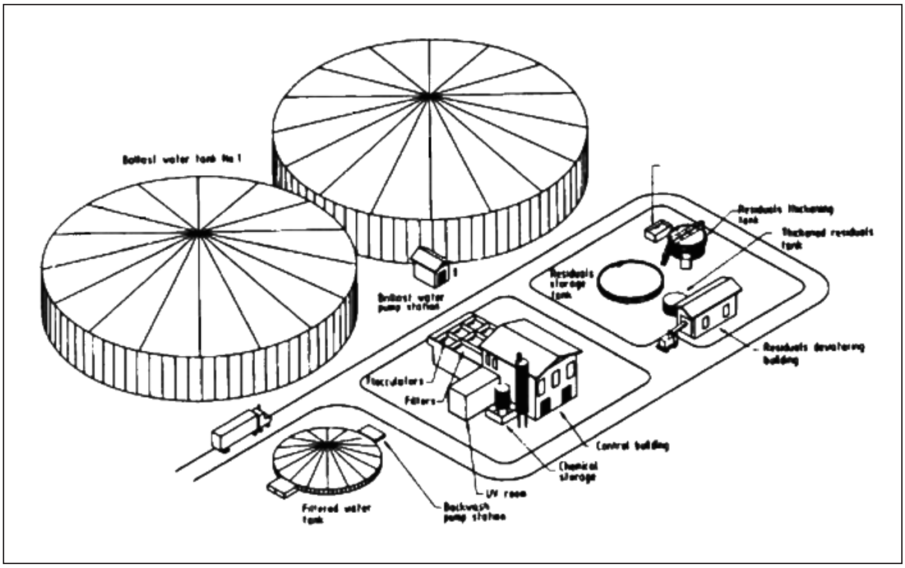

Figure 1. Lay-out of hypothetical on-land treatment Facility (Source: AQIS (1993))

Feasibility studies on on-land treatment stations have been commissioned by the U.S. government, considering ports and terminals such as the ports of Baltimore and Milwaukee (Brown and Caldwell 2006; Greenman et al. 1997) and the terminal for cruise ships in San Francisco (Bluewater network 2005).

Figure 2. On-land treatment station for ballast water
(Source: OASIS Environmental Inc, 2004)

There are three treatment units for ballast water around the world, responsible for separating oil from ballast water, located in the following ports: Valdez in Alaska, Sullom Voe in Scotland and Scarpa Flow in the United Kingdom. They have been operating since the 70's, and they are evidence that it is operationally possible build an on-land treatment station for ballast water, without compromising the operation in the harbor. The terminal port of Valdez in Alaska is shown in Figure 2.

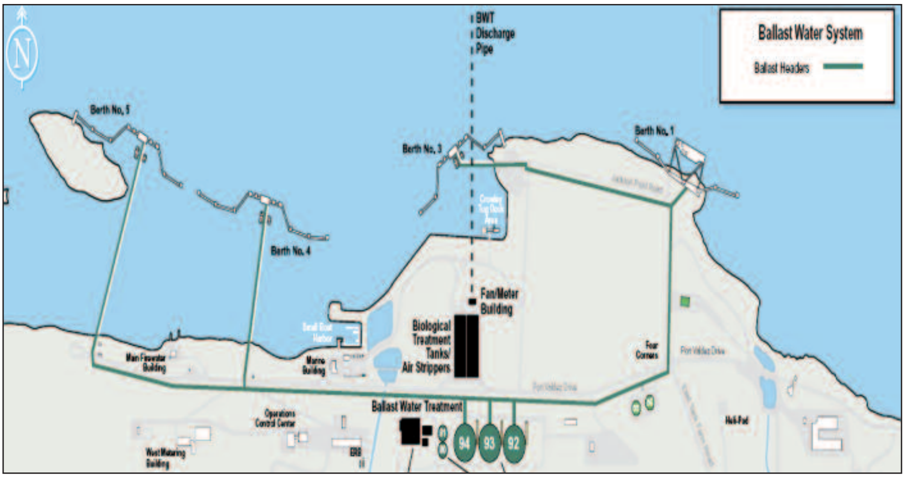

Figure 3. Ballast water system at Valdez Terminal
(Source: OASIS Environmental Inc, 2004)

At Valdez Terminal, it is usual for ships to fill up their cargo tanks, besides the ballast water tank. As consequence of environment constrains, the mixture of water and oil is discharged in a water treatment station: *Alyeska Pipeline Service Company*. The process is structured in 4 stages: (1) the "Chicksan Arms" are connected to the ship in order to transfer ship ballast water to storage tanks; (2) oil is separated from water inside the 90s tanks, and the water is transferred to the 80s tanks; (3) dissolved air flotation (DAF units); (4) biological treatment tanks (BTT) and air strippers.

The three 90s tanks, with a capacity of 430,000 bbl each, provide both equalization and gross oil/solids removal. Two 36,000 bbl recovered oil tanks provide oil storage and gravity separation. Six DAF units remove further oil that is not recovered in the 90s tanks. The BBT are two concrete above-ground tanks with a capacity of 5.5 million gallons each. The system uses microorganisms to remove dissolved hydrocarbons by enhancing phase separation through release of supersaturated water with air. The BWT Facility has a capacity to treat an average of 21 million gallons per day (mgd) and a daily maximum of 30 mgd.

In Flotta Oil Terminal (Figure 4), in the port of Scarpa Flow, oil tankers can only dump the ballast water from cargo tanks into two storage tanks, with capacity of 159,000 m^3. The treatment system follows the same pattern of Valdez terminal (Figure 3).

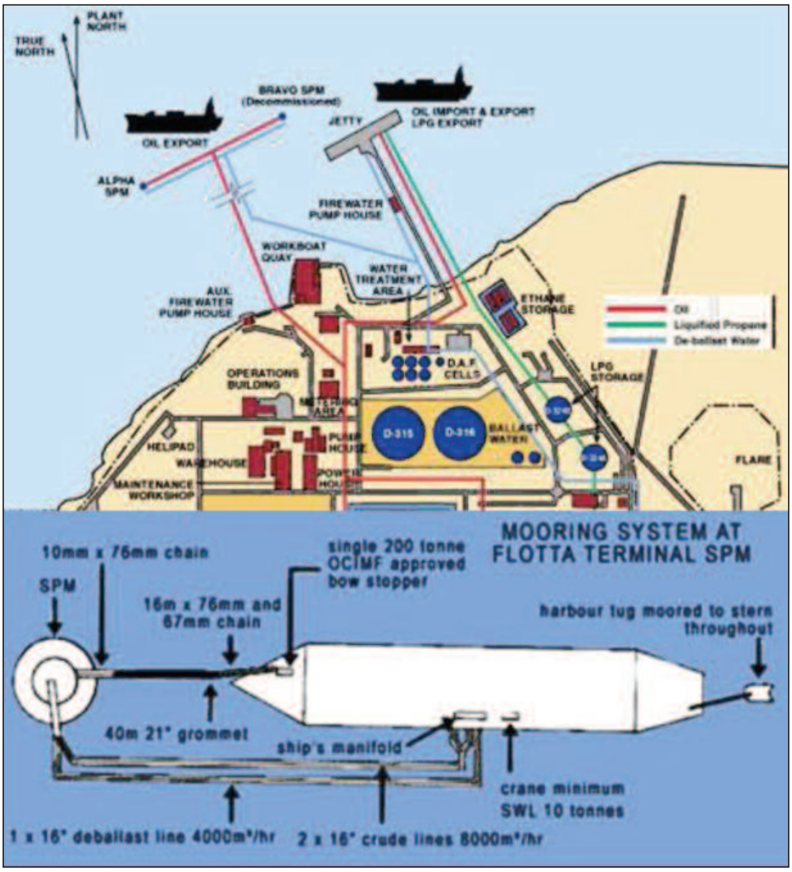

Figure 4. Treatment Station in Flotta Terminal (UK) (Source: Flotta Terminal)

These water receiver units were required by MARPOL 73/78. These stations can be modified so the ballast water can be treated and non-native aquatic organisms can be eliminated (Stemming the tide 1996). However, the costs of these modifications have not been evaluated so far.

In Florida, United States, the Ballast Water Treatment Test Facility has tanks for collection of ballast water, chemical and biological control units, as well as a transfer unit of treated water for disposal in sea. This station was built in 2007, being the first one to treat ballast water in the world, on a small scale. This was an initiative of Great Ships to inhibit the proliferation of exotic species in the country, supported by the maritime industry of the Great Lakes, federal agencies and other government agencies. The station is composed of 4 tanks, with a capacity of 50,000 gallons, or 189 $m^{3,}$ each.

The Port of Milwaukee, in the United States, carried out a study commissioned by the Wisconsin Department of Natural Resources (WDNR), providing a technical evaluation for a ballast water treatment station in the port. The assessment of several existing alternatives for ballast water treatment was made, considering the technology costs. The feasibility of three transport systems – truck, rail (down rail) and barge – intended to collect ballast water from ships was also evaluated. In addition, all equipment costs related to the treatment station were computed in the study. The best option is to transfer the ballast water from the ship to a barge, which would transport the water to an on land station, where the ballast water would be treated by ultraviolet radiation.

Stemming the tide (1996) mentions that the main advantages of onshore treatment are:

- The port authorities could operate and maintain the facilities and could monitor them routinely to determine the treatment extent and effectiveness;
- Operations onshore allow better control of the treatment, in comparison to potentially difficult operating conditions on board the ship;
- The waste coming from the treatment process can be eliminated in an environmentally acceptable manner, under the control of an appropriate authority;
- Onshore treatment plants can merge the treatment alternatives in order to ensure better efficiency in the process, as well as it may be done on board the ship.

Cohen (1998) cited the following advantages of this system:

- Ballast water can be treated with sewage disinfection station in the vicinity of the port or of the municipal;
- Methods similar to filtration can be applied to on-land stations, removing many tough life stages (cysts and spores), as well as organisms and inorganic sediments, and it can combine methods such as biocides, uv that are cheaper and more efficient;
- Higher safety for the crew, since there is no contact with toxic components of treatments on board, as well as lower corrosion problems and structural stress due to temperature variations in some methods;
- Additional room in the vessel (especially in the engine room) is not required, the ship energy consumption is not increased, and there is no new facilities or modifications of the original design;
- The method can provide an economy of scale in construction and operation of onshore stations in contrast with the number of devices required on ships to handle the same amount of ballast water.

Gollasch et al., (2007) mentions the advantages as follows:

- Currently, the onshore treatment of ballast water of tankers is an example of the possibility of developing a standardized system in ports. Pumping systems in all petroleum terminals are standardized, so that any ship is able to load and unload. Thus, the same concept of standardized oil pipelines can be applied in ballast water systems development;
- Stations on-land can supply, with treated water, ports and vessels that must carry clean ballast water.

However, the authors also mention the main disadvantages of treatment facilities on land, such as:

- Demand of pipe connection between the treatment plants and all the berths, and each ship would have to change its own ballast water pumping system, if there is no possibility of using hoses to connect to the ballast tanks (AQIS 1993). The largest ports would need multiple units to receive ballast water;
- Delays in shipping may occur when the capacity of the ships ballast tanks exceed the capacity of the treatment plan (including storage tanks);
- If vessels were able to exchange ballast water at sea, the ship's operators would probably rather this option than facilities onshore, thus limiting the economic viability of such facilities;
- High cost of land acquisition for implementation of storage systems;
- The ballast water discharged by the vessel to diminish its draft while entering into an access channel might not be treated, which may contribute to the bioinvasion

Despite these drawbacks, the treatment on land remains a feasible alternative within a range of options currently available to treat ballast water, provided that the criteria for safety, environmental acceptability, technical feasibility, practical and profitable operations are considered.

To assess the feasibility of this alternative, a model of discrete-event simulation was developed. The simulation model aims to represent the operations of an iron ore terminal considering loading and unloading processes. The objective of the model is to evaluate whether the terminal will be impacted by an onshore treatment station. For that reason, the assessment of the average queuing time in and berth occupancy will be carried out.

An iron ore terminal was chosen once its vessels usually operate in specific routes and most of the time there is no return cargo, which forces them to carry large quantities of ballast water during their return trip. According to UNCTAD (2008), Brazil was the largest exporter of iron ore in 2007, and therefore a special attention should be given to ships that navigate the Brazilian coast, as main ports of destination are major donors of exotic species, such as China. In addition, there are several cases of marine bio-invasion in the Brazilian territory, such as the notorious mussel from China, which settled in the south of the country and has caused severe damage to the environment and economy of Brazil.

Simulation of Ballast Water Treatment Facility on Land

Regarding the problem described and the lack of publication concerning treatment of ballast water, as well as considering the characteristics of an iron ore port, such as being a ballast water receiver, a simulation model has been created in order to assess the feasibility of a water treatment facility on land. The simulation model was built using the Arena simulation software.

It is intended to evaluate if the berths occupancies, ships average waiting time and number of ships in queue are affected by the system. Thus, the conceptual model is as follows:

- Arrivals of vessels at the terminal;
- Berth seizing;
- Berthing process, considering the terminal constraints such as currency, tides, accessibility and environment;
- Pre-operation process after berthing;
- Loading process and deballast. The debalast rate of the ship (m^3/h) is equal to the onboard pumping rate;
- Transfer of the ballast water to a land storage;
- Unberthing process, considering the terminal constraints such as currency, tides, accessibility and environment;
- Treatment and discard of the storage ballast water.
- The conceptual model flowchart is presented in the following Figure 5.

This representation is very similar to a standard operation, except for the fact that the ballast water is collected and treated instead of dumped on the sea. The simulation model is generic, that is applicable to any port with similar characteristics. Thus, the main characteristics can be inputted, such as ballast water storage capacity (m^3) and type, treatment process (chemical, physical or biocide) and treatment rate (m^3/h), as well as operational characteristics such as accessibility constrains, tide, currency, number of berths, equipment rates, fleet profile and ballast volume on board.

Simulations will be carried out considering the iron ore port due to its operational characteristics and number of vessels. Moreover, other ports in Brazil with similar features will be selected and analyzed through the simulation model.

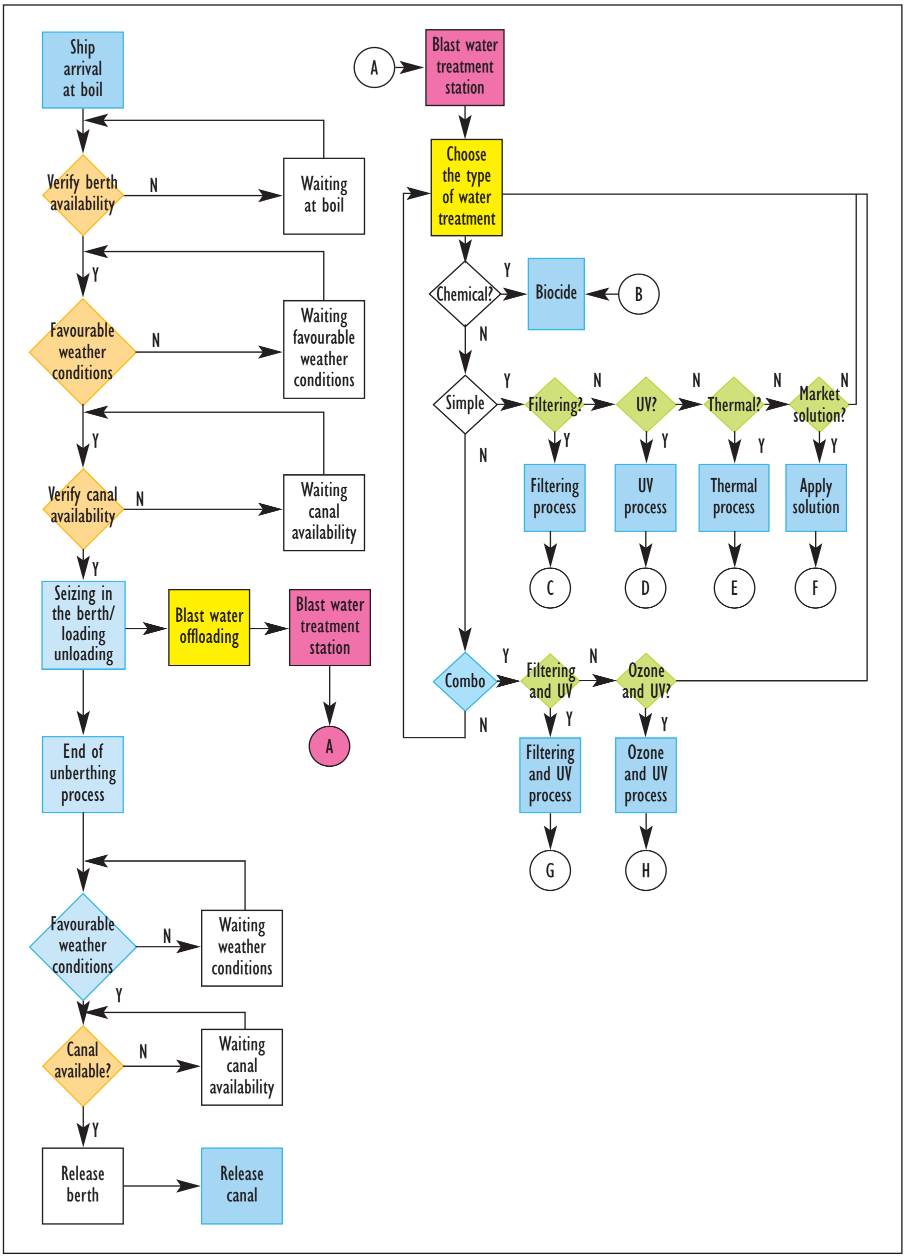

Figure 5– Flowchart of conceptual model

Case Study

The chosen port is located in Itaguaí, at the Bay of Sepetiba – RJ. The terminal has one pier with a capacity to receive ships of up to 230,000 DWT, with draft of 17.5 meters.

The operational features of the berth are as follows:

- 1 main conveyor operating at 9,000 t/h (nominal rate)
- 1 ship loader operating at 10,000 t/h (nominal rate)

The terminal provided all database necessary to verify the simulation model results. The following data was analyzed during this step:

- The ship arrival is an exponential distribution with a mean of 2.19 days;
- The demand is around 25 million tons per year. The ships generated by the model are able to carry 25 million tons after 1 simulation year;
- The number of vessels generated in the simulation was similar to the number of vessels received by the terminal (around 166 ships per year). The fleet profile is: 5% of Handmax, 25% of Panamax, 60% of Capesize and 10% of Large Cape;
- The water pumping rate are as follows:
  - Handsize: 2,504 m^3/h
  - Panamax: 1,875 m^3/h
  - Capesize: 4,030 m^3/h
  - Very Large Cape: 5,236 m^3/h
- The average loading rate is 3,800 tph including losses, and it varies according to the ship class. A triangular distribution was adopted.
- The average queuing time obtained was 4 days, which is approximately the same of the terminal average queuing time, as well as the occupancy rate, around 83%.
- The total volume of ballast water received by the terminal was 7.5 million m^3 per year, considering that each vessel was carrying 30% of its DWT in ballast condition. The maximum water ballast volume reached in the tank was 80,000 m^3, considering a treatment rate of 1,000 m^3/h;

The treatment type is characterized, in the model, only by the treatment nominal rate (in tons per hour), which can reach up to 4,600 tph, such as Ecochler equipment.

Conclusions

There are few studies regarding ballast water treatment when it comes to installation costs of these systems (storage tanks, pipelines, maintenance and operation). In addition, there are no studies proving the disadvantages of this system. This study focused on a small iron ore port, in comparison with Brazilian ports. Considering the simplifications assumed in modeling, the collection, storage and treatment of ballast water by an onshore station did not affect the operation of this terminal.

Moreover, deballast of the iron ore ships occurs concomitantly with the loading process. The vessels follow the loading plan, obeying the loading sequence of the holds. Thus, the deballast time is less than the total loading time of the vessel, since the volume of ballast is 30% of DWT. However, the cargo loading may be interrupted since the pumping rate is usually lower than the loading rate. The treatment rate has an important influence on the level of service and on the capacity of onshore tanks. The higher the treatment rate, the smaller is the on-land tanks.

In order to perform a comprehensive assessment, the model may be simulated in larger terminals, with more constraints such as tides, currents or other access constrains. In addition, an economic evaluation should be performed, considering the use of land, area for ballast tanks and adjustments to the berths and equipment, as well as the suitable method for onshore treatment of ballast water. Thus, a cost per cubic meter will be determined, and it will be compared with different alternatives, such as on-board treatment.

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Ballast Water Technology Availability – An Update

Captain Graham J Greensmith[*]

Abstract
This paper is an overview of ballast water treatment systems, their availability, the approval process and the status of system approvals in accordance with the International Convention for the Control and Management of Ship's Ballast Water and Sediments. An assessment is provided of the regulatory mechanisms and available technology for Ballast Water treatment, the IMO approval processes and those treatment systems currently approved.

Key words: Ballast Water Management, Treatment Systems, Approvals

1 Introduction

The International Convention for the Control and Management of Ships' Ballast Water and Sediments in regulation B-3 requires that:

> 1. *A ship constructed before 2009:*
>
> *.1. with a Ballast Water Capacity of between 1500 and 5000 cubic metres, inclusive, shall conduct Ballast Water Management that at least meets the standard described in regulation D-1 or regulation D-2 until 2014, after which time it shall at least meet the standard described in regulation D-2;*
>
> *.2. with a Ballast Water Capacity of less than 1500 or greater than 5000 cubic metres shall conduct Ballast Water Management that at least meets the standard described in regulation D-1 or regulation D-2 until 2016, after which time it shall at least meet the standard described in regulation D-2.*
>
> 2. *A ship to which paragraph 1 applies shall comply with paragraph 1 not later than the first intermediate or renewal survey, whichever occurs first, after the anniversary date of delivery of the ship in the year of compliance with the standard applicable to the ship.*

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[*] Lead Specialist, Lloyd's Register, 71 Fenchurch Street, London.

3. *A ship constructed in or after 2009 with a Ballast Water Capacity of less than 5000 cubic metres shall conduct Ballast Water Management that at least meets the standard described in regulation D-2.*

4. *A ship constructed in or after 2009, but before 2012, with a Ballast Water Capacity of 5000 cubic metres or more shall conduct Ballast Water Management in accordance with paragraph 1.2.*

5. *A ship constructed in or after 2012 with a Ballast Water Capacity of 5000 cubic metres or more shall conduct Ballast Water Management that at least meets the standard described in regulation D-2.*

6. *The requirements of this regulation do not apply to ships that discharge Ballast Water to a reception facility designed taking into account the Guidelines developed by the Organization for such facilities.*

7. *Other methods of Ballast Water Management may also be accepted as alternatives to the requirements described in paragraphs 1 to 5, provided that such methods ensure at least the same level of protection to the environment, human health, property or resources, and are approved in principle by the Committee.*

In other words eventually all ships will be required to use an approved ballast water "treatment system".

The various dates in regulation B-3 were purposely included in the Convention in order to set a goal for systems manufacturers to aim for, as it was it being felt that without such a goal there would be little incentive to invest developing systems.

At the time of drafting the Convention there where few viable treatment systems however since adoption of the Convention numbers have rapidly grown. This has been achieved by the commitment of the manufactures and researchers in developing systems and bringing them through the complex approval process and then to the market. Often forgotten in this are those ship-owners and operators that had the courage to work with manufacturers and have allowed prototype systems to be installed on there ships. By doing so owners have enabled valuable in service data to be gathered and proved that these systems are capable of operating in the harsh environment found onboard ships.

2 An Overview of Available Technologies

There are a large number Ballast Water Treatment Systems either available or under development at the time of writing with over 50 manufacturers involved. Treatment systems employ various processes and methods to treat ballast water to meet the IMO required standards. Many use a filter or hydro-cyclone to remove larger organisms in combination with one or more of the disinfection methods shown in the table below.

2.1 Treatment Processes

Table 1. Ballast Water Treatment Process Types

Physical Solid-liquid Separation	**Disinfection**	
	Chemical	**Physical**
Filter	Chlorination	De-oxygenation
Hydrocyclone	Electro chlorination	Ultraviolet
Coagulant	Chlorine dioxide	Ultrasonic
	Hydrogen peroxide	
	Peracetic acid	
	Vitamin K	
	Ozonation	

There are advantages and disadvantages to each treatment and different systems will suit different ships types and sizes.

2.2 The Approval Process

Technologies developed for ballast water treatment are subject to approval through specific IMO processes and testing guidelines designed to ensure that such technologies meet the relevant IMO standards (Figure 1), are sufficiently robust, have minimal adverse environmental impact and are suitable for use in the specific shipboard environment.

A company offering a treatment process must have the process approved by a Flag Administration. In general, the manufacturer will use the country in which it is based to achieve this approval. Although, this is not a specific requirement and some companies may choose to use the Flag State where the testing facility is based or the Flag State of a partner company. In general the Flag State will probably choose to use a recognised organisation – such as a classification society – to verify and quality assure the tests and resulting data.

The testing procedure is outlined in the IMO's Guidelines for Approval of Ballast Water Management Systems (frequently referred to as the 'G8 guidelines'). The approval consists of both shore based testing of a production model to confirm that the D2 discharge standards are met and ship board testing to confirm that the system works in service. These stages of the approval are likely to take between six weeks and six months for the shore based testing and six months for the ship based testing.

Further requirements apply if the process uses an 'active substance' (AS). An AS is defined by the IMO as 'a substance or organism, including a virus or a fungus that has a general or specific action on or against harmful aquatic organisms and pathogens'. For processes employing an AS, basic approval from the GESAMP Ballast Water Working Group (BWWG), a working committee operating under the auspices of IMO, is required before shipboard testing proceeds. This is to safeguard the environment by ensuring that the use of the AS poses no harm to the environment. It also prevents companies investing heavily in developing systems which use an active substance that is subsequently found to be harmful to the environment and is not approved.

The GESAMP BWWG assessment is based largely on data provided by the vendor in accordance with the IMO approved Procedure for Approval of Ballast Water Management Systems that make use of Active Substances (frequently referred to as the 'G9 Guidelines').

Basic Approval is the first step in the approval process when using an active substance. In most cases basic approval has been granted with caveats and the request for further information for the purposes of Final Approval. Basic Approval is thus an 'in principle' approval of the environmental impact of an active substance, which may then expedite inward strategic investment or marketing within the supplier's organisation and allow testing of a system at sea. After Basic Approval for active substances, treatment systems can be tested both on land and onboard ship according to the IMO Guidelines for Approval of Ballast Water Management Systems ('commonly known as the G8 guidelines'). Final Approval by the GESAMP BWWG will take place when all testing is completed. Once final approval is granted by GESAMP, the Flag Administration will issue a Type Approval certificate in accordance with the G8 guidelines in accordance with the aforementioned guidelines. If the process uses no active substances the Flag Administration will issue a Type Approval certificate without the need for approval from the GESAMP BWWG.

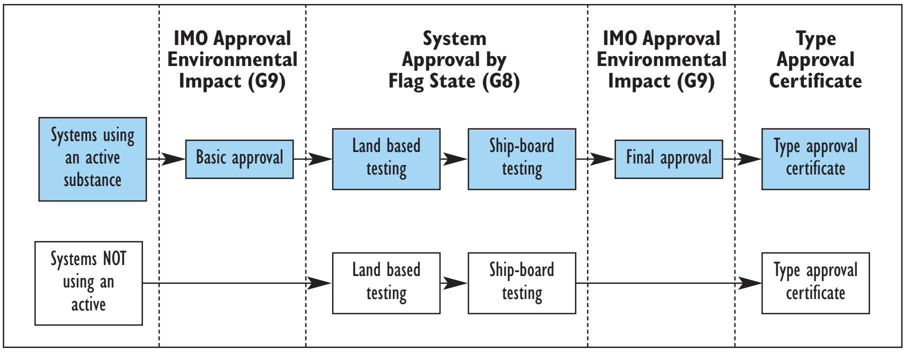

Figure 1. IMO Approval prosess

2.3 An Overview of Current System Approvals

At the time of writing nearly 50 manufactures of technologies have been identified who are at various stages of development of their systems. Of these, approximately 40 appear to have systems that appear to be either in the approval process or are likely to be approaching the stage where they could enter the approval process. The remainder are either a very early stage or no useful information on the systems could be found.

To date, 16 Systems have achieved basic G9 approval with a further 4 expected at MEPC 60, while 8 Systems have achieved final G9 approval with a further 2 expected at MEPC 60 in March 2010.

GESAMP will hold another meeting in May 2010 to consider further applications for final and basic approval.

At the time of writing, 8 systems had been approved under the G8 guidelines (MEPC.174(58) Guidelines for the Approval of Ballast Water Management Systems or its predecessor MEPC.125(53). Systems must be approved in accordance with the G8 guidlines to enable ships to be in compliance with the Convention.

2.4 A View of Future Approvals

Up to 6 to 8 systems may have completed land and ship tests up to end 2009 with some awaiting G9 approval in 2010, perhaps there may be as many as another 10 that could gain G8 approval. It is, however, difficult to predict exactly how many systems will achieve G8 approval over the next 2 to 3 years.

GESAMP can only deal with limited submissions per meeting, However, the number of GESAMP meetings per year has increased to meet this demand such that one meeting will be held in May 2010 with the possibility of further meeting(s) later in the year.

It can expected that more G8 and G9 approvals will be granted over the short and medium term perhaps there may be as many as 20 or even 30 G8 approvals by early 2012. Should this number of approved systems be reached in that time, it would most certainly reduce the fears of some that there might still be insufficient approved systems available. However, even if there were more approved systems available in the next few years, the question remains if the manufacturers can produce the numbers of treatment systems required to meet demands.

2.5 The IMO View

The IMO at MEPC 59 concluded that ballast water treatment technologies are currently available for ships built in 2010. The IMO will undertake a further review of technologies availability at MEPC 61 and at future meetings, to assist the IMO in deciding if the dates in the BWM Convention can be met.

More approved technologies will be available in the near future. However, the question remains there will be sufficient approved systems available to meet the demand, and will those systems have a treatment capacity large enough for ships with high ballast water pumping capacities.

One reason that may have delayed countries from ratifying the Convention was the lack of availability of approved systems. This may not now be such a concern given the steady increase in ratifications in the last one to two years.

For the ship owner the increasing number of available systems and approvals means greater choice and perhaps ease of system selection. However, ship owners still face significant problems in choosing the right system for their ships.

3 Conclusion

Since the adoption of the Convention in 2004 there has been a great deal of progress towards approving treatment systems. In addition, much has been learnt about the approval process and knowledge learned has been used to amend the guidelines. This learning process will, of course, continue for a long time to come and the knowledge gained will be used to further refine the approval requirements and processes. The number of available systems and approvals will no doubt grow in the coming years. However, the acid test of these systems will be through their use over time onboard ships.

Ballast Water Treatment Ashore Brings More Benefits

Patrick Donner[*]

Abstract

This paper first presents a brief overview of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention), 2004, the status of ratification and its applicability to ships. After introducing the main methods for ballast water treatment required by the BWM Convention the paper discusses why port-based reception and treatment facilities would offer many benefits compared to treatment of ballast water on board – shore-based facilities would be more efficient and provide both economical and environmental advantages. The choice to impose the ballast water treatment obligations on the ships and their crews may have been the solution of least resistance, but it may also be the solution, which represents the least efficiency and the greatest overall cost.

Key words: Ballast Water, Reception Facilities, Treatment Ashore, Desalination, Efficiency.

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1 Introduction

Although the first observations of invasion of alien aquatic species were made over a century ago, it was not properly identified as a problem until the 1970s. The issue was recognised already in the United Nations Convention on the Law of the Sea (UNCLOS), 1982, which in Article 196 states:

> *States shall take all measures necessary to prevent, reduce and control pollution of the marine environment resulting from the use of technologies under their jurisdiction or control, or the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto.*

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[*] Associate Academic Dean, World Maritime University, P.O. Box 500, 201 24 Malmö, Sweden.

Thus, the obligation to prevent and control the introduction of alien species into the marine environment basically rests with each coastal state. In principle, the introduction of alien species into a new marine environment through ballast water could be prevented in several ways. One way would be to design ships, which do not need or use ballast water, but since such ship designs do not exist commercially today, this is only a solution in theory and even if such ship designs were to be developed, it would take a minimum of 30 years to replace the entire world fleet. Using fresh water for ballast does not in itself eliminate the risk of transfer of alien species and is not feasible due to the fact that fresh water is a scarce commodity in most places. Similarly, pumping ballast water ashore to be stored and used again as ballast on other ships does not present a viable solution simply due to a common problem for shipping – imbalances in trade. As far as ballast water is concerned, more often than not ports are either import or export ports, which mean that ships either arrive in ballast for loading or arrive with cargo and leave in ballast. There are some major ports, which have cargoes coming in as well as cargoes going out, but even then, ships leaving in ballast would be destined for other ports than those from which the ballast water originated, so the water would still need to be treated to eliminate harmful aquatic organisms.

The issue was brought onto the agenda of the International Maritime Organization (IMO) in the 1980s, eventually resulting in the adoption of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) in 2004. The BWM Convention is a complex instrument covering operational issues regarding exchange and management of ballast water and record keeping as well as technical and scientific issues regarding performance standards and issues relating to administration and enforcement, such as survey, certification, inspection and penalties for violations – a complex set of regulations to deal with a complex set of problems. In the BWM Convention practically all operational obligations for ballast water management were put on the ships, rather than the ports, with states limiting their role to policing and enforcing the rules. The BWM Convention does in fact, in Article 5, oblige states to provide reception facilities ashore, but only for reception of sediments in connection with cleaning or repair of ballast tanks and reception facilities for ballast water as such are only hinted at. Consequently, the methods contemplated by the BWM Convention for treating ballast water and sediments focus on methods to be applied onboard the ships carrying the ballast water.

2 The BWM Convention – Entry into Force and Applicability

The time taken to raise awareness of the need for action and then for preparation of the convention was rather long and with an additional, relatively long transition period allowed for implementation in stages, it could be said that when the BWM Convention is fully implemented, it will have been long overdue. However, at the same time it could be said that the adoption of the convention was premature in the sense that it prescribes performance standards for ballast water management, using technical systems, which at the time of adoption of the convention did not exist, at least not for installation and use onboard ships. The assumption, or hope, was that the necessary technology would be developed by the time the need arose.

The BWM Convention has not entered into force yet, but in the last year or two the rate of ratification has increased significantly. Only two years ago the number of ratifying states was only 10, but the current number stands at 21, representing 22.63% of the world merchant fleet tonnage. Since the BWM Convention will enter into force 12 months after ratification by 30 states, representing 35% of the world merchant shipping tonnage (Article 18), it is now safe to assume that this level of ratification will be achieved in the not too distant future, but even so, one cannot reasonably expect entry into force before 2012, at the earliest. However, the BWM Convention contains earlier dates, which will have consequences for ships.

For example, take a ship with a ballast water capacity of less than 5,000 cubic metres. If the ship was constructed before 2009, it can continue to apply ballast water exchange during the transition period until 2014 and in some cases even 2016, but will have to comply with the ballast water management provisions and meet the performance standards after that. However, if that ship was constructed in or after 2009, it will have to meet the performance standards as soon as the BWM Convention enters into force. It is not unusual or illogical that new ships have to comply with regulations immediately while existing ships are given a grace period to allow for retrofitting of necessary equipment, but in the present case, the BWM Convention will impose requirements on ships, which will have been ordered and built well before the entry into force of the convention.

The BWM Convention will apply to practically all ships. Naval ships are excluded and ships, which only operate within the waters of a state party, may also be excluded as well as ships that are designed or built not to carry ballast water at all. For all practical purposes this means the convention will apply to almost all cargo carrying merchant vessels.

The world fleet consists of over 90,000 vessels. Roughly half of this number consists of fishing vessels and most fishing vessels are small and operate only in local waters so they may fall outside the scope of the BWM Convention. However, that still leaves upwards of 50,000 vessels, which will have to comply with the BWM Convention and although many smaller cargo vessels trade within limited areas where the risks of transferring harmful invasive species are limited, they will still need to have appropriate ballast water treatment equipment installed, or retrofitted, in order to be commercially viable. This represents a massive undertaking and investment for the entire shipping industry.

3 Ballast Water Management under the BWM Convention

The BWM Convention has an Annex entitled "Regulations for the control and management of ships' Ballast Water and Sediments" and Section D of the Annex contains the "Standards for ballast water management," which are defined in terms of a Ballast Water exchange standard (Regulation D-1) and a Ballast Water performance standard (Regulation D-2).

3.1 Ballast Water Exchange

When the BWM Convention was adopted, there were no approved methods of achieving the prescribed performance standards. Therefore, at that time the only method for preventing the transfer of harmful alien aquatic species from one region to another through ballast water was to exchange the ballast water en route in deep waters. However, ballast water exchange is not an ideal solution as it only reduces, but does not completely eliminate the risk of transfer of living organisms. In fact, the design and construction of the ballast tanks have a great influence on how effectively the ballast water is actually replaced. Furthermore, ballast water exchange on the high seas exposes the ship to potential dangers both in terms of physical stresses on the hull and potential loss of stability. Naturally, the procedure must be carefully performed and monitored, but erring is human and there have been recorded incidents where ships have come close to foundering due to loss of stability during a ballast water exchange procedure.[1] There are no records available regarding structural damage or increase of metal fatigue caused by stress forces due to ballast water exchange procedures – but they are almost certain to have occurred.

According to Regulation A-3 in the Annex to the BWM Convention, the requirements do not apply in some situations. For example, it does not apply to discharge of ballast water in the same location where it was originally taken or to uptake and discharge of the same ballast water on the high seas. This is perfectly logical as there would be no transfer of aquatic organisms from one location to another in these cases. Furthermore, the requirements do not apply to accidental discharges resulting from damage to a ship or its equipment or when it is necessary to take or discharge ballast water to avoid or minimise pollution, which are also easily justifiable exceptions. Finally, the requirements do not apply to "uptake or discharge of Ballast Water or Sediments necessary for the purpose of ensuring the safety of a ship in emergency situations or saving life at sea". Consequently, one could argue that if adverse weather conditions were to prevent a ship from undertaking ballast water exchange on the high seas without prejudicing the safety of the vessel and its crew, it would, at least in principle, be exempted from the requirements of the

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[1] For example, on 23 July 2006 the M/V Cougar Ace, a 55 328 GT car carrier, developed a list of up to 85 degrees during a ballast water exchange operation while en route from Japan to Canada and the United States (http://en.wikipedia.org/wiki/MV_Cougar_Ace).

BWM Convention. This makes perfect sense, of course, but on the other hand, one can easily imagine that Port State Control inspectors and other "desk drivers" involved in the implementation and enforcement of the convention might second-guess the Captain's judgment and question the decision not the perform the ballast water exchange.

However, ballast water exchange procedures can never ensure a complete removal of all organisms so it is not a fully effective method for prevention of transfer of harmful aquatic organisms and, in any case, it is only an interim solution, which will be allowed for some ship types, but only until 2016.

3.2 Ballast Water Treatment

There are a number of methodologies to treat ballast water in order to limit, eliminate or render harmless aquatic organisms and sediments in ballast water to the extent defined in the ballast water performance standard. The treatment process could be mechanical, physical, chemical or electrical, but the various processes cannot be discussed within the scope of this paper.

3.3 Implications – and the Alternative

The obvious implication is that appropriate equipment for treatment of ballast water must be installed on most ships and that equipment will then have to be properly operated by the crew who also need to maintain accurate records of all ballast water operations undertaken. Although most ships, irrespective of size, carry ballast water, the problems facing ships in effectively managing the ballast water tends to differ depending on the size of the ship. For a smaller ship the amount of ballast water is obviously less, but at the same time, smaller ships often carry cargoes over shorter distances, so time may be a constraining factor in achieving effective treatment of the ballast water. On the other hand, large ships, such as crude oil tankers, large dry bulk carriers and car carriers are mostly operated on long routes, which provide more time to treat the ballast water, but on the other hand, they have to treat huge volumes of ballast water. If the technology chosen treats ballast water only while ballast is taken on, capacity constraints might add considerably to the time the vessel has to stay in port before departure and this could have significant effects on the cost of operation/earning capacity of the vessel.

The issues may be best illustrated by looking at the largest ships carrying cargo in bulk – tankers and dry bulk carriers. These ships almost invariably operate one-way services; they carry primarily crude oil, iron ore or coal from a limited number of loading ports and subsequently, having delivered their cargoes, they return to the same limited number of ports in ballast. It is not too difficult to imagine that these relatively few ports for export of bulk commodities could be equipped with reception facilities for ballast water so that a ship arriving in ballast would discharge all its ballast water ashore. It is true that the volume of ballast water on such ships is measured in the tens of thousands of tons so that the envisaged reception facility would need to have capacity to receive and store huge amounts of water. On the other hand, the volume of ballast is no greater than that already carried on board the ships, so building storage capacity commensurate with the cargo handling capacity of the port is not an unreasonable undertaking.[3] Terminals that export oil already have storage tanks for much greater volumes of liquids than that as the ships' cargo carrying capacity is much greater than the amount of ballast they carry. The storage tanks (or basins) would certainly need to be constructed, but the problem should not be exaggerated. One quick way to provide the storage capacity would be to convert existing very large crude carriers (VLCCs) into reception facilities, which would provide the extra benefit of reducing the current oversupply of tankers. One such tanker should be able to handle the ballast water from several arriving ships.[3] Another argument for port-based reception and treatment facilities is that the received ballast water could be desalinated, which is a relatively effective treatment method in itself, and after some further treatment like chlorination it could provide fresh water for household use or irrigation – a scarce and valuable commodity in many places. Building a desalination plant with sufficient capacity could not be a problem considering the fact that the largest cruise ships in operation have installed capacity for desalination of more than 3,000 m^3 of seawater per day. From this perspective, the failure to provide port-based ballast water reception and treatment facilities seems like a missed opportunity.

4 Ballast Water Management Onboard or Ashore?

It is true that any ballast water received into a port-based reception facility would still need to be treated before it can be released into the environment. The methods for treatment of the ballast water may be the same as those contemplated by the BWM Convention, but the difference lies in the effectiveness of the processes employed where ship-based installations would appear to have several disadvantages compared to treatment of ballast water ashore.

Firstly, it is contended that a ballast water reception and treatment facility ashore would offer economies of scale. Assuming that there would be ships arriving at the port in ballast on a regular basis, the ballast water reception and treatment facility could operate more or less continuously, which would appear to be more effective

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[2] A simple expression of the necessary storage capacity is: the number of ships arriving per day times the volume of ballast water on each ship divided by the daily capacity of the treatment equipment.

[3] VLCCs and Capesize bulk carriers would typically have ballast capacity corresponding to approximately one third of the deadweight capacity, i.e. 100,000 and 50,000 m^3, respectively while the deadweight of a VLCC is 250,000–325,000 dwt and a Capesize bulk carrier 150,000–185,000 dwt.

and rational than only operating the equipment from time to time when a vessel is taking, carrying or discharging ballast water.

Secondly, officers and crew of merchant ships are not experts in the fields of marine biology or the physical, chemical or biological processes that will be used in the treatment of the ballast water. The shipping companies will certainly provide training for their crews to make them understand the objectives of ballast water management and to enable them to use the equipment installed onboard the ships – the IMO Guidelines (IMO 1997) for implementation of the BWM Convention prescribe this. However, officers and crew do move from one employer to another and even within the same company they are often rotated between different ships in the fleet. Since different ships will have equipment from different suppliers and even equipment applying different ballast water treatment processes, even within the same fleet, the Ballast Water Management Plan must be specific to each ship and the crew has to be familiar with the Ballast Water Management Plan for the specific ship on which they serve. It is, therefore, rather obvious that the people who are charged with the ballast water management onboard will have adequate knowledge, but not expertise in the optimal use of the ballast water treatment equipment installed. Some of the ballast water treatment methods, which have received final approval from the IMO make use of chemicals or biocides, so depending on the chosen method of ballast water treatment, issues of occupational safety and health for the crew may also arise.

One further complication for onboard ballast water treatment is the fact that the regulatory requirements will not be uniform. The states forming the Regional Organization for the Protection of the Marine Environment (ROPME) in the Arabian Gulf[**] have already decided to give effect to the ballast water rules from 1 November 2009 (Hart 2009). Another example is the United States, which have introduced legislation, which requires a Vessel General Permit, which aims to eliminate all forms pollution from ship covering 26 different possible discharges from ships. With regard to ballast water the rules differ from the BWM Convention and require a much higher “kill standard” than the convention. These rules came into effect on 19 September 2009, but are apparently not fully implemented yet (Grey 2009). Such unilateral regulations impose varying and sometimes additional requirements on the crew in the management of the ballast water.

By contrast, in a shore-based facility permanent employees who could, therefore, be much better trained to use and operate that particular facility would operate the equipment and they would always be operating the same equipment. Furthermore, they would presumably be primarily or specifically tasked with the operation of the ballast water treatment facility rather than having ballast water treatment

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[**] Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates.

as only one of a multitude of tasks relating to the safe operation of the ship, some of which would probably be perceived as having higher priority or be more important to the safety and wellbeing of the crew themselves.

5 Conclusion

According to UNCLOS, the responsibility for preventing the introduction of invasive species into the marine environment rests with the State Parties and the prevention is also very much in the interest of the various coastal states. However, when it comes to devising regulations to protect the coastal environment from the potential harmful effects of ballast water, the regulators have imposed almost all obligations on their subjects, or rather, their customers. One very unfortunate effect of this is that there will inevitably be instances where ships' masters and officers will face criminal charges for violations of the ballast water management regulations. The officer in charge of a ballast water operation must record it fully and accurately and the master will have to sign each page of the Ballast Water Record Book, thereby certifying the accuracy of the records. A single erroneous entry may – or will – be seen as presenting falsified evidence to the inspecting authorities with potentially long prison sentences to follow. There have been many examples of this with regard to the Oil Record Books and it is hard to believe that the Ballast Water Record Book will be any different.

The idea of shore-based reception facilities for ballast water is not new, but it appears never to have been considered as a viable option, probably due to lack of interest or willingness of states to consider any option, which would require investments by (or in) the states themselves. As is so often the case, it was easier to impose the obligations on the shipping industry, which does not get to vote on the issue, but eventually will have to comply with any new regulations that are put into place. From the perspective of protecting the environment, that is probably just as well, because otherwise ratification would probably have been even slower and implementation inadequate. The obligation for states to ensure the availability of reception facilities for various substances, required by the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), is a case in point. Even if the ports had been obliged to provide reception facilities, the cost to recover the investment and cover operating costs would certainly have been transferred to the shipping sectors through fees, but in terms of overall cost effectiveness imposing the ballast water treatment obligation on ships appears unfortunate. Surely, the total investment in reception and treatment facilities in a few thousand ports around the world would have been less than fitting and retrofitting the necessary equipment on nearly 50,000 ships and it appears reasonable to assume that the same applies to the operating costs.

The decision to place the obligations to treat ballast water onboard the ships can be seen as representing the solution of least resistance – the decision makers decide to make everyone else do the job, pay the cost and suffer the consequences for any failure to do so. Unfortunately, this approach may also represent the least efficiency and greatest overall cost.

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Ballast Water Management in the Baltic Sea

Monika Stankiewicz[*], Reetta Ljungberg[**] and Markus Helavuori[***]

Abstract

The Helsinki Commission (HELCOM), comprising of nine Baltic Sea countries and the European Commission, is working to protect the Baltic Sea from all sources of pollution, including biological pollution from alien species. HELCOM Baltic Sea Action Plan, singed by Contracting States' environment ministers and EU, includes a Road Map for harmonized implementation and ratification of the International Convention for Control and Management of Ships' Ballast Water and Sediments, with an overall aim of all Baltic Sea countries ratifying the Convention latest in 2013.

HELCOM has compiled information on the alien species present in the Baltic Sea and species that might still invade from other sea regions, possibly impairing or damaging the environment, human health, property or resources.

The HELCOM MARITIME Group has decided in its 8th meeting (2009) that Ballast Water Exchange is not a suitable management option for intra-Baltic shipping, and the Baltic Community has taken action with OSPAR Commission to promote voluntary exchange of ballast water outside the Baltic Sea and in OSPAR areas meeting the Convention requirements.

Further HELCOM work will focus on how to assess risks related on intra-Baltic voyages, and on following developments of ballast water treatment technologies suitable for the small and semi-enclosed Baltic Sea.

Key words: Helsinki Commission, Ballast Water, Management, Alien Species, Shipping, Ballast Water Management Convention.

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[*] Professional Secretary, Helsinki Commission (Baltic Marine Environment Protection Commission), Helsinki, Finland.

[**] Project Researcher, Helsinki Commission (Baltic Marine Environment Protection Commission), Helsinki, Finland.

[***] Maritime Inspector, Finnish Transport Safety Agency, Helsinki, Finland.

1 Introduction

1.1 Helsinki Commission

For more than three decades, the Baltic Marine Environment Protection Commission, more usually referred to as the Helsinki Commission or HELCOM, has been acting as the main environmental policy-maker for the Baltic Sea area by developing specific measures to protect and conserve its unique marine environment. The Helsinki Commission, working through intergovernmental co-operation between all the nine Baltic Sea coastal countries (Figure 1) and the European Community, has achieved many environmental objectives in the course of the past 30 years, thus validating the belief that the deterioration of the environmental status of one of the most polluted seas in the world can be arrested and the state of the sea improved.

HELCOM is the governing body of the "Convention on the Protection of the Marine Environment of the Baltic Sea Area" (Helsinki Convention), which has been signed by all the Baltic Sea coastal countries already in 1974, and further amended in 1992. It is the first international agreement in the world to cover all sources of pollution, whether originating from land, sea or air. The Helsinki Convention covers pollution from the whole surrounding drainage area, which comprises more than 1.7 million km^{-2}.

HELCOM work focuses on curbing eutrophication, preventing chemical pollution involving hazardous substances, improving maritime safety and accident response capacity, and halting habitat destruction and decline in biodiversity. HELCOM efforts to reduce pollution, and actions taken to repair the damage already caused to the marine environment, have led to prominent improvements in many sea areas.

In 2007, the environment ministers of the Baltic Sea countries and the European Commission adopted the HELCOM Baltic Sea Action Plan (BSAP) [1] with concrete and meaningful actions to solve the major problems which have a negative impact on the Baltic Sea, and thus aiming to achieve a healthy Baltic Sea by 2021. The BSAP has been seen as a first ever attempt by a regional seas convention to incorporate the ecosystem-based approach into the protection of the marine environment.

The HELCOM BSAP contains, among other topic-specific sections, a Road Map towards a harmonized implementation and ratification of the International Maritime Organisation's (IMO) "International Convention for Control and Management of Ships' Ballast Water and Sediments" (BWM Convention) in the Baltic Sea area. This section in the Action Plan includes 17 specific measures and a timetable for their implementation. These specific measures aim to reduce a risk posed by international shipping; the spread of alien species to and within the HELCOM maritime area through ballast water. Over 100 non-indigenous and cryptogenic species, or most often referred to as alien species, have been encountered in the Baltic Sea environment to date and the numbers of new introductions have been rising (Figure 2).

Figure 1. Map of the HELCOM area and the Baltic Sea basins. (Source: HELCOM)

So far 21 countries have become parties of the BWM Convention, bringing around 23% of world's shipping tonnage under the Convention [3]. To bring the Convention internationally into force, ratification by 30 countries is required, representing at least 35% of the world's tonnage. A number of countries globally and around the Baltic Sea are close to accession to the Convention in 2010. The HELCOM Contracting Parties account in total for about 5% of the world's shipping tonnage (Table 1). All the HELCOM Contracting States have agreed to ratify by 2010, or at the latest by 2013, the IMO BWM Convention.

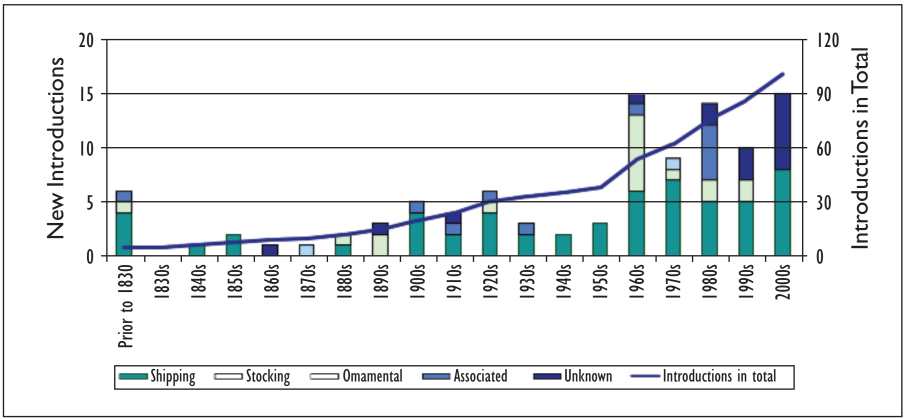

Figure 2. Numbers of new alien species introduced (various vectors) into the Baltic Sea prior and since 1830 and the accumulating numbers of all encountered alien species. (Source: HELCOM [2])

Table 1. The Gross Tonnage of shipping (2008) in HELCOM Contracting Parties and country-wise share (%) of the World's Shipping Tonnage (Source: UNTAC, Review of Maritime transport 2008)

Country	**Gross Tonnage 2008**	**Percentage of World's Tonnage**
Germany	15,282,810	1.84
Denmark	10,569,967	1.27
Russian Federation	7,572,020	0.91
Sweden*	4,389,273	0.53
Finland	1,564,949	0.19
Lithuania	423,708	0.05
Estonia	363,492	0.04
Latvia	289,703	0.03
Poland	212,940	0.03
Total	40,668,862	4.89

1.2 Information Gathered on Alien Species in the Baltic Sea

In order to reach harmonized implementation of BWM Convention in the Baltic Sea countries, HELCOM has compiled a comprehensive list [4] of all alien species encountered in the Baltic Sea. The aim of listing the species is to provide background information for further consideration of a selection of species of particular relevance in the context of the BWM Convention and the related IMO Guidelines. The list is also to serve the information needs of other marine regions and has been developed based on readily available information in the Baltic Sea and Europe, including the Baltic Sea Alien Species Database [5], the DAISIE database [6], a Swedish web site on alien species in Swedish seas and coastal areas [7] and the NOBANIS database [8]. This HELCOM list of non-indigenous and cryptogenic species includes information on the species regarding their origin, distribution in Baltic Sea basins, first observations and current status, characteristics, pathways (or vectors) of introduction into the Baltic and potential impacts in the Baltic Sea. At this stage the list does not include any native species that have the potential to affect human health or result in substantial ecological or economic impacts when transferred to other regions, although information on these species is needed according to Guideline G7 (in IMO document MEPC.162(56)) [9]. Such information will be gathered during 2010.

Another list [4] of Target species of special concern has been gathered by HELCOM. These species may yet be introduced to the Baltic Sea from other marine areas, or already occur in parts of the Baltic Sea and may potentially impair or damage the environment, human health, property or resources. This list has been developed based on the report by Leppäkoski and Gollasch (2006) [10] and information received from the Black Sea Commission, the OSPAR Commission (Convention for the North-East Atlantic) and the Great Lakes Commission. Because not all species in world-wide marine areas can be evaluated, the HELCOM Target Species list covers as a first step the relevant species from the North Sea region, the Ponto-Caspian region and the North American Great Lakes. These high risk donor regions are areas with dense maritime traffic to the Baltic Sea and with similar climate and salinity ranges as in the Baltic Sea. In the past these regions are also known to have donated alien species to the Baltic Sea. It is widely accepted that species which have invaded elsewhere, are likely to invade other areas too. A simple and efficient way of identifying target species is therefore to concentrate on non-indigenous species in the high risk donor areas. This information from the three regions have then been narrowed down to target species by excluding species already present and established in the Baltic Sea, and to some extent by excluding those that have characteristics that make them unlikely invaders to the Baltic Sea.

The HELCOM list of Target species aims to identify species relevant for risk assessments, which are required according to Regulation A-4 of the BWM Convention, if any exemptions are to be granted from ballast water management. The risk assessments should follow IMO Guidelines (G7). Which outlines three risk assessment methods: environmental matching risk assessment, species' biogeographical risk assessment and species-specific risk assessment.

An indicator on the numbers of alien species in Baltic coastal and open sea areas has also been developed to show the distribution of alien species on a finer scale in different parts of the Baltic. For the first time ever alien species are being taken into account in ecological status assessments in the Baltic Sea, within the HELCOM HOLAS Project. The project is assessing the ecological status of the marine environment of the Baltic Sea holistically combining the four aspects of the Baltic Sea Action Plan – eutrophication, biodiversity, hazardous substances and maritime traffic – also incorporating socio-economic factors in the assessment. The assessment will be made available for the 2010 HELCOM Ministerial Meeting.

2 Ballast Water Management Concept in the Baltic Sea

The Baltic Sea is a unique semi-enclosed marine area, with shallow waters and high anthropogenic pressures and distinctive gradient from freshwater (<0.5 psu) to saline water (35 psu) on north to south axes and from shore to open sea. These characteristics demand region specific solutions to efficiently prevent introductions and spreading of alien species.

Distances within the Baltic Sea are generally short, in comparison to oceanic shipping voyages, and invasive species have a higher likelihood of surviving on intra-Baltic voyages. Species are also likely to spread within the Baltic Sea to proportionally wide areas on their own, without shipping acting as a vector, unless salinity, temperature or other factors limit their natural range of dispersal. Hence certain special considerations are required and HELCOM Contracting States have agreed on a No Ballast Water Exchange –policy within the Baltic Sea, for both intra-Baltic voyages and oceanic voyages. The HELCOM Contracting Parties together with OSPAR Contracting States have also agreed on specific Guidance concerning Ballast Water Exchange for ships engaged in oceanic voyages.

2.1 No Ballast Water Exchange on Intra-Baltic voyages

The BWM Convention offers two solutions for ballast water management on ships not discharging ballast water in Port Reception Facilities. Regulations D-1 and D-2 of the BWM Convention outline the standards for Ballast Water exchange and Ballast Water performance.

There are no areas meeting the ballast water exchange area requirements of Regulation B-4 of the BWM Convention (depth & distance from land, Figure 3) and no areas suitable for designation of ballast water exchange areas according to IMO Guideline (G14) [11]. Therefore the 8th Meeting of the HELCOM Maritime Group (2009) agreed that Ballast Water Exchange (BWE) is not a suitable management option for ships engaged on Baltic voyages. Several factors have led to this decision, one being the fact that the ballast water exchange is only an option until the ballast water performance standard (D-2) becomes obligatory for all ships.

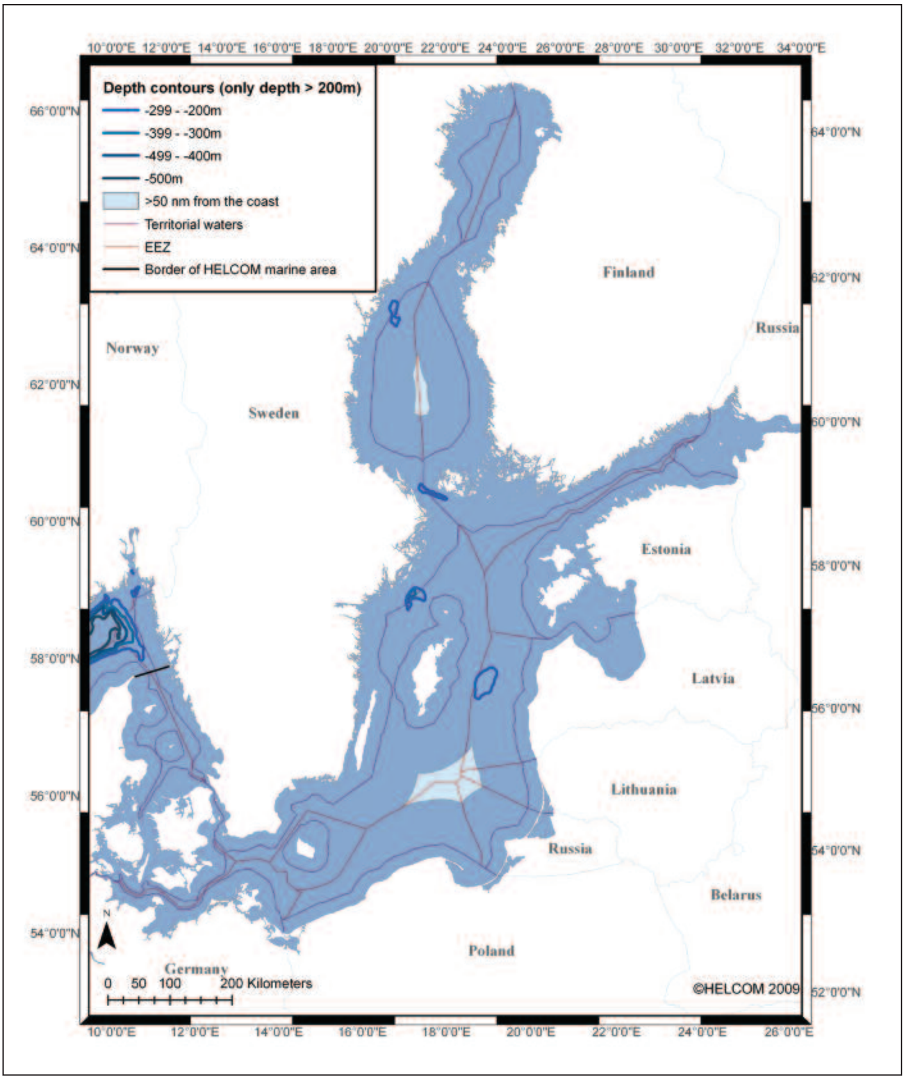

Figure 3. Map of areas in the Baltic Sea, meeting either the depth (>200 m) or distance (>50 nm) Ballast Water Management Convention requirements for ballast water exchange. (Source: HELCOM)

More importantly, since a lot of the alien species have a broad tolerance to salinity and large parts of the Baltic have intermediate salinity, no uniform ballast water exchange zones for reducing the risk of further invasions of the species can be identified [12]. All the potential exchange zones in the open sea areas are so close to shore, and combined with water currents, the risk of alien species reaching the coastal areas remains high. Technically the ballast water exchange is also very time-consuming and distances required to complete ballast water exchange are not found within the Baltic Sea. Therefore, the option of ships discharging to reception facilities is not feasible either at the moment due to lack of suitable facilities. The Maritime Group instead underlined that the ballast water treatment is the only available management option for ships carrying ballast water in the Baltic Sea.

The risk of spreading alien species on specific Baltic voyages yet needs to be assessed by risk assessments, in order to establish whether a ship is on an unacceptable high risk or acceptable low risk voyage. Ships heading for voyages with a low risk may be exempted from the ballast water treatment. As a specific measure (Road Map) to promote risk assessments, following the BSAP Road Map, HELCOM has drafted criteria on how to distinguish between unacceptable high and acceptable low risk voyages. These criteria, aiming for a harmonised exemption system in the Baltic Sea and giving guidance on which IMO Guideline (G7) risk assessment solution to follow, are under development.

2.2 Criteria to Distinguish between Unacceptable High Risk and Acceptable Low Risk Scenarios for Intra-Baltic Voyages – in Short

The Ballast Water Management Convention does not give special definitions for the spatial aspects of ports or locations, which are the start and end points of the ships' voyages. In the Baltic Sea context it is recommended that individual ports are preferred over use of locations as the units for risk assessments.

Most non-indigenous and cryptogenic species in the Baltic Sea have a wide tolerance to environmental conditions, not least the most invasive ones. Carrying out only risk assessments comparing the environmental conditions between recipient and donor ports (environmental matching risk assessment)[9] or using non-indigenous species, that are present in both in donor and recipient ports, as an indicator of environmental similarity (species' biogeoraphical risk assessment) are recognized too easily leading to a conclusion that most voyages between Baltic ports pose a high risk.

The difficulty of using environmental matching risk assessments and biogeographical risk assessments lies in identifying the environmental conditions that are predictive of the ability of the harmful species to successfully establish and cause harm in their new environment. As the variability of general environmental conditions (temperature and salinity) have gradual shifts from South-West to North-East parts of the Baltic, the overlap of conditions is generally high. Hence, to a ship on a sea voyage between specified ports; or to a ship which operates exclusively between specified ports or locations, the draft criteria recommend the use of species-specific risk assessment. The environmental conditions in Ports or near-by locations should be used as background information and combined with information regarding species' biology, the risk assessments attains greater reliability.

As measuring the salinity and temperature are straight-forward and cost-efficient, monitoring should be adequately arranged in the Baltic Sea to record seasonal variations in surface water and bottom salinities and temperatures. These environmental conditions, in particular salinity, but also other parameters that might be predictive of the ability of the harmful species to successfully establish and cause harm in the new locations (e.g. temperature, nutrients, habitats available and anoxic conditions) should be regarded. Natural barriers separating ports must be taken into account.

The Criteria's data requirements for species-specific risk assessment follow the IMO Guideline (G7) data requirements. Comparisons of known physiological tolerances from other regions in comparison to possible reported adaptations in the Baltic Sea must be taken into consideration. All species that might be harmful either in the donor or recipient port, must be taken into account when conducting a risk assessment. If a target species is already present both in the donor and the recipient port, it is reasonable to exclude that species from the overall risk assessment, unless the species is under active control.

Distances between ports in the Baltic Sea are relatively short and there are few natural barriers separating areas from each other. Therefore species, both indigenous and non-indigenous, are in most cases able to spread throughout the Baltic Sea area by natural means unless salinity, temperature or other factors limit their natural range of dispersal. This was also one of the conclusions of Leppäkoski and Gollasch[10] by managing ballast water on intra-Baltic routes, ships are only slowing down the spread of some species – the species which have high tolerance to environmental changes and efficient natural dispersal – without fully preventing it. This is something that needs to be taken into consideration when conducting risk assessments.

Supportive Criteria to assess the invasiveness of the non-indigenous and cryptogenic species in the Baltic Sea, in a harmonised manner, are under preparation within HELCOM. With the HELCOM list of target and non-indigenous and cryptogenic species, and the indicator describing their presence-absence status on different Baltic Sea basins, provide other useful tools for intra-Baltic risk assessments.

2.3 Ballast Water Management for International Shipping

For shipping entering or exiting the Baltic Sea, the HELCOM Contracting States with OSPAR countries have jointly adopted the OSPAR/HELCOM "*General Guidance on the Voluntary Interim Application of the D1 Ballast Water Exchange Standard in the North-East Atlantic*" [13], applicable from 1st of April 2008. The Guidelines requests vessels transiting the Atlantic or entering the North-East Atlantic from routes passing the West African Coast, to conduct on a voluntary basis ballast water exchange before arriving at the OSPAR area or passing through the OSPAR area and heading to the Baltic Sea.

Similarly, vessels leaving the Baltic are requested, starting from 1st of January 2010, to apply ballast water exchange in the North-East Atlantic, and so avoid ballast water exchange within HELCOM and OSPAR areas unless the requirements of the BWM Convention are met so that the vessel is 200 nm off the coast of North West Europe and in waters deeper than 200 m.

3 Conclusion

The Baltic Sea countries have committed through in the HELCOM Baltic Sea Action Plan to ratify the Ballast Water Management Convention by 2010, or 2013 at the latest. The HELCOM Contracting States are all well under way towards the ratification of the Convention and Sweden has already set an example by having ratified the Convention on 24th of November, 2009. HELCOM is working to increase data availabilitys, by collecting information on alien species and environmental parameters around the Baltic Sea. Contracting States are as well working towards a common understanding on the requirements and finding harmonised solutions to the implementation of the BWM Convention in the Baltic Sea. Voluntary measures have already been adopted before the BWM Convention enters into force, in order to avoid the uncontrolled ballast water discharge in the Baltic Sea and the adjacent North Sea by ships engaged in oceanic voyages. This effort reduces the risk of invasions, but also serves as good practice for ship-owners and crew before entry into force of the mandatory requirements.

As the Baltic Sea countries have jointly agreed that ballast water exchange is not a suitable management option in the Baltic Sea, other solutions must be considered – mainly for short voyages within the Baltic Sea and on voyages connecting the Baltic with the North Sea – before the D-2 standard becomes mandatory for all ships. Voluntary ballast water treatment, provision of port reception facilities and exemptions are the available options, although this holds some challenges for the future. Not all already developed and prospective ballast water treatment methods are suitable for short voyages and brackish water, nor could all ports receive, or all ships deliver, ballast water in reception facilities. Some challenges remain with identifying ships which are on a low risk voyage and can be exempted from ballast water management in accordance with Regulation A-4 of the BWM Convention. However, there is a strong political will in the Baltic Sea region to tackle the problem of alien species, which coupled with scientific advice and solutions delivered by the industry will eventually lead to preventing more alien species from reaching the Baltic Sea.

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Alternative Ballast Water Management Options for Caspian Region Shipping: Outcomes of a Recent CEP/IMO/UNOPS Project

R. W. Hilliard* and J. T. Matheickal**

Abstract

A major regional collaborative project, supported by the Caspian Environment Project (CEP), the International Maritime Organization (IMO) and the United Nations Office for Project Services (UNOPS), was undertaken in 2006–2007 to better understand movements of ballast water (BW) in the Caspian region and to identify appropriate BW management (BWM) strategies. The project was centred around a joint technical study by a local shipping expert and an international BWM consultant who examined regional trading patterns and ballasting activities and evaluated BWM alternatives on the basis of their potential practicality, affordability and ability to comply with the requirements of the International Convention on the Control and Management of Ships' Ballast Water and Sediments. Study tasks included developing and distributing bilingual BW Record Forms (BWRFs) and guidance notes to ships using the Volga-Don Waterway (VDW) to transit between the Black and Caspian Seas in the summer of 2006. Eighty-eight returned BWRFs were used for the analysis, together with VDW hydrographical, navigational and shipping information collated at Astrakhan (the largest port near the Volga River mouth). The study confirmed that ship-based trade from and to the Caspian has been growing and becoming more internationalised, with a continuing dominance of westward exports of dry and liquid bulk products, versus a smaller but by no means decreasing eastward importation of goods, containerised freight and special cargos (particularly heavy equipment for petroleum field developments). The associated transfers of BW along the VDW were also compared with those along the Volgo-Baltic Waterway (VBW), as estimated from the shipping data collated at Astrakhan.

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* InterMarine Consulting Pty Ltd, Darlington, Western Australia 6070.

** GEF-UNDP-IMO GloBallast Partnerships, International Maritime Organization, London.

The appraisal of BWM options concluded that (1) a land-based BW reception and treatment facility, using standard water industry methods, would provide a cost effective solution if based at a port that provides convenient access, bunkering, supply and maintenance services to all vessels entering the Lower Don, such as Rostov-on-Don. Costs will depend on the availability and price of riverside land, and the number and spacing of suitable existing wharves (and/or moorings) that are fitted to enable simultaneous servicing of two or three vessels; (2) such a facility would be less useful for the more modern international River-Sea vessels that also make short-sea voyages between European ports. Many of these ships have more ballast tanks that provide a higher total BW capacity, so would take more time and expense to stop at a land-based facility. It was also recognised that their operators would probably prefer to equip them with a small shipboard BW treatment (BWT) system for complying with the Convention's requirements.

This paper summarises the key findings of the 2006 technical study, including the various VDW navigation factors and ship design features that influence contemporary ballasting activities, notes the key BWM recommendations that were adopted in 2007 by an inter-governmental Regional Task Force within the CEP framework, and reviews these with respect to recent advances in BWM.

Key words: Aquatic Invasive Species, Ballast Water Management, Ballast Water Treatment Technology, Caspian Region, Land-based Ballast Reception Facility, River Sea Ships, Volga-Don Waterway

1 Introduction

The Volga-Don waterway (VDW) has connected the Black Sea (BS) with the Caspian Sea (CS) since 1952, and it plays a major role in Russia's 6,500 km of inland shipping routes known as the Unified Deep Water System (UDWS). Recognised by the *European Agreement on Main Inland Waterways of International Importance*, the major UDWS arteries are the Don, Volga, Kama and Neva Rivers while the Volgo-Don, Volgo-Baltic and Moscow Canals are its key connections. By connecting the BS to the UDWS, the VDW also enables international short-sea/inland shipping trade between the Mediterranean and eastern Baltic via St Petersburg, as well as Moscow and even the White Sea via Lake Onega.

Historically, predominant west-to-east transfers of ballast water (BW) to the CS has led to introductions of aquatic invasive species (AIS), some of which have contributed to substantial fishery and biodiversity impacts such as the comb jellyfish (*Mnemiopsis leydi*) which invaded the CS after establishing in the BS (e.g. Aladin *et al.* 2002; Gornoiu *et al.* 2002; Grigorovich *et al.* 2004; Zaitsev & Öztürk 2001).

While the principal BW pathway of concern has been west-to-east, the CS is part of the Ponto-Caspian bioregion that has sourced many ongoing AIS invasions to the Baltic Sea, Western Europe and North America via the Volgo-Baltic Waterway

(VBW) and other north European corridors, including dreissenid mussels, gobies and a range of invasive crustaceans including cladocerans and water fleas (e.g. Cristescu *et al.* 2004; de Vaate *et al.* 2002; Jazdzewski & Konopacka 2002; Nehring 2002; Ojaveer *et al.* 2002; Panov *et al.* 2007, 2009, Reid & Orlova 2002; Rodionova *et al.* 2005; Rodionova & Panov 2006, Slynko *et al.* 2002).

To better understand the BW movements in the region and identify appropriate BW management (BWM) strategies, a regional project was undertaken in 2005–2007 with support from the Caspian Environment Programme (CEP), the International Maritime Organization (IMO) and the United Nations Office for Project Services (UNOPS). A key part of the project was a technical study on the ballast-mediated transfer of AIS to and from the CS, including a preliminary review of practical BWM options for reducing these introductions.

This study, undertaken in consultation with pertinent Russian Federation (RF) maritime authorities, was conducted by a local shipping expert based at the Port of Astrakhan and a BWM consultant appointed by the IMO (Hilliard & Kazansky 2006). The objective was to collate shipping and navigation information to help identify contemporary ballasting operations and practicable BWM options, and to evaluate the latter on the basis of their potential effectiveness, affordability and compliance with the IMO *International Convention on the Control and Management of Ships' Ballast Water and Sediments* (the Convention). The study therefore, included gathering data on:

- Navigational features of each section of the VDW, including the water source/s, salinities, depths, wave regimes, turbidity and winter ice characteristics between the Sea of Azov (SoA), which forms the northeast arm of Black Sea, and the Astrakhan Roads (AR), which are located in the north-western part of the CS;
- Age, design and trading patterns of the various River-Sea ship types that move BW along the waterway;
- Principal BW sources and destinations, including where, why and when ballasting operations are made *en route* between the SoA and AR;
- Historic and projected patterns of aquatic bioinvasions to and from the CS, including the salinity-related and biodiversity reasons for the dominance of ship-mediated eastward invasions via the decreasing salinity gradient from the Mediterranean to the SoA and Don River;
- Implications of the Convention to both RF and foreign-flagged River-Sea ships trading between European and Caspian ports, after entry into force of its BWM requirements and the RF's intention to accede to the World Trade Organisation (e.g. Kormyshov 2005; Isaeva 2006); and
- Land-based reception versus promising shipboard BW treatment (BWT) options that may provide effective and affordable measures to prevent aquatic species transfers.

2 The Study

Study tasks included developing and distributing bilingual Ballast Water Record Forms (BWRFs) and guidance notes to ships undertaking east-west and west-east transits along the VDW in the summer of 2006. Ballasting records in eighty-eight BWRFs returned by 30 September 2006 were analysed, together with geographical, navigational and shipping information collated at Astrakhan for the period 1 April to 30 September 2006.

The VDW closes during the winter freeze (late November–early April), but ice-hardened tugs are used to escort vessels along the VDW in spring and late autumn, and ice breakers are used to maintain a more year-round navigation between the BS and the Ports of Azov and Rostov-on-Don, and between Astrakhan and the CS. These and other relevant navigation features, physical characteristics and biological aspects of the VDW were reviewed to identify where, why and when ballasting operations are usually undertaken; and what features along the route may prevent or reduce the effectiveness of particular BWM options.

Figure 1. Waterways of the Unified Deep Water System (UDWS) that connect the Caspian Sea to the Black Sea, Moscow and Baltic Sea (reproduced from Hilliard & Kazansky 2006)

It is important to note the study was a data collation and desk-top review that was not intended to provide an executable BWM strategy for the VDW. The Convention was not entering into force soon after 2006–07, and it was assumed that on-board BWT options and their specific characteristics would continue to expand and mature in the years following the study. It was therefore recognised the study provided the first step on the pathway to such a strategy by identifying the key features of the VDW and the ships that use it, the future compliance requirements of the Convention, and potentially practicable and cost-effective BWM options (Hilliard & Kazansky 2006).

3 Waterways Leading to and from the Caspian Sea

Ships move to and from the CS via the Unified Deep Waterway System (UDWS) of the RF. As shown in Figure 1, the UDWS provides ~3.5 m navigable depths that connect the CS to the BW via the 1670 km long VDW, as well as to the Baltic Sea via the VBW. The VDW and VBW share the same route along the Lower Volga (LV), between the city of Volgograd and the Volgo-Caspian Canal (VCC)(Figure 2). The VCC is a dredged channel that provides safe navigable depths between the Volga Delta and the Astrakhan Roads (AR), which are in the shallow northeast part of the CS (Figure 2). In terms of BW movements to and from the CS via present and projected shipping activity, the VDW is the more important connection than the VBW, a fact confirmed by the 2006 study.

Figure 2. Main sectors and regional ports of the Volga-Don Waterway (from Hilliard & Kazansky 2006)

As shown in Figure 2, ships transiting the VDW from the BS to the CS sail along the following sectors:

- **Sea of Azov** (SoA): the shallow sea that connects the Black Sea to the Don River mouth via the Bay of Taganrog;
- **Azov-Don Sea Canal** (ADSC): a dredged channel giving navigable access to the Don River;
- **Lower Don** (LD): the western sector of the Volga-Don Waterway (VDW);
- **Tsymlyanskoye Water Reservoir** (TWR): the large artificial lake which forms a key central part of the VDW in terms of water level control and its navigational characteristics;
- **Volgo-Don Shipping Canal** (VDSC): the canal that connects the TWR with the Volga River;
- **Lower Volga** (LV): this extends from Volgograd to Astrakhan and the Volga Delta; and
- **Volgo-Caspian Canal** (VCC): the shipping channel enabling navigation through the Volga Delta mouth and adjacent shallow sector of the northern CS to the Astrakhan Outer Roads (AOR).

4 Results from Study

4.1 Shipping Activity and Ballast Water Movements in 2006

River-Sea' ships are purpose built and dual classed for trading on protected coastal and short sea routes as well as inland waterways, and they have dual displacement and deadweight tonnages and BW capacities for undertaking voyages at sea draft (3.5–4.5 m) or UDWS draft (<3.6 m). The present River-Sea trading fleet includes a range of general cargo ships (dry bulk, break-bulk, mixed bulk/container and some reefer types), tankers (product oil, chemical, vegetable oil), and a few oil-bulk-ore ships (OBOs), and there are several classes that a vessel may also operate for short-sea passages, depending on the maximum distance from land and nearest port of refuge (ASMO 2001; Shalaev 2006). The 88 returned BWRFs showed that at least eighteen different vessel types with a 1966–2006 age range were trading to and from the CS during 2006 (Table 1).

Port records indicated that ship-based trade from and to the CS was continuing to grow and internationalise, with a continuing westward dominance of exported dry and liquid bulk products, over a lesser but by no means decreasing eastward import of goods, containerised freight and special cargos, particularly heavy equipment for petroleum field developments (Table 2). Table 2 indicates that >95% of all BW carried into the Lower Volga and Caspian Sea ports was sourced from the SoA, BS and Mediterranean by eastbound ships using the VDW. BW carried south from the Baltic Sea via the VBW (13,420 tonnes) between April and September was only 8.3% of the estimated total, and virtually equal to the amount carried north into the Baltic (13,820 tonnes; Table 2).

Table 1. Vessel types that returned completed BWRFs by 30 September 2006 (from Hilliard & Kazansky 2006)

No.	Vessel Type	Design Type	No. of Ships	Years of Build	From Caspian		To Caspian	
					Without BW	With BW	Without BW	With BW
1	General cargo ships	Omskiy	9	1978–1988	3	2	6	
2		ST-1300 (Refrig.)	5	1985–1989		1	2	2
3		Sormovskiy	4	1973–1990	2	1	1	
4		STK P326.1	4	1980–1988	3		4	
5		Volgo-Balt 2-95A	4	1970–1983			2	2
6		Volzhskiy 5074M	3	1980–1990	2		3	1
7		Amur 92-040	2	1987–1989			2	
8		Volgo-Don	2	1980–1981				2
9		Ladoga 787	1	1989				3
10		Morskoy	1	1968				1
11		Okskiy R97	1	1980				1
12		Vyg	1	1993				1
–		*Unidentified*	8	1966 / 2006	2		6	1
13	Ore-bulk-oil	Nefterudovoz-55M	1	1986	1			1
14	Oil product and chemical tankers	Volgoneft	8	1968–1983	1			10
15		Lenaneft	4	1982–1987	1		2	1
16		005RST01/6	6	2003–2006				6
17		NNov P19614	1	2002				1
18		RST14.03 (conv. ST-1321)	1	2004 (1986)			1	
–		*Unidentified*	7	1981–2005				7
Total voyages recorded by BWRF			**88**	**1966–2006**	**15**	**4**	**29**	**40**
Average year of build (or major conversion) and BW capacity (metric tonnes; mt)		45 General cargo ships ~1986 YoB			BW capacity ~1,394 mt (max. 3 572*; min. 509 mt)			
		26 Tankers + 1 OBO ~1991 YoB			BWC ~2 718 mt (max. 3 812*; min. 550 mt)			

* large maximum BW capacities reflect the additional ballasting /deeper draft requirements of River-Sea ships for short-sea passages. Maximum amounts carried for VDW and VBW passages are less to ensure draft remains less than 3.6 m.

Table 2: Total estimated BW moved to and from the Caspian Sea from 1 April to 30 September 2006. (from Hilliard & Kazansky 2006)

Direction	**To Caspian**		**From Caspian**		**Source or Destination**	**% of Total BW**
	tonnes	%	tonnes	%		
Eastbound (VDW)	267,360	95.2%	–	–	from SoA, BS, Med ports	81.3%
Southbound (VBW)	13,420	4.8%	–	–	from Baltic ports	4.1%
Westbound (VBW)	–	–	34,200	71.2%	to SoA, BS, Med ports	10.4%
Northbound (VBW)	–	–	13,820	28.8%	to Baltic ports	4.2%
Totals	**280,780**	**85.4%**	**48,020**	**14.6%**	**328,800 tonnes**	**100%**

4.2 Pertinent Features of the Volgo-Don Waterway

The technical study identified the following features of the BS-VDW-CS corridor that are significant in terms of present ballasting activities and future BWM options:

- **Susceptibility of CS to further ship-mediated bioinvasion**: The CS remains susceptible to AIS that become adapted (or are native) to the low salinity environments of both the BS and Baltic Sea regions. Species that can complete their lifecycle in freshwater in the BS, including the SoA, can readily colonise Taganrog Bay and LD (Figure.2) (e.g. Zaitsev & Öztürk 2001).
- **Shallow but unprotected approaches to the VDW**: Both the western (SoA) and eastern (AOR) approaches to the VDW involve long traverses across shallow (<10 m) but open seaways with gradually shoaling grounds. Strong winds and relatively steep wind-wave conditions are frequent in both the Bay of Taganrog and AOR. Undertaking BWE or just lightening up in preparation for the transit can be incomplete or abandoned as it is important for small ships to minimize slamming, propeller emersion and windage, and to maintain steerage in the narrow ADSC and VCC dredged channels. Effectiveness of BWE in these approaches is also limited in terms of removing AIS.
- **Shallow water depths and high turbidity**: Small underkeel clearances and high turbidity levels occur on several sections of the VDW and its approaches due to wind-waves, surge currents, spring floods and movement of silty sand shoals and mud banks. These factors add to sediment uptake and accumulation within ballast tanks – particularly in rough weather and the spring floods. High levels of suspended silts present challenges to BWT methods that rely on compact mechanical filters, ultraviolet (UV) or membrane-filter (RO) units. The organic content of the suspended sediments elevates chemical oxidant demand (COD) and, together with the water coldness in the spring and autumn, may promote formation of long-lived by-products depending on the BWT method.
- **Locks between the LD-TWR form the present boundary between the BS and CS catchments**: The TWR supplies water that maintains navigable levels in the VDSC. This water enters the LV at the canal's junction near Volgograd. The locks

between the LD and TWR (near Volgodonsk) therefore form the only barrier that inhibits self-spread of freshwater-tolerant species from the BS/SoA/LD to the Volga River and thence CS. To prevent ballast-mediated transfer of fresh- or brackish-tolerant AIS to the CS, unmanaged BW should not be allowed to pass these locks.

- **Wind-wave conditions on the Tsymlyanskoye Water Reservoir (TWR)**: The large TWR forms the middle sector of the VDW, where strong winds and relatively high wind-waves can cause bow slamming, propeller emersion, reduced steering and undue windage to part-loaded or ballasted ships. Vessel control is maintained by temporarily adding BW, but its mixing with unmanaged BW (including unpumpable water and sediment) then subsequent discharge to negotiate locks and other shallow sectors provides an additional pathway for freshwater tolerant AIS.
- **Uniform Brackish-Freshwater Salinity Regime**: There is little difference in the low salinity regimes of the northern BS and northern CS, especially their respective approaches to the VDW. This precludes the use of fresh BW as a method for killing euryhaline biota that tolerate fresh and brackish waters, but allows the possibility of adding salt to kill low-salinity AIS. For example, rapidly increasing BW salinity from <8 PSU to 35 PSU produces a massive osmotic shock and is a BWE method for ships going from north Europe into the Great Lakes.
- **Low levels of halide ions (Cl^-, Br^-, I^-)**: The virtually freshwater regimes in the SoA, VDW and AOR inhibit BWT systems that use electrolysis to produce OBr’, OCl’ and associated oxidants. The peculiar ionic content of the CS (relatively low Na^+ Cl^- content versus very high SO_4^{2-} [25% of total], Ca^{2+} and CO_3^{2-} content; e.g. Jazdzewski & Konopacka 2002) may also adversely influence electro-generation of oxidants, by-products or long-lived residuals.
- **Seasonal ice formation/ice clearance**: At the start and end of the winter freeze, ice breakers and tugs escort convoys of ships through the VDW. The spring and autumn rush of shipping activity also leads to ship ‘clusters’. Seasonal occurrence of groups of ships has design implications for any land-based BW reception/treatment facility.

4.3 Pertinent Features of the River-Sea Ships

The study identified the following features of the River-Sea fleet that pertain to the choice of practical and affordable BWM options:

The present ‘fleet’ that moves BW along the VDW is a mix of ship types with a wide range of designs and build dates, from the 1960s to modern double-skinned vessels. The more modern tankers and mixed freight cargo ships are making an increasing proportion of international ‘direct’ voyages to and between European ports, particularly in December-March to avoid the frozen VDW.

A large proportion of the present fleet are >20 year old ships facing the end of their commercial life. Many of them cannot be classed for international short-sea trade, so their operators may understandably be unwilling to pay for retrofit of BWT equipment for ships with a potentially limited lifespan on 'domestic' SoA – VDW or VBW routes. On the other hand, since many of the older ships have relatively fewer BW tanks and generally smaller ballasting needs (<1,500 m^3) than their modern counterparts, their internal layouts may be amenable to affordable modifications that enable BW discharge/uptake to a reception/treatment facility via a standard over-deck coupling.

The more modern River-Sea ship types have 8–16 ballast tanks and ballast capacities well above 1,500 m^3, particularly the tankers. Many are designed and equipped for international trade between ice-free ports in winter. These younger vessels will need to comply with the Convention's D-2 requirements if needing to discharge BW in European ports and waterways that have no BW reception facilities. Irrespective of vessel age and type, space is a premium on all River-Sea ships owing to the UDWS constraints on their dimensions and draft. Limited space for retrofitting BWT systems and associated additional power generation, pumps and pipe work pose problems for systems with large or power-hungry units.

There are many capable shipyards on the Volga specialising in River-Sea vessel construction, modification, and maintenance. Some should be well positioned to provide reliable advice and cost estimates for reticulating ballast tanks in the various ship types to enable BW discharges to shore, and/or for retrofitting onboard BWT systems. RF ship operators and fleet managers will provide sources of valuable advice.

4.4 Pertinent Features of BW Movements and Ballasting Operations in 2006

Most BW continues to be moved east to the CS owing to present and projected trade that is skewed towards substantial liquid and some dry bulk exports from this region. Much less BW is moved from the CS, either westward to the SoA/Black Sea or northward to St Petersburg and the Baltic. The minor amounts of BW being moved south from the Baltic to the CS are unlikely to rise until bottlenecks on the central/upper Volga system are removed by modernization programs, including some hydroelectric facilities. There is no methodical ballast tank sampling program to monitor sources of BW and tank sediments, check claims of reported BW exchanges (BWE) and provide data allowing the effectiveness of the present BWM requirements to be formally assessed.

There are several reasons why present BWE requirements in the approaches to the VDW (i.e. the SoA, LD and AOR; Figure 2) are likely to remain ineffectual in reducing the risk of AIS transfers, including:

a. the shallow SoA/LD and northern CS are not free of native biota and all AIS;
b. frequent strong winds and short steep seas in these approach areas constrain or prevent BWE attempts;

c. not all ships follow the present BWM requirements (operators do not want ships to delay to ensure ≥95% BWE);
d. high sediment entrainment into the tanks is likely in these areas; and
e. un-pumpable BW and sediment (and hence organisms) will remain in tanks even after a complete BWE.

Unladen ships need to conduct temporary ballasting operations in the TWR and other sectors of the VDW to maintain adequate control and for other navigational purposes. Four of 41 eastbound vessels that were in ballast reported doing this (~10%), while informal interviews with vessel masters indicated the percentage of transits involving a ballasting operation within the VDW is probably much higher (not all ships necessarily log such operations). In fact it is unsafe and impractical to expect all ships not to make draft or trim adjustment within the TWR when coping with rough wind-wave conditions, as recorded in four of the BWRFs. There are also other circumstances and locations where a ballast adjustment is made for air draft, speed/trim, underkeel clearance or other reasons.

4.5 Appraisal of Practicable Ballast Water Management Options

The study confirmed that the principal BW pathway of concern remains, for the projected future, west to east from the BS, SoA and LD. It was also concluded that to limit BW-mediated transfers of AIS from the BS to the CS catchments, the most effective measure is to prevent ships carrying unmanaged BW past the locks at the head of the LD (Volgodonsk) into the TWR and beyond. An appraisal and a preliminary ranking exercise was therefore undertaken to help determine if land-based BW reception will merit a more in-depth and detailed consideration. Salient considerations and findings for a land-based BW reception and treatment facility were as follows:

- All River-Sea ships that undertake international trade to and between European ports as well as across the VDW will need BWM after the Convention enters force, including BWT to D-2 for many vessels.
- The Convention allows use of land-based BW reception facilities, as this option may be commercially attractive to trading vessels that are dedicated to particular routes and ports, and which have predictable and well defined ballasting/deballasting cycles. Discharges of BW treated at a reception facility will need to meet standards outlined in Convention Guideline 5, the particular performance level depending on discharge location.
- A land-based reception facility on the VDW should be an economically attractive management option if there will be a sufficient number of ships with no capacity for onboard BWT for at least 15–20 years, and if the facility is designed to minimise ship queuing and so avoid undue delays. There may need to be a regulation requiring all such ships to use the facility, and a payment scheme to ensure all users contribute a fair share towards the costs of operating the facility.

- A reception facility may not provide an attractive long-term option to vessels that use the VDW only occasionally and trade elsewhere for much of the year. Owner/operators of these ships may prefer to install an onboard BWT system when the Convention comes into force.
- Therefore, a key first step in determining the value of building a reception facility on the VDW will be to consult with ship owners and operators to estimate how many existing ships will be dedicated to 'domestic' trade along the VDW until 2020–2025. If the older ships become phased out quickly and their replacements are fitted with onboard BWT, the resulting operational time-frame may be short (10–15 years), thereby increasing the capital component of the total facility investment.
- The most effective location for the facility in terms of reducing AIS transfers to the CS and allowing ballasting flexibility in the TWR and LV is a convenient, frequently visited port on the Lower Don, such as Azov or Rostov-on-Don. Placing the facility near the mouth of the Lower Don assumes that eastbound ships that replace their unmanaged BW have no subsequent need to uptake additional BW until they enter the TWR. Alternative facility locations, such as on the Volga River at Krasnoarmeysk, Akhtubinsk or Astrakhan, would require ships not to discharge any unmanaged BW during their transit of the LD, TWR and VDSC. This appears to be unsafe and impractical requirement (the 2006 study found that at least 10% of eastbound ballasted ships make temporary draft adjustments involving BW uptake and discharge on the TWR).
- The average number of ballasted eastbound and westbound ships in 2006 was close to one a day (~32 per month). Typical volumes per ship are between 500 and 2,300 tonnes, with the average close to 1,700 tonnes. Sequential tank discharges at a facility would therefore take 5–10 hours to complete if normal deballasting rates are used (100–500 m^3/hour). The additional time required to deliver treated water to the empty tanks will depend on the ability of a ship to receive and distribute this water to the tanks that were initially emptied, i.e. during the period when its remaining tanks are being emptied.
- An ability to receive treated water well before the end of discharging unmanaged BW could almost halve the total servicing time, thereby helping to avoid undue delays. Ships incapable of this (e.g. because of loading stresses or lack of separate pipework for distributing this water to the emptied tanks), then the total empty/refill time will be double the emptying time if the delivery and pump out rates are the same.
- A facility that receives and delivers BW at the same time must have separate pumps, storage tanks and piping infrastructure to avoid cross-contamination. The 'delivery' water can be treated BW (received from previous ships) and/or local river water that is treated and stored at the facility. It could also be sourced from an uncontaminated groundwater aquifer, if a suitably large source is available near the port.
- Need for ice-breaker or tug escorted 'ice caravans' in late autumn and spring means the facility will need to handle the simultaneous arrival of 3–4 ships

wishing to replace unmanaged BW before continuing their voyage. Multiple reception points will therefore be needed to avoid undue queuing delays. Candidate locations would include bunkering jetties, service wharves and/or moorings used for port control inspections and border clearances.

- Few ships have the pumping capability to lift their BW to a shore-side facility at practical flow rates (e.g. URS 2000). Ships wishing to use the facility will need to be retrofitted with pipework and booster pump/s to allow all tanks to be discharged to the land connection, via a standardised coupling on the main or weather deck.
- The faster that unmanaged BW can be pumped out and replaced by treated BW, the shorter the total delay to the voyage. Retrofitting will need to be tailored to each ship type to ensure BW can be lifted from the lowermost tank to the main or weather deck at a suitably fast rate to avoid undue delays. For River Sea ships and typical wharf heights when water levels are low, this may require 5–8 m vertical lift at rates of 200–500 tonnes per hour.
- Consideration will need to be given to fitting tank eductor pumps and other modifications for pumping out as much BW and sediment as practicable from each tank. If design work shows that significant quantities of un-pumpable BW and sediment will remain despite the best affordable retrofit designs, then the facility could add salt or a biocide with a limited half-life to its delivery water stream to help kill any organisms remaining in the tanks. This option will increase the facility's operational cost, and any biocide would need to be an approved type and concentration that avoids enhancing tank corrosion and the formation of long-lived residuals or toxic by-products.
- Irrespective of location, the following infrastructure will be needed for an onshore BW reception facility:
  1. Equipping a sufficient number of wharf and/or mooring points with standard couplings, pumps, reliable power and separate mains dedicated to piping water to and from the plant.
  2. Procuring land for the plant, including reception storage tanks large enough to handle peak BW inflows that could otherwise overwhelm the capacity of the plant (i.e. when two or three ships are discharging at the same or overlapping times). A total storage volume of 6,000 tonnes would also permit the facility to receive BW for 2–4 days in case of unexpected shut-down (plant maintenance/overhaul can be scheduled for winter).
  3. A treatment unit that has sufficient upgradeable capacity to treat the projected mean volume of BW received per day (~2,000 tonnes), plus storage tank/s large enough to provide uninterrupted deliveries of clean water.
  4. An outfall or groundwater injection points enabling disposal of excess treated water. The potential salinity of this water may preclude its sale to existing irrigation or industrial recycling/supply schemes via a link-main.
  5. Access to a suitable land-fill site for the burial of used filter media, filter cake or other forms of tank sediment and sludge that are generated at the plant. The value of this waste as a soil improver may merit investigation.

6. Standard water industry treatment methods could be used, such as coarse prefilters, fine filter-bed and biological units then tertiary treatment by UV or oxidants. An existing public sewage treatment plant (STP) may be capable of an expansion/adaptation for treating the BW, especially if saline discharges are not delivered in large pulses (elevated salinities inhibit the freshwater bacteria used in the biological units of many STPs).

Overall cost per metric tonne of received BW will depend on a combination of factors including land acquisition cost (this varies markedly from port to port; e.g. URS 2000) as well as vessel retrofitting costs and increased voyage time. Retrofitting costs will vary according to tank number and layout, existing pipework and pump capacity and demand (number of vessels requiring retrofit per year). Price estimates from studies that have examined the cost of reticulating ocean-going container ships and bulk carriers for onshore BW discharge (e.g. URS 2000) were not suited for extrapolating to River-Sea ships for several reasons (Hilliard & Kazansky 2006). However, a preliminary appraisal was made to compare the practicality of the land-based reception concept versus possible onboard BWT options. The treatment methods examined were filtration, ultraviolet light (UV), chemical dosing, de-oxygenation, hydrodynamic cavitation, osmotic shock and thermal shock. A simple, semi-quantitative scoring method was used to score then rank the various BWM options (Hilliard & Kazansky 2006).

It was also recognised that the BWT systems emerging in 2006 were in their infancy and that each BWM option, whether by land-based reception or onboard treatment by one or combined technologies, will pose inherent advantages and limitations. What may be fitted to one ship type to provide a satisfactory, reliable BWM option may also pose intractable problems and issues to another ship type and/or trading route. The following assumptions were, therefore, used to help evaluate and score which options appeared potentially more practical, cost-effective and ecologically acceptable than others for use by River Sea ships that trade through the VDW:

- Space(s) in the motor room and near the BW pumps will be cramped and small.
- There will also be space and weight limitations for storing BWT chemicals or other consumables.
- Availability, quality and stability of phase power from existing onboard generator/s may be limited.
- BW pump(s) are not located in double bottoms or other inaccessible compartments.
- Ballast tanks and pipework may have limited corrosion coating protection.
- Tank sediment accumulation rates are high and deposits are removed manually, typically at slipping.
- BW uptake/discharges of 200–500 m^3/hour for total volumes of 500–2,500 m^3.
- Between 4–18 ballast tanks, with the highest in the modern tankers.

- No additional crew available for BWT system monitoring and maintenance.
- Many BS-CS waterway sectors, berths and cargo transfer sites have turbid waters with shallow silty floors.
- Small underkeel clearances are frequent.
- Low salinity waters from the SoA to the CS have low Cl^-, Br^- and I^- ionic strengths.
- Water temperatures range from ~0°C (spring/late autumn) to high summer peaks of +25°C.
- Sectors and reservoirs of the VDW provide industrial, agricultural, urban and ecologically important sources of water, so a high value is placed on water quality in the VDW.

The basic 'pros and cons' of the land-based reception facility option versus those of onboard BWT technologies under development in 2006 were scored using a matrix of 13 operational features (Hilliard & Kazansky 2006). The following predictive scores were ascribed to each feature, for a typical (un-modern) River Sea ship using the VDW:

0 = Likely to be very difficult/very disadvantageous.
1 = Likely to be moderately practical/moderately suitable.
2 = No substantial difficulty or disadvantage envisaged.

All factors had equal weight and their scores were summed to provide a preliminary ranking (more sophisticated scoring methods needed specific manufacturer information that was highly limited in 2006). The 'first-pass' preliminary ranking placed the land-based reception facility at the top of the list. Since it was inevitable that onboard BWT systems were continuing to evolve and improve, the study emphasised that the preliminary ranking should not be used to guide or support any strategic decision as to which type of BWT system may be most suited for particular River-Sea ship-types in the future (Hilliard & Kazansky 2006).

5 Study Conclusions

The study found that ship-based trade from and to the Caspian region was likely to grow and continue to internationalize, with a continuing dominance of westward exports of liquid and dry bulk products, plus a lesser but by no means decreasing eastward movement of goods, containerised freight and special cargos. Other conclusions and recommendations made by the study were as follows:

1. The principal BW pathway of concern will remain west-to-east for the projected future. New AIS that invade and adapt to the BS will spread, including into the SoA. Those that can complete their lifecycle in freshwater can colonise Taganrog Bay and the Lower Don.
2. BW exchanges undertaken in the SoA (or in the North CS/AR) will remain relatively ineffectual for several reasons. It is also unsafe and impractical to expect

all ships not to make a draft adjustment in the TWR when coping with rough wind-wave conditions.

3. The locks between the Lower Don and TWR provide a barrier against the natural spread of introduced and native species from the BS catchments into the Volga and hence CS catchments (via the TWR control station that feeds the VDSC). Effective BW measures to prevent future CS invasions therefore need to prevent ships carrying unmanaged BW past the head of the Lower Don into the TWR.
4. Any land-based BW reception facility for servicing ships with no onboard BWT system, should therefore, be in the Lower Don (such as at Azov or Rostov-on-Don) and not at Astrakhan or other Volga River port.
5. The present River-Sea 'fleet' contains a broad mix of different ship types, with a small (<15%) but increasing proportion making international voyages to and between a range of European ports, particularly in winter. Ships engaged on this trade (typically the younger vessels) will need to comply with the Convention requirements in ports or waterways that have no land based reception facility.
6. A large proportion of the fleet are >25 year old ships nearing their end of commercial life. Most appear unsuited to upgrade for international trade, and their operators may also be unwilling to pay for expensive modifications to enable BWT for the domestic trade along the BS-CS waterway. A land-based facility that services these ships when they enter the Lower Don from the SoA may therefore be financially attractive and cost effective.
7. Irrespective of vessel age and tank layout, space appears to be a premium on all River-Sea ships owing to lock-constrained dimensions and draft. Lack of convenient space/s for retrofitting treatment units, additional power generation, pumps and pipework may pose problems for technologies requiring bulky or power hungry units.
8. Selection of workable onboard BWT systems will also need to account for:
   - high levels of turbid water and entrained sediment due to the shallow waterways, dredged channels, river flood waters and small under-keel clearances (a potential challenge to filtration-UV or RO systems);
   - very low salinities and water temperatures (constrain electrolysis, heating methods and decay of toxicants);
9. A preliminary ranking of BWM options indicates:
   a. A land-based BW reception/treatment facility using standard water industry methods could provide a cost effective option if based at a port that can be conveniently accessed by all eastbound unladen vessels entering the Lower Don. Cost per tonne of BW will depend on a range of factors, especially the availability and price of riverside land, and the number of berths and moorings that are fitted to enable simultaneous servicing of vessels versus the cost of queuing (voyage delay). The advantages of linking the reception facility to regularly used bunkering and service/supply berths will deserve close attention.
   b. Option (a) will be less useful for the more modern (and typically larger) River-Sea ships that undertake international voyages to and between European ports.

These ships tend to have more ballast tanks (particularly the double bottom/double skin types) so would be more expensive to reticulate. To enable conformance with the D-2 discharge standard at foreign ports, the operators of these ships will probably prefer to equip them with an onboard BWT system that has small dimensions and power requirements. Of the various technologies that were under development and testing in 2006, those that added active substance/s appeared promising for River-Sea ships. Of the various mechanical filter systems, auto-cleaning screen filters also appeared promising owing to their small power need, compactness, modular form and ability to be fitted vertically, horizontally or at other angles. It was emphasised that the preliminary ranking should not be used to guide or support any strategic decision since BWT technologies were continuing to evolve and improve.

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Progress with Conventional Ballast Water Systems

Iver Iversen*

This Key Note presentation will address some experience from evaluating, installing and testing a Unitor BWT system and some reflections about the industry's challenges ahead.

Taking environmental responsibility is good business for all, and as part of the maritime industry we must focus on compliance and beyond, to achieve the following important benefits:

- Improved operational performance and efficiency
- Better image and profiling
- Reduced total cost of ownership
- A healthy environment for the future

The Wilhelmsen Group became involved in ballast water treatment (BWT) through the acquisition of the Unitor Group some 5 years ago. Unitor had since about 2000 been following the development of BWM regulation, culminating in the 2004 Convention. Being well positioned in the market with an extensive geographical network and a substantial customer base, Wilhelmsen was in no hurry to decide on what BWT technology to choose. The Wilhelmsen Group decided rather to evaluate the emerging technologies against certain selection criteria:

- Compliance with the IMO standard
- Ease of installation/retrofitting
- Low energy consumption
- Scalable to meet large requirements
- Commercially attractive (attractive cost of ownership)
- Safe and simple to operate

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* Business Development Director, Wilhelmsen Ships Equipment AS, Norway.

After reviewing some 30 alternatives and having DNV assess the two alternatives on the top of our list we decided to go for a technology being developed by the South African company RBT.

The RBT ballast water treatment system is based on:

- **Mechanical** (**Primary Treatment**) mechanical patented design creating ultrasonic cavitation,
- **Electrochemical** to produce gases that assist the mechanical process (NaOCl),
- **Ozone** to create additional cavitation gases and assist with sterilization, and
- **Filtration.**

The RBT system is introduced to the market by Wilhelmsen Ships Equipment under the brand Unitor Ballast Water Treatment system (UBWTS). Our system is expected to have the IMO final approval by MEPC 60 in March this year. Shipboard testing will be completed later this spring.

Currently UBWTS systems are installed and in operation on two ocean going ships. The first is the WW ship MV "Toronto", (Figure 1) a car and truck carrier built in 2004, having a capacity of 6,500 cars, ballast capacity of 10,000 tons and 2 x 500 m^3/h ballast pumps. Toronto was outfitted with UBWTS matching the ballast pump capacity during dry-docking in Japan.

Figure 1. UBWT system installed on MV "Toronto" (Source-Wilhelmsen Group)

The main challenges with this installation were the following:

- Very limited original drawings available.
- Space limitations between decks i.e. height of filters to be installed.
- Very congested space under the deck plating where the ballast piping was arranged.
- Control system integration to the existing ballast control system, where we experienced a total lack of support from the supplier of the original ballast control system, resulting in having the UBWTS operate independently of the ship ballast system.
- Toronto being designed for heavy cargo has an automatic heel compensation system.
- The original ballast piping had a lining that required a 5–6 days preparation that was not expected, that consequently created a lot of stress during the limited time of the dry-docking period.

On the very positive side was the very good relationship and support from the owner and the crew. Vessel owner and crew support are crucial for a successful retrofit installation.

The second retrofit installation was on the VLGC "Berge Danuta", (Figure 2) built in 2000, having a capacity of 78,550 m^3, ballast capacity of 26,500 m^3 and 2 x 800 m^3/h. Berge Danuta is so far outfitted with one UBWTS with the capacity of 800 m^3/h to match one pump. However, the plan is to install a second system at a later stage. This BWT system was installed completely while the ship was in operation, with no "off-hire" of the ship.

Figure 2. UBWTS installed on "Berge Danuta"(Source-Wilhelmsen Group)

With regard to the Berge Danuta, there was a lack of original drawings, so the installation was very much dependant on a very thorough inspection and accurate engineering. We had fantastic support from the ship crew and the owner. Most of the actual installation was carried out by the crew members themselves. With the support of the owner, this system is integrated into the ship ballast control system.

It would now be appropriate to address a number of concerns from shipyards as well as from ship owners having to comply with the BWM requirements, global in the IMO BWM Convention as well as regional.

Mr. Okuda from Mitsubshi Heavy Industries Ltd., has provided the author an opportunity to share some of his considerations from a shipyard's perspective related to implementation of BWT systems.

- Engine room lay-out.
- Engine room of modern ships are designed to be as small as possible to increase the capacity of the cargo area.
- Engine room re-design is essential for fitting BWMS.
- If necessary, modification or renewal of hull form must be considered.
- Ballast piping diagram as well as piping layout in engine room are much affected by the BWMS type and which supplier is chosen.
- Difficult to standardize the ballast piping system.
- Increase of electric power demand is one of the biggest issues.
- BWMS and ballast pump (increased power) are the consumers.
- Ships carrying liquid cargoes such as LNG, LPG, crude oil, chemicals etc., have peak load during unloading cargo. Ballasting operations are done during this peak load period and the increase of power demand may require electric generation system capacity increase.
- Oil and chemical tankers with pump rooms in hazardous areas have to have BWT systems meeting the hazardous area classification. i.e. being intrinsically safe for ships built before 2007 and explosion proof for ships designed after 2007.
- Tankers with aft peak ballast tanks may have to install a separate ballast treatment system in the engine room for the aft peak tank. Alternatively, can a pipe connection between engine room and pump room be accepted by SOLAS and the class societies?

The last commentary I have would be to ask a question to the legislators. Currently, the treatment options for tanker owners are very limited as most systems in the market today cannot easily be modified to meet the hazardous area requirement.

The next concern is related to scalability and the options that owners of the very large tankers and bulkers have. From recent statistics, there are some 2,000 tankers, 1,500 bulkers planned or under construction that are larger than 100,000 tons. What are their BWT options? We see a lot of BWT systems being introduced to the market, but again how many of these systems are practically suitable for pumpingcapacities in the range of 5–10,000 m^3/h without having to completely redesign the engine room and add extra generator capacity? All of these very large vessels must meet the BWM Convention obligations by 2016.

Another concern is the development of regional BWM requirements that dramatically exceed the IMO standard. California has imposed a BW standard that is 1,000 times more stringent than the IMO standard. The USCG is preparing a staged process to implement a similar standard for all US waters, dependent upon proven technologies being available. A question in this respect is – Will land based laboratory testing will be representative for real life and shipboard conditions, and how many, if any, systems today can meet this virtually "0" standard? How is this going to affect the ship owner's decision about when and what to install on his ships?

We also have to realise that in addition to the BWM regulations, over the next ten years the ship owners have to comply with the new emission to air regulations imposed in MARPOL Annex VI, where they have to either operate their ships on distillate fuels, install SOx/NOx abatement systems and consequently increase their operational costs or have massive investment costs in new equipment. On top of these requirements in the same period, we know there will be regulations and costs related to carbon emissions with additional burdens on ship owners.

Conclusion

Finally, I would like to include some of the Wilhelmsen Group's perspectives as an integrated shipping and industrial company:

- Wilhelmsen Group believes future commercial success depends on finding new and innovative solutions to the environmental challenges international shipping (and the world) is facing;
- The shipping industry is well positioned to develop innovative solutions for reducing the environmental footprint of the maritime transport industry (due to vast manpower resources with extensive maritime competence having an in-depth knowledge of the specifics and the challenges of the shipping industry);
- Wilhelmsen Group intends to maintain its position as "environmental front-runner" and "leading developer of green technologies for shipping"by combining the group's competencies and experiences as:
  - A well reputed international ship owner,
  - A leading provider of maritime logistic services, and
  - A global supplier of maritime services and products.

Microwaves + Ultraviolet + Ozone Ballast Water Treatment

Alex Taube*

Abstract

To comply with the International Maritime Organization's Convention for the Control and Management of Ships' Ballast Water and Sediments, TS Innovations has developed a novel triple effect synergistic ballast water treatment system SeaLifeCare, where the total effect of the combined process on the microorganisms is more than the sum of individual microbial inactivation effects of: Microwaves, Ultraviolet and Ozone. The triple effect Microwaves + UV + Ozone technology effectively and economically kills pathogenic microorganisms in air, water, liquids, sediments and sludge complies with, or exceeds (preliminary tests), all performance parameters under Regulation D2, Ballast Water IMO Performance Standards and has a great potential as a ballast water treatment method.

Key words: Ballast Water Treatment, Non-indigenous Pollutants, Microwaves, UV, Ozone, Sterilization

1 Introduction

Ship's ballast water discharge typically contains a variety of biological materials, including **plants**, **animals**, **viruses**, and **bacteria**. Ballast water transfers and invasive marine species that this practice promotes, is perhaps the biggest environmental challenge facing the global shipping industry this century. In Australia, it is estimated that over 200 harmful species have been introduced from overseas via ships' ballast water or hull fouling (Hillman 2004). Many of these introductions arrived inadvertently in ballast water carried by ships servicing the multi-billion annual Australian export trade.

To comply with the International Maritime Organization's Convention for the Control and Management of Ships' Ballast Water and Sediments, TS Innovations

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[*] Dr., Senior R&D Director, TS Innovations Pty Ltd, Australia.

has developed a novel triple effect synergistic ballast water treatment system SeaLifeCare, where the total effect of the combined process on the microorganisms is more than the sum of individual microbial inactivation effects of: Microwaves (MW), Ultraviolet (UV) and Ozone (O_3).

SeaLifeCare is a synergistic technology in which microwaves are used for energising UV-radiation via microwave plasma created inside of electrode-less bulb. In electrode-less MW-UV-Ozone lamps the power needed to generate light is transferred from the outside of the lamp envelope by means of microwave electromagnetic fields, so the energy is transferred through the bulb glass solely by electromagnetic radiation. Unlike an incandescent lamp or conventional UV lamps, there are no electrical connections (filaments) inside the glass bulb. No ancillary control devices (transformers, starters, ballast resistors) are required, Figure 1.

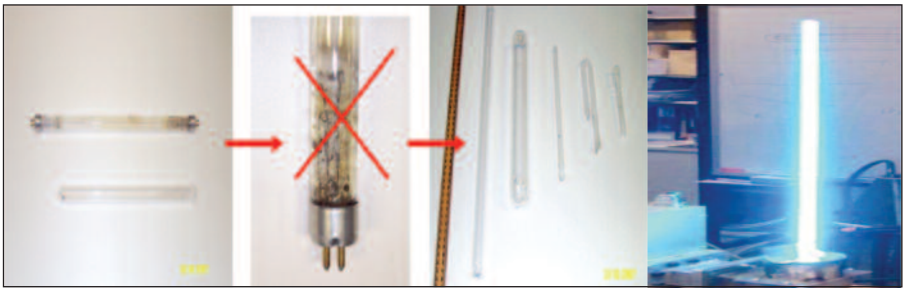

Figure 1. Microwave-powered electrode-less UV bulbs

The microwave-powered UV radiation in turn generates Ozone as air is passed over an ultraviolet lamp, which splits oxygen (O_2) molecules in the gas. The resulting oxygen atoms (O^-) attach to other oxygen molecules (O_2), forming Ozone (O_3). The microwave lamp is able to produce ultraviolet light at 254 nm, the germicidal wavelength, and 185nm, the Ozone – forming wavelength, simultaneously. The quartz-based UV bulbs produce large amounts of Ozone for water treatment, whereas VYCOR glass-based bulbs do not produce the Ozone that is vital for some air and water cleaning applications.

The microwave plasma UV lamp technology has no limitations in terms of power and shape of the lamp in contrast to the conventional electrode configuration in which the power is constrained lengthwise. Electrodeless lamps can have a very long service life, whereas, in conventional lamps the electrodes are usually the life-limiting factor in bulb life. If you include all the ancillaries that are needed to operate traditional UV lighting fixture, the total cost is more than twice that of *TS Innovations* electrode-less bulb.

The microwave-powered electrode-less lamps are the better solution due to their high efficiency, low running costs, low surface temperature, and longer working lives. Test results have shown that the novel synergistic technology which combines the advantages of Microwaves + UV + Ozone is the most efficient and economical compared with other conventional methods.

2 Principles of Operation

The main principle of MW + UV + Ozone lamps operation is based around inelastic scattering of electrons. An electric field of sufficiently high frequency applied to electrons in a gas may deliver energy to the electrons without imparting to them any continuous drift motion due to the field. The criterion for breakdown of a low-pressure gas at microwave frequencies is therefore that ionization by collision of electrons with neutral gas molecules replaces loss by diffusion to the walls of the discharge tube. The kinetic energy of the electrons is built up through successive accelerations until the loss of energy by elastic and inelastic collisions and diffusion equals the gain of energy from the field. The motion consists of a large random and a small drift component. The energy transferred to the electrons is a function of E/p, where E is the electric field strength and p is the pressure. This quantity determines the energy gained between the collisions.

An incident electron accelerated by microwave field collides with an atom in the mercury gas. This causes an electron in the atom to temporarily jump up to a higher energy level to absorb the kinetic energy delivered by the colliding electron. This collision is called “inelastic” as some of the energy is absorbed. This higher energy state is unstable, and the atom will emit an ultraviolet photon as the atom’s electron reverts to a lower, more stable, energy level. The photons that are released from the chosen gas mixtures tend to have a wavelength in the ultraviolet part of the spectrum.

Ultraviolet light has two important properties relevant to this application: disinfecting capabilities and the production of Ozone. Ozone is produced with the photolysis of oxygen molecules (O_2) which occurs when oxygen strongly absorbs ultraviolet radiation. Photolysis is a chemical process by which molecules are broken down into smaller units through the absorption of light. When the UV rays encounter an oxygen molecule (O_2), the molecule splits into two oxygen atoms (O). After that, the released oxygen atom can link up with an oxygen molecule, and produce an ozone molecule (O_3).

It is important to note that the innovation in this development is a system capable of killing bacteria using both microwave energy and microwave induced ultraviolet energy in a single system. One part of the input microwave energy is used to kill bacteria and the other part is in turn to light up an UV bulb that generates energy for killing bacteria. The SeaLifeCare equipment effectively and efficiently kills bacteria using both microwave energy and microwave-induced ultraviolet energy at the same time.

3 *SeaLifeCare*: Bactericidal/Sterilization Effects

3.1 Microwave Sterilization

The effectiveness of microwaves for sterilization has been well established by numerous researchers over recent decades. Studies of the effects of microwaves on bacteria, viruses and DNA were performed and included research on heating, biocidal effects, dielectric dispersion, mutagenic effects and induced sonic resonance.

The interaction between microwaves and biological materials does appear to be lethal and the lethality obtained is directly derived from the both specific non-thermal microwave electromagnetic field and the heating effects, which in turn depends on the composition of the microorganism being targeted, including its water content. Microwaves interact with polar water molecules and charged ions. Microwaves consist of mutually perpendicular electrical waves and magnetic waves. Each of these components has an effect on the water molecules and other organic molecules, which make up the bacterial cell or viral structure.

A microwave works by vibrating materials molecules ~ 2 billion times per second (TS Innovations used frequency 2.45×10^9 Hz) and the heat and mechanical forces results from the friction between molecules. Water molecules rotate at or near the microwave frequency, and this energy translates into linear motion. Linear motion of gas or liquid defines heat, and this thermal activity ultimately disrupts the cell and viral structures.

The cell membrane is considered as the primary site for microwave interaction with cellular systems. Microwaves have produced hyperthermic conditions that interfere with cell membranes. There is evidence from various studies of microwave frequencies to demonstrate a direct effect on the cell membrane that may be due to alteration of the membrane molecular composition. The microwave energy also causes the moisture in cells to boil, resulting in high steam pressure in cells that leads to rupture of cell's membranes. Since the heat is produced directly in the material, the thermal processing time is significantly reduced.

Apart from gross effects on metabolism and membrane structure that may result from substantial bulk heating, there is good supporting evidence of discrete changes in cell membrane permeability where heating does not occur. Microwave non-thermal exposure conditions can sensitise and affect cell membrane responses. Interference with membrane-mediated signal detection, transduction, or amplification processes may underlie many of the biological non-thermal effects reported in the literature (Barnett 1994).

3.2 Germicidal Effect of Ozone Treatments

SeaLifeCare technology using short wave length UV light at 185 nm to photochemically produce Ozone and other activated oxygen radicals has been developed and successfully applied in air and water treatments (e.g. secondary effluent treatments, polluted and foul smelling water). Ozone is second only to fluorine as the strongest known oxidiser, and is the most powerful readily-available water sanitiser. Ozone is used as an alternative to chemical sanitisers such as chlorine or chlorine dioxide. Ozone inactivates bacteria and viruses 3,000 times faster and is a 50% stronger oxidiser than chlorine (Ozonic 2009). It is unsurpassed for control of many types of common bacteria such as E. coli and faecal coli forms, in the deactivation of viruses, fungi, moulds, mildew and cysts, and is non-carcinogenic.

3.3 Germicidal Effect of Ultraviolet (UV)

UV light has been used for many years to maintain sterility in air-conditioning systems, operating theatres and hospital wards. The use of UV is 10 to 20 times more efficient and effective than air filters alone (UV Air Balance 2009). The portion of the UV spectrum (the "germicidal" region) that is important for the disinfection of water and air is the range that is absorbed by DNA (RNA in some viruses). This "germicidal range" is approximately 200–300 nm, with a peak germicidal effectiveness at about 260 nm, (Figure 2).

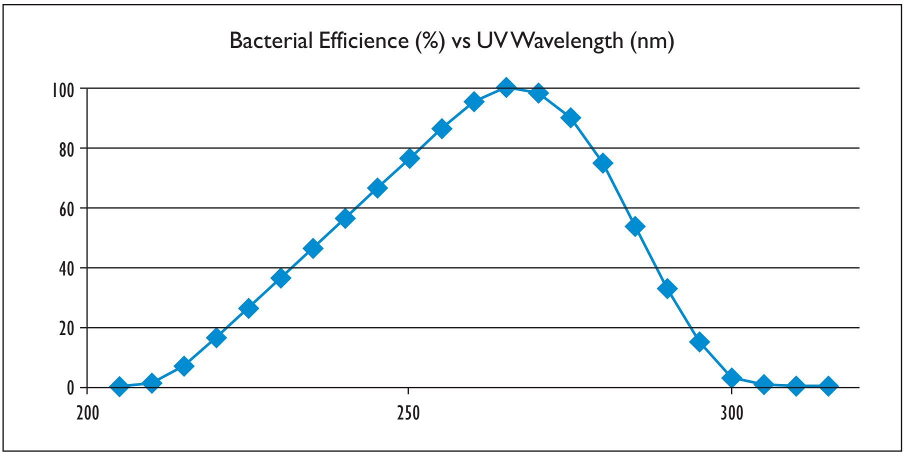

Figure 2. Bactericidal Efficiency (%) vs. UV Wavelength (nm)

Emitted UV radiation has a powerful bactericidal effect. Ultraviolet radiation is capable of destroying and inactivating all types of bacteria and microbial contaminants rendering them sterile. UV is absorbed by the DNA, breaks up its structure and kills living cells. UV exposure does produce a dose-dependent decrease in monocyte membrane. It is understood that UV radiation leads to changes within the cell membrane that inhibit the ability of monocytes to express selected molecules necessary for binding of T-cells. UV light also affects cell membrane and cytoplasmic targets. Research findings indicated that UV changes the flip-flop of phospholipids and that the cell membrane is a molecular and cellular target of UV. Micro-organisms such as viruses, bacteria, yeasts and fungi are destroyed in micro-seconds with UV radiation (Shamma'a 2001). If microbes are irradiated with enough dosage germicidal UV, they can no longer reproduce and over time disappear from the indoor environment. Most water-borne pathogenic microorganisms are destroyed after exposure to UV with an intensity of 10 J/cm^3 (Clarke and Bettin 2006).

The microwave-powered UV bulbs are manufactured by *Australian Ultra Violet Services Pty/Ltd*. In cooperation with industrial partners TS Innovations has developed the microwave-powered electrode less amalgam lamps, which are doped with a mercury indium amalgam. Amalgam lamps are very efficient at converting electrical energy into 254nm UV light. However, in order to maintain effective disinfection it is important that UV lamps are provided with the correct power. For these reasons TS Innovations has designed the microwave powered UV system that matches lamp power exactly to its needs under any conditions. Systems are sized with a level of redundancy, so that even in the event of one lamp failing, the remaining lamps will still provide the minimum dose of UV for the required disinfection.

All low pressure and amalgam UV lamps are called *monochromatic* because almost 80–85% of their spectral output is at 254 nanometres (nm) and 15–20% is at Ozone producing region 184 nm, Figure 3.

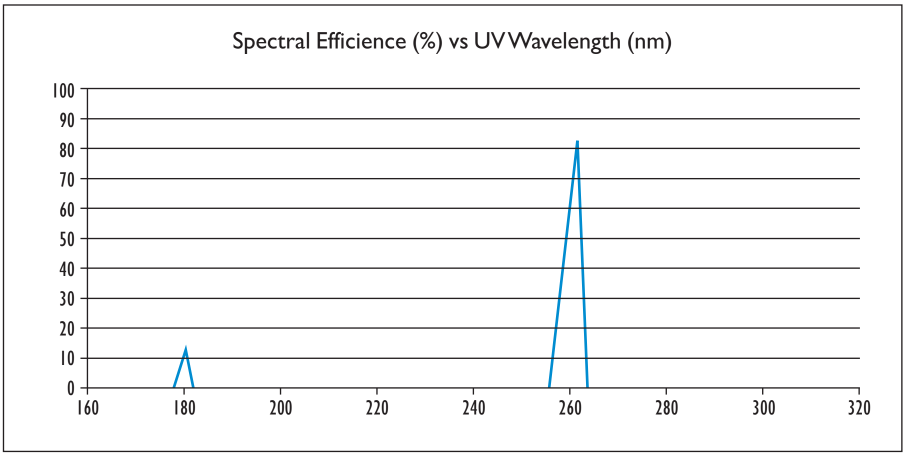

Figure 3. Spectral Efficiency of Amalgam UV Bulbs.

UV energy flux (germicidal intensity) can be evaluated by approximate formula:

$$UV\_Energy\_Flux = \int UV\_Intencity \times Bactericidal\_efficiency \times d\lambda$$

The monochromatic feature is what makes TS Innovations microwave-powered electrode-less amalgam lamps so much more efficient because power is not wasted on "useless" non- germicidal frequencies and visible light. Partially, the microwave power is also absorbed by the plasma in the UV lamp. This additional microwave heating increases the plasma temperature, thus very substantially increasing the proportion of useful UV light emitted by the lamp. As a result, our microwave-powered amalgam lamps produce much more UV output than conventional low pressure UV lamps.

Additionally, the use of harmful or toxic chemicals can be reduced or totally eliminated. All these make UV disinfection and oxidation one of the most cost-effective and environmentally-friendly processes and one which is increasingly being used in innovative applications.

Moreover, when combining Ozone with UV light, the air and water can be cleaned 2,000 times quicker than Ozone alone and 200 times faster than just UV light alone (Wig 2003).

3.4 Treating Turbid Water

The biggest challenge in ballast water treatment systems is effective treatment of turbid water. This is because microbial reductions are decreased or prevented by turbidity particles, suspended in the water, that reduce access to target microbes or otherwise protect them from inactivation by other mechanisms. The more turbid or darker the water, the more problems there are in these areas, negatively impacting the effectiveness of many treatment application systems. Suspended matter in water reduces the micro-biocidal efficacy of chlorine and other chemical disinfectants, and it physically shields microbes from the UV radiation that is emitted from mercury arc lamps and responsible for much of its disinfection activity. Cloudy water interferes with UV transmittance and reduces the effectiveness of the device.

In contrast to conventional UV cleaning that work only in transparent situations, TS Innovations triple effect SeaLifeCare Microwaves + UV + Ozone apparatus is capable of sterilizing in any environment, including dusty, cloudy, turbid, dirty, non-transparent, colloidal, suspended solids.

The fact that microwaves have the ability to penetrate various media and excite water regardless of the water turbidity, numerous attempts have been made to capitalize on this phenomenon for commercial applications. As the microwaves are strongly absorbed by micro-organisms, it means that in cloudy water where UV is blocked, the micro-organisms will still be subjected to the microwave field and Ozone that will kill them since microwaves have the ability to penetrate regardless of the water turbidity. No chemical is required and disinfection takes place regardless of the water turbidity. It is believed that this ability alone puts TS Innovations technology ahead of similar sterilizing technologies.

4 SeaLifeCare Triple Effect Synergistic Sterilization Technology

SeaLifeCare triple-effect Microwave-UV-Ozone synergistic technology effectively and economically kills pathogenic microorganisms in air, water, liquids, sludge, and even in non-transparent environment, by simultaneously and instantaneously using different sterilization mechanisms.

4.1 Mechanisms of Volatilisation

Synergistic effect is achieved from combinations of chemical (Ozone), and radiation (UV and Microwaves) sterilization technologies. SeaLifeCare mechanisms of etching (volatilization) of pathogenic bacteria & micro-organisms are (Taube 2008, 2009):

- Physical breakdown by microwaves: Microwave energy causes the moisture in cells to boil, resulting in high steam pressure in cells that leads to rupture of cell's membrane.
- Electrical breakdown by microwaves: Microwave radiation interacts directly with cell membranes to induce functional alterations of membrane transport mechanism.
- Chemical breakdown –
  - by Ozone: Ozone oxidizes and destructs bacteria cell's components
  - by UV: UV cause damage in the DNA of microorganisms or animal cells
- Catalysts: The microwaves, ozone and ultraviolet light combination also act as the catalysts, breaking down the ambient oxygen and water vapour molecules into O – and OH – (hydroxyl) radicals.

4.2 SeaLifeCare Crucial Advantages

SeaLifeCare ballast water treatment technology eliminates expensive biocides/chemicals (hydrogen peroxide, chlorine, chlorine dioxide, ozone, gluteraldehyde, copper/silver ion systems). This technology creates more options for ships and other maritime vessels as in addition it can be effectively used for on-board sludge & sediments sterilization, effluent disinfection and waste/water treatment.

One of the many advantages that SeaLifeCare triple effect system exhibits is the ability to be fitted to new or existing water treatment schemes and any mechanic barrier filters or equipment can be used in conjunction with TS Innovations system. The apparatus is compact, has modularity in design that can be used in diverse systems to drive multiple functionalities and be easy modified for different customers' requirements as well as being tailored for use in any application.

The SeaLifeCare multifunctional equipment can be used on-board ships as well as shore/land-based or mounted on dedicated water treatment vessels. This option may prove attractive for many Port Authorities for use where ship's, without ship borne ballast-water treatment plants, enter Port, the ship's ballast water can thus be effectively treated during cargo-loading, ballast discharge operations. This service could also be an income generator for the Port Authority.

5 Case Studies & Conclusion

5.1 Secondary Effluent Treatment

In cooperation with *Australian Ultra-Violet Services* (Melbourne) we have successfully used this equipment for waste water/sludge – secondary effluent treatment and odour elimination. Tests carried out by official government representatives demonstrated that the new technology effectively sterilized Escherichia coli bacteria: more than 99% E-Coli destroyed @ 7,000 l/h, 2 kW MW Power, 4 bulbs, with almost 100% of odour eliminating, Figure 4.

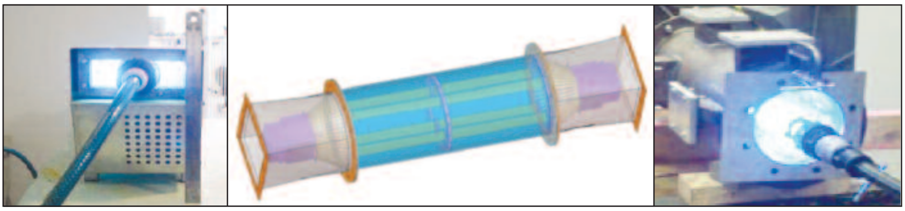

Figure 4. Water treatment sterilization Apparatus

5.2 SARS Outbreak – Air Sterilizing

During the 2003–2005 SARS outbreak in South East Asia TS Innovations Pty Ltd was selected by the Hong Kong Government Environment Productivity Council as the primary manufacturer of devices for air sterilizing. Tests show that ***TS Innovations*** equipment is able to diminish the viral infectivity, and killed Mycobacterium Tuberculosis, Adenoviruses, Streptococcus, Influenza and SARS viruses and other human pathogens in air and water, Figure 5, (Taube 2004, 2005).

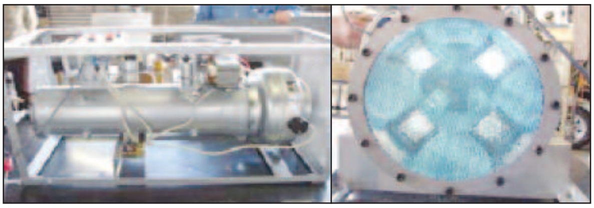

Figure 5. Air Sterilizing Apparatus

5.3 Conclusion

The SeaLifeCare novel triple effect Microwaves + UV + Ozone synergistic technology that effectively and economically kills pathogenic microorganisms in air, water, liquids, sediments and sludge *(preliminary tests)* complies with, or exceeds, all performance parameters under Regulation D2, Ballast Water IMO Performance Standards.

By combining SeaLifeCare technology with shipbuilding industry expertise, TS Innovations can develop a system that has great potential for ballast water treatment and removal of harmful pathogenic microorganisms from maritime environment.

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Thermal Aqua-Filtration (TAF) System: A New Concept of Environment-Friendly BWMS Applying "Retrieved Heat" to Eliminate Living Organisms

Kazuhiko Koike*, Nobuhiko Fujiki**, Kenji Yamane***,
Yoshiyuki Inohara** and Izuo Aya**

Abstract

A new type of ballast water management system (BWMS), which simply utilizes "retrieved thermal energy" to eliminate living organisms in ballast water, is under development. The system mainly consists of a Thermal-treatment Tank (TT) with heating coils for sub-heating and a high efficiency plate-type Heat-Exchanger (HX). Prior to discharging, water in the TT is initially heated up to 70ºC and then introduced to the HX, where retrieved thermal energy heats up untreated ballast-water newly flowing into the HX. In moderate seawater temperatures (ca. 15ºC), efficiency of the energy recovery is more than 95%, which means HX simultaneously cools down the waste water to nearly equal to the ambient seawater, and heats up ballast water to 68ºC prior to inflowing to the TT. Therefore, during the continuous treatment, energy input in the TT is needed just enough to cause an increase of 2ºC. Thus, the system requires no filtering devices, chemical supplies, and extra thermal energy if utilizing stored waste-heat from the main engine. It means the system is almost free from maintenance and expendable supplies, and cuts down on running cost. Utilizing "heat" without any active chemical substances should be very favorable for environmental concerns. Together with a land-based small-scale plant (15 m^3/h for maximum treatment rated

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* Thermal Aqua-Filtration (TAF) System: A New Concept of Environment-Friendly BWMS Applying "Retrieved Heat" to Eliminate the Living Organisms. Graduate Shool of Biosphere Sciences, Hiroshima University, Kagamiyama 1-4-4, Higashi-Hiroshima, Hiroshima, 739-8523, Japan.

** Taiko Sangyo Co., Ltd., Mukaishima 9515-1, Onomichi-shi, Hiroshima, 722-0073, Japan.

*** National Maritime Research Institute, Osaka Branch, Amanogahara 3-5-10, Katano-shi, Osaka 576-0034, Japan.

capacity; 5 min treatment), it showed sufficient performance which can satisfy all D-2 requirements, and moreover, a four-order decrease of marine heterotrophic bacteria. In our system, organisms are killed but not "removed" from the treated water. Therefore, a simple and reliable method that will enable us to instantly determine the viabilities is needed. For this purpose, a classical but reliable vital staining method using "Neutral Red (NR)" has been employed with much success.

Key words: Ballast Water Management System, Retrieved Thermal Energy, Neutral Red, Taiko Sangyo Co., Ltd.

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1 Introduction

Toward the implementation of the International Convention for the Control and Management of Ships Ballast Water & Sediments in the near future, many ballast water management system (BWMS) have been approved and are already in the market, and with more models being tested. Mostly because it is difficult to eliminate bacteria from a massive volume of ballast water, the majority of the treatment principles employed in the existing BWMS rely on chemical/active substances. However, of great concern to environmentalists is the potential for such elements used in treatment systems to cause secondary pollution in marine environments if not adequately neutralized at the time of discharging. Other particular concerns would be on the supply of those substances, if they are not produced *in situ*, and apprehension for handling risks by ship's crews.

A less environmentally burdensome, but rather, a perfectly reversible way to eliminate any aquatic organisms, is "heating." It has been widely advocated as a possible treatment regime based on theoretical (e.g. Hallegraeff et al. 1997; Montfort et al. 1999) and on-board testing (e.g. Rigby et al. 1997; Mountfort et al. 2001; Quliez-Badia et al. 2008). Among them, there can be found several different settings in heating time and temperature; 20 h over 35°C (Rigby et al. 1997), 15 h at 42°C (Mountfort et al. 2001), 80 h at above 30°C (Mountfort et al. 2001), and a few seconds at 55–80°C (Quliez-Badia et al. 2008). Under any type of setting, the only significant concern of utilizing heating theory is how much heat energy should be introduced to achieve sufficient elimination of organisms. This is very critical when considering bacterial elimination only by heating. Because it is far difficult to sufficiently heat a massive water volume in the ballast tank, most of the heating methods were accompanied with a "heat exchanger," which enables preheating the water before reaching a desired temperature. However, even in the reported cases, preheating was not sufficient to minimize subsequent energy input; in this context, initial heating by the heat exchanger was considered "preheating" and further heating constitutes "main heating." For applying this environmentally-attractive principle of "heating" to BWMS on a practical treatment-rated-capacity (TRC), and especially aiming to eliminate bacteria only by heating, efficient preheating would be very critical.

We have developed a new type of BWMS applying heating theory. This "Thermal Aqua Filtration System (TAF-System)" is basically similar to the ones previously reported, but much different by using a highly-efficient, plate-type Heat Exchanger (HX). The HX enables retrieval of 95% heat energy from the heat-treated water and to input the energy toward the newly incoming water. Since more than the 95% heating was previously achieved before the final heating process in the "Thermal-treatment Tank (TT)", the preheating at the HX is substantially "main-heating," and additional heating in the TT is complementary. Therefore, continuous treatment of discharging ballast water, by heating for 5 min at 70°C, is achieved. We report here the system and performance of the TAF-System based on a land-based small scale plant (maximum TRC =15 m^3/h).

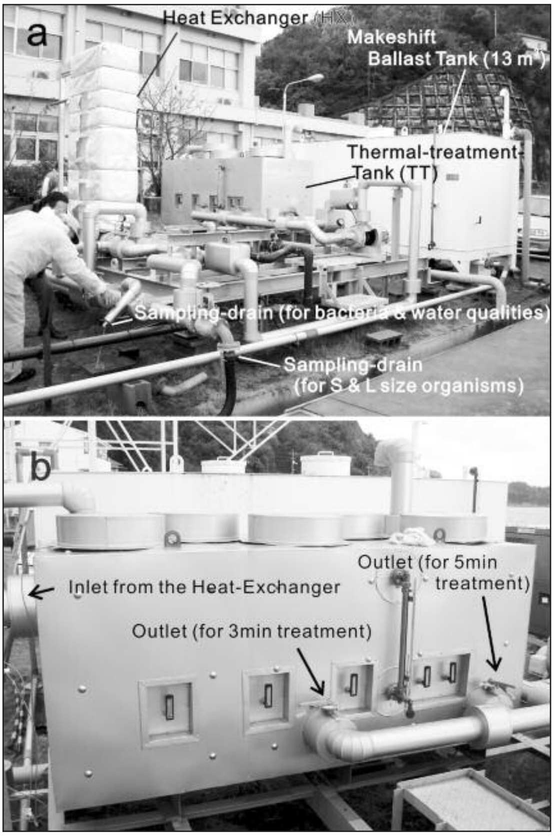

Figure 1. Setup of the Thermal-Aqua-Filtration System (land-based small-scale plant). (a) External view of the whole unit including a makeshift ballast tank. (b) External view of the Thermal-treatment Tank (TT). It consists of five cells, a electric heater is installed at the bottom of each cell. Thermally treated water by HX further flows through the TT for 3 min or 5 min and be additionally heated

2 The System

Figure 1 shows the setup of the TAF-System (land-based small-scale plant). The unit mainly consists of a Thermal-treatment Tank (TT) with 1.25 m^3 capacity, divided by five internal cells (Figure 1-b), and a highly-efficient plate-type Heat Exchanger (Figure 1-a: HX). The HX has four-layered units of multiple titanium plates (0.5 mm thickness; total 226 plates). On the both sides of the each titanium plate, heated and heating water flow counter and exchange heat energy until reaching to the temperature difference of 2°C (ΔT). Heat-exchanging area is 161.28 m^2. The system is also accompanied with a makeshift square ballast tank (13 m^3). For additional heating in the TT, four electric heaters (15 kW each) are installed at the bottom. Note that the electric heaters would be substituted to the heat source from the boiler or 90°C hot-seawater (e.g. stored waste heat from main engine) in real operational applications. Main piping works and the TT are made of stainless steel for primary sterilization by circulating boiling water prior to the bacterial count test, and reduce rust particles possibly generated from ordinary steel walls that interfere with biological microscopic observation according to the G8 guidelines. The size of the TT is determined by a combination of desired TRC and treatment time. In the present setting, 5 min treatment at 70°C was tentatively chosen, because the D-2 regulated enterococcal bacterium is most highly heat-tolerable, and its *D*-value (minute leading one order decrease) at 70°C has been reported as 1.4–1.9 (*Enterococcus faecium* in 1.15M Sørensen buffer).

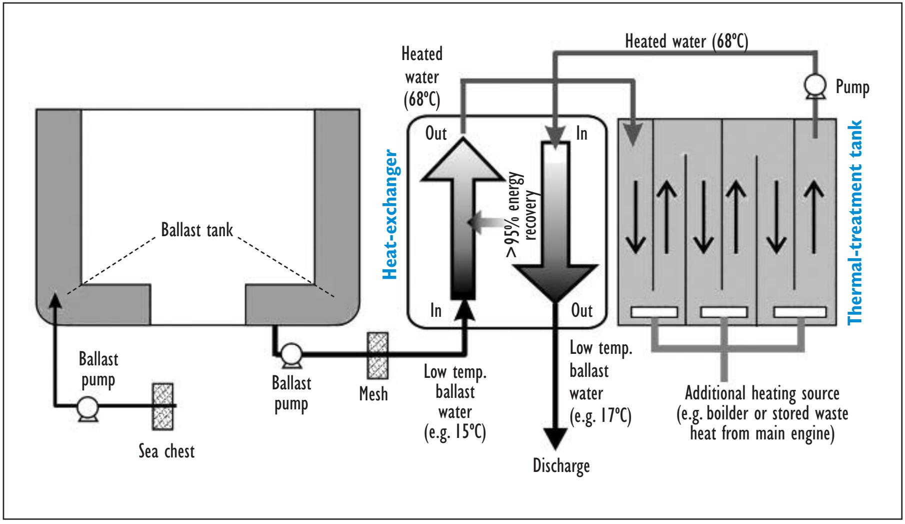

Figure 2. A schematic drawing of Thermal-Aqua-Filtration System (TAF-System)

Figure 2 shows a schematic drawing of the TAF-System. The system is basically categorized as "discharge- treatment." Prior to discharging, seawater in the TT is initially heated up to 70°C and then introduced to the HX, where retrieved thermal energy heats up untreated ballast water newly flowing into the HX. In moderate seawater temperatures (e.g. 15°C), efficiency of the energy recovery is more than 95%, which means HX simultaneously cools down the water to be discharged nearly equal to the ambient seawater, and heats up ballast water to 68°C prior to inflowing to the TT. Consequently, during the continuous treatment, energy input in the TT is needed just enough to cause an increase of 2°C.

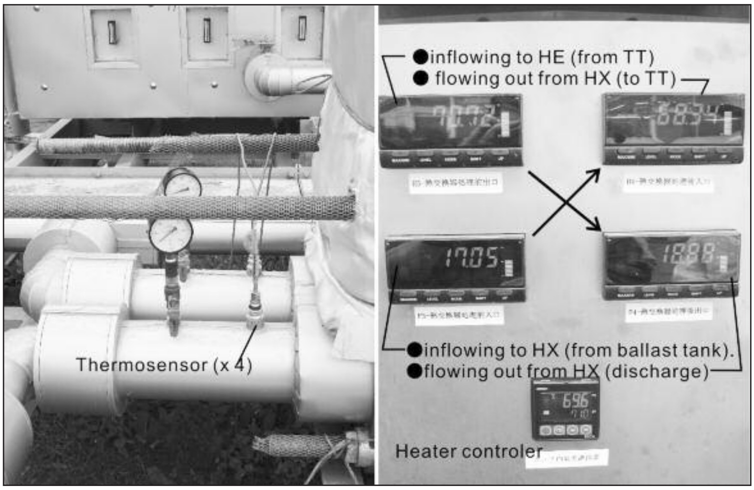

Figure 3. Location of the thermosensors (left photo) at the pipes connecting to the Heat-Exchanger (HX). The control panel (right photo) shows ballast water, which is initially at ca. 17.1°C, is heated up to ca. 68.3°C at the HX, and at the same time, additinally thermal-treated water flowing out from the Thermal-treatment Tank (TT; ca. 70.7°C) is cooling down to ca.18.9°C

Figure 3 shows an example of temperature measurements at each inlet/outlet of the HX. On the testing day (described below), the seawater temperature in the makeshift ballast tank was nearly 17°C. Newly incoming water to the HX is ca. 17.1°C and flowing out from the HX at ca. 68.3 °C. Simultaneously, the treated water in the TT inflowing to the HX at ca. 70.7 °C and cooled to ca. 18.9 °C after coming out from the HX. In this case, energy retrieval was achieved up to 95.6%, and thus further 4.4%-equivalent heat energy was input into the TT.

3 Performance Test Methodologies

3.1 Efficacy of Vital staining Method for Biological Test

The TAF-System does not have any filtering component to remove the treated particles, and initial densities of S- (10 µm≤, < 50 µm) and L- (50 µm ≤) size organisms will not significantly change even after the treatment. Therefore, to test the D-2 requirement for S- and L-size organisms, we needed to apply some vital staining method to determine the surviving live individuals. For that purpose, we applied a most widely used staining method, neutral red (NR) staining (Crippen & Perrier 1974). The stain is taken up by cellular active uptake and stored in lysosomal organelles. Basic protocol is as follows: an aqueous solution of neutral-red is added to the specimens in water at the final concentration of 5×10^{-4}% w/v, kept under environmental temperature for 45–60 min, and counted for red-stained individuals or cells under transmission light of a light microscope (S-size) or a binocular microscope (L-size).

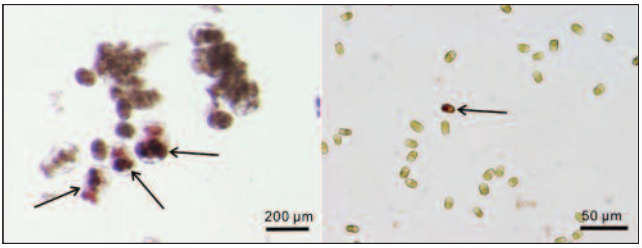

Figure 4. Photomicrographs of neutral red stained Brachionus rotundiformis (rotifer; left photo) and Tetraselmis sp. (chlorophyte, right photo). Live individuals or cells are stained in red-color (arrows) and easily distinguished from the un-stained ones (dead)

According to our laboratory trials, scarce presence of live individuals of the representative species for S- or L-size organisms, *Tetraselmis* sp (chlorophyte) and *Brachionus rotundiformis* (rotifer), were well tracked by observing red-stained cells or individuals (Figure 4). From the triplicated trials made by mixing certain numbers of live cells or individuals with heat-killed 10^5 assemblages, 972 ± 99.7 stained cells and 10 ± 0 stained individuals were counted for the mixtures representing 1,000 live cells of *Tetraselmis* sp. and 10 live individuals of *B. rotundiformis*, respectively. An advantage of this neutral red staining method is that stained samples can be kept in formalin fixation up to 28 weeks, according to a report by Fleming & Coughla (1978).

3.2 Biological Test on the Land-based Small-scale Plant

On December 11, 2009, a biological test was performed using a test soup based on the G8 guidelines. Water qualities of the initial test soup were measured by a CTD (for water temperature, salinity, and turbidity; JFE Allec, ASTD687 sensor) and a hand-held sensor (for dissolved oxygen and pH; TOA DKK, WQC-24 sensor). To increase dissolved organic carbon (DOC), particulate organic carbon (POC) and total suspended solids (TSS) concentrations above the G8 criteria, 13 g of glucose and 40 g of an assorted feed for bivalve culture (M-1, Nosan Co.) were initially added to 12 m^3 of the initial test soup in the makeshift ballast tank.

For adjusting the density of heterotrophic bacteria, seawater (10 L) near the test site was initially sampled and incubated for 7 days with addition of 50 g glucose, and added to the initial test soup. Representative species of S- and L-size organisms were *Tetraselmis* sp. (chlorophyte) and *Brachionus rotundiformis* (rotifer), respectively. They were initially dense-cultured in aquaria. For other phyla and species combinations, L-size organisms were collected by plankton-net hauling (GG54) at Ujina-Port, Hiroshima on the day before the test, and kept in 30 L of ambient seawater. Other S-size organisms were found in that water sample. The densities of these S- and L-size organisms in the initial test soup, including the representative species, were counted after the neutral red staining for triplicated samplings; under the water volumes of 100 μl for *Tetraselmis*, 100 ml-equivalent (concentrated by meshes) for other S-sizes, 2 L-equivalent (concentrated by meshes) for *B. rotundiformis*, and 20 L-equivalent (concentrated by meshes) for other L-sizes.

Figure 5. One m3-capacity tanks (upper photo) tentatively storing the treated water for L-size organisms. The water in the tanks were siphoned out and concentrated through plankton net (lower photo

After confirming that the initial test soup in the makeshift ballast tank met the G8 criteria for land-based testing, the system was operated according to the above mentioned procedure. The treatment setting was 5 min at 70°C and monitored on the control panel (Figure 3). TRC was 12 m^3/h. After flushing 4 m^3 test soup through the TT, the thermally treated water was sampled for the biological tests. For microbes and water-quality analyses, the treated water was directly retrieved from the sampling drain connected to the piping work (Figure 1). For S- and L- size organisms, the treated water was tentatively transferred to 1 m^3–capacity PP tanks in triplicate, and they were concentrated through plankton nets (diagonally 50 μm mesh for L-size and 10 μm for S-size) for the designated volumes according to the G8 protocol (10 L for S-size and 1 m^3 for L-size) (Figure 5). All the microscopic works and bacterial treatment were finished within four hours after the treatment.

3.3 Control Experiment

We should here again emphasize that our system will treat the ballast water during “discharging,” therefore, the ballast water on this test was not stored for five days nor analysed as a control water which is determined under the G8 guidelines. Nevertheless, obtaining the control water should have added benefits to know some possible false-negative effects derived from inadequate sampling procedures (e.g. transfer, concentration, microscopical operations). Consequently, prior to the performance test, viabilities and concentrations of *Tetraselmis* sp. and *B. rotundiformis* were compared between the initial test soup in the ballast tank and that discharged from the sampling drain (Figure 1) but without system operation. As a result, we could not find any significant differences in the viabilities or the densities between the initial test soup and that obtained after discharging without operation (Table 1.)

Table 1. Concentrations and neutral-red stainabilities of Tetraselmis sp. and Brachionus rotundiformis between the initial test soup and that discharged from the sampling drain (without system operation). The number is expressed as an average ± standard deviation in triplicate samplings.

	***Tetraselmis* sp. (cells/ml)**		***Brachionus rotundiformis* (ind./m^3)**	
	Neutral red +	Neutral red –	Neutral red +	Neutral red –
Initial test soup	1320 ± 6	380 ± 130	103167 ± 2625	167 ± 236
After discharging (without system operation)	1130 ± 80	330 ± 60	95500 ± 2000	0

4 Performance Test Results

Table 2 shows a list of water qualities of the initial test soup. These met the G8 criteria for a testing under the salinity range above 32.0 PSU

Table 2. Water qualities of the initial test soup in the ballast tank, tested on December 11, 2009.

Base Sea Water	**Sensor Measurements**					**Analytical Measurements**		
	Water Temperature	Salinity	Turbidity	DO	pH	DOC	POC	TSS
12 m^3 (Anthracite filtered)	16.78 °C	32.99 PSU	0.70 NTU	8.14 mg/L	8.06	1.5 mg/L	1.1 mg/L	1.7 mg/L

Figure 6 shows neutral-red stainability of S- (a–c) and L- (d–f) size organisms in the initial test soup. They were clearly stained in red colour, indicating they were alive. Table 3 shows densities of bacteria (colony forming unit), and S- and L-size organisms with positive neutral-red indication. All the densities met the G8 criteria as a test soup.

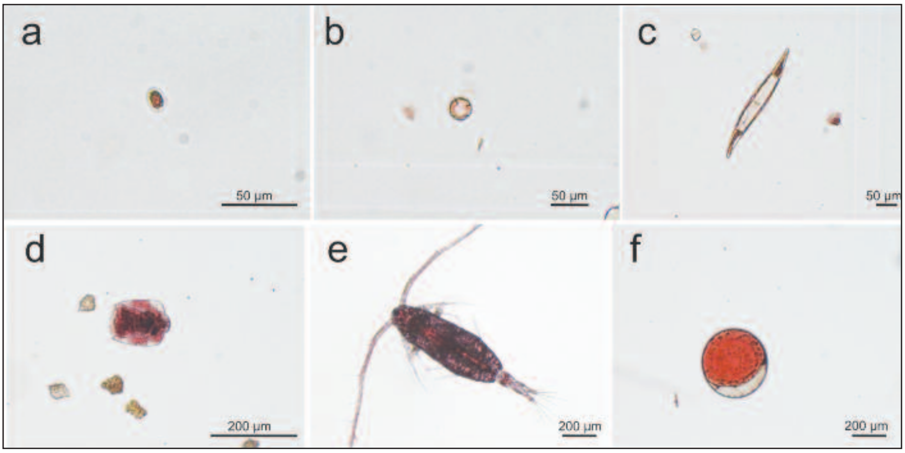

Figure 6. Photomicrographs of neutral-red stained organisms in the initial test soup. (a) Tetraselmis sp.,(b) Thalassiosira sp., (c) Pleurosigma sp., (d) Brachionus rotundiformis, (e) Acartia omorii, (f) Coscinodscus wailesii

Figure 7 shows photomicrographs of S- and L-size organisms in the heat-treated discharging water after the neutral red staining. The representations for S- and L-size organisms, *Tetraselmis* sp. and *B. rotundiformis*, were not stained positively in red-colour (Figure 7-a and -d), as well as any other organisms in the treated water (Figure 7-b and -c).

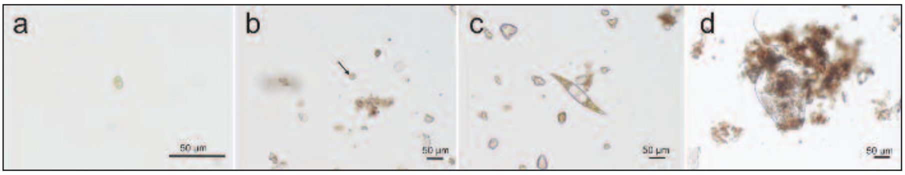

Figure 7. Photomicrographs of organisms in the heat- treated discharging water. They were stained with neutral red, but did not show any of red-color, indicating they were dead. (a) Tetraselmis sp.,(b) Thalassiosira sp.(an arrow), (c) Pleurosigma sp., (d) Brachionus rotundiformis

Table 4 shows density of these organisms in the thermally treated water. While it is not mentioned in the guideline, we have also counted non-living, neutral red negative cells or individuals for S- and L-size organisms. Note that none of neutral red positive cells or individuals were detected in the observed volumes.

Table 3. Biological conditions in the initial test soup. For S- and L- size organisms, the densities are expressed in numbers of neutral red positive cells or individuals (an average ± standard deviation in triplicate samplings).

Live Bacteria				**Live S-size Organisms**			**Live L-size Organisms**		
Hetero-trophic bacteria	Coli-form	Entero-coccus	*Vibrio cholerae*	Phylum*	Species (min dimension)	Density (neutral red +)	Phylum*	Species (min dimension)	Density (neutral red +)
4.8±0.8 × 10^4 cfu/ml (Marine Agar)				C	*Tetraselmis* sp.	1.21±0.14 × 10^3 cells/ml	R	*Brachionus rotundiformis* (80–130 μm)	1.22±0.43 × 10^5 ind./m^3
				H	*Thalassiosira* sp. (20–30 μm)	176.7±73.6 cells/L	Art	*Paracalanus parvus*	683±165 ind./m^3
				H	*Pleurosigma* sp. (45 μm)	116.7± 45.0 cells/L	Art	*Pseudodiaptomas marinus* (270–340 μm)	50 ind./m^3
	328± 27 cfu/100ml	N.D. **	N.D. **	H	*Amphiprora* sp. (20–30 μm)	53.3±23.6 cells/L	Art	*Corycaeus* sp. (250–270 μm)	133±47 ind./m^3
1.0±0.5 × 10^3 cfu/ml (R2A Agar)				D	*Prorocentrum micans* (20 μm)	53.3±28.7 cells/L	Art	*Oithona davisae* (270–340 μm)	83±24 ind./m^3
							Ann	Polychaeta larvae (90–130 μm)	100±40 ind./m^3
							H	*Coscinodiscus wailesii* (220–240 μm)	81330±193 cells/m^3

* C, Chlorophyta; H, Heterokontophyta; D, Dinophyta; R, Rotifera; Art, Arthropoda; Ann, Annelida

** detectable level ≥ 0.2 cfu /100 ml

According to the aforementioned results, the TAF-System is shown to sufficiently eliminate living organisms in ballast water. While most of the large-sized organisms as L- size were decreased to less than the detectable levels (< 1 cells or individuals/m^3), probably due to destruction by strong water stream or rupture by pump impeller or HX surfaces after thermal treatment, the smaller organisms as S- size were somewhat retained in the discharging water. For these retained cells, staining with neutral red worked quite effectively and clearly demonstrated that all of them were actually killed (Figure 7).

In our previous interpretations, while it is not described in the D-2 regulation, elimination of heterotrophic bacteria would be the most critical criterion for an objective test performance in our system, since they should be an assemblage of physiologically unknown bacteria and our system does not employ any active chemical substances to eliminate them. Despite such concern, 99.98% of them were eliminated and kept at less than the statistically significant levels (10 cfu/ml); to several colonies per ml from more than 10^4 cfu/ml in the initial test soup (for Marine Agar- growing bacteria).

Table 4. Changes of organisms densities in the thermally treated discharging water. None of the S- and L- size organisms showed positive staining by neutral red, and are not shown in this table. Instead, while it is not mentioned in the G8 guidelines, cells or individuals with negative neutral-red staining (means dead) are listed. They are express as an average ± standard deviation in triplicate samplings.

Live Bacteria				**Dead S-size Organisms**			**Dead L-size Organisms**		
Hetero-trophic bacteria	Coli-form	Entero-coccus	*Vibrio cholerae*	Phylum*	Species (min dimension)	Density (neutral red +)	Phylum*	Species (min dimension)	Density (neutral red +)
8 ± 4 cfu/ml (Marine Agar) 4 ± 8 cfu/ml (R2A Agar)	N.D. **	N.D. **	N.D. **	C	*Tetraselmis* sp.	$7.3 \pm 2.2 \times 10^2$ cells/ml	R	*Brachionus rotundiformis*	N.D. ***
				H	*Thalassiosira* sp. (20–30 μm)	54±12 cells/L	Art	*Paracalanus parvus*	N.D. ***
				H	*Pleurosigma* sp. (45 μm)	26± 7 cells/L	Art	*Pseudodiaptomas marinus*	N.D. ***
				H	*Amphiprora* sp. (20–30 μm)	5±2 cells/L	Art	*Corycaeus* sp.	1 ind./m^3
				D	*Prorocentrum micans* (20 μm)	30±10 cells/L	Art	*Oithona davisae*	N.D. ***
							Ann	Polychaeta larvae	1 ind./m^3
							H	*Coscinodiscus wailesii*	32±27 cells/m^3

* C, Chlorophyta; H, Heterokontophyta; D, Dinophyta; R, Rotifera; Art,Arthropoda; Ann, Annelida
** detectable level ≥ 0.2 cfu/100 ml
*** detectable level ≥ 0.3 ind./m^3

5 Conclusion

Although we further need to repeatedly and correctly test the performance according to the G8 guidelines, our system potentially showed significant performance for elimination of microbes and planktons, without using any active chemical substances, and with practical and low operational cost for heating due to the highly efficient HX. Application of a vital staining method, neutral red staining, worked well for distinguishing living and non-living organisms in the initial and treated waters. Our remaining and most vital tasks should be: (1) exploring energy-source for additional heating, and (2) positioning of the TT on ships. Desired TRC determines the energy input for additional heating, which should be added to the TT, and the size of the TT is decided by the combination of the TRC and the treatment time. Moreover, heat-transfer area in the HX should increase linearly according to the TRC if the ΔT will be kept constant. If we assume TRC=200 m^3/h and same ΔT (=2°C) level, the HX area would be 13.3 times wider than that in the current land-based small-scale plant, and a 16.7 m^3-capacity TT would be necessary.

For positioning of TT in ships, we might expect one of existing ballast water compartments in exchange for installing new TT. Moreover, if other large existing ballast water compartments could be insulated and utilized as storing of waste-heat from a main engine during voyage, these waters can be alternative heat sources by mixing to the treating water in the TT. In our numerical analysis, 1/20 volume of the existing ballast water (e.g. 1,000 m^3 for 20,000 m^3-capasity ballast tank) can be reached to over 90°C by retrieving heat-energy e.g. from exhaust gas, in such corresponding vessel, and be sufficiently used for heating source in treating such ballast water volume without any other heat input. Availability of abundant heat-source should allow lower ΔT and consequently decrease the initial investment of HX. Trials of these ideas are now in progress, and we are expecting this perfect cost-free and environmental-friendly BWMS will be presented in the near future.

6 Acknowledgments

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Development of Novel VUV Photocatalysis System for Ballast Water Treatment

Yansheng Yin, Lihua Dong, Li Zhang*, Chunhua Fan, Tao Liu, Yun Zhou, Dongsheng Wang, Yunlian Xu** and Baojia Xiao

Abstract

A novel system (named VUVPhotolysis) was designed for the control and treatment of ballast water to minimize the risk of invasive species into port and territorial waters by ships' ballast water and sediment discharges. The major findings of the VUVPhotolysis system and some onshore testing results using the prototype VUVPhotolysis system achieved were also presented. it was demenstrated that photocatalytic disinfection by VUVPhotolysis system can overcame the shortcomings of traditional UV disinfection and the VUVPhotolysis system was a promising new BWMS for ballast water treatment.

Key words: Invasive Species, Ballast Water Management System, Photocatalyst, Photocatalysis, Onshore Testing

1 Introduction

In view of the large volumes and frequency of use, ballast water is currently the most frequently cited method for the worldwide transference of non-indigenous organisms. Combating invasive species in ballast water is a matter of global urgency. International agencies such as the International Maritime Organization (IMO), United States Coast Guard (USCG), and U.S. federal and state governments are combating the problem by mandating ballast water exchange in the open ocean or utilizing ballast water treatment systems. In 2004,The IMO adopted a new convention called the International Convention for the Control and Management of Ships' Ballast Water and Sediments. This convention will phase in ballast water treatment standards over the coming years, beginning in 2009 with requirements for smaller new ships. And now worldwide regulations are set to take effect.

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[*] Ph. D, Institute of Marine Materials Science and Engineering, Shanghai Maritime University, China.

[**] Shanghai Haida Assets Management Co.Ltd. China.

The National Research Council evaluated a variety of approaches or systems for removing indigenous organisms from ballast water. Among these systems, Ultraviolet(UV) irradiation system was recommended as one of the most promising technology[1]. However, the biggest concern raised with regard to UV systems is the threat of organisms can sometimes repair and reverse the destructive effects of UV after retention in the ballast system through a "repair mechanism", known as photoreactivation, or in the absence of light known as "dark repair"or "re-growth."[2,3,4]

Heterogeneous photocatalysis, as a promising advanced oxidation process for water and wastewater treatment, has attracted interests of many researchers. Its superiority was demonstrated by numerous investigations for purification of widely organic contaminants[5,6]. Such as it can work well under room temperature, it involves nearly no chemicals except the photocatalyst which is stable and reuseful, it has no selectivity to organic pollutants (including bio organisms), it is low cost and significantly low energy consumption. especially it can completely kill the microorganisms by cell degradation of the whole, which overcomes the shortcomings of "dark repair" in traditional UV disinfection[2].

In this work, a novel ballast water management system (named VUVPhotolysis BWMS) by using the photocatalytic technology is developed for ships for the control and treatment of ballast water to minimize the risk of organisms and pathogens invasion.The design of our VUVPhotolysis system and some tested results using a prototype VUVPhotolysis system under onshore testing achieved so far are also presented.

Principles of VUVPhotolysis System in Treatment of Ballast Water

The principles of the VUVPhotolysis system is based on the traditional well established UV photocatalysis. But it is an enhanced photocatalysis by improvement of the core light source.

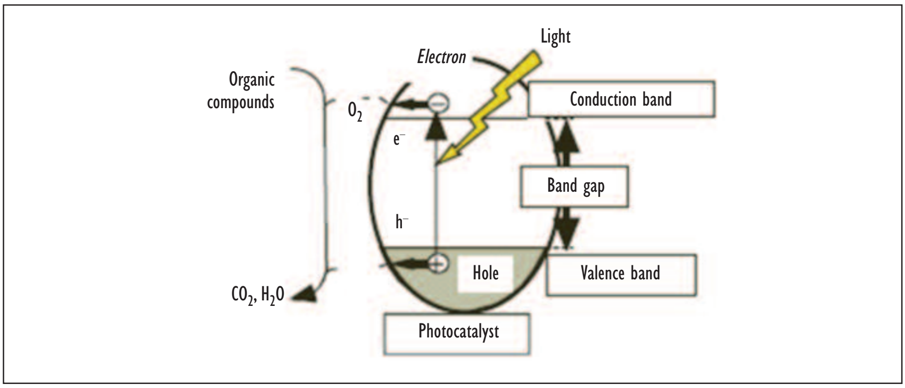

Figure 1. Mechanism of traditional photocatalysis

Figure 1 shows the basic mechanism of traditional heterogeneous photocatalysis[7]. By restructuring semiconductor photocatalyst such as titanium dioxide particles in nano-scale, and irradiation the photocatalyst by a light with energy larger than the band gap of the photocatalyst (for TiO2, light WL needs: l<387.5nm), pairs of electrons and holes will be produced.The electron of the valence band of titanium dioxide becomes excited when illuminated by light. The excess energy of this excited electron promoted the electron to the conduction band of titanium dioxide therefore creating the negative-electron (e–) and positive-hole (h+) pair.

The positive-hole of the photocatalyst breaks apart Hydroxyl ions or water molecules adsorbed to surface of the photocatalyst to form hydrogen gas and hydroxyl radical. The negative-electron reacts with oxygen molecule adsorbed to surface of the photocatalyst to form super oxide anion. This cycle continues when light is available[8].

The hydroxyl radical is known as one of the strongest oxidants, with the fluorine oxidizing power, far stronger than the other chemistry oxidant. Its reaction rate is extremely quick, such that the reaction with C – H, C – C key's organic matter can be up to above 10^9 L/(mol·s), achieving or surpassing the proliferation speed limit value[10^{10} L/(mol·s)], and it is higher than the ozone reaction speed with 7 magnitudes. The biochemistry reaction time is between 1 to 10 seconds. Once the hydroxyl free radical forms, it will induce a series of free radical reaction chain, oxidizing all organic matters and organism, leaving CO_2 and H_2O and micro inorganic salt as the final degeneration. So under the irradiation of the UV light, photocatalyst, such as titanium dioxide, could rapidly breakdown organic substances. And there will be nearly no harmful byproducts left because of the strong oxidation.

The hydroxyl radical is strong enough to degrade most pollutants effectively. But the traditional photocatalytic oxidation process actually is of low efficiency, and it takes a long period of time to purify water, which results in a high cost and no competitiveness. Many modification methods have been well established to improve the efficiency of photocatalytic oxidation process, such as ozone and hydrogen peroxide were added in the reaction system, which significantly increased the overall oxidation rate[9,10] although the cost of the traditional photocatalysis was still high.

Therefore, as the new excimer light sources with much lower wavelength become available, the cost effective enhancement method for photocatalysis is promoted. In this work, a vacuum ultraviolet (VUV) lamp with lmax=185 nm is chosen to be the light source in a photocatalysis system. Under irradiation with VUV light, water itself is homolyzed into hydrogen atom and hydroxyl radical, and other oxidative species, such as hydrogen peroxide and ozone, could be formed simultaneously[11]. Thus synergic effects of hydroxyl radical reaction and ozone, hydrogen peroxide enhanced photocatalysis would occur in the VUVphotocatalysis process. Thus, the oxidation efficiency of the VUV photocatalysis would significantly increase compared to the traditional photocatalysis and UV disinfection.

3 Basic Concept of the Prototype VUVPhotolysis BWM System

3.1 Construction of the Prototype VUVPhotolysis BWM System

According to the requirement of IMO's G8 and G9 regulations, the VUVPhotolysis BWM system was designed for fulfillment of both lab test and onshore tests of the novel VUV photocatalysis process.Its treatment capability can be adjusted from 20 m^3/hr to 60m^3/hr.

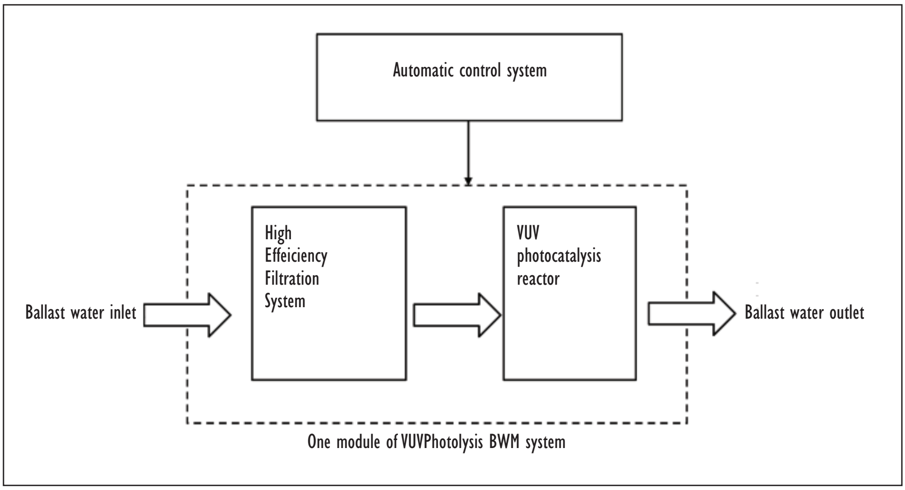

Figure 2. Schematic diagram of the consistent of VUVPhotolysis BWM system (one module)

Figure 2 shows the schematic consistent of one module of VUVPhotolysis BWM system. It is a kind of modular system consisted of three main components, the self-cleaning filtration system, VUV-Photcatalysis reactor and an automatic control system, which made the system easy to be enlarged according to the field application circumstances.

The self-cleaning filtration system is designed for reducing the number of organisms taken in and the amount of sediment build-up in the tanks. The filtration system is special designed for our experiment by Shanghai LeRan Mechanic & Electrical co.,Ltd. who is a local leading filtration manufacturer in China. It is equipped with a 50 micron fine screen and an automatic built-in by-pass. When it works, dirty inlet sea water from the ballasting site enters the center of the fine screen. The water then passes through the fine screen from the inside out and exits the outlet. The unwanted solids accumulate on the inner surface of the fine screen, creating a pressure differential. Once the pressure drop reaches a preset level, a backflush stream is created, which sucks the dirt off the screen, similar to a vacuum cleaner. The backwash water is carried through a collector in the filter and ejected out of the filter. Then the dirty backwash water flows to the ocean directly at the ballasting site through the corresponded connection tubes. The cleaning cycle takes just a matter of seconds, and does not interrupt the filter system flow. One of the advantages of our filter is that, during operation, a layer of dirt accumulates on the surface of the screen. This layer of dirt actually removes much finer particles than the original screen itself. In fact, the 50 micron screen we are using is removing particles all the way down to 10 microns. This significantly raises the water quality, which facilitated well for our treatment.

The VUV-Photcatalysis reactor. It is a specific VUV-Photcatalysis reactor with cuboid shape (50cm × 50cm × 167cm in volume) constructed with Titanium alloy plate to help prevent corrosion. It consists of three main components. The high output VUV lamp, the immobilized TiO_2 photocatalytic films, a sensor for light strength detection and automatic mechanical lamp cleaners. The sensor and the automatic lamp cleaners are sourced from the Newisland Co.,Ltd. in China. The novel high output VUV lamps are specially developed by Yaguang Lighting Co., Ltd. for our experiments. It is a kind of strong amalgam lamp whose UV output is three times higher than the normal UV lamp with the same length of which more than 50% is in the VUV region. It is also demonstrated that the novel lamp provides more than 0.01ppm ozone under the irradiation of VUV light in water when the flowing rate is within $20m^3/h$–$60m^3/h$ at room temperature. The immobilized TiO_2 photocatalytic films used in the reactor are developed by ourselves. It's surface micrograph observed by the Atomic Force Microscopy (AFM) shows in the Figure 3. It is clear that to fine the crystal grains of our films are uniform spheres and compactly bonded together all over the surfaces. The average size of TiO_2 crystals on the film is about 21nm. The photocatalytic activity and lifetime performance are very much higher comparing to the immobilized TiO_2 photocatalysts. The lifetime of our film is up to 9,000 hours under a continuously flowing reactor test, which has been reported in our previous work. The assembling of the VUV-Photcatalysis reactor is described as follows.

In the novel VUV-Photcatalysis reactor, a total of 25 VUV novel lamps are used. All lamps with quartz sleeves are placed around the top plate and their ends extended through holes onto the top plate for electrical connections. Electrical wires are connected to the lamps through stainless steel holders that are screwed around the lamps end. This part acts as a clamp for the lamps. The UV light sensor is assembled near the VUV lamp and perpendicular to the light axial direction by a stainless holder. The automatic lamp cleaners are assembled outside of the quartz sleeves of lamps by sliding rails with stopper. The TiO_2 photocatalytic films are vertically inserted in the reactor vessel by parallel to the lamp direction. In the rectangular reactor vessel, a feed is introduced at the bottom of the vessel and is equally distributed over the width of the reactor through five inlet ports thereby minimizing formation of any dead zones. Similarly, the flow exits the reactor through five ports at the other end. The effective illuminated surface areas of the catalyst and the volume of the reactor are 16 m^2 and $0.36m^3$, respectively.

Within the specific designed VUVphotocatalytic reactor, it make our new VUV-photocatalysis technology whichs combines the principles of the conventional UV photolysis, H_2O_2–UV/photocatalysis and O_3–UV/photocatalysis processes into reality.

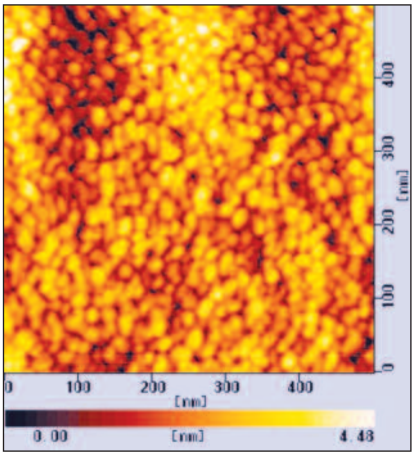

Figure 3. AFM Micrograph of TiO2 Films

The VUVPhotcatalysis automatic control system, is controlled from a Control Panel (CP) installed at any convenient location for the operator. System controls and indicators based on a programmable logic controller (PLC) platform are located in the CP. Real-time data on operation including UV light intensity, temperature and pH sensors readings are stored in a data logger in the CP. The control system makes the whole ballast treatment process fully automated, especially in the light sources maintenance. For example, when the intensity of VUV light detected by the sensor is below the preset value, the mechanical lamp self-cleaner will start to wipe, which can clean foullings outside the quartz sleeves of the VUV lamp and significantly help to maintain the VUV lamps efficiency and performance during operation in different sites world wide. Further, the system is designed to provide the necessary signals for remote control operation from either the ship's ballast control system or from a Remote Control Unit (RCU). All the hardware and software are jointly developed by teams from SHMTU and the Shanghai Haida Assets Management Co.Ltd.

3.2 Operation of the VUVPhotocatalysis BWM System

For a typical VUVphotocatalysis BWM system, the VUVphotocatalytic reactor vessel is installed at the suction side of the ballast pump, and a screen-type self-cleaning filter is installed after the pump. A picture of the pilot VUVphotocatalysis BWM system is shown in Figure 4.

During ballasting, water passes through the self-cleaning filter to remove any larger particles and organisms. This helps reduce the amount of sediment build-up in the ballast water tanks. The water then continues to the VUVphotocatalysis unit, which produces radicals that effectively break down organisms that have passed the filter. Any backwash water is returned to the ocean directly at the ballasting site. During deballasting, water passes the VUVphotocatalysis unit a second time, rapidly disinfeeting the water once again. The filter is bypassed at deballasting so as not to produce or discharge any backflushing water. This way there is no risk of contamination at the deballasting site.

In brief, the VUVphotocatalysis BWM system is fully automated and simple to operate. It can be started and stopped at the push of a button, either locally or via remote control. Since no chemicals are involved, there is nothing to be handled or stocked on board.

Figure 4. Picture of One Module of VUVPhotolysis BWM System Prototype 1. VUVphotocatalysis Reactor 2. Self-cleaning Filtration System 3. Automatic Controll System 4. Assistant Pump for Onshore Testing mimic a ballast pump

4 Pilot Testing Results of VUVPhotolysis BWM System

4.1 Pilot Test Results in Lab

Before the onshore pilot test, 5 test cycles were operated in lab by treatment artificial Sea-water with mimic organisms pollutants additive. Figures 5 and 6 were pictures of the two mimic organisms we used for test the VUVPhotolysis BWM system in lab. The active algaes named Nitzschia closterium f. minutissima and Isochrysis Galbana Parke 8701i were indicated in red dotted line frames respectively. They are two real organisms in the natural sea water, whose sizes are 70ummm–120mm and 10mm–20mm respectively, and are conveniently cultivated in lab. Therefore, the two algae are ideal for our test according to the size requirements. The fraction of the organisms are inspected with a Leica YD400 binocular biomicroscopy and monitored by a BD FACSCount TY7350 flow cytometry. The Escherichia Coli was selected as the mimic bacteria and detected by the standard plate counting method.

The lab results demonstrated that the Self-cleaning filtration system can effectively removed those of a size larger size than 50mm. There was no detectable active Nitzschia closterium f. minutissima among the 5 cycles. The smaller sized Isochrysis Galbana Parke 8701i (<20mm >10mm) were killed with high efficient in the final VUV-Photocatalysis step. The average killing rate among the 5 cycles is up to 99.5% with a STDEV of ±0.003 when the flow rate is up to 60m^3/h. The average killing rate of Escherichia Coli after the final VUV-Photocatalysis step is over 99.99%±0.0001. It was interesting to note that when we observed the treated water sample collected from the discharge port, the cell membrane of many Isochrysis Galbana Parke 8701 was found to be destroyed. It was clear to see the cellular organelle flowed out of cells. The fraction of destroyed algae cell was up to 30%. This demonstrated that our VUVPhotolysis BWM system has a much stronger capability compared to traditional UV disinfection. It is accredited to the VUV photocatalytic principles which had been also confirmed by Wang et al.[11]

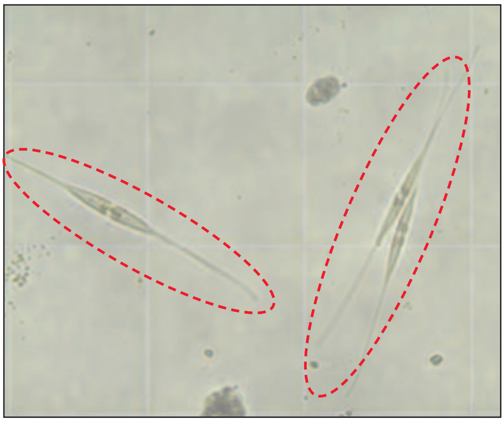

Figure 5.Picture of active Nitzschia closterium f. minutissima

In total, the VUVPhotolysis BWM system demonstrated good performance and repeatability and passed the lab test.

4.2 Onshore Pilot Test Results

The onshore pilot testing was run under the supervision of the Pudong Entry-Exit Inspection and Quarantine Bureau(PEEIQB). Natural East sea water in China with turbidity up to 7.9 was collected and added the appropriate concentration of E Coli. cause there was no E Coli. available in the natural sea water we used for test. The detection methods to active organisms and bacteria are consistent with the methods used in the previous lab test.

Larger zooplankton was effectively removed with the filter.The smaller sized fraction(<50mm >10mm) containing larvae were finally killed in the final VUV-Photocatalysis step. Bacteria in ballast also passed all mechanical treatment steps unharmed but were killed in the final step before being discharged. The detail results showed in Table 1. The onshore test results of our VUVPhotolysis BWM system meet the target of IMO D2 Regulation very well.

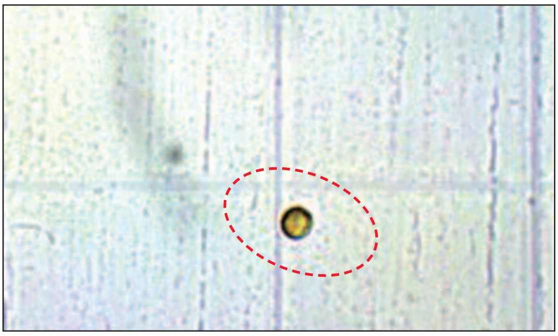

Figure 6. Picture of active Isochrysis Galbana Parke 8701 under Biomicroscopy

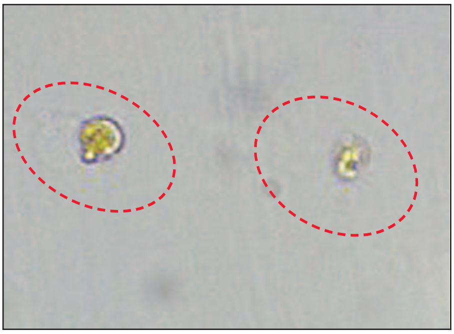

Figure 7. Picture of Dead Isochrysis Galbana Parke 8701 Under Biomicroscopy After treatment by VUVphotocatalysis BWMS

Table 1. Results of the pilot onshore tests performed by team under the supervision of PEEIQB.

Organism category	Initial	Control Day 0	Control Day 5	Treated Day 0	Treated Day 5	Discharge Dtandards (IMO-D2 Regulation)
Organisms >50μm	3200	3310	4250	0	3	<10 Ind/m^3
Organisms 10μm–50μm	5530	4380	1060	0	0	<10 Ind/ml
Escherichia Coli	6.3×10^5	4.12×10^5	1.6×10^4	0	0	<250 cfu/100ml

5 Conclusion

In conclusion, three clear advantages of our system were that it kept the UV systems advantage of operating without existing any type of chemicals which is more environmentally acceptable. It also overcame the main shortcoming of traditional UV disinfection systems and it was much more effective than regularly UV photocatalysis process. Within the specific design of the VUVphotocatalytic reactor, it makes into reality our new VUVphotocatalysis technology wich combines the principles of the conventional UV photolysis, H2O2-UV/photocatalysis and O3-UV/photocatalysis processes.

The new emerged modular VUVPhotocatalysis system was a promising ballast water treatment system which would meet the requirement of the International Maritime Organisation’s International Convention for the Control and Management of Ships’ Ballast Water and Sediments. Based on the current pilot 60 m^3/h VUVphoocatalysis BWMS, a scaled up 200 m^3/h system design is underway and also planning for onboard testing.

Acknowledgement

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Beyond-Ballast: Integrating Shipboard Environmental Technologies: Ozone as a Single-source System for Treating Multiple Waste Streams On-board

*Sung-Jin Park, Ki-Wook Kim, Seung-Je Yoon,
Kyeong-Hoon Kim and In-Joo Tark

Abstract

This paper offers an overview of the ozone-based NK-O3 ballast water treatment system developed by NK Co. Ltd of Korea; which received Final Approval from the International Maritime Organization and Type Approval from the Korean Maritime Administration in 2009. The paper describes the working principles of the system, the rigorous testing programme undertaken by NK to obtain regulatory approval and the advantages and benefits of the NK-O3 system as an effective ballast water treatment solution for the shipping industry. The paper goes on to explore how NK is developing the system further to address multiple ship-board waste streams; including oily-water separation, black and grey-water treatment and air-emissions, thereby reducing the ship-board footprint, energy consumption and capital and operating costs of multiple waste treatment systems.

Key words: Ozone, Ballast Water Treatment, Oily-water Separation, Black and Grey-water Treatment, Ship Air-emissions, Integrated Ship-board Waste Treatment.

1 Introduction

In 2002 NK Co. Ltd of Korea began developing ship-board ballast water treatment systems at the urging of major Korean shipyards and the South Korean Government, in response to rising global concerns about ballast-mediated marine bio-invasions, and the development of the *International Convention on the Control and Management of Ships' Ballast Water and Sediments* (IMO Convention). After

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[*] NK Co. Ltd, Busan, Republic of Korea.

exploring several technologies including filtration, chlorination, ultra-violet light and ozonation, NK chose to focus on ozonation as the most promising technology, based on likely biological efficacy, practicality and cost-effectiveness.

In consort with national and international partners including major universities and research institutions, including the Korean Marine Engineering Research Institute (KOMERI) and Dong-A University, NK implemented a comprehensive R&D programme to test the NK-O3 ozone system as a ship-board ballast water treatment system, in compliance with the IMO Convention. Testing protocols were designed in accordance with the IMO *Guidelines for the Approval of Ballast Water Management Systems* (G8) and the IMO *Procedurs for the Approval of Ballast Water Management Systems that Make Use of Active Substances* (G9).

Testing included lab-scale bench tests, land-based tests using a mobile test barge and ship-board testing on the 82,000 DWT container ship *Hyundai Hong Kong*. Test results have shown that the *NK-O3 BlueBallast* system meets the requirements of the IMO Convention under test conditions, including meeting the D2 biological efficacy standard and passing eco-toxicity criteria under the IMO G9 Procedure. The NK-O3 system was granted Final Approval by the IMO Marine Environment Protection Committee (MEPC) in July 2009, in accordance with the G9 Procedure, and Type Approval by the Korean maritime administration on 24 November 2009, in accordance with the IMO G8 Guidelines. NK is also developing plans to test the system against more stringent US standards.

2 Working Principles of the NK-O3 System

2.1 General Principles

In the *NK-O3 BlueBallast system*; a ship-board oxygen generator takes ambient air and strips away the nitrogen, concentrating the oxygen content – which is then passed through a high frequency electrical field in an ozone generator, to produce ozone (O_3). The ozone is then injected into the incoming ballast water to oxidize and neutralize entrained aquatic species.

Although Ozone has an extremely short life-span, it is one of the most powerful oxidizing agents produced – effectively neutralizing endo-toxins, viruses, bacteria, fungi and organic material extremely rapidly. For this reason Ozone has been widely used in the medical sterilization and water treatment industries for many years.

When ozone is injected into influent ballast water by the NK-O3 system, a percentage of the entrained aquatic species are killed by direct contact with the ozone. The remainder are killed or neutralized when the ozone reacts with other chemicals that occur naturally in seawater, to form TRO (Total Residual Oxidants; hypobromous acid and hypobromide ion), which are highly effective disinfectants in their own right. Both ozone and hypobromous acid disintegrate extremely rapidly – ensuring that there is no damage to the receiving waters into which the treated ballast water is discharged.

In cases where ships take on fresh-water as ballast (e.g. ports located in lakes or rivers), brominated compounds are not formed and the ozone alone acts as the Active Substance, and no residuals are formed.

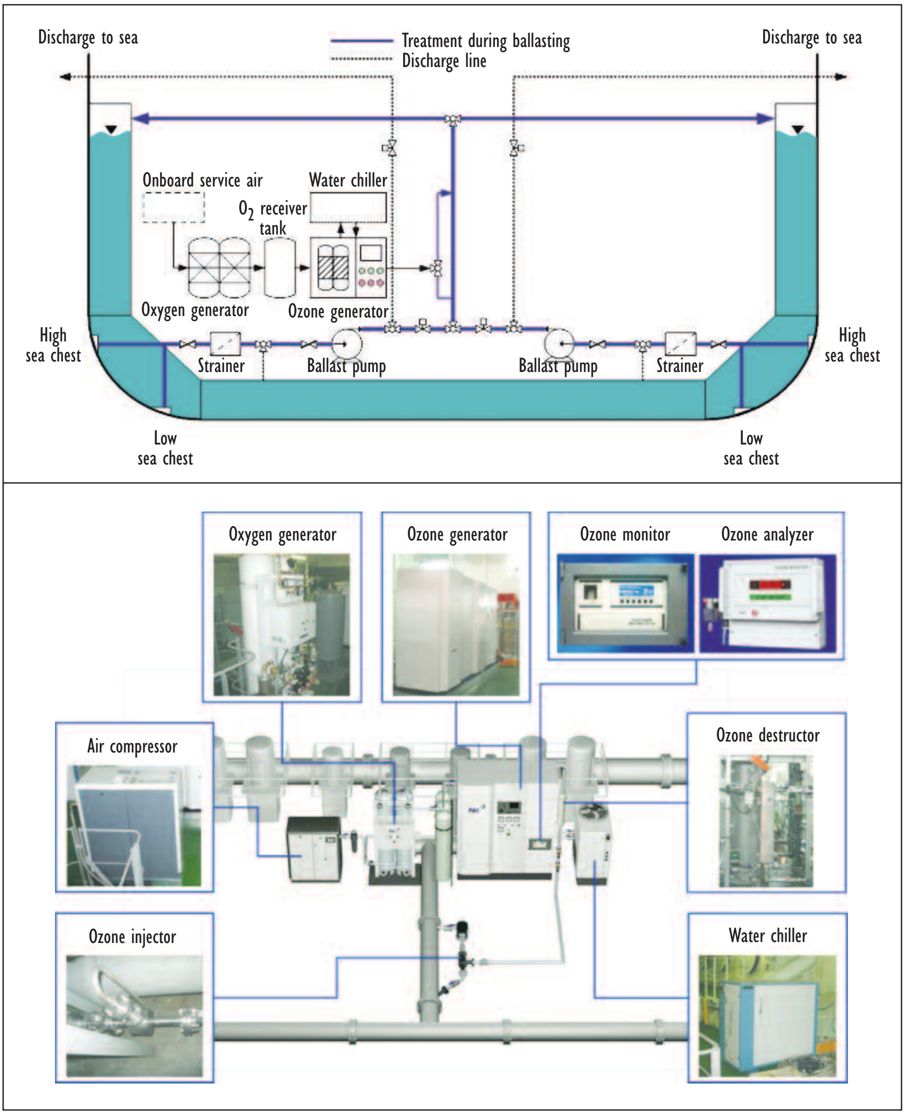

Figure 1. Schematic of the NK-O3 BlueBallast system installed onboard a ship (Source: NK)

2.2 Main System Components

The NK-O3 system is composed of five integrated modules:

1. Oxygen Generator
2. Ozone Generator
3. Ozone Injector
4. TRO Neutralizer
5. Monitoring and control system

The Oxygen Generator is based on standard, off-the-shelf technology, thereby keeping costs very low compared to other systems. The Oxygen Generator takes air from a compressor and strips away the nitrogen, concentrating the oxygen and providing the raw material to produce ozone.

Figure 2. Oxygen Generator (Source: NK)

The Ozone Generator is also based on standard, off-the-shelf technology, again keeping costs very low. The Ozone Generator passes the incoming oxygen through a high frequency electrical field to produce ozone.

Figure 3. Ozone Generator (Source: NK)

The Ozone Injector is based on a purpose-built, patented 'side-stream injector'. This diverts incoming ballast water from the main ballast pipes into a 'side-stream', where it is injected with ozone before re-entering the main ballast stream. The side-stream injector ensures a high kill-rate through optimal saturation of the incoming ballast. The side-stream injector also ensures a restricted dosage area – compared to trying to inject ozone into the large volumes of the ballast tanks. This eliminates potential for corrosion, by concentrating the ozone in the injector area only, which is made from high-grade, non-corroding stainless steel.

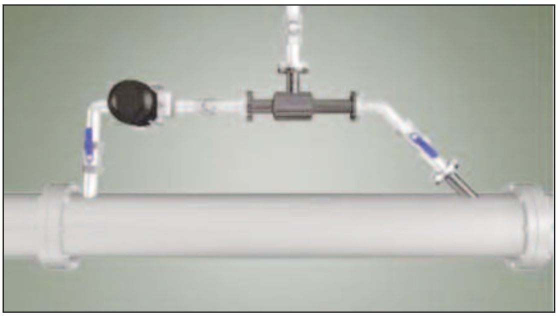

Figure 4. Ozone (side-stream) Injector (Source: NK)

The TRO Neutralizer system works according to the following sequence/procedures:

- There are two sets of co-located redundant pairs of TRO sensors in the ballast discharge system, one pair in the ballast discharge pipe immediately after the ballast tank and before the neutralizer feed injector (in effect this is the same TRO sensor pair as that located between the ozone injector and the ballast tank during ballasting, as ballasting and deballasting use the same piping system), and one pair is locatedafter the neutralizer feed injector and before the ballast water discharges overboard.
- Upon activation of the ship's ballast discharge procedure, the ship's overall ballast water management system sends a signal to the TRO sensors to activate, and also to the neutralizer feed system, to confirm functionality. Activation and operation of the TRO sensors and functionality of the neutralizer feed system, are inter-locked to the ship's overall ballast water management system, so that ballast water discharge will commence as soon as the system confirms that the TRO sensors are operational and the neutralizer feed system is functional.
- Once deballasting commences, the first TRO sensor pair monitors TRO levels. Should these exceed 0.45 mg/l as Br_2 (1 mol Cl_2 = 0.44 mol Br_2), a signal is sent via the NK-O3 PLC, to initiate feed of TRO neutralizer (thio-sulfate). Thio-sulfate feed is regulated by the PLC, based on feed-back from the TRO sensors (the screening level of 0.45 mg/l equates to the estimated PNEC value for TRO. It

should also be noted that the manufacturer specified reliable limit of sensitivity of the TRO sensors is 0.08 mg/l as Br_2, although during NK's testing these units recorded TRO down to 0.02 mg/l).

- Should any single TRO sensor fail, the second sensor in the redundant pair will continue to operate, providing a fully functional monitoring and control system. Under normal operation, both sensors in a pair will be simultaneously active, so should one fail, there will be no gap in monitoring of TRO in the effluent ballast water.

Figure 5. TRO Neutralizer (Source: NK)

The monitoring and control system again uses standard, off-the-shelf technology, and includes a variety of sensors, alarms, meters, valves and switches connected to central control software, and integrated with the ship's overall ballast management system. This allows all aspects of the system to be monitored and controlled, and for all data on system operation to be kept electronically and printed as required by inspectors. The system includes safety alarms and automatic cut-off switches.

To ensure maximum operational efficiency of the NK-O3 system, it is important to be able to control ozone production and flow in order to maintain an effective level of TRO in the ballast water stream, while avoiding overdosing the system. Excess ozone production could result in the release of increased TRO levels in treated water with the potential for residual toxicity. Although this will now be mitigated by a neutralizer, minimal TRO residual remains an important goal for optimal operational and economic efficiency.

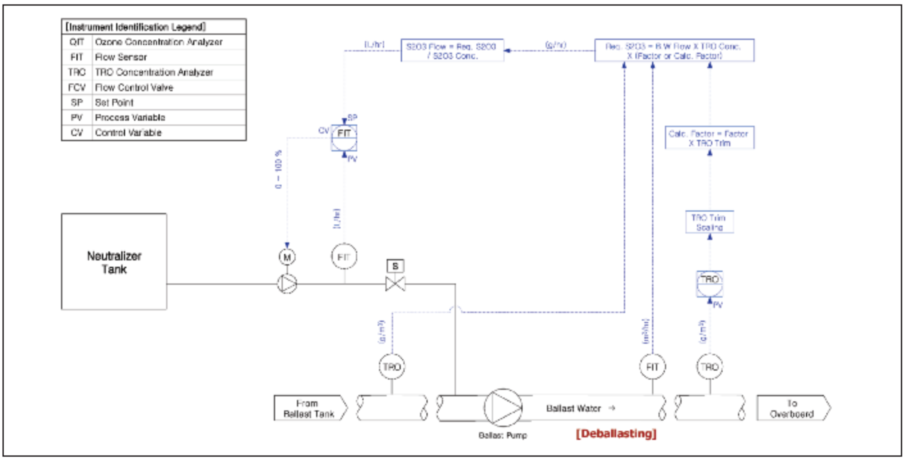

Figure 6. Schematic of the NK-O3 TRO neutralization system (Source: NK)

A control system employing onboard TRO-sensors has been developed to provide a precise real-time measure of TRO levels in the treated influent ballast water. Under NK's original concept, this control system was to be based on a reproducible relationship between ozone dosage and TRO production (i.e. a correlation coefficient), so that a positive feedback could maintain constant and effective TRO levels. However, as has been clearly identified both in the published literature and NK's tests, this relationship is affected significantly by various water quality parameters, including salinity, temperature, suspended solids and organic content.

We have, therefore, simplified our ozone dosage control system in that it is now based purely on maintaining TRO levels in the treated ballast water below the maximum set level of 7.5 mg/l. This allows effective disinfection of the influent ballast water, while maintaining TRO at the maximum level equated to an ozone dosage of around 2.5 mg/l (as noted by GESAMP from other tests), irrespective of influent ballast water quality, and independent of any highly variable relationships between ozone dosage and TRO production. A similar feedback loop will control neutralizer feed as required.

In summary, the ozone dosage control system works according to the following sequence/procedure (noting that the NK-O3 monitoring and control system will be integrated with the ship's overall ballast water management system, which is controlled from the ship's bridge and/or cargo control room, depending on the ship):

- Prior to ballasting, the NK-O3 system is activated, "primed" and "stabilized". This involves switching power on to system, establishing oxygen supply pressure and flow to the ozone generator, starting the cooling water supply from the chiller to the ozone generator, and ensuring that oxygen supply pressure and operating temperature are stabilized at the set operating levels, as indicated on the system control panel (green lights for all).

- Once the NK-O3 system is primed and stabilized, the ships' ballasting system is activated from the ship's bridge and/or cargo control room (depending on the ship), and the ballast pumps start, drawing ballast water into the ship.
- The commencement of ballasting sends a signal from the ship's overall ballast water management system to the NK-O3 monitoring and control system, to commence ozonation.
- As ozonation commences and proceeds, TRO levels in the treated influent ballast water are measured by the TRO sensors (co-located redundant pair), placed in the ballast pipe after the ozone injector and before the ballast tanks. The measured TRO levels are fed back to the NK-O3 monitoring and control computer (PLC or Programmable Logic Controller). The PLC is programmed so that if TRO levels reach 7.0 mg/l, the ozone dosage automatically reduces to maintain TRO below 7.5 mg/l.

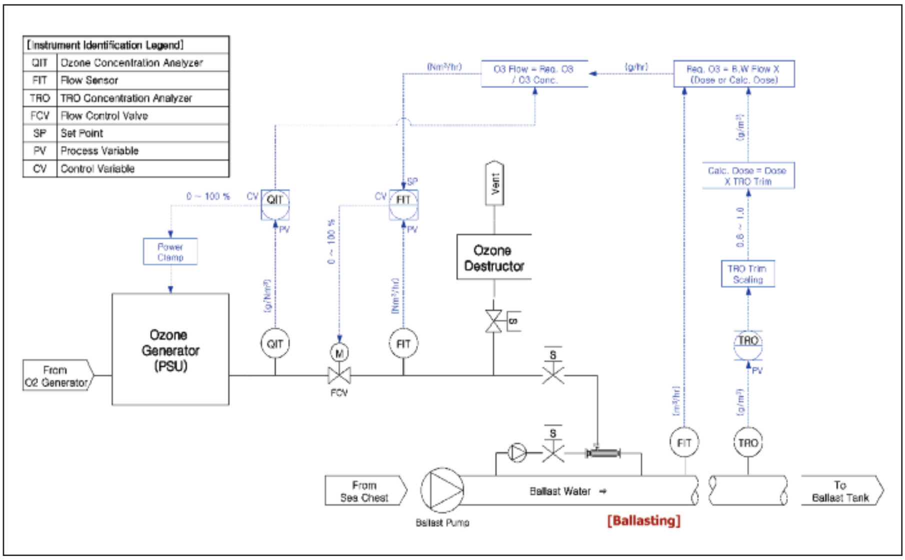

Figure 7. Schematic of the NK-O3 ozone dosage control system (Source: NK)

2.3 Support Components

There are also several items of ancillary equipment which support these modules:

- Power Supply Unit (PSU) to provide overall power to the system.
- Compressor to feed air to the oxygen generator (in some cases this can be based on the ship's existing air compressors).
- Refrigerated Dryer (RD) to de-humidify air being fed to the oxygen generator.
- Chiller for the Closed Loop Cooling System (CLCS), which keeps the Ozone Generator cool.

- Ozone Destruct System (ODS) to convert any unused ozone back to oxygen before release to the atmosphere.

3 Testing and Regulatory Approval

As outlined above, in consort with national and international partners including the Korean Marine Engineering Research Institute (KOMERI) and Dong-A University, from 2006 to 2009 NK implemented a comprehensive R&D programme to test the NK-O3 ozone system as a ship-board ballast water treatment system, in compliance with the IMO Convention. Testing protocols were designed in accordance with the IMO *Guidelines for the Approval of Ballast Water Management Systems* (G8) and the IMO *Procedure for the Approval of Ballast Water Management Systems that Make Use of Active Substances* (G9). Testing included land-based tests using a mobile test barge and ship-board testing on the 82,000 DWT container ship *Hyundai Hong Kong*, as outlined below.

3.1 Methods

The experimental design was conducted in accordance with G8 as follows:

Project period

Table 1. Landbased test schedule

Test Cycle	Test Date (d/m/yr)		Test Site	Salinity (PSU)
	Ballasting	Deballasting		
1 – 1	07/09/07	12/09/07	Busan Port	32.0
1 – 2	14/09/07	19/09/07	Busan Port	32.5
1 – 3	21/09/07	26/09/07	Busan Port	32.0
1 – 4	28/09/07	03/10/07	Busan Port	32.0
1 – 5	05/10/07	10/10/07	Busan Port	34.0
1 – 6	12/10/07	17/10/07	Busan Port	34.0
2 – 1	18/10/07	23/10/07	Nakdong River Estuary	20.0
2 – 2	25/10/07	30/10/07	Nakdong River Estuary	21.5
2 – 3	01/11/07	06/11/07	Nakdong River Estuary	20.0
2 – 4	05/12/07	11/12/07	Nakdong River Estuary	18.5
2 – 5	13/12/07	18/12/07	Nakdong River Estuary	19.0
2 – 6	28/12/07	02/01/07	Nakdong River Estuary	19.0

Study sites: Landbased tests

As indicated in Table 1, the land-based tests were performed at two different sites with more than 10 PSU difference in salinity, as required by the G-8 guidelines. The test locations were Busan port (saline concentration of 32~35 PSU) for seawater, and down stream of Nakdong river (saline concentration of 15~22 PSU) near

Busan for brackish water. Use of the mobile barge (Figures 8 & 9) for the land-based tests facilitated moving the test system between these environments.

Table 2. Shipboard test schedule

Test Cycle	Test Date (d/m/yr)		Test Site	
	Ballasting	Deballasting	Ballasting	Deballasting
1	16/11/07	20/11/07	Rotterdam, Netherlands	Thames Port, UK
2 (original)*	20/11/07	09/12/07	Thames Port, UK	Brani Terminal, Singapore
2 (new)	09/12/07	17/12/07	Brani Terminal, Singapore	HBCT, Busan, Korea
3	17/12/07	21/12/07	Busan, Korea	HIT, Hong Kong
4	16/06/07	20/06/07	Busan, Korea	HIT, Hong Kong

* The original Test Cycle 2 was compromised due to accidental mixing of ballast water into the test tanks from non-test tanks by the ship's crew. This Test Cycle is therefore considered to be invalid and results are not used.

Figure 8. The mobile barge used for full-scale land-based testing of the NK-O3 system, moored alongside in Busan port. The two large white feed tanks can be seen on deck. The NK-O3 system is fitted below decks. In this picture the system is deballasting, as indicated by the ballast discharge at lower right.

Study sites: Shipboard tests

Shipboard tests were undertaken using a NK-O3 system fitted on the container ship *M.V. Hyundai Hong Kong* (Figures 10 & 11). The voyages and ports of call for the shipboard tests were selected to provide a spread of environmental conditions across different bioregions from Europe to South East Asia to North East Asia.

Figure 9. The barge-mounted laboratory allowing on-site biological analysis of ballast water samples following each Test Cycle.

Figure 10. The M. V. Hyundai Hong Kong used for full-scale ship-board testing.

Results

Presentation of the full results of the testing is beyond the scope of this brief paper, however, a full report on the NK-O3 G8 testing is available from NK for readers who are interested. All tests were conducted according to the requirements of the G8 Guidelines. Test results, including statistical analysis, show that the NK-O3 system meets the Ballast Water Performance Standard contained in Regulation D-2 of the IMO Ballast Water Management Convention, as well as all of the operational, safety, and environmental testing requirements of the G8 Guidelines, as required for Type Approval.

Figure 11. NK-O3 system fitted on the container ship M.V. Hyundai Hong Kong.

4 Ozone as a Single-source System for Treating Multiple Waste Streams On-board

As a long-term supplier of various ship-board systems to the global shipping industry, NK is acutely aware of the need for practicality, efficiency and cost-effectiveness when adding new systems to the already heavy burden of complex equipment, that must be carried by ships in order to comply with ever-increasing regulation. Modern ships must not only have new ballast treatment systems but there are also increasing demands for reducing energy consumption and the production of air emissions, as well as systems to treat oily water, sewage and grey-water. NK therefore takes a holistic, integrated, systems approach when designing and developing technological solutions for its customers.

As a highly effective oxidant and disinfectant, ozone has significant potential to treat not only ships' ballast water, but may also be used to assist oily-water separation and treat other ship-board waste-water streams and even air-missions. NK has therefore launched an R&D program to develop the NK-O3 system as an integrated, single source system for treating multiple waste streams on-board, thereby reducing the ship-board foot-print, energy consumption and capital and operating costs of multiple systems. A schematic of this concept is shown in Figure 12.

The technical solution is based on the same concept as the NK-O3 ballast water treatment system for treating ballast water, with the addition of ozone feeds to waste water and a gas treatment lines for the treatment of waste-water and exhaust gas generated from ships main engine, whereby all waste streams can be treated from the one ozone generator.

The process of distributing ozone to treat the different waste streams is managed by a Mass Flow Controller (MFC) controlled by a Programmable Logic Controller (PLC). The Ozone Generator is connected to a MFC via the main ozone supply pipe and the MFC is connected to a PLC via the ozone generator and a cable. NK commenced its research on this integrated system in 2009 and plans to have a pilot plant ready for ship-board testing by June 2010.

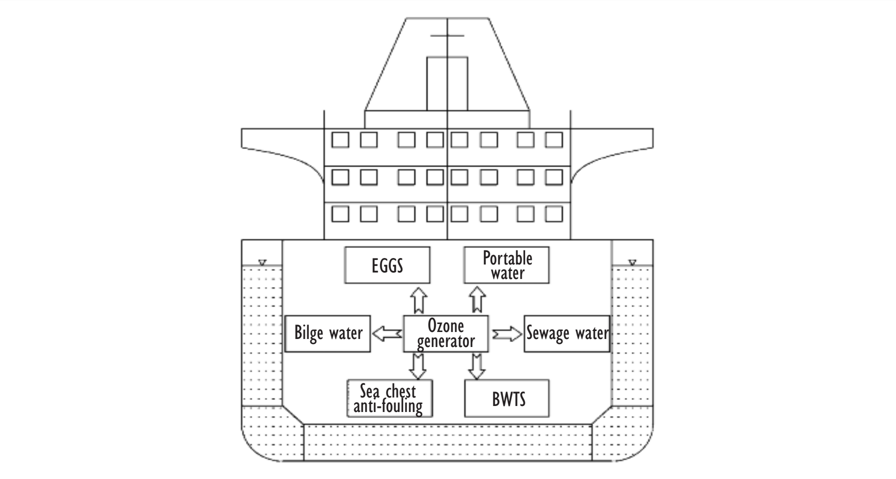

Figure 12. Schematic of the multiple Ozone treatment onboard a ship (Source: NK)

4.1 Ship's Sewage and Wastewater Treatment System

NK is also conducting an R&D project on the development of an ozone-supported sewage and wastewater treatment system for cruise ships. The system consists of biological treatment, membrane filtration and ozone disinfection. The R&D time frame of this project is June 2009 through to May 2013. The aims of this project is to develop a sewage and wastewater treatment system meeting MARPOL Annex IV, and to obtain Type Approval from IMO and USCG for ships carrying up to 5,000 passengers.

4.2 Ballast Water Monitoring System Using Optical Sensors

Finally, NK is also conducting an R&D project on development of a ballast water monitoring system using optical sensors, to allow in-line, real-time assessment of organism viability in ballast water. There is an urgent need for the development of standardized sampling, testing and analytical protocols for monitoring the biological content of treated/discharged ballast water against the IMO D-2 standard. The time frame of this project is December 2009 through to December 2011.

5 Conclusions

Testing of the NK-O3 system against the IMO G8 and G9 Guidelines show that the system is capable of meeting (and exceeding) the Ballast Water Performance

Standard under Regulation D2 of the *International Convention for the Control and Management of Ships' Ballast Water and Sediments*, and also the more stringent standards being proposed under US legislation. The tests also show that:

- With appropriate monitoring and control systems; the system is an inherently safe and environmentally-friendly system; which does not require chemicals or other potentially harmful substances to be carried on the ship.
- It can be based on existing, readily available, off-the-shelf technology (oxygen generator, ozone generator, monitoring and control systems etc), fitted together in modular, plug-and-play format; thereby keeping costs very low compared to many other systems.
- It can be easily scaled, using the modular components; to suit different vessel types, sizes and ballast capacities.
- It has a compact design requiring minimum on-board space and can be easily integrated into ships' existing ballast systems.
- It has low capital cost and low operating costs and is easy to maintain and is simple to operate.

In addition, NK's ongoing R&D program shows that the NK-O3 system has significant potential to provide shipowners with an integrated, single source system for treating multiple waste streams on-board, thereby reducing the ship-board footprint, energy consumption and capital and operating costs of multiple systems.

Finally, NK's work on a ballast water monitoring system using optical sensors, to allow in-line, real-time assessment of organism viability in ballast water, holds significant promise to provide a practical, workable tool for monitoring the biological content of treated/discharged ballast water against the IMO D-2 standard.

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Applicability of Approved Ballast Water Management Systems that Make Use of Active Substances or Preparations under the Ballast Water Regulations in Victoria, Australia

Marlos Jhonny Melo De Souza*

Abstract

Non-indigenous aquatic species pose a significant threat to the Victorian environment, economy and public health. They disrupt ecological processes, pose risks to fish stocks and aquaculture operations, affect infrastructure and tourism, and threat in both the interstate and international trade. Since 2004, Victoria has been the only State in Australia to regulate ships' domestic ballast water in accordance with the International Convention for the Control and Management of Ships' Ballast Water and Sediments. The aim of this paper is to evaluate if ships fitted with approved Ballast Water Management Systems (BWMS) that make use of Active Substances or preparations would meet existing water quality standards in Victoria. The determination of the Active Substances and preparations' holding time by the Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP) is established based on data covering areas such as half-life, decay and dosage rates, system parameters and toxicity. Holding time is a critical factor in degrading active substances before ships in short voyages can deballast into Victorian waters. Victoria is concerned that BWMS that make use of some biocides would fail to comply with water quality standards. Therefore, ships would still need to operate conventional ballast water management methods before deballasting in Victorian waters.

Key words: Ballast Water, Treatment System, Biocides, Active Substances, Regulations, EPA, Victoria

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* Dr. Marlos De Souza, Program Leader – Ballast Water and MARPOL 73/78, Environment Protection Authority of Victoria, Australia.

1 Introduction

Australia is the world's smallest continent with no land borders with any other country. Over 90% of Australia's trade is transported by sea. Victoria has the largest container port in Australia, the Port of Melbourne, which handles approximately 40% per cent of Australia's container trade. Including coastal trade, this represented in 2007–08 over 90 million mass tonnes of cargo, valued at over A$100 billion, carried by over 4,500 ships.

Globalisation has sharply increased the movement of people and goods around the world. Humans are moving species either intentionally or accidentally to all parts of the world accelerating global redistribution of species (Lonhart 2008). Ship's ballast water has long been recognised as an important vector on the introduction of non-indigenous species globally (Bax et. al 2003). In 2008/09 alone over 519,000 tonnes of managed ballast water were discharged into Victorian waters.

Non-indigenous aquatic species pose a significant threat to the Victorian environment, economy and public health. They disrupt ecological processes, pose risks to fish stocks and aquaculture operations, affect infrastructure and tourism (Bax et. al 2003), and threaten both the interstate and international trade. Although the Victorian aquaculture and fisheries industries do not respond for a massive part of the Australian production, both industries have an annual combined production value of approximately A$160m. These industries are under constant threat of invasive aquatic species which can either disrupt or extinguish the existing production in Victoria. To protect Victoria interests, the Environment Protection Authority (EPA) has ballast water legislation in place since 2004.

2 The Victorian Ballast Water Regulations

The south coast of Australia has been isolated for approximately 65 million years resulting in many species that only exist in this area of the globe (VCC 2008). Therefore, Victoria has a distinctive and diverse marine environment supporting a range of different values. Victoria has four major commercial ports being Port of Melbourne, Port of Geelong, Port of Hastings and Portland. The high traffic of ships coming to Victorian ports has also increased the number of translocations of non-indigenous species into Victorian waters. Port Phillip Bay is home of the two major Victorian ports (Port of Melbourne and Port of Geelong) receiving over 3,500 ships' visits every year. As a result, Port Phillip Bay has been classified as one of the most invaded marine ecosystems in the Southern Hemisphere (Hewitt and Campbell 1999).

The Australian Government has regulations in place since 2001 targeting ships coming from international waters into Australian waters. In June 1996, the Victorian Governor in Council referred the introduction of marine pests matter to the

Environment and Natural Resources Committee of the Victorian Parliament. The final Report released in 1997 recommended EPA Victoria to minimise further marine pests introductions in Victoria through a Victorian Ballast Water Management System, incorporating various components under a statutory Industrial Waste Management Policy. Under the Victorian legislation, ballast water is classified as industrial waste.

EPA Victoria first introduced its domestic ballast water management arrangements on July 1, 2004, which are outlined in the Waste Management Policy (Ships' Ballast Water). This Policy is a statutory document made under the *Environment Protection Act* 1970 and forms part of Victoria's legal system. It introduces ballast water management arrangements that enable the shipping industry to help contain and reduce the spread, through high risk domestic ballast water, of non-indigenous species that are established in other areas in Australia. The Victorian ballast water arrangements complement the Australian regulations for ballast water sourced internationally.

2.1 The Environment Protection (Ships' Ballast Water) Regulations 2006

The Regulations came in force in 2006 to support the implementation of the waste management policy (Ships' Ballast Water) and are applicable to all ships visiting Victorian waters. Exemptions apply only to ships that: a) utilise permanent fresh water ballast; and b) does not take up or discharge marine waters as part of their operation.

Reporting

The Victorian ballast water management system is based upon prior reporting. All ships must ensure that a completed ballast water report form is provided to EPA at least twenty-four hours before entering the Victorian waters. EPA's ballast water report form is a single page "pdf" file covering information such as: ship details (including IMO number, vessel type and net tonnage), last port of call, Victorian port destination, if the ship has ballast water on board, if the ballast water was sourced within Australian territorial waters and if the ship has used the risk assessment tool. The report was designed to be a simple "box tick" type of report without long text to be entering.

Ships carrying ballast water, which was sourced within Australian territorial waters must also complete and submit a ballast water log to EPA together with the report form. This form includes information on ballast water management that has been applied by the ship to manage high-risk ballast water including: uptake port, date and volume, exchange location (geographical coordinates), exchange date and time (when the operation started and ended), list of pumps used and their capacity, residual volume when empty (for empty/refill only), volume pumped and percentage exchanged (for flow-through/dilution only), final volume, port of discharge, discharge date and volume to be discharged.

EPA may exempt a ship from the need to submit the report form and log if that ship is the subject of a current domestic ballast water accreditation agreement. Although accredited ships do not need to submit their forms, they still have to keep information available to EPA inspectors. Inspection might happen at any time without warning as part of the accreditation agreement.

Discharge

Under the regulatory framework in Victoria, there will be no discharge of domestic ballast water into Victorian waters unless authorized by EPA. In making a decision on whether a ship will be able to deballast into Victorian waters or not, the following will be taken into consideration by EPA: the satisfactory completion of the ballast water report form and log; the assessment made based on the information provided; and whether the ship is carrying high-risk ballast water; the general level of risk posed to the environment by the domestic ballast water; and if any compliance monitoring or inspections have been conducted, the outcomes of that compliance monitoring or inspection.

EPA is not restricted to the above information when making a decision of approving a ballast water discharge. A written advice will be sent by EPA to the ship master or to an agent acting on his/her behalf informing whether the domestic ballast water could be discharged or not.

Cost recovery

The Victorian ballast water system is a cost recovery program. All ships visiting Victorian port must pay a fee per port visit. The fees collected from the ships must cover costs associated with the ballast water system including personnel, vehicles, safety gear, computers and laboratory analysis.

3 The Risk Assessment Framework for Ballast Water Introductions

Import risk assessment framework (IRAF) and the Quantitative Risk Assessment (QRA) paradigm were recommended by Hayes (1997) as the base for a ballast water risk assessment framework. IRAF view the risk of marine pest introduction as the culmination of a long chain of events having parallels with the ballast water introduction cycle (Hayes 1997). QRA is a methodology used to organize and analyse scientific information to estimate the probability and severity of an adverse event (Cassin et al. 1998).

The risk assessment developed in Australia is based on a targeted approach addressing marine pests of interest. The risk assessment consists of four modules, A, B, C and D. Each module addressing respectively: the probability that the donor port is infected with a target species; the probability that a vessel is infected whilst ballasting assuming that the port is infected; the probability that the target species survives the vessel's journey assuming that the vessel is infected; and, the probability that the species will complete its life-cycle in the recipient port assuming that it survives the journey and is discharged into the port (Hayes and Hewitt 2000; 2001).

> According to Hayes and Hewitt (2007), these modules or events are treated as independent random variates where the ballast water risk is predicted as a product of these probabilities:
>
> $\text{Risk} = P(A).P(B).P(C).P(D)$
>
> Due to a more conservative approach, currently only the Module C is not used. All species are simply assumed to survive all vessel journeys (Hayes and Hewitt 2007).

The risk assessment is a table-based one wherein the risk associated with all routes between Australian ports is assessed and summarised in a series of look-up tables that are periodically updated (Hayes and Sliwa, 2003). Currently, the target species under the risk assessment approach are: *Alexandrium minutum, Asterias amurensis, Carcinus maenas, Crassostrea gigas, Gymnodinium catenatum, Musculista senhousia, Sabella spallanzanii, Undaria pinnatifida and Varicorbula gibba.*

4 Victorian Water Quality Guidelines

The state environment protection policy (waters of Victoria)

The State Environment Protection Policy (Waters of Victoria 2003) – SEPP WoV – sets the framework for Victorian government agencies, businesses and the community to work together, to protect and rehabilitate Victoria's water environments. The purpose of the Policy is to help achieve sustainable waters by: (1) setting out the environmental values and beneficial uses of water that Victorians want, and the environmental quality required to protect them; and (2) setting, within a 10 year timeframe, goals for protection agencies, businesses and communities and means by which they can be met.

The Policy is formed by a number of principles particularly the precautionary principle. If there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. Decision making should be guided by: (i) a careful evaluation to avoid serious or irreversible damage to the environment wherever practicable; and (ii) an assessment of the risk-weighted consequences of various options.

SEPP WoV sets the beneficial uses of the water to be protected (Figure 1). A beneficial use is defined in the *Environment Protection Act* 1970 and includes a current or future environmental value or use of water that communities want to protect. A beneficial use does not prohibit or permit the use of water for any particular purpose, but requires water to be of a suitable quality and quantity to support that use or value.

Table 1. SEPP WoV beneficial uses to be protected (Source: EPA 2003)

Beneficial uses			**Rivers & Streams**					**Marine & Estuarine**				
	Aquatic Reserves	Wetlands and Lakes	Highlands	Forests-A	Forests-B	Cleared Hills & Coastal Plains	Murray & Western Plains	Estuaries & Inlets	Open Coasts	Port Phillip Bay	Western Port	Gippsland Lakes
Aquatic Ecosystems that are:												
largely unmodified	X		X	X	X				X	F6	F8	F3
slightly to moderately modified		X				X	X	X				
highly modified												
Water suitable for:												
primary contact recreation	X	X	X	X	X	X	X	X	X			
secondary contact recreation	X	X	X	X	X	X	X	X	X			
aesthetic enjoyment	X	X	X	X	X	X	X	X	X			
indigenous cultural and spiritual values	X	X	X	X	X	X	X	X	X			
non-indigenous cultural and spiritual values	X	X	X	X	X	X	X	X	X			
agricultural and irrigation		X	X	X	X	X	X					
aquaculture		X		X	X	X	X	X	X			
industrial and commercial use				X	X	X	X	X	X			
human consumption and appropriate treatment		X	X	X	X	X	X					
fish, crustacea & molluscs for human consumption		X	X	X	X	X	X	X	X			

* F6 means refer to the beneficial uses et in the SEPP (Waters of Victoria) -Schedule F6.Waters of Port Phillip Bay
* F8 means refer to the beneficial uses et in the *SEPP (Waters of Victoria) -Schedule F8. Waters of Western Port and Catchment*
* F3 means refer to the beneficial uses et in *the SAPP (Waters of Victoria) -Schedule F3. Gippland Lakes and Catchment*

Although SEPP WoV sets most of the water quality targets and objectives, the Policy also defaults back to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC Guidelines).

The Australian and New Zealand guidelines for fresh and marine water quality (2000) – ANZECC Guidelines

The ANZECC Guidelines are primarily based on the philosophy of ecologically sustainable development. Their main objective is intended to provide an authoritative guide for setting water quality objectives required to sustain current or likely future environmental values for natural and semi-natural water resources in Australia and New Zealand.

According to ANZECC (2000), the guidelines are designed to help users assess whether the water quality of a water resource is good enough to allow it to be used for humans, food production or aquatic ecosystems (these uses are termed environmental values). If the water quality does not meet the water quality guidelines, the waters may not be safe for those environmental values and management action could be triggered to either more accurately determine whether the water is safe for that use or to remedy the problem. The Guidelines set recommended limits to acceptable change in water quality that will continue to protect the associated environmental values.

5 Active Substances and Possible Impacts on the Marine Environment

The microbial inclusion in the D2 regulations (ballast water performance standard) of the International Convention for the Control and Management of Ships Ballast Water & Sediments has created a significant challenge for technological development of treatment systems. It tends to favour the use of chemical biocides instead of environmentally sound treatment options such as heat. In order for any chemical treatment to be successful, broad-spectrum toxicity must be accompanied by rapid degradation into environmentally benign disinfection by-products (DBPs) due to concerns of chemical discharge into the receiving environment (Greg and Hallegreaff 2007).

Determination of holding time

The determination of the Active Substances and preparations' holding time by the GESAMP BWWG (Ballast Water Working Group) is established based on data provided by the ballast water management system (BWMS) applicant covering areas such as half-life, decay and dosage rates, system parameters and toxicity (IMO – BWM.2/Circ.13). Although the GESAMP BWWG has developed a comprehensive approach to assess all possible impacts on the environment that could happen when ballast water that was treated with Active Substances or preparations is deballasted, a great level of uncertainty still remains due to environmental factors such as temperature, pH, salinity and sediment.

SEDNA® Ballast Water Management System (Using Peraclean® Ocean) was the first system to get final approval by IMO. SEDNA® makes use of Active Substances or preparations on a combined process with physical separation (hydro cyclone) and fine filtration. A study conducted at Tasmania University, Australia (Gregg and Hallegraeff 2007) analysed three commercially available ballast water biocides including Peraclean® Ocean. The study found that, although the manufacturer indicates that Peraclean® Ocean has a half-life of 4 hours in unfiltered seawater and recommends a holding time of only 1–2 days in ballast tanks due to its rapid degradation, low concentrations (200 ppm) did not degrade to a level non-toxic to marine microalgae until 3–6 weeks when prepared in filtered seawater.

Lafontaine et al. (2008) studied the efficacy and the potential toxicological impact of Peraclean® Ocean as a ballast water treatment system in very cold water temperatures in Canada. Although the research concluded that the treatment was efficient in killing almost 100% of the living organisms, it also concluded that saltwater samples exhibited toxic responses up to 3 days post treatment when low concentrations of Peraclean® Ocean (100 ppm) were used.

Toxicological testing

The GESAMP BWWG Methodology defines that the discharge toxicity tests should include chronic test methods performed as part of the land-based type approval process with test species (fish, invertebrate, algae) that address the sensitive life stage (IMO – BWM.2/Circ.13). The effects of contaminants on fish can be assessed via two different approaches (Sinclair and Valdimarsson 2003): a) studies carried out in laboratories (where fish are exposed to controlled concentrations of contaminants) and b) field studies (where fish are exposed to natural and anthropogenically induced environmental stresses). As concluded by Sinclair and Valdimarsson (2003) laboratory studies can help elucidate the responses to specific contaminants at the level of the cell or individual, however those studies will not comprehensively inform the responses to contamination at the population level.

The spatial-temporal fate of biocides in marine environments is still not well understood by science. There are only a few studies done indicating a much lower degradation potential than predicted from laboratory tests or freshwater observed data. This is related to the lack of understanding of the influence by temperature, metabolic activity of the biomass, redox potential, presence of other toxic compounds, and toxicity of transformation products (Ranke and Jastorff 2000, Ranke 2002). Arzul et al. (2006) confirmed the higher toxicity of biocides toward marine phytoplankton than toward freshwater phytoplankton providing further evidence that it is worth developing standard ecotoxicological tests for the marine environment.

In a report to the California Government in December 2007[1], the Marine Facilities Division concluded that a major challenge associated with assessing treatment systems using Active Substances is the lack of sufficient toxicological testing. The report also concluded that there is a lack of standardized tests and procedures necessary to determine whether or not treated ballast water meets existing water quality standards.

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[1] Marine Facilities Division. 2007. Assessment of the efficacy, availability and environmental impacts of ballast water treatment systems for use in California waters.

Potential effects in enclosed areas

Although Añasco et al. (2008) suggested that some biocides such as sodium hypochlorite (NaOCl) are effective to treat ballast water without adverse effects of residuals, the study concluded that whenever accumulation of residual chlorines occurs in coastal waters, this will only happen in enclosed bays or estuaries. A study conducted by Zamora-Ley et al. (2006) found that enclosed marinas with low flushing rates and high density of anti-fouling treated boats present the potential to exceed biocide concentrations at which negative effects on the primary producers' community have been observed.

The potential effect of many ships discharging treated ballast water from approved treatment systems that make use of different Active Substances and preparations in an enclosed area, with respect to the effects of elevated residual chemicals from biocides was also identified as an issue by the European Maritime Safety Agency in a workshop held in Lisbon in November 2008[2].

6 Conclusion

EPA Victoria is concerned that BWMS that make use of biocides such as Peraclean® Ocean would not have enough time to degrade their chemicals during short domestic/international voyages before deballasting. Based on the studies previously discussed, ships coming from short voyages into ports will need to hold their treated ballast water for at least 3 days before deballasting with potential extra costs to the shipping industry.

Holding time is provided to GESAMP BWWG as part of the information needed for the approval process. However, the holding time information does not form the future IMO regulatory framework. This missing piece of regulatory information can weaken government agencies ability to enforce holding time before deballasting. It may also have future legal implications due to existing water quality standards as ships may not be allowed to discharge treated ballast water.

EPA Victoria is also concerned that both the limited potential of the existing conventional ecotoxicity testing to assess ecotoxicity of treated ballast water on marine ecosystems and the lack of standardized tests and procedures to analyse treated ballast water could contribute to negatively impact the receiving environment.

Finally, EPA Victoria is apprehensive that poorly flushed enclosed areas in Victoria such as Port Phillip Bay and Western Port could be negatively impacted by ships deballasting treated ballast water that made use of Active Substances or preparations such as sodium hypochlorite. It is clear that there is a lack of scientific knowledge on the possible impacts of residuals in enclosed areas and estuaries.

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[2] European Maritime Safety Agency. Implementing the Ballast Water Management – the EU dimension. Lisbon 10th and 11th November 2008. Final report.

EPA Victoria welcome new research developments on technologies more environmentally sound such as the zero ballast water. Until these new technologies are available to the shipping community, EPA Victoria would prefer to support the existing ones that do not generate DBPs or other residues to the receiving environment.

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A Summary of Findings from the First 25 Ballast Water Treatment Systems Evaluated by GESAMP

Tim Bowmer[*] and Jan Linders[**]

Abstract

As part of the preparations for entry into force of the Ballast Water Convention (2004), the International Maritime Organization has initiated a process to evaluate the safety and efficacy of potential technologies for disinfecting ballast water on board ships. Ballast Water Management Systems intended to remove potentially 'harmful aquatic organisms' are subjected to a review process, one aspect of which is aimed at ensuring safety by assessing the risks of the system to the environment, human health (including the ships crew) as well as the safety of the ship. With 25 systems in the various stages of the evaluation process and some already approved, this paper takes a first look at the types of systems under development, especially their environmental characteristics and look for any emerging trends. Quite a wide range of different technologies are being developed based on chemical, physico-chemical and physical mechanisms. Of these, chlorination by electrolysis in-situ is the most common and indications are that such systems may become even more common.

1 Introduction

The Ballast Water Convention (2004) was set up under the auspices of the United Nations by the International Maritime Organization (IMO); its ratification is gaining momentum and it is expected to enter into force in the coming years. The Convention resolved to:

> *prevent, minimize and ultimately eliminate the risks to the environment, human health, property and resources arising from the transfer of harmful aquatic organisms and pathogens through the control and management of ships' Ballast Water and Sediments, as well as to avoid unwanted side-effects from that control and to encourage developments in related knowledge and technology.*

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[*] TNO – The Netherlands Organisation for Applied Scientific Research,The Netherlands.
[**] National Institute for Public Health and Environment, The Netherlands.

The Convention was motivated by many well known examples of invasions of 'harmful aquatic organisms', such as those caused by the zebra mussel *Dreissena polymorpha* establishing itself throughout the Great Lakes and many of the waterways of North America and the invasion of the Black and Caspian Seas by the predatory comb-jellyfish *Mnemiopsis leidyii*. Both of these invasions in the 1980 and 90's caused lasting changes to the ecology of large water bodies, the former leading to wide-scale retrofitting of cooling systems to reduce fouling and the latter to a massive decline in fisheries (GESAMP 1997); both ultimately had severe economic consequences.

GESAMP is the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, an inter-agency advisory body of the United Nations. It was founded in 1969 and is currently sponsored by FAO, IAEA, IMO, UNEP, UNIDO, UNESCO-IOC, UN (DOALOS) and WMO. Its function is to provide independent scientific advice at the request of its sponsoring agencies on the assessment and thereby protection of the marine environment.

IMO requested GESAMP to assist the Ballast Water Convention by assessing the risks of Ballast Water Management Systems (BWMS) to the marine environment, to human health, including the ships crew, and to the safety of the ship. In response, GESAMP set up the Ballast Water Working Group (BWWG) in 2006 for this purpose, comprised of a multidisciplinary team of experts in the fields of chemical risk assessment, ecotoxicology, occupational hygiene and toxicology as well as ships architecture and engineering. This review was deliberately restricted to environmental and human health criteria; ship's safety was considered to be outside of its scope.

2 The Ballast Water Management System Evaluation Process

It is important to note that the BWWG only evaluates the safety of BWMS; it is not responsible for assessing their efficacy or effectiveness in treating ballast water. On behalf of the manufacturer, administrations submit applications regarding a given BWMS to the Marine Environment Protection Committee (MEPC) of IMO. These submissions once accepted for evaluation are processed by IMO on a first-come-first-served, fee-paying basis and sent on to BWWG. The submissions are first checked for completeness and their content summarized in a standard format by BWWG's consultants and then evaluated by BWWG for Basic Approval according the IMO "Procedure for approval of ballast water management systems that make use of Active Substances" (G9) and following the BWWG methodology, as published by IMO. As part of Basic Approval, BWWG makes a series of recommendations which the manufacturer is advised to take care of prior to re-submitting for Final Approval which is handled in a similar manner. BWWG, through MEPC, may make additional recommendations to the Administration in question with a bearing of the Type Approval. Once approval through the first two steps has been achieved by a given BWMS, the submitting administration is then responsible for issuing a Type Approval for commercial scale installation on board ships.

The reports containing the findings and recommendations of BWWG are peer reviewed by its parent body GESAMP and once approved, the recommendations are communicated to IMO for consideration by MEPC. Once endorsed by MEPC, the Type Approval process can begin.

The data referred to in this paper is contained in the 12 reports to date of the GESAMP Ballast Water Working Group as published by IMO (see References).

2.1 Active Substances

The working definition of 'active substances' indicates those chemicals which ensure disinfection, while 'relevant chemicals' are usually auxiliary substances or preparations added to ballast water or produced in the course of disinfection as by-products. There is often an overlap between the two due to complex speciation and chemical equilibrium in water. In practice, all systems are considered by GESAMP BWWG to potentially produce active substances and/or relevant chemicals – until proven otherwise.

2.2 Quality of Submissions

Submissions for the evaluation of BWMS are inherently complex and need to be well constructed in a logical manner with clear referencing to supporting data. The arguments used to demonstrate acceptable risk need to be traceable in the submission documents so that GESAMP can reconstruct and check them for accuracy. Most, if not all submissions have been found by GESAMP to be technically incomplete, although to date none have been rejected for evaluation on this basis alone. With all submissions, supporting data quality is a concern for the reviewers and analytical chemistry data particularly so. In order to evaluate the dosage of active substance applied, the residual concentrations after treatment and the concentrations of any by-products, a range of quality assurance measures are required:

- a quality assurance plan,
- properly calibrated instrumentation,
- the use of appropriate standards,
- a clearly demonstrated chain of sample control & preservation,
- a well documented and acceptable time to analysis, and
- appropriate limits of detection.

Ecotoxicity studies which can be critical for assessing the residual toxicity of the treated ballast water prior to discharge, also need to be carried out to an acceptable quality standard, using appropriate test organisms, examining a relevant phase of the BWMS cycle and under acceptable environmental conditions, e.g. salinity, pH, temperature and in particular Total Organic Carbon (TOC).

2.3 Success Rate of Systems Evaluated

GESAMP BWWG has evaluated 46 submissions on 29 different systems over the course of 12 meetings (the last four systems evaluated for Basic Approval are considered to be too recent to be included in this paper). The results for the first 25 BWMS are presented in Table 1.

Table 1. Ballast Water Management Systems submitted for evaluation from 2006 to 2009 (BWWG sessions 1 to 11).

No. of Systems	**Status**	**Comment**
Basic Approval		
25	Evaluated by BWWG	
23	Recommended for approval on the first attempt*	
2	Failed on the first attempt	Not re-submitted in the same form
Final approval		
14	Evaluated by BWWG	
9	Recommended for approval on the first attempt	
5	Failed on the first attempt	
3	Recommended for approval on the second attempt	
2	Not yet resubmitted	
Type approval		
4	Granted by Administrations	

* To date all systems recommended for basic or final approval by GESAMP BWWG have been later endorsed by MEPC, occasionally after considerable discussion. The systems evaluated in BWWG Sessions 10, 11 and 12 will be considered by MEPC 60 in March.

2.4 Common Reasons for Rejection of Final Approval

Some common characteristic of submissions which fail to gain final approval in particular can be identified as follows:

- The system components appear from the documentation to be poorly integrated so that a functional system cannot be evaluated. The control system may sometimes be incomplete or at a conceptual stage, in which case, the credibility of the claimed maximum dosed concentrations or the residual concentrations on discharge are difficult to evaluate,
- Especially with electrolytic chlorination systems, a proposed neutralization step to reduce the total residual oxidant (TRO) concentration of treated ballast water may be insufficiently detailed,

- The relationship between an efficacious dose (this is generally known for many systems) and safe discharge concentrations has not been clearly established in the submission and the concentrations on discharge appear too high,
- The environmental risk assessment has been poorly carried out and the model or the assumptions used are unconvincing.

3 Ballast Water Treatment System Technology

3.1 Emerging Technology Types

To place the emerging BWMS currently progressing through approval in a technological context, it may be helpful to compare them with standard technologies available in other sectors, e.g. drinking water disinfection as summarized by Kerwick et al. (2005; see Table 2 below).

Table 2. The types of available disinfection technologies in comparison to Ballast Water Management System technologies submitted to IMO between 2006 and 2009.

Examples of Drinking Water Disinfection Systems (from Kerwick, et al. 2005)	Types of Ballast Water Disinfection Systems Reviewed by BWWG up to December 2009	No. of Systems
Chemical: ozone, silver, copper, ferrate, iodine, bromine, hydrogen peroxide, and potassium permanganate	• peracetic acid/peroxide (dosed from tanks) • ozone (dosed from tanks) • flocculation technology based on polyacrylic acid, polyaluminium chloride and iron tetraoxide	1 1 1
Physico-chemical: titanium photocatalysis, photodynamic, and electrochemical disinfection	• titanium photo-catalysis • electrolytic chlorination • ozonation (on board extraction/generation) • combination of 2 main electrochemical/physical systems	1 9 4 2
Physical: ultraviolet irradiation, ultra-sonication, pulsed electric fields, magnetic enhanced disinfection, and microwave systems.	• UV irradiation • plasma technology • cavitation (as an auxiliary treatment)	4 1 1
Other:	• deoxygenation (as an auxiliary treatment)	1

From Table 2, it can be seen that all of the main drinking water disinfection categories are represented among the BWMS evaluated to date but that there are many more alternative technologies which, for whatever reason, have not been investigated or simply have not yet appeared in the evaluation process. No chemicals other than oxidizing biocides have so far been submitted, e.g. no evidence has been seen of metals such as silver, bromine releasers, organic pesticides, etc. which would present quite a challenge to evaluate, one more akin to an EU Biocidal Products dossier. The oxidizing biocides have one advantage over organic chemicals in that they degrade sooner or later to simple compounds without leaving complex and possibly undesirable metabolites. The issue of oxidation by-products is discussed further below. The physico-chemical category is well represented by a variety of electrochemical systems, combination systems and titanium photocatalysis.

Physical systems are mainly restricted to ultraviolet (UV) thus far, with the one recent exception of plasma technology.

Some additional details of the systems reviewed are presented in Table 3 and relate to filtration, neutralization and double disinfection as components of a given BWMS. The majority apply filtration to >50um on uptake. Some use hydrocyclone technology to augment filters by removing coarser material and one system claims to be able to filter to >20um. A total of 7 out of 25 systems use neutralization prior to discharge in order to reduce Total Residual Oxygen (TRO); these are mainly the electrolytic chlorination systems which also depend on the storage of 'Relevant chemicals' on board, which is a complicating factor.

Table 3. Additional design features of Ballast Water Management Systems

Further Design Details	**No. of Systems**
Filtration on uptake (pre-disinfection, only 1 post disinfection) – most commonly >50µm	20
No filtration on uptake (with one system this is deliberately left out to allow a cavitation unit to function as part of the disinfection system)	3
Hydrocyclone technology to augment or replace standard filters (one claims to achieve >20um)	2
Neutralization with Na bisulfite or thiosulfate (mainly electrolytic systems)	7
Disinfection on both uptake and discharge (mainly UV systems)	4 or 5

3.2 Disinfection By-products

Chlorination of ballast water has been shown by nearly all submissions to GESAMP BWWG to produce disinfection by-products, amongst others, trihalomethanes and halo-acetic acids, i.e. relatively stable, small molecular weight compounds containing chlorine and bromine.

Table 4 illustrates typical quantities of disinfection by-products produced by a chlorination system; bromate ions are considered as part of the active substances. Some electrolytic chlorination systems reviewed are intended to produce mainly free chlorine as the active substance, while others seem capable of producing less free chlorine and different active species with the benefit of much shorter half-lives in seawater and potentially less chlorination of organic matter.

This serves to illustrate that even though the risks from individual ships to the marine environment and human health may have been found to be acceptable, significant quantities of stable chemicals will still enter the marine environment through this route. At TOC concentrations of greater than the 10 mg/L illustrated above, the levels of chlorination by-products may be even higher. Consideration should therefore be given to designing systems of similar efficiency with lower levels of, or even without, such by-products. The effective operation of filtration units to remove as much organic matter as possible from the ballast water prior to treatment may be a factor to consider in order to reduce disinfection by-products in the treated ballast water, e.g. hydrocyclone technology.

Table 4. An example of disinfection by-products produced by an electrolytic clorination system. Total Organic Carbon levels (TOC) in the samples are given in italics for comparison with Table 5.

Test compound	Unit	Deballasting Situation 1	Deballasting Situation 2
TOC	*mg/L*	*9.9 (2.3–29.3)*	*11.2 (3.25–31.1)*
Bromate	µg/L	27	55 (26–87)
Trichloromethane	µg/L	<0.3	<0.3
Dichlorobromomethane	µg/L	0.2 (0.2–6)	0.54 (0.5–9)
Dibromochloromethane	µg/L	6.8 (<1–8.5)	13 (<0.1–16)
Tribromomethane (Bromoform)	µg/L	180 (170–260)	330 (260–410)
Sum THM	**µg/L**	**190 (180–270)**	**340 (270–430)**
Monochloroacetic acid	µg/L	0.14 (<0.1–1.3)	0.57 (0.57–0.76)
Dichloroacetic acid	µg/L	0.12 (0.12–0.26)	0.26 (0.26–0.44)
Trichloroacetic acid	µg/L	<0.05 (<0.05–0.16)	0.06 (<0.05–0.15)
Monobromoacetic acid	µg/L	0.33 (0.33–1.2)	3 (2.3–4.2)
Dibromoacetic acid	µg/L	21 (20–47)	43 (43–93)
Tribromoacetic acid	µg/L	0.66 (0.66–1.3)	1.6 (1.6–2.1)
Sum HAA	**µg/L**	**22.25 (22.3–50.1)**	**48.5 (48.5–100)**

3.3 Human Health Concerns

The GESAMP BWWG is in the process of developing a 'human exposure scenario' which is needed to apply a more quantitative human health risk assessment to BWMS. Currently, a qualitative risk assessment is used based on the application of common risk management and industrial hygiene measures related to chemicals in the workplace. GESAMP BWWG, therefore, advises manufacturers to take appropriate precautions in dealing with BWMS on board as well as the treated ballast water. To this end, the emission of disinfection by-products may need further consideration as part of integrated local and regional exposure scenarios (overall impact as well as individual systems).

4 Discussion

This overview of progress in the evaluation of BWMS comes at a relatively early point in the development of technology to serve the Ballast Water Conventions requirements. Its main aim, using the published evaluations of GESAMP BWWG was to check for early trends in this developing market. Against such a dynamic background, the numbers presented here are subject to change.

A very positive development is that a wide variety of systems using chemical, physico-chemical and physical technologies are under development and this is reflected at all stages of the evaluation and approval process. It is already clear that the front runner technology is electrolytic chlorination. Such systems pass a rigorous environmental and human health risk assessment but the question of chlorination by-products could make them less attractive in the long run from an environmental point of view than some of the other candidates entering the market.

Table 5. Summary of Ballast Water Management technologies evaluated by GESAMP BWWG on behalf of IMO form 2006 to 2009

Main Disinfection Method	Issues to Consider	FA	TA
Electrochemical Chlorination	Residual TRO & chlorination by-products	3	2
UV irradiation	Irradiation – double disinfection to prevent regrowth	2	
Ozonation	TRO	1	
Stored chemicals which are dosed to the ballast water as preparations	TRO, Safety of storage and loading	2	1
Combination of 2 main (chlorination/ozonation/physical) disinfection techniques	TRO, chlorination by-products	2	
Titanium photo-catalysis	Irradiation plus very short lived active species	1	1
Drinking water flocculation technology	Waste floc	1	
Plasma technology		1	

The ideal BWMS needs to be effective in its primary aim of disinfecting ballast water, should pose a minimum risk to the environment, human health and the safety of the ship and should occupy the least space on board for the lowest price. Inevitably, the market will reach equilibrium between these goals. Based on the BWMS information submitted in the public part of the dossiers received to date, it seems likely that not all systems are scalable from small to very large.

Therefore, further consideration needs to be given to the prevalent types of systems which, on the one hand, may serve the small ship market and on the other, the medium to large sized ship market, as this will influence their global environmental impact. Regarding the environmental characteristics of the BWMS entering the market, the emphasis should continue to be place upon environmental acceptability in the broad sense and to this end a broad range of technologies is desirable.

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Note: IMO documentation on Ballast Water Management, including the reports of the GESAMP Ballast Water Working Group can be found through the following link: www.imo.org > marine environment (top menu) > Circulars (left side bar) > BWM (Ballast Water Management Convention; right side bar).

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Monitoring of Bacteria in Ballast Water

Ingun Tryland* Else-Marie Fykse**, Anne-Marie Bomo*,
Tor Gunnar Jantsch*, Agnete Dessen Nielsen* and Helge Liltved*

Abstract

This paper discusses monitoring of bacteria in ballast water according to the International Maritime Organization (IMO) Guidelines for approval of ballast water management systems (G8), MEPC 58/23/, Annex 4, Res. MEPC 174 (58), 2008. During land based testing of BWMS, high numbers of vibrios (none identified as the common human pathogens) were associated with the algae and zooplankton added to the test water for fulfilling the IMO requirements set for the influent water. Disinfection of influent water significantly reduced the number of heterotrophic bacteria (HPC) and vibrios, but consecutive storage in ballast tanks for 5 days in general caused high regrowth of HPC. Regrowth of vibrios seemed to depend on the ambient temperature and previous water treatment. Standard methods performed well for detection of culturable coliforms, E. coli, intestinal enterococci and HPC in the marine test water. However, the Colilert® Quanti-Tray method could not be used for detection of coliforms due to interference of vibrios. The high numbers of vibrios in some samples on deballasting also caused challenges for the detection of the required less than one per 100 millilitre of V. cholerae. Protocols for detection of low numbers of V. cholerae among high number of interfering bacteria are discussed.

Key words: Ballast Water, *Vibrio cholerae*, *Vibrio* spp., Heterotrophic Bacteria, Regrowth, Land Based Testing

1 Introduction

There are indications that pathogenic bacteria, for example *Vibrio cholerae*, can be spread to surface water bodies by ships' ballasting operations (Drake *et al.* 2007). The International Maritime Organization (IMO) Convention on ballast water management has therefore included requirements concerning indicator bacteria

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* Norwegian Institute for Water Research, Gaustadalléen 21, 0349 Oslo, Norway.

** Norwegian Defence Research Establishment, Kjeller, Norway.

in the ballast water performance standard, in addition to requirements concerning organisms in the ≥10–50 µm group and in the ^{3}50 µm group (IMO 2008). According to the guideline the discharged water should be proven to contain less than 1 colony forming unit (cfu) per 100 millilitres of toxigenic *V. cholerae* (O1 and O139), less than 250 cfu per 100 ml of *Escherichia coli* and less than 100 cfu per 100 ml of Intestinal Enterococci. In land based testing of ballast water treatment equipment these bacteria, as well as coliforms, enterococcus group, *V. cholerae* and heterotrophic bacteria (HPC) have to be measured in the influent water during ballasting and in the effluent water during deballasting (IMO 2008). Several methods are available for detection of these bacterial groups. IMOs requirements are specified as colony forming unit (cfu), which indicate that methods based on cultivation should be used. Such methods may underestimate the numbers of viable *V. cholera*e in a water sample since *V. cholerae* often occurs as viable but not culturable (VBNC) in the environment (Huq *et al.*, 2006). On the other hand, methods which depend on cultivation surely do not detect the dead bacteria, which is important when the purpose is to test the disinfection efficiency of ballast water management systems (BWMS). Besides, methods based on direct detection (immunological or molecular methods) at present do not have the required sensitivity to detect one bacterium in 100 ml without pre-cultivation/enrichment.

Thiosulfate citrate bile salt sucrose (TCBS) agar is recognized as the most appropriate medium for selective isolation and purification of *V. cholerae* (Pfeffer and Oliver, 2003). Bacterial strains which are able to ferment sucrose, e.g. *V. cholerae*, form yellow colonies on TCBS. Several vibrios, as well as some non-vibrios, are able to grow on TCBS agar. Further confirmations of characteristic colonies, by traditional biochemical tests or molecular methods, are therefore required for identification of specific strains. Toxigenic *V. cholerae* (O1 and O139) are in general confirmed after isolation by serotyping by slide agglutination using specific antisera and/or by multiplex PCR (Huq *et al.*, 2006).

The microbial content of ballast water may vary widely. In a survey conducted by Burkholder *et al.* (2007), the number of viable *Vibrio* spp. in U.S. military ships (obtained using TCBS plating) varied from <1 to 10^6 cfu per 100 ml. If the purpose is to detect *V. cholerae*, the non-*V. cholerae* bacteria growing on TCBS may be defined as interfering bacteria. If such bacteria are present in high numbers they may totally overgrow on the isolation media, thus making the confirmation of less than 1 cfu per 100 ml of *V. cholerae* (O1 and O139), for showing compliance with the IMO standard, time-consuming and/or difficult.

The objective of this paper was to present and discuss our experience with monitoring of bacteria in ballast water according to the IMO Guidelines for approval of BWMS, with focus on methods for detection of indicator bacteria and *V. cholerae*, bacterial regrowth after disinfection and needs for further research. The discussion is based on 3 years of experience with land based testing of BWMS, as well as supplementary laboratory experiments.

2 Materials and Methods

2.1 Bacterial Detection Methods

Indicator bacteria

HPC were recovered by spread plate on Difco Marine Agar, colonies were counted after 2–3 days incubation at 22°C. Intestinal enterococci, total coliforms and *E. coli* were quantified by membrane filtration using the standard methods described in Norwegian Standard (NS)-EN ISO 7899-2 (m-Enterococcus agar), NS 4788 (m-Endo agar) and NS 4792 (m-FC agar), with confirmations according to the respective standards. For some samples total coliforms and *E. coli* were also enumerated using the commercially available kit Colilert 18® QuantiTray (IDEXX Laboratories).

Methods for detection of total *Vibrio spp.* and *V. cholerae*

The total number of *Vibrio* spp. was determined by membrane filtration or spread plate on TCBS agar (24–48 h incubation at 37°C). All yellow and green colonies were counted as total *Vibrio* spp. Yellow colonies with morphology similar to *V. cholerae* were further confirmed by traditional biochemical tests (Huq *et al.* 2006). A simple protocol for elimination of *V. cholerae* (Baron *et al.* 2007) based on testing growth on nutrient agar without added NaCl followed by oxidase test and API 20E (Biomerieux) was found useful. Some of the colonies were also tested by *V. cholerae*-specific PCR by the Norwegian Defence Research Establishment.

A presence-absence method for detection of *V. cholerae* was also used, based on membrane filtration of 100 ml water sample and enrichment of filter with bacteria overnight (37°C) in alkaline peptone water (APW) with pH 8.6. The surface growth from APW was further examined by three different procedures: 1) by the traditional method described by Huq *et al.* (2006) based on culturing the surface growth from APW on TCBS and further identification of isolated colonies from TCBS by biochemical methods 2) by culturing of the surface growth from APW on TCBS, further culturing of the main growth (not only isolated colonies) from TCBS on nutrient agar without NaCl followed by confirmation of isolated colonies with oxidase test and API 20E 3) by direct *V. cholerae*-specific real-time PCR of the surface growth from APW. The PCR-based method was performed by the Norwegian Defence Research Establishment and is further described by Fykse *et al.* (2010).

2.2 Sample Collection and Preparation

Test water used for land-based testing of ballast water treatment equipment

The test water was produced at the BallastTech-NIVA AS land-based test centre at Solbergstrand, at the eastern coast of Norway. Biological additives (algae and zooplankton), as well as chemical additives, were supplemented to brackish water for fulfilling the requirements of the IMO guidelines for influent water. High numbers of HPC were associated with the algae and zooplankton, and the IMO-requirements of more than 10,000 cfu per ml of HPC were met without further bacterial additives. The most challenging water according to the IMO guidelines, i. e. brackish water with supplements was used in the presented work (typical characteristics: salinity: 21 PSU, pH: 8.0, dissolved oxygen: 8 mg per litre, turbidity: 40 NTU, Total Suspended Solids: 60 mg per litre, Particulate Organic Carbon: 7 mg per litre, organisms ^{3}50 µm: 10^5 per m^3 and organisms 10–50 µm: 10^3 per ml). The brackish water with supplements typically contained 10^4–10^5 cfu per ml of HPC, and 10^3–10^5 cfu per 100 ml of total *Vibrio* spp. (non-*V. cholerae*).

Water samples spiked with *V. cholerae*

Environmental isolates of *V. cholerae* (non-O1/non-O139), kindly donated from the Norwegian Defence Research Establishment, were used as positive controls and for spiking of water samples. *V. cholerae* were grown on Tryptic Soy Agar before use as positive controls or overnight in APW, followed by dilution in sterile seawater before spiking of environmental water samples.

Brackish water with supplements was added V. *cholerae* to levels 1–10^4 *V. cholerae* per 100 ml water sample. The purpose was to test the sensitivity of different methods for detection of *V. cholerae* in water samples with high levels of interfering bacteria/*Vibrio* spp.

Environmental seawater samples used in laboratory experiments

Environmental water samples collected at the Oslo coastline (salinity: 28 PSU, pH: 7.8, Turbidity: 1.9 NTU, Particulate Organic Carbon: 1.9 mg per litre) were used in laboratory experiments for testing the bacterial regrowth potential in seawater after disinfection.

2.3 Land Based Testing of Ballast Water Treatment Systems

The performance of different commercial BWMS (with regard to bacteria) were tested by monitoring the bacterial counts in inlet water (brackish water with supplements), in treated water immediately after water treatment (day 0) and in untreated (control), and treated water after 5 days storage in artificial ballast tanks (day 5), all according to the the IMO Guidelines (IMO, 2008). Some treatment technologies included disinfection of the water both at inlet and during deballasting (day 5), others only at the inlet water. Tests were performed all over the year at ambient temperatures.

2.4 Laboratory Experiment for Studying Regrowth Potential after Disinfection

Environmental seawater samples were treated by different disinfection techniques in laboratory experiments at room-temperature: 1) No treatment 2) Sterile filtration using a 0.2 µm pre-washed cellulose nitrate filter 3) UV-treatment (120 mWs per cm^2) using collimated beam equipment as described by Liltved *et al.* (1995), 4) Chlorination by adding sodium hypochlorite (3 mg per litre), Total Residual Oxidant (TRO) was measured to 1.7 mg Cl_2 per litre after 30 minutes using the colorimetric DPD-method and 5) Ozonation by bubbling ozone-containing ozygen (Liltved *et al.* 1995) to 400 ml test waters in glass flasks via a diffusor for 30 seconds. Immediately after removal of the diffusor and after 30 minutes contact time the TRO level was measured to 5 mg Cl_2 per litre. Sodium thiosulphate (30 mg per litre) was added to the chlorinated and ozonated water samples after 30 min reaction time for neutralizing the residual oxidants.

50 ml of the different water samples (no treatment, sterile filtered, UV-treated, chlorinated and ozonated) were placed in 100 ml brown glass bottles (for simulating ballast tanks), 3 parallels of each water sample. For simulating an episode of re-contamination, each bottle was added 0.5 ml natural inoculum (seawater stored at 30°C overnight). After the re-contamination episode the bottles were stored at 20°C and the numbers of culturable HPC and *Vibrio* spp. in the bottles were measured after 0, 2 and 5 days storage. The purpose was to investigate whether the previous water treatment had an effect on the growth potential of bacteria during the consecutive storage in "artificial" ballast tanks.

3 Results and Discussion

3.1 Evaluation of Bacterial Detection Methods

Vibrio spp. and *V. cholerae*

The Norwegian coastal water, used for production of test water for ballast water treatment equipment, in general contained low levels of *Vibrio spp.*/TCBS plate count in wintertime (<10 cfu per 100 ml), but higher levels in warm summer-months (about 10^3 cfu per 100 ml). High numbers of *Vibrio* spp. were associated with the algae and zooplankton added during the production of test water for land based tests. Such biological additives were required for fulfilling the IMO guidelines set for the influent water with regard to test organisms ≥10–50 µm and ^{3}50 µm. High numbers of *Vibrio* spp./bacteria forming colonies on TCBS (10^3–10^5 cfu per 100 ml) were therefore present in the test water. Several of the colonies were yellow (sucrose positive) and some had morphology like *V. cholerae*, others represented an obstacle since they grew well and outnumbered the *V. cholerae*-like colonies. In opposite to *V. cholerae*, most of the interfering colonies were not able to grow in nutrient broth or nutrient agar without added NaCl. Examination of 1,000 *V. cholerae*-like colonies from TCBS plates revealed that about 80% were not able to grow on nutrient broth or agar without NaCl supplement. In particular in summertime when the TCBS plate count was highest, most of the interfering bacteria were not able to grow without NaCl supplement. Among the one which were able to grow on nutrient agar without added NaCl, about 90% were oxidase negative. A simple protocol, recommended by Baron *et al.* (2007), based on colony morphology and these two tests, combined with API 20 E, was therefore useful for elimination of *V. cholerae*. None of the interfering colonies were identified as *V. cholerae* or other human pathogens by API 20E or molecular methods. However, the interfering colonies represented a practical challenge for the demonstration of less than 1 cfu per 100 ml of *V. cholerae*.

During three years of experience with land based testing, and simultaneous testing of the Norwegian coastal water, we have never detected *V. cholerae*. The use of positive controls, i. e. samples spiked with *V. cholerae*, is therefore essential for evaluation of the detection methods. While *V. cholerae* (mainly non-O1/non-O139) are frequently isolated from aquatic ecosystems in temperate and tropic areas (Huq *et al*. 2006), they are more rarely isolated from boreal/Norwegian areas. According to the Norwegian surveillance system for infectious diseases, all *V. cholerae* isolated from water or other matrixes should be sent to the National Institute of Public Health for confirmation and serotyping. In a Norwegian study Bauer *et al*. (2006) tested the occurrence of *Vibrio* spp. in 885 blue mussels. As a filter feeder, blue mussels tend to concentrate bacteria associated with planktonic algae and animals. *V. cholerae* was detected in only nine (1%) of the samples and all isolates were non-O1 and non-O139 serotypes. To our knowledge, *V. cholerae* serotype O1 and O139 have never been isolated from Norwegian costal waters. By using culture-independent molecular methods (without serotyping) Eiler *et al.* (2006) detected *V. cholerae* from water samples along the entire Swedish coastline, which indicate that these bacteria may be present in boreal coastal water to a higher extent than indicated by using culture-dependent methods. Culture-independent methods, however, need further development to be able to distinguish viable from dead cells after water disinfection, which is essential for testing the effect of ballast water treatment equipment.

By using direct plating on TCBS, the detection limit of *V. cholerae* in samples containing interfering bacteria is theoretically about one *V. cholerae* per 100 other colonies, i. e. it is not possible to isolate the one *V. cholerae* if there are more than 100 other colonies on the plate. Direct plating on TCBS is moreover considered as insufficient for detection of stressed *V. cholerae* and enrichment in alkaline peptone water (APW) is recommended. The detection limit of different protocols based on enrichment in APW for detection of *V. cholerae* in samples with high levels of interfering bacteria were tested by spiking the coastal water with supplements (containing 10^5 culturable *Vibrio* spp. per 100 ml) with different levels of *V. cholerae*. When the traditional protocol (Huq *et al.* 2006) was used, i. e. by culturing of the surface growth from APW on TCBS and further identification of isolated colonies from TCBS, *V. cholerae* was only detected from spiked samples containing >100 *V. cholerae* per 100 ml. By following a modified protocol where the main growth on TCBS (not single colonies) were re-striked on nutrient agar without NaCl, *V. cholerae* was isolated from samples containing down to 6 cfu per 100 ml. The best recovery (<1 cfu per 100 ml) was observed using a protocol based on enrichment in APW followed by real-time PCR (Fykse *et al.* 2010). This was found to be a useful presence/absence method for detection of one *V. cholerae* in 100 ml water sample.

Indicator bacteria

In general, standard methods for detection of culturable coliforms, *E. coli*, intestinal *enterococci* and HPC performed well for monitoring of the respective bacterial groups, even in the most challenging marine water (brackish water with supplements). The Colilert® Quanti-Tray method could however not be used for detection of coliforms due to interference of the vibrios. Dilution of the water samples (1:10) as recommended for seawater by the manufacturer did not reduce the problem with false positive since the Colilert® medium did not inhibit the growth and b-galactosidase activity of the large number of vibrios. Similar results are reported by others (Pisciotta *et al.* 2002; Waite *et al.* 2003).

3.2 Results from Land Based Testing of Ballast Water Treatment Systems

Different ballast water treatment systems, based on different methods for inactivation of bacteria (in general filtration followed by chemical oxidation or UV-treatment), all significantly reduced the number of HPC and *Vibrio* spp. immediately after treatment of influent water. Storage in ballast tanks, however, caused regrowth, and after 5 days storage the HPC was sometimes at least as high in the treated water as in the untreated control water. This is illustrated in Figure 1 which shows results from one of the tested ballast water treatment systems. Other ballast water treatment systems showed a lower regrowth, in particular if the concentration of Total Residual Oxidants (TRO) remained high during the 5 days storage period. The importance of a high TRO was also reported by Perrins *et al.* (2006). They treated marine ballast water with ozone and showed that when the TRO concentration fell below the bacterial inhibition threshold (below 0.5–1.0 mg per L as Br_2), HPC grew rapidly, sometimes to higher levels than in the controls.

The bacterial reduction after treatment and the consecutive regrowth during storage caused a shift in the bacterial community in the artificial ballast tanks. The regrowth of *Vibrio spp*. varied, and seemed to depend on the ambient temperature and on the previous disinfection method; i.e. in general higher regrowth of *Vibrio* spp. was observed if the ambient temperature was high (summertime) and if the previous disinfection method was based on chemical oxidation. No *V. cholerae* were found in the inlet water, so obviously no regrowth of *V. cholerae* was observed. Faecal indicators (*E. coli* and Intestinal enterococcus) in general showed no or low regrowth during storage in ballast tanks in our studies, and the effluent water therefore fulfilled the requirements set by IMO (less than 250 cfu per 100 ml of *Escherichia coli* and less than 100 cfu per 100 ml of Intestinal Enterococci). Regrowth of *E. coli* after UV-treatment of marine water has been reported by others (Waite *et al.* 2003).

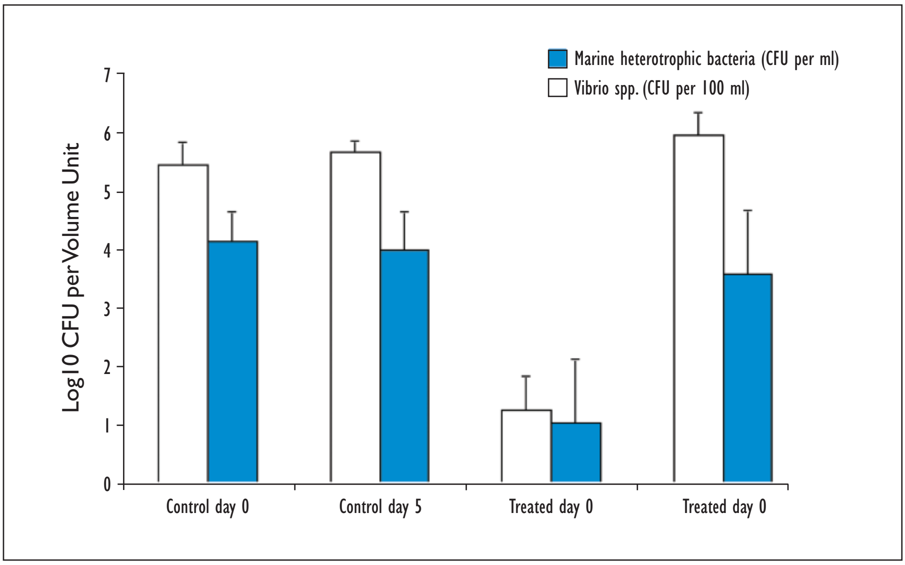

Figure 1. Example showing results from land based testing of a ballast water treatment system based on chemical oxidation for inactivation of bacteria. Numbers of marine heterotrophic bacteria and Vibrio spp. are shown before treatment (control day 0), after treatment (treated day 0), as well as in untreated control water and treated water stored for 5 days in ballast tanks. The data represents mean values and standard deviation from 5 separate tests

Many of the tested ballast water treatment systems also included disinfection during deballasting. For such systems, the numbers of HPC and *Vibrio* spp. were in general low in the effluent water since this additional disinfection also inactivated bacteria that had grown up during storage in the ballast tanks.

3.3 Laboratory Experiments for Studying Regrowth Potential after Disinfection

The land based testing of BWMS was performed using test water with high levels of organic materials, as required in the IMO Guidelines. Laboratory experiments were performed for studying the bacterial growth in seawater with low levels of organic material. After disinfection the residual oxidants were removed by sodium thiosulphate since the purpose was to study the influence of the disinfection processes on the bacterial growth potential.

When untreated seawater, with natural inoculum, was stored in small bottles (simulating ballast tanks) at 20°C, the heterotrophic plate count increased by about 1 $\log_{10}$ unit after 5 days storage (Figure 2). A more rapid and higher increase in HPC was observed in the bottles containing treated water samples, in particular in the bottles containing water exposed to high levels of ozone (about 2 $\log_{10}$ units increase in HPC after 5 days storage). Lower numbers of predators in disinfected water samples is one possible explanation of the higher bacterial growth compared with the untreated seawater. An explanation of the highest growth in ozonated water is that the ozone treatment oxidized non-biodegradable organic matter in the water, and thereby produced a higher fraction of biodegradable organic matter, allowing more bacteria to grow up. Oxidation-based disinfection processes (e.g. ozonation and chlorination) are known to increase the fraction of biodegradable dissolved organic carbon in drinking water, which may cause increased growth of HPC in the distribution system (Yavich *et al.* 2004).

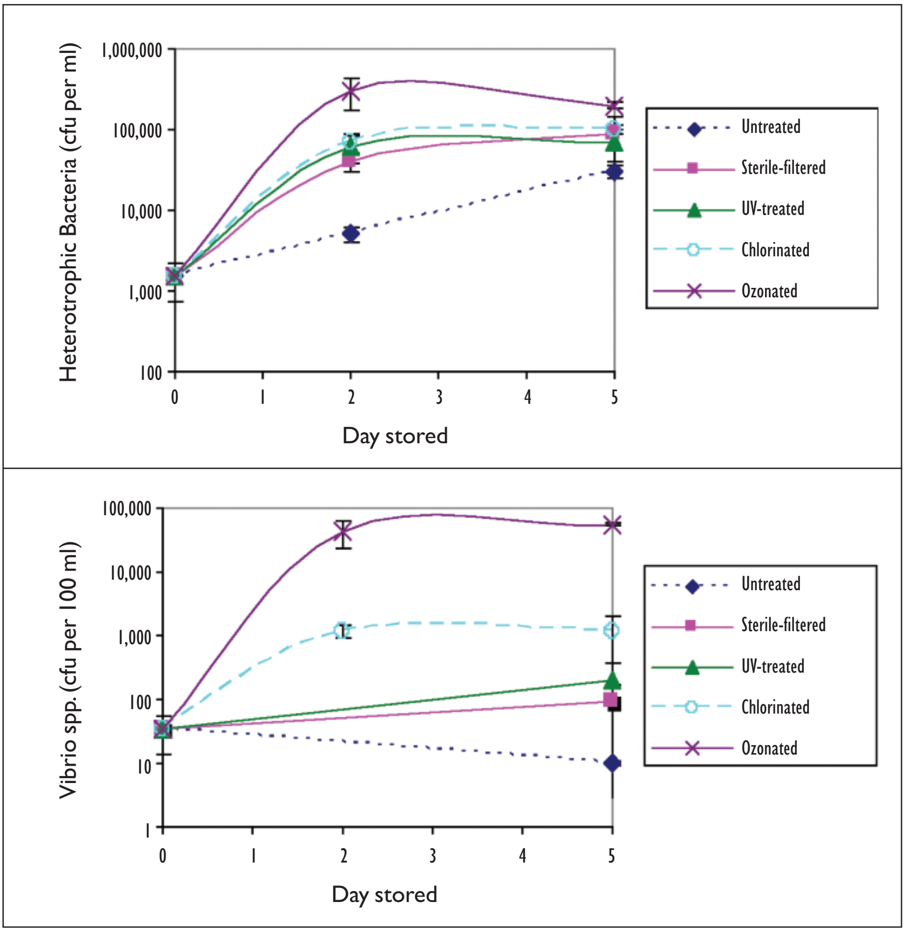

Figure 2. Results from laboratory experiments studying growth of heterotrophic bacteria and total Vibrio spp. in untreated seawater and treated seawater during storage in bottles simulating ballast tanks at 20°C. Each data point show mean value and standard deviation from 3 replicate bottles.

Interestingly, the increase in total *Vibrio* spp. was relatively higher (3 $\log_{10}$ units) that the increase in HPC (2 $\log_{10}$ units) in the ozonated water (Figure 2). This was in opposite to the untreated seawater where the HPC increased while the *Vibrio* spp. decreased (Figure 2). Also in the sterile-filtered water and the UV-treated water, the growth of *Vibrio* spp. was minor. It may be hypothesized that ozonation produced bio-available organic matter or conditions that favoured the growth of *Vibrio* spp. Regrowth of *Vibrio* spp. relative to other HPC is known to depend on factors such as temperature, salinity and bio-available organic matter. For example cyanobacterial dissolved organic matter was shown to stimulate growth of *V. cholerae* and *V. vulnificus*, and the contribution of *V. cholerae* to total *Vibrio* abundance, and total bacterial counts, increased with increasing dissolved organic matter (DOM) concentration (Eiler *et al.*, 2007).

The conditions used in our laboratory experiments are somewhat different from real conditions, i. e. high ozone doses were used and residual oxidants were neutralized with sodium thiosulphate before the ozonated water was re-contaminated. They nevertheless point out some questions which need further investigation, e. g. whether harmful bacteria (e. g. *V. cholerae*) may grow up in ballast tanks if most predators and competitive bacteria are removed and more biodegradable organic matter are available after treatment. Even if *V. cholerae*, or other human or fish pathogenic bacteria, are assumed to be removed by the disinfection process, they may potentially be present in sediments or biofilm. Biotic and abiotic particles are shown to protect marine HPC during UV and ozone disinfection (Liltved and Cripps 1999, Hess-Erga *et al.*, 2008).

4 Conclusions and Recommendations

High numbers of *Vibrio* spp. were associated with the algae and zooplankton added to the test water for fulfilling the IMO-requirements for land based testing. None of these vibrios were identified as human pathogens. The *Vibrio* spp. grew well on TCBS agar and therefore interfered with the conventional methods for detection of *V. cholerae*, i. e. direct plating on TCBS or selective enrichment followed by culturing on TCBS. Most of these bacteria did not grow on nutrient agar without NaCl supplement. Re-striking of bacterial growth from TCBS on nutrient agar without added NaCl was therefore found to be a useful step for isolation of low levels of *V. cholerae* from samples with high levels of interfering *Vibrio* spp. A presence-absence method based on enrichment in alkaline peptone water followed by PCR was useful for demonstrating less than one *V. cholerae* per 100 ml, as required in the IMO Guidelines, even in the most challenging water samples.

In general, standard methods performed well for detection of coliforms, *E. coli*, intestinal enterococci and HPC in the marine test water. However, the Colilert® Quanti-Tray method could not be used for detection of coliforms due to interference of the marine vibrios.

Results from land based testing of BWMS showed that disinfection of influent water significantly reduced the number of HPC and total *Vibrio* spp, but consecutive storage in ballast tanks for 5 days in general caused high regrowth. Laboratory experiments showed that ozonation increased the growth potential of *Vibrio* spp. relatively more than of HPC.

The results indicate that disinfection also during deballasting may be required for reducing the HPC and vibrios in the discharged water. Alternatively, a high disinfection residual must be present during storage in the ballast tanks. For BWMS which also include disinfection during deballasting, bacterial regrowth in ballast tanks represent a minor problem. For technologies which do not include disinfection at de-ballasting, further studies are recommended for investigating health relevance of regrowth during storage in ballast tanks. An important question is whether harmful bacteria (pathogenic for humans or aquatic life) which survive the disinfection process may grow up in ballast tanks after disinfection, or if their growth are suppressed by harmless HPC.

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Ballast Water Treatment Testing and Discharge Toxicity

[*]Mario Tamburri, Greg Ziegler, Dan Fisher, Lance Yonkos and Kitae Rhie

The Maritime Environmental Resource Center (MERC) has been established to provide test facilities, information, and decision tools to address key environmental issues facing the international maritime industry. The Center's primary focus is to evaluate the mechanical and biological efficacy, associated costs, and logistical aspects of ballast water treatment systems and the economic impacts of ballast water regulations and management approaches. A full description of MERC's structure, products, and services can be found at www.maritime-enviro.org.

Through land-based and shipboard testing of ballast water treatment systems, based on IMO G8/G9 guidelines and Environmental Technology Verification (ETV) program protocols (developed for the US Coast Guard), MERC has found several unanticipated issues associated with testing logistics and treatment system efficacy. For a treatment system to successfully complete (i.e., pass) a test trial it must not only meet discharge standards for all categories but also have no mechanical failures during the trial and treated water cannot be toxic upon discharge. One unanticipated issue recently discovered is the toxicity of oxidant treated water after neutralization. Sodium thiosulfate and sodium bisulfite are commonly used to detoxify water after treatment with sodium hypochlorite, chlorine dioxide and other related treatments. While this approach has been safely and successfully used in a variety of water treatment applications, including ballast water, care must be taken to assure that precise concentrations of sodium thiosulfate or sodium bisulfite are used based on chlorine levels in ballast water upon discharge.

Both evaluations of ballast water treatments and laboratory experiments conducted at our toxicity test facility have demonstrated that the use of neutralizing compounds in excess might result in a statistically significant reduction in growth of marine phytoplankton when using US Environmental Protection Agency (EPA

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[*] Maritime Environmental Resource Center, University of Maryland and Kyung Hee University.

2002) and the American Society for Testing and Materials (ASTM 2006) approved methods. However, toxic effects were only found on algae, not zooplankton or larval fish.

Our initial hypothesis is that the excess neutralizing compounds likely reacted with metal micronutrients in the algal growth media, making them unavailable to the algae. This chelation of nutrients by neutralizing compounds could then result in a reduction in the growth of the algal population, which is the toxicity endpoint of the chronic algae bioassay. However, additional studies are underway to clearly identify the factors causing these observations.

The lesson to be learned is that simply removing active substances, such as chlorine, to below detection limits may not always result in water safe for discharge.

A Novel Approach to Determine Ballast Water Vitality and Viability after Treatment

*Peter Paul Stehouwer, Frank Fuhr and Marcel Veldhuis

Abstract
The spread of invasive species through ballast water is a major threat to the world's oceans. For that reason the International Maritime Organisation (IMO) has set rules for ballast water treatment. In response, many companies have developed ballast water treatment systems (BWTS). Different techniques are used to reduce the numerical abundance of organisms; UV-radiation, active substances, etc. To accurately measure the efficacy of different BWTS methods have to be developed that are applicable to each of the treatments. Two specific points are addressed in this paper. The first is if no re-growth of organisms is observed during the tests, is re-growth still possible? The second concerns the delayed effect of UV disinfection, does this lead to an underestimation of its performance? To answer these questions a set of incubation experiments was developed. Treated water is incubated up to three weeks under optimal conditions to stimulate growth of micro-organisms that survived the treatment. The moment of re-growth differed strongly, sometimes even within the same BWTS. The data from these incubations also allowed for calculating the estimated minimum number of organisms from the slope of survival, providing an accurate estimate of the number of organisms even when numbers were below the detection limit. These examples show that the incubation experiment is a useful method to get an accurate view of ballast water vitality and viability.

Key words: IMO, Ballast Water Treatment, Incubation, Re-growth, Micro-organisms, Estimated Minimum Number

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1 Introduction

The steady increase in size and speed of ships has led to more ballast water being transported and shorter holding times of ballast water (Carlton 1996, 97). Ballast

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* Royal Netherlands Institute for Sea Research.

water contains organisms from the intake location. Ballast water, therefore, results in transport of non-indigenous organisms to other regions. More ballast water implies more organisms and shorter holding times mean more chance of surviving transit to the discharge location. When organisms survive and become a dominant species, they are recognised as invasive species. Invasive species can cause large ecological and economical damage (Ruiz et al. 1997, 621; Pimentel et al. 2000, 53). Some species can even form a threat to human health.

In view of the damage caused by invasive species the International Maritime Organization (IMO) adopted the Ballast Water Management Convention. The Convention Regulations specify the D2-standard, which specifies the amount of organisms allowed to be present in ballast water upon discharge (Anonymous 2008). One of the limits set in the D2-standard is for organisms in the size class between 10 and 50 micron; less than 10 viable organisms per mL of that size class are allowed to be in the ballast water on discharge. To meet these standards, different Ballast Water Treatment Systems (BWTS) are developed and need to be tested according to IMO requirements. Different techniques are used for BWTS, usually based on a mechanical step (filter, hydrocyclone) and a disinfection step (UV-radiation, active substances, heat, etc (Gregg et al. 2009, 521).

For land-based tests, the IMO requirements state that ballast water must be stored for five consecutive days in holding tanks (simulated ballast tanks) and sampled on intake (T0) and discharge (T5). This method of testing fails to answer some important questions. The first question concerns re-growth potential of the discharged ballast water. If no organisms can be detected on discharge, is this because there are no organisms left or are they only reduced to below detectable levels? Phytoplankton is especially difficult in this respect, capable of making cysts (resting stages) which can survive periods of physical stress (Hallegraeff 1998, 297; Gregg and Hallegraeff 2007, 567). Cysts are completely inactive and therefore almost impossible to detect, but when conditions improve they reactivate. The second question concerns systems with a delayed effect. Some BWTS (UV-radiation based systems for example) have a delayed effect in their treatment, organisms are not dead immediately after treatment, but samples to determine the number of viable organisms are taken immediately after treatment. Are UV systems at a disadvantage because of this? To answer these questions, an incubation experiment was developed. In the incubation experiment samples from the holding tanks are incubated under optimal conditions and samples for determining vitality and viability of phytoplankton are taken daily for a period of up to 25 days.

2 Materials and Methods

Land-based testing. Water from the harbour of the Royal Netherlands Institute for Sea Research (NIOZ, Texel, The Netherlands) was pumped up through the treatment system (200 m^3/h) and stored in an underground holding tank. Control water was pumped straight into a separate holding tank, by-passing the treatment systems. Water was stored in the tanks for five consecutive days before being discharged. Depending on the treatment system, water was also treated on discharge. The two types of system tested are filter with UV-disinfection and filter with active substance disinfection.

Incubation experiment. Incubation samples were taken during land-based testing. Samples were collected in 10 L Nalgene bottles at both uptake (T0) and discharge (T5). Samples are transported to a climate-controlled room. This room is kept at a stable temperature of 15°C (+/–2°C) and a 16:8 hour light/dark period is used. Bottles were placed on magnetic stirrers, which maintained the water movement (130 rotations/min.) that marine plankton is used to. Nutrients were added at concentrations typical for the Wadden Sea during winter (PO_4 1,6 µmol/L, NO_3 20 µmol/L, SiO_3 20 µmol/L).

For every BWTS two long-term incubation experiments of up to 25 days were done where samples were taken daily. Samples were taken for phytoplankton abundance and viability. Phytoplankton is quantified by flow cytometry (Coulter Epics XL-MCL with a 488 nm argon laser). Samples were measured in triplicate, using red fluorescence to differentiate between phytoplankton and other particles. Phytoplankton viability, in terms of photosynthetic efficiency, is measured using Pulse Amplitude Modulated (PAM) fluorometry (Water-PAM, Walz GmbH). Phytoplankton viability is expressed as a number between 0 and 1:

- ≥ 0.5: a healthy phytoplankton population
- $0.3 < r < 0.5$: a phytoplankton population which is not under optimal conditions
- $0.1 < r < 0.3$: a phytoplankton population which is dying
- ≤ 0.1: phytoplankton population is considered to be dead

3 Results

3.1 Incubation Experiment

After five days of incubation, the amount of phytoplankton decreased in the control holding tanks, while the amount of phytoplankton increased in the control incubation (Figure 1). PAM viability values support this. At T0 phytoplankton viability values were usually between 0.51 and 0.66, after five days in the control holding tanks phytoplankton viability values were usually between 0.11 and 0.31 while phytoplankton viability values after five days in the control incubation were usually between 0.44 and 0.64. Figure 1 also shows that treated incubation samples had lower numbers of phytoplankton than control incubations. Treated holding tank samples and treated incubation samples did not show a clear pattern for phytoplankton abundance. Phytoplankton viability was similar after five days in both treated incubation and treated holding tank, both generally had values between 0.08 and 0.

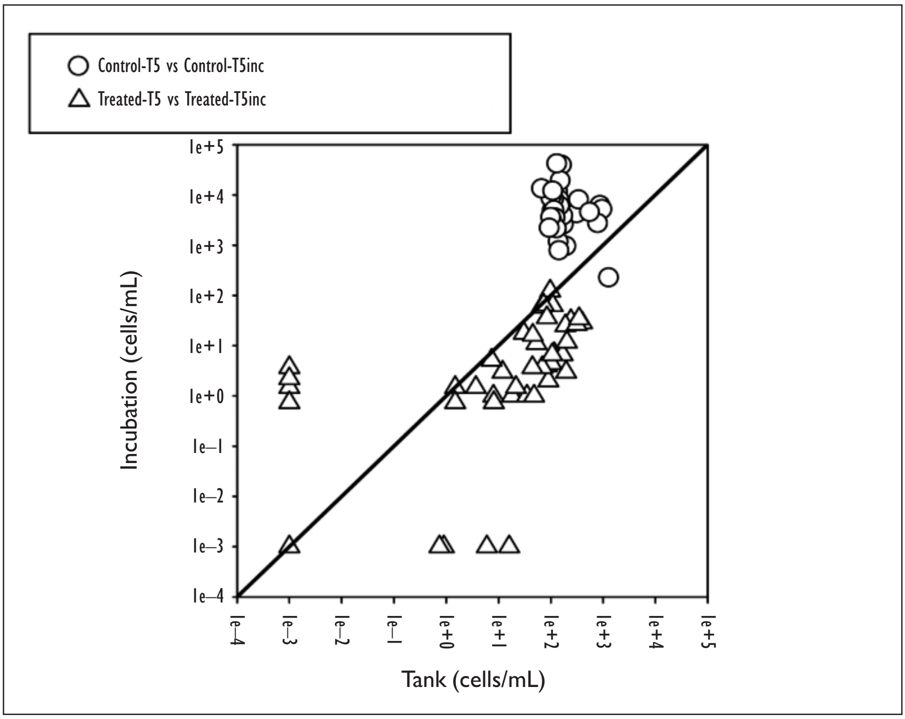

Figure 1. Phytoplankton abundance in incubated samples and samples from the holding tanks for both control water (circle) and treated water (triangle)

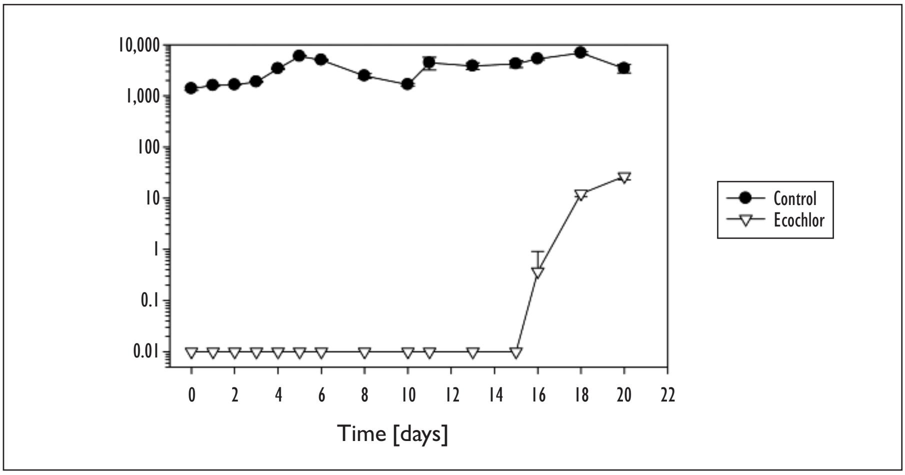

Figure 3. Phytoplankton abundance in a control, intake UV (UV treated once) and discharge UV (UV treated twice) long-term incubations. UV discharge samples were collected on T5 (discharge day), incubation and sampling for this experiment thus started on T5

3.2 Long-term Incubation Experiment

Active substance. Long-term incubation samples treated with an active substance showed re-growth of phytoplankton, but this may take a considerable period (Figure 2). Incidentally, for the same system (Ecochlor®, using chlorine dioxide), there were also samples where no re-growth of phytoplankton was found during the whole three-week sampling period.

UV irradiation. Phytoplankton abundance showed a gradual decrease after UV treatment (Figure 3). Both single treated UV intake samples and twice treated UV discharge samples show this pattern. However, initial phytoplankton abundance is lower for UV discharge than for UV intake. Phytoplankton abundance also decreases further for UV discharge than for UV intake (Figure 3). In both cases re-growth started around 7 or 8 days after start of the long-term incubation.

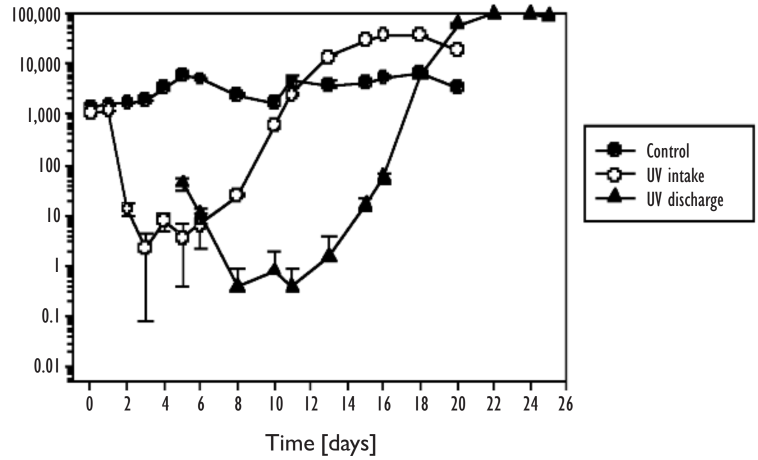

Figure 3. Phytoplankton abundance in a control, intake UV (UV treated once) and discharge UV (UV treated twice) long-term incubations. UV discharge samples were collected on T5 (discharge day), incubation and sampling for this experiment thus started on T5

Estimated minimum number. In order to quantify the delayed effect seen in UV treatments, an extra experiment was performed using different UV concentrations and an intensive sampling regime. This experiment showed that with a higher UV dose (400%) phytoplankton abundance decreases faster than the normal (100%) dose (Figure 4). A lower UV dose (25%) showed an even slower decrease in phytoplankton abundance. From the slope of decrease (i.e. survival rate) in Figure 4 and estimated minimum number of phytoplankton can be calculated. This is an established method in cancer research and uses the formula: $y = a * e^{(bx)}$.

Where a = the initial value at T0 and b is the factor with which y changes. Using this formula the exact time can be calculated at which the number of phytoplankton is below 10 per mL. As shown in Table 1, this time differs considerably when comparing the UV doses used in this experiment.

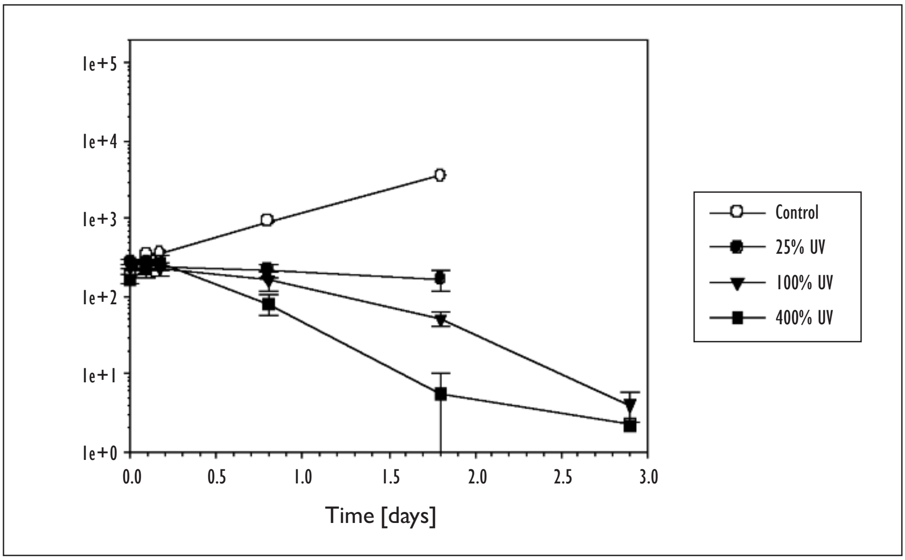

Figure 4. Phytoplankton abundance in samples subjected to different UV-intensities. UV-intensities expressed as % of normal treatment dose

Table 1. Estimated time before the number of phytoplankton drops below 10 per mL after treatment with different UV doses. 0% UV shows a negative number, this means that the phytoplankton were actually growing.

UV dose (%)	0	25	100	400
Time (days)	-0.970	16.080	1.694	0.886

4 Discussion and Conclusion

Treatment of ballast water by BWTS results in different vitality and viability of phytoplankton. BWTS always reduce phytoplankton vitality and viability, however differences can be found when comparing different treatment systems. After treatment with an active substance, re-growth of phytoplankton can occur in ballast water. However, the time period differs before re-growth occurs within one BWTS and when comparing BWTS (Figure 2). Sometimes no re-growth occurred, suggesting that it is a matter of chance. It might depend on the survival rate of phytoplankton cysts in the water, which can not be confirmed by flow cytometry. The species present in the water are also important, since cysts of some phytoplankton species are much more resistant to active substances or UV-radiation than those of other species (Gregg and Hallegraeff 2007, 567). Further analysis is needed to confirm this assumption.

Treatment with UV-radiation also resulted in a decreased abundance of phytoplankton, however a delayed effect was found. While treatment with active substance results in an immediate decrease in phytoplankton abundance, after UV treatment phytoplankton abundance shows a gradual decrease. Even the highest UV dose needs almost one day to meet the requirement of less than 10 cells per mL. Waite et al. (2007, 51) observed a similar effect using the amount of chlorophyll a as indicator of phytoplankton survival. Immediately after UV treatment there were still detectable levels of chlorophyll a. The IMO requires the number of organisms in the size class between 10 and 50 micron (phytoplankton) to be below 10 per mL. The five-day storage period in ballast tanks provides sufficient time for the delayed effects of the first UV-treatment to occur, but values can be close to the IMO limit (Figure 3). The second UV-treatment further reduces phytoplankton abundance (Figure 3) and thus allows the UV-based BWTS to meet the IMO requirements.

The incubation experiment, especially the long-term incubation experiment, provides data on phytoplankton survival and re-growth. This data can be compared with data from the holding tanks to gain a better understanding of how various BWTS affect phytoplankton viability and vitality. Data from the incubation experiments can also be used to calculate the estimated minimum number of phytoplankton per mL of treated ballast water, even if those numbers are below detection limits of flow cytometry and PAM fluorometry. It is therefore recommended to include incubation experiments in BWTS tests.

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New Data Experiments Using Viability Stains on Treated Ballast Water for IMO Compliance Monitoring

*Kent Peterson and Harry Nelson

Abstract
The FlowCAM® is a continuous imaging flow cytometer now being used in the U.S., Europe and Asia for analyzing ballast water. It combines microscopy, flow cytometry, imaging and fluorescence technologies. It can detect, image and count phytoplankton and zooplankton. It also offers cell counts, minimum dimensions and viability, as well as, pattern recognition, organism classification and image management. Applications include pre-treatment, post-treatment, IMO D-2 standards validation and sampling protocols. This paper will present an overview of both the current technology and new technology (FlowCAM-HF) along with select case study data.

Key words: FlowCAM, FlowCAM-HF, Organism Detection, Counting, Classification

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1 Introduction

Fluid Imaging Technologies, Inc. was founded in 1999 and is located in Yarmouth, Maine. The company produces the FlowCAM (which is an acronym for a **Flow Cyto**meter **And M**icroscope) and related products. The FlowCAM combines three areas of technology (flow cytometer, camera, microscope) and custom software to produce an advanced analytical instrument. Proprietary features include Depth-of-Focus enhancer lenses and Interactive Scattergram Software (VisualSpreadsheet™). FlowCAMs are in use around the world for multiple industries and applications. The purpose of this paper is to present some relevant specifications and data regarding the use of the FlowCAM/FlowCAM-HF in the treated ballast water industry.

2 Materials

In the FlowCAM system (Figure 1), sample is drawn into the flow chamber by a pump. When a particle passing through the flow cell or laser fan (488nm blue or

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[*] Fluid Imaging Technologies, Inc., Yarmouth, ME 04096 USA.

532nm green) the camera is triggered to take an image of the field of view. The computer, digital signal processor, and trigger circuitry work together to initiate, retrieve and process images of the field of view. The size range of particular interest for treated ballast water analysis (organisms from 10–50μM and 50μM+) are encompassed by the analytical range of the FlowCAM. Other specifications include:

- Particle sizes
  - Imaging – 3 µm to 3 mm
  - Detection – 0.5 µm to 3 mm
- Objectives – 2x, 4x, 10x, 20x
- Flow Cell – 50 µm to 2 mm
- Processing Capability
  - Flow – 0.25 ml/min to 12 ml/min
  - Density – 50,000 particles/ml (AutoTrigger mode)

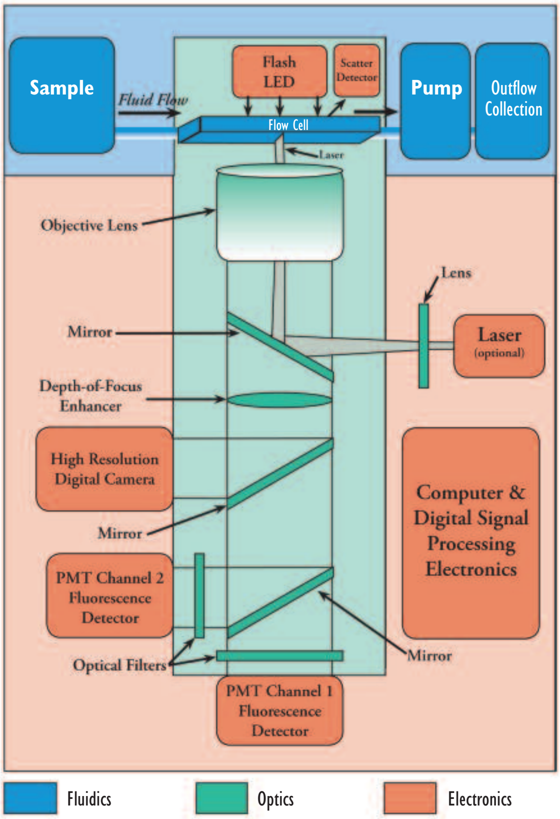

Figure 1. Illustration of FlowCAM's exchangeable optics and flow cell (Source: Fluid Imaging Technologies, Inc. FlowCAM Manual)

The software also provides the Particle Parameters for each imaged particle. The Image Parameters include Transparency, Intensity, Sigma Intensity, Compactness, Roughness, Average Red, Average Green, Average Blue, Red/Green Ratio, Blue/Green Ratio, and Red Blue Ratio. The Morphological Parameters include Length, Width, ESD, ABD, Aspect Ratio, Elongation Perimeter, Particles per Chain, Relative Chlorophyll, Relative Phycoerythrin, and Scatter Signal. The FlowCAM software generates at least five files during an experimental analysis. These files include a *.lst (an interactive scattergram), *.ctx, *_notes.txt, *_run summary.txt, and *.tif files (image files). Finally the software can do autoclassifications, build libraries and apply custom filters.

3 Data & Results

Previous work conducted by The Naval Research Laboratory (Key West, Florida) included a comparison of FlowCAM counts to manual hand counts (See Figure 2). Samples were homogenous diluted *Thalassioria weissflogii* stock solutions. The figure demonstrates the counting accuracy and consistency thus minimizing the impact of operator error or fatigue.

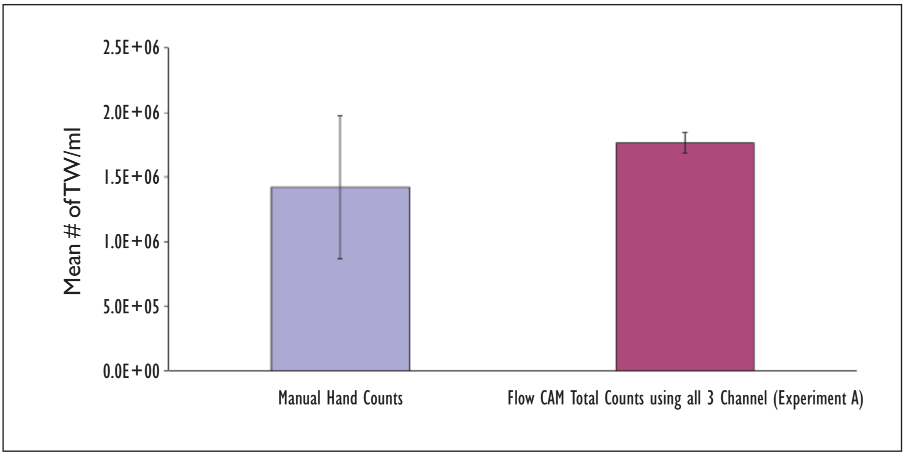

Figure 2. FlowCAM vs. Manual Hand counts (Source: Naval Research Laboratory)

Table 1 illustrates the automated recognition accuracy (of a sample obtained from Lake Kinneret, Israel) of the FlowCAM. The automated recognition accuracy is just one feature available when using the FlowCAM. Another application for the FlowCAM technology involved both a biocide and sonic treatment of water containing micro organisms. See Table 2 on the following page. Disrupted cells were visible as they were imaged and these results were used to substantiate the chemical and sonic success.

Table 1. Automated recognition accuracy of a sample obtained from Lake Kinneret, Israel (Source: Unpublished Data by Fluid Imaging Technologies, Inc.)

Organism	Run	# Class'd	# Mis-Class	% Accurate	# Missed	% Missed
Cladoceran	1	2	0	100	0	0
	2	4	0	100	1	25
Copepod	1	13	0	100	0	0
	2	31	1	97	0	0
Egg	1	12	0	100	0	0
	2	18	0	100	0	0
Diatom Chain	1	2	0	100	2	100
	2	9	0	100	1	11
Average				99		17

Table 2. Biocide and sonic treatment of water results (Source: Unpublished Data by Fluid Imaging Technologies, Inc.)

Treatment	Cells/ml	Mean	Morphotypes Observed
Inlet-Harbour water Rep 1	65		Dinoflagellates, diatoms, spherical cells
Inlet-Harbour water Rep 2	57	61	Dinoflagellates, diatoms, spherical cells
Outlet-sonic treatment Rep 1	33		Many unidentified particles and disrupted cells
Outlet-sonic treatment Rep 2	26	30	Many unidentified particles and disrupted cells
Outlet-sonics & ozone Rep 1	1		Small spherical cells, if any
Outlet-sonics & ozone Rep 2	1.5	1	Small spherical cells, if any

Finally, both fluorescent and visible metabolic probes were used to determine cell viability via analysis with the FlowCAM (see Table 3). The probes included fluorescein diacetate (FDA), 5-carboxyfluoroscein diacetate (CFDA) with cultures of *Heterocapsa* and *Tetraselmis suecicia* and Neutral Red for a harbour sample. For FDA, the *Heterocapsa* fluoresced green with blue laser excitation once incorporated into the cell.

Table 3. Neutral Red Staining Initial Data Results using Color Filtering-Boothbay Harbour, Maine. (Source: Unpublished Data by Fluid Imaging Technologies, Inc.)

Sample Type	Total Count	Zooplankton Concentration	% LIVE using Color Filter
LIVE	289	51 cells/ml	84
DEAD	210	37 cells/ml	15
MIX 50:50	243	43 cells/ml	51

4 Summary

The data and results presented in this paper were generated using a standard FlowCAM. The benefits of the standard FlowCAM model include custom software, proprietary technology, portability, size/concentration/viability analysis, and ballast water treatment monitoring and validation. Fluid Imaging Technologies, Inc. will soon introduce the FlowCAM-HF. This new model of the FlowCAM will expand the sampling rate up to 60mL/minute of treated water. This enhanced rate will use new software features (including edge gradient) to capture a sample of in focus particles in the larger liquid stream. Additionally, the software will have a new user interface that will present data and results in an easy to read manner. The abilities and performance of FlowCAM technology presented in this paper will be available to serve the emerging treated ballast water industry for both viability and concentration analysis per IMO Regulation D-2 standards, or for “indicative monitoring” for port state authorities.

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Recommendations how to Take a Representative Ballast Water Sample

Stephan Gollasch[*] and Matej David[**]

Abstract

Sampling ballast water of ships is very different compared to water samplings in nature. For scientific and regulatory purposes it becomes more and more relevant to develop sampling strategies resulting in accurate, i.e. representative, results of biota in ballast water. One reason being compliance control samplings with the standards set forth in the Ballast Water Management Convention of the International Maritime Organization and also to proof the effectiveness of ballast water treatment systems onboard vessels. The authors sampled ballast water of more than 250 vessels and have extensive experience in onboard ballast water samplings also including performance tests of ballast water treatment systems. Results from these studies were reviewed and recommendations are given how to take representative ballast water samples.

Key words: Ballast Water Sampling, Sample Representativeness, Biological Invasions, Compliance Control

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1 Introduction

Ballast water sampling is a challenging task as sampling biota from a vessel is fundamentally different from sampling in the natural environment. The majority of the sampling gear used so far to sample ships ballast water was not designed for the purpose of compliance control samplings with the standards set forth in the IMO Ballast Water Management Convention. Consequently, it becomes more and more relevant to develop sampling strategies resulting in accurate, i.e. representative, results of biota in ballast water.

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[*] GoConsult, Grosse Brunnenstr. 61 22763 Hamburg Germany.

[**] University of Ljubjana, Faculty of Maritime Studies and Transport, Pot pomorscakov4, 6320 Portoroz, Slovenia.

This study was undertaken to contribute to the ongoing discussions regarding procedures and methods to take samples which result in representative numbers of organisms in discharged ballast water. Representative samples need to be taken according to the organisms addressed in the Ballast Water Performance Standard as outlined in Regulation D-2 (see below) of the International Convention on the Management of Ships' Ballast Water and Sediments (BWM Convention). This convention was adopted at the International Maritime Organization (IMO), the United Nations body to deal with shipping, during a diplomatic conference in 2004 and will come into force after ratification of 30 IMO Member States with more 35% of the world fleet tonnage. As per today 21 countries with ca. 23% tonnage have ratified this environmental protection instrument.

1.1 Ballast Water Performance Standard (D-2)

Regulation D-2 of the Ballast Water Management Convention stipulates that ships meeting the requirements of the Convention shall discharge:

- less than 10 viable organisms per cubic meter greater than or equal to 50 micrometers in minimum dimension, and
- less than 10 viable organisms per millilitre less than 50 micrometers in minimum dimension and greater than or equal to 10 micrometers in minimum dimension, and
- less than the following concentrations of indicator microbes, as a human health standard:
  - Toxigenic *Vibrio cholerae* (serotypes O1 and O139) with less than 1 Colony Forming Unit (cfu) per 100 millilitres or less than 1 cfu per 1 gramme (wet weight) of zooplankton samples,
  - *Escherichia coli* less than 250 cfu per 100 millilitres, and
  - Intestinal Enterococci less than 100 cfu per 100 millilitres.

2 Material and Methods

The study was undertaken on the Wilhelmsen Lines Pure Car and Truck Carrier Toronto. The vessel particulars are IMO Number 9302205, DWT 19,628 t, cargo capacity 6,350 car units on 12 car decks, maximum ballast water capacity 9,669 t in 19 tanks.

The vessel voyage took place in September 2009 between ports of the Republic of Korea and China.

The samples were taken from the ship's ballast water line and all in-line sampling points were of identical design (Figure 1).

Inline sampling was also conducted during discharge of ballast water to compare a sequential sampling approach with samples over the entire pumping time. For the sequential samplings water was sampled in the beginning, middle and end of the pumping process.

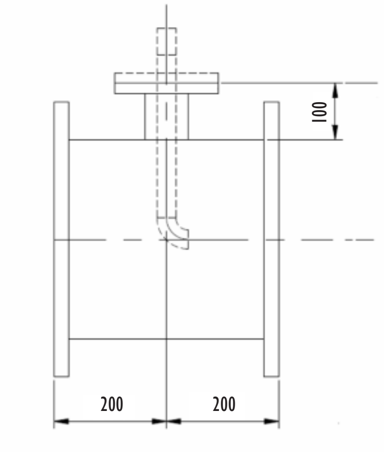

Figure. 1. Design of in-line ballast water sampling point.

All samples were analysed for living organisms above 50 micron (mainly zooplankton) in minimum dimension and for organisms below 50 micron and above 10 micron (mainly phytoplankton) in minimum dimension. For the zooplankton samples a plankton net with a removable filtering cod-end with a meshsize of 50 µm in diagonal dimension was used. Phytoplankton samples were taken unconcentrated.

The zooplankton samples were processed and organisms counted onboard. The viability of the phytoplankton organisms was measured onboard by using a Pulse-Amplitude Modulation (PAM) Device. Thereafter, the samples were preserved with Lugol solution and organisms were counted later on land by using a FlowCAM at the ballast water unit of the Royal Netherlands Institute for Sea Research (NIOZ), Texel Island, the Netherlands.

3 Results

Sample volumes of the phytoplankton samples ranged from 4 to 6 L of which, after proper mixing, a subsample of ca. 60 ml was taken for later analysis on land. For zooplankton samples the water volumes were between 303 and 6,152 L.

The number of phytoplankton and zooplankton organisms was different in all samples indicating that the organisms were not homogenously distributed in the sampled water.

4 Conclusion

The exercise has demonstrated the great variability in the ability of the different sampling methods used. For this reason caution must be exercised when making any quantitative comparisons with ballast sampling methods used. The sequential trials showed different organism numbers of the samples taken in beginning, middle and end, but no consistent trend could be identified.

In another onboard sampling event, undertaken during an EU-funded project in 1997, several nets and pumps were used to sample the ballast water. The results where published elsewhere (Rosenthal et al. 2000, Gollasch et al. 2003). During the 1997 experiment and for the first time in ballast water studies, traps were used with bait and light as attractants, catching taxa not seen in the net samples before. In another ballast water sampling campaign, conducted in 2002 in the Port of Koper, Slovenia, different gear constructed for sampling ballast water in tanks was used (David and Perkovič, 2004), and the results were published in David et al., 2007. All studies have shown that full recovery of organisms contained in ballast tanks may remain impossible, indicating that results of ballast water samplings may well underestimate the actual number of organisms (and species) being present in the ballast tank.

5 Acknowledgements

The study was funded by the German Bundesamt für Seeschifffahrt und Hydrographie, Hamburg and we in particular like to highlight the support and valuable comments provided by Karin Schröder and Kai Trümpler.

This voyage would not have been possible without permission and the essential support of Thamba Rajeevan (Technical Manager-BWT Wilhemsen Ships Equipment, Norway), Filip Svensson, Vice President Marin Operations (Whil. Wilhelmsen ASA, Norway), Sarah Walsh (Vessel manager, WLCC, United Kingdom) and Bernard Jacobs (Resource Ballast Technologies ltd (Cape Town, South Africa)). Further essential support was provided by of Whil. Wilhelmsen ASA as ship owner and Wilhelmsen Lines Car Carriers Ltd in Southampton (WLCC) as ship managers. We further like to express our grateful thanks to the vessel crew and especially the Captain Eric L. David, Chief Officer Almer C. Samaniego and Chief Engineer Daniel N. Berondo. Only their outstanding support made it possible to undertake 13 ballast water pumping events and subsequent sample analysis within this 8 day voyage. The sampling team comprised of the authors and Mariusz Slotwinski (Wilhelmsen Ships Equipment, Poland) whom we thank for his essential support and his availability to work very long hours at sea.

For analysis of the phytoplankton samples we thank Marcel Veldhuis and Peter-Paul Stehouwer of the Royal Netherlands Institute for Sea Research (NIOZ), Texel Island, the Netherlands.

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Factors Influencing Organism Counts in Ballast Water Samples and Their Implications

Frank Fuhr*, Jan Finke**, Peter Paul Stehouwer*,
Swier Oosterhuis* and Marcel Veldhuis*

Abstract

Sampling strategies are of crucial importance for both certification and compliance control of ballast water treatment systems. Sampling is done during pump operations from the pipes to prevent spatial effects. This poses the question whether a time-dependent bias can be detected between replicate samples, due to organisms emerging from sediment in the tank. Organism counts in the size class above 50 microns were analysed for five full-scale G8 land-based tests on five different types of BWT systems. During the tests, in total 57 independent test runs, sampling was done in triplicate. Triplicates were sampled sequentially over the whole pumping and treatment cycle. All tests were conducted at the same location in spring with natural plankton. Deviating from shipping practice, tanks were cleaned between test runs according to IMO requirements. Tests were conducted in the period 2007–2009. Statistical analysis showed that time of sampling during a test run has no significant effect on the results for land based testing. Human factors and natural fluctuation in species composition have a much higher impact on the results. These factors are discussed in more detail and possible strategies for quality assurance are presented based on field experience of applying guideline G8 of IMO.

Key words: Ballast Water, Zooplankton, Organism Counts, Sampling, Compliance Control, Treatment System

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1 Introduction

The importance of ballast water as a vector for the transport of non-native species is widely recognized. Efforts are taken by different entities to prevent further harmful

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* Royal Netherlands Institute for Sea Research, Den Burg, The Netherlands.
** Department of Earth and Ocean Sciences, The University of British Columbia, Vancouver, British Columbia, Canada.

effects of the use of ballast water by ships. This includes, but is by no means limited to, governmental and inter-governmental organisations like the International Maritime Organization (IMO), the EU or the US coastguard, but also classification societies, ship owners and companies developing ballast water treatment units (BWTU). They are all working on solutions in the scope of their respective expertises. The aim of this paper is to give information on some of the biological aspects of the problem, i.e. sampling strategies and sampling analysis for planktonic organisms. The engineering part, i.e. different system configurations is not in the scope of this paper.

In order for the ongoing efforts to succeed it is necessary to thoroughly evaluate presented solutions and to monitor their performance under real-life conditions. Evaluation of presented solutions, as far as technical and not administrative solutions are concerned, is done via land-based and ship-board tests of the equipment according to guidelines G8 and G9 (Anonymous 2008a and 2008b) of the IMO.

Long-term monitoring will occur by means of compliance control through port state authorities. Only by such a long-term monitoring over several years can be determined whether the implemented techniques are reducing the invasion risk sufficiently to render ballast water usage safe for the environment. This monitoring aspect of future compliance control is crucial and likely to be more important than the underlying policing component of it.

Unfortunately, up to now, no sufficient protocols and methods exist to actually perform this task. Some attention has been given to sampling but the crucial aspect of sample analysis has not been covered yet. There is a number of reasons for this situation. Firstly, the existing protocols for testing the biological performance of a BWTU are developed by biologists and applied under test conditions. Most of the actual field work for compliance control, however, will be done by personnel without biological training, while most of the existing methods require biological training to be applied. Since it is highly unlikely that every port state authority is going to employ sufficient numbers of biologists to join the existing inspection teams, the methods used to date in testing need to be adapted for use by non-biologists. Secondly, sample analysis takes too long to be applied in compliance control, at least if ships will only be allowed to discharge after the results show that they are in compliance with standard D2 of IMO. Some of the current analysis techniques may require almost a day before results are obtained. This would cause undue delays and disruptions in shipping operations. Thirdly, the available methods are limited by the volumes of ballast water that can be analysed by them in a statistically sound manner, i.e. in order to cover even a smaller vessel's discharge the number of samples per ship has to be brought up to currently unmanageable numbers. Guideline G8 is aimed at test beds ranging in tank capacities from 200 to maybe 5–600 m^3 per tank. Given the fact that one big oil tanker can and will easily carry quantities exceeding 50,000 m^3 the numbers of samples and volumes sampled, however challenging their handling already is, fall utterly short.

Therefore. the aim of this paper is to point out possible or identified challenges, to suggest potentially practicable solutions and identify future research requirements within the general scope set above. This will be done based on data and experiences obtained during land-based testing at the Royal Netherlands Institute for Sea Research (NIOZ) over the last 3 years.

2 Methodology

The data presented here originates from the land-based testing activities conducted at the NIOZ. Most of the methods used can be found in the test reports that are published by the responsible national administration overseeing the certification tests. For the tests conducted at the NIOZ so far, those are the German "Bundesamt für Seeschifffahrt und Hydrographie" (BSH) and the British "Maritime and Coastguard Agency" (MCA). The basic methodology is also described in Veldhuis et al. (2006). An update, thereof, is currently being worked on at the NIOZ, incorporating the practical experience gained during the last three years. For this paper, the focus was on the organism counts in the size class above 50 microns. They were analysed for five full scale G8 land-based tests on five different BWTU's. During the tests, in total 57 independent test runs, sampling was done in triplicate. Triplicates were sampled sequentially over the whole pumping and treatment cycle. All tests were conducted at the NIOZ harbour on the island of Texel, the Netherlands, in spring and early summer of the respective years. Tests were conducted with natural plankton.

3 Time of Sampling

Numerous authors have shown the challenges faced to obtain representative ballast water samples from the tanks itself (e.g. David and Perkovič 2004 and references therein). Most of these challenges can be overcome by inline sampling during discharge. System failures, incorrect operations or other forms of contamination can always occur and lead to ballast water being not in compliance upon discharge. Therefore, it is desirable to get samples as early as possible during the discharge to be able to stop the operation if necessary. This approach poses the question if the samples change over time, i.e. if numbers of organisms per volume increase during discharge. A possible source for such an increase is the sediment deposited on the bottom of the tank.

In order to provide data on this topic we analysed the control samples from 30 test runs (10 test runs per year of testing) upon discharge. Only valid G8 tests without additional experiments were considered in this dataset to be able to compare the different years. We looked at the triplicate samples and the ranking of counts from the respective samples. As can be seen from Figure 1 we could not observe any significant trend in the samples for organisms larger 50 micrometer. For 2008 and 2009 the results show that the first replicate taken had in five out of ten cases the highest count of the respective triplicate samples. For the whole dataset (n = 30) this is a non significant trend. These preliminary results still need to be tested on board ship, since the requirements for land-based testing state that tanks have to be cleaned between tests. This creates conditions not quite comparable to ship operations. In ships tanks sediment builds up over longer periods of time. The conditions in respect to chemistry and resting stages of organisms cannot be simulated in the land-based tests and do require on board research once ships will be equipped with and using operational BWTU's. Doing research on this topic during ship-board testing for certification might already be sufficient. Even though the requirements state, that the control section has to remain untreated and cross contamination cannot be ruled out. In the scope of this question a potential cross contamination would not affect the outcome since it will increase total numbers but is highly unlikely to affect the organisms distribution in the tank and the samples.

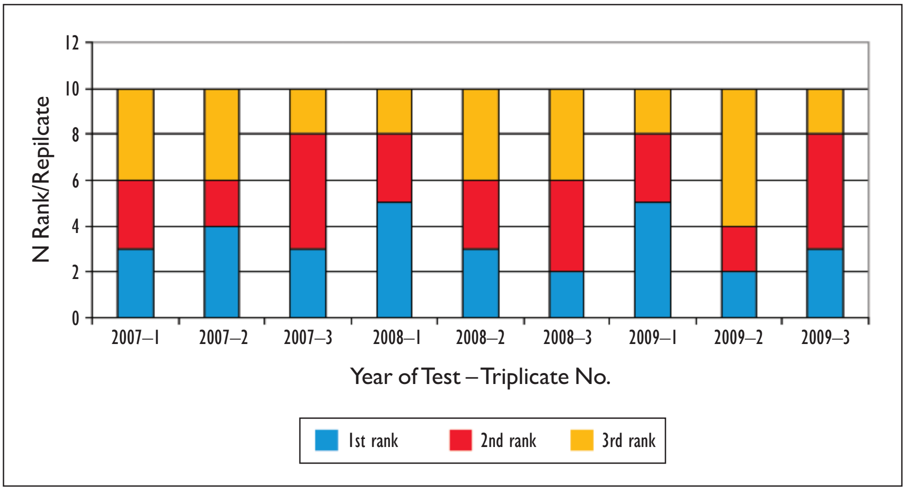

Figure 1. Number of scored rankings regarding number of organisms per time dependent replicate (1 – 3) during 10 test runs per year. 1st rank means therefore that the highest organism count for that particular test run was seen in the respective sample. Replicate samples took some time to obtain, but were generally taken at the beginning (1), roughly halfway (2) and towards the end (3) of pumping operations.

4 Sample Analysis

In the size class larger than 50 microns many challenges concerning sample analysis have to be faced. The most obvious for compliance control is that, up to now, no automated method for counting and life-dead determination is available. State of the art is still classical microscopic analysis, partly aided by the use of live stains. This needs specialised, trained personnel and lots of time.

The challenges in developing an automated sample analyser are caused by a number of factors. The most obvious is the size and the size range of the organisms in question. The size range usually encountered after pumping the water encompasses organisms just larger than the 50 micrometer threshold up to those of several millimetres. This poses a challenge to any detector (including human operators) to not overlook the smaller organisms as well as to perform viability testing. Furthermore, an automated sample analyser, of what kind so ever, will need a rather big inlet to deal with mesoplankton. This means that debris of all sort can also enter. With devices tested so far this does lead to clogging of the sampler and obscuring of the organisms. For the smaller sized plankton this was solved by lining up the particles and organisms through the use of a so called sheath fluid (cf. flow cytometry). For the larger organisms this is not an option, since their mass is to big for such an approach and any mechanical lining, e.g. with a grid, would damage the organisms under study and be prone to clogging. For BWTU's using a filter as part of the treatment this might be less of an issue, since assuming a correct functioning of the system, the discharge samples should not contain more particles of larger size then currently available particle analysers such as the FlowCam®-System can handle. It could then be a viable approach to use such an automated sample analyser as a quick tool and only proceed to more thorough and time-consuming analysis, if too many particles are detected. Even then a method for ships with a BWTU operating without filter and therefore discharging huge amounts of particles in the size range in question would be lacking. A possible solution to this might be a combination of fluorescent stains with advanced picture recognition software. The fluorescent stain has to be a live stain in this approach, since this would enable to trigger on living organisms only and then using the software to separate the detected organism from debris possibly present in the captured picture. We are currently conducting research on this approach. It is necessary to find a stain that is able to penetrate the different types of outer layers found in the organisms. They range from a comparatively thick hide (as in worms) to outer skeletons made of chitin (as in Copepods) and silicate casings of diatoms. The autofluorescence of many organisms in question makes the problem even more complex.

The next important factor are the volumes that need to be sampled and analysed. Current practice in land-based testing is to sample three times one cubic meter. Collecting this amount of water does require time and manpower. In our tests it usually takes one person fully on the task for about one and a half hour to sample one system or the control respectively in triplicate. In line sampling with an automated analyser is beyond the capacities of currently available systems, which can run (in case of the FlowCam®-System) at about 200 ml per minute. Even if this rate could be increased 10 fold in the near future, without compromising data analysis, it would still take over eight hours to process one cubic meter.

Therefore, sampling is not likely to be replaced by inline analysis in the near future. Even so, it is advisable to search for an automated or semi-automated sample analyser. Human operators are prone to fatigue, increasing the mistake rate, but they are also prone to boredom and personal preferences regarding a certain organism group, leading to over or underestimations (cf. Culverhouse et al. 2006, 303). These are factors often beyond the control of the individual and certainly not easy to quantify and analyse statistically.

One human factor that was observed with all persons during our tests and which does have a big impact on the counts could be called “taxonomic confusion”. Except for the minimum requirements of 5 different species from 3 different phyla for challenge water, guideline G8 does not concern itself with taxonomic questions. This led to the notion, that anyone can count samples, because it is not strictly necessary to know what you see. We found in contrast, that mistake rates increase by up to 50% if operators encounter organisms they are unfamiliar with (unpub. data). If organisms are present, which the operators are only vaguely familiar with, they tend to misinterpret organic detritus more often as living organism. Misinterpretation of shapes and structures seen in detritus as organisms happens more easily the less samples an operator has seen. But also more experienced operators show elevated mistake rates after longer breaks in doing this kind of work (unpub. data). Especially given the global nature of shipping and therefore the potential presence of all types of organisms, continuous practice and exchange with other analysts is mandatory for quality insurance. This adds another cost factor to the analysis by human operators.

5 Conclusion

It is possible to conduct compliance control with the available methods. This can be seen from the data obtained by us and others during land-based and ship-board tests. Nevertheless, there are certain limits to this. Especially, the volumes that can be dealt with are too small. Sediment load in the samples is also a challenge. Both issues could be addressed, but the main obstacles for usage of today’s methods are cost and time. The infrastructure and personnel needed to analyse the samples is not available and can not be paid for, even when acknowledging that ballast water will be a cost factor in future shipping operations. Furthermore, the time loss for shipping due to sample analysis would add up to even higher costs. These are economically not feasible. Faster and cheaper analysis might be achievable by using automated sample analysers.

Developing such devices is the challenge for the upcoming years prior to the convention coming into force. An intermediate solution could be the development of a mobile laboratory, that caters a group of harbours. This approach will reduce the cost for each harbour to a fraction, while still ensuring sufficient compliance control sampling to fulfil both policing and monitoring requirements. The mobile laboratory would not speed up sample analysis, but could still contribute to ease the problem. It would allow to await ships with suspected non-compliant ballast water in their next port of call and to immediately conduct all tests on site. That would limit the time and consequently money loss for the shipping industry to a minimum until more rapid tests are available.

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Validation Protocol for Performance Testing and Scaling Ballast Water Treatment Systems Employing UV Disinfection and Filtration

Jim Cosman[*], Jim Fraser[**], Glen Latimer[***] and Jennifer Gerardi-Fraser[****]

Abstact

Several ballast water treatment system vendors are employing UV disinfection and filtration in systems designed to meet the IMO D2 Ballast Water Performance Standard. A key issue that has been identified is the application of performance test results for one ballast water treatment system to an up or down-scaled version of the exact same system so that type approval can be given to a range of capacities. A proposed validation protocol for performance testing and scaling ballast water treatment systems employing UV disinfection and filtration is discussed. In addition, the concepts of UV dose delivery and factors that impact the performance of UV systems, UV transmittance, and bioassay validation protocol for performance testing UV systems are discussed. In addition, the factors that impact the scaling of filtration systems are discussed.

Introduction

Over the past three decades, ultraviolet (UV) systems have gained increasing popularity as a means of disinfecting wastewaters, drinking water, and industrial process waters. Further, several ballast water treatment system vendors are also employing UV disinfection in systems designed to meet the IMO D2 Ballast Water Performance Standard. UV disinfection is considered a viable technology for ballast water treatment because it is simple to operate, no additional chemicals are required (no chemical storage or handling), there are no residuals, andthe efficacy of UV is not impacted by salinity or pH. In addition, the performance of some UV lamps is not impacted by water temperature variations.

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[*] Regulatory Affairs Manager, Trojan Technologies, London, Ontario Canada.
[**] Product Architect, Ballast Water Trojan Technologies.
[***] Engineering Team Leader, Ballast Water Trojan Technologies.
[****] Product Platform Manager, Ballast Water Trojan Technologies.

Several design standards and UV system validation protocols have evolved to support the effective implementation of UV technologies. Examples include the National Water Research Institute (USA) Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse, the ÖNorm 2001 (Austria) and DVGW Standard W294 (Germany) developed for drinking water applications, and the USEPA UV Design Guidance Manual (UVDGM) which was developed to support the implementation of UV disinfection for drinking water applications in the United States. Not all of these protocols are relevant to the ballast water treatment market, however key principles and concepts derived from these protocols may be applied when considering what factors need to be accounted for when findings for one BWMS are applied to an up (or down-) scaled version of this system, or a type approval is issued for a range of capacities.

Background

Dose Delivery

Historically, the concept of "average dose" has been used to estimate the dose delivered by a UV reactor. This technique is based on the assumption that the delivered dose is equal to the average intensity within the reactor multiplied by the average retention time of the fluid within the reactor. An average UV dose calculation is only relevant for an ideal UV reactor. An ideal UV reactor is defined as a reactor in which every targeted organism receives the exact dose it requires, no more, and no less, and where no UV-C photons are 'wasted' or absorbed by the walls of the reactor.

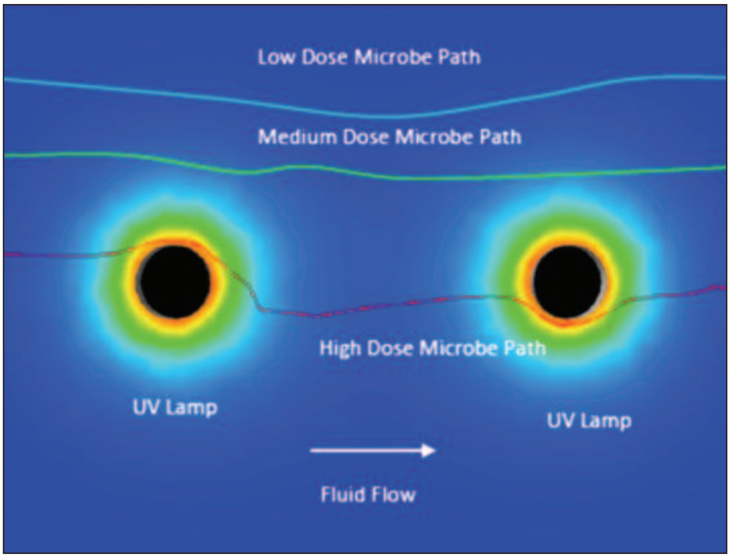

Figure 1. Computational Fluid Dynamics Model Depicting Particles Flowing Through a UV Reactor

In a real flow-through reactor, no two microbe, or particle, trajectories are the same and thus each microbe flowing through the reactor will receive a unique dose. (See Figure 1). Thus, in a real UV reactor, the interplay of flow fields and light fields determine true dose delivery.

Several authors have pointed out that hydraulic profiles and intensity gradients within UV reactors give rise to a distribution of delivered doses as opposed to a fixed value (Qualls *et al*. 1989; Scheible 1985; Chiu *et al*. 1997). A dose histogram of a real UV reactor achieved by Computational Fluid Dynamics (CFD) modeling is depicted in Figure 2. The key to predicting real UV reactor performance is in the ability to accurately quantify the dose distribution for thereactor at each UV transmittance (UVT), flow rate and lamp power condition.

Roughly, dose equals the intensity of the UV-C imparted on the target multiplied by the time the target is exposed to this intensity. In a 'normal' reactor, the goal is to give all targets an equal dose. However, in real life, each target receives varying intensities and retention times during its path through the UV system. The accumulation of dose of the target at the end of the path is what matters, and it is what determines the efficacy of the reactor as a whole. Each reactor is unique in its hydraulic flow patterns and its intensity distribution.

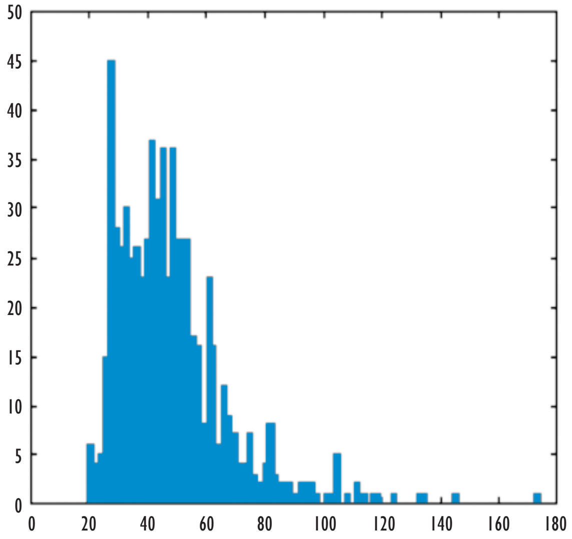

Figure 2. CFD generated histogram of dose delivered to microbes in a UV reactor

UV Transmittance (UVT)

UV dose depends on the UV intensity, the flow rate, and the UV transmittance (UVT). Thus, UV transmittance is also a key parameter to consider when designing UV systems. UVT is the percentage of light passing through a water sample over a specified distance relative to distilled water. The UVT is usually reported for a wavelength of 254 nm and a path length of 1-cm. UVT is often represented as a percentage and is related to the UV absorbance (A254) by the following equation (for a 1-cm path length): % UVT = 100 x 10-A. If the average UVT of ballast water reported in the literature is approximately 90%, this would mean that 90% of the light penetrates one centimeter of water, and 81% of the light would pass the second centimeter (Figure 3). If the UVT value is 50%, this would mean that 50% of the light penetrates one centimeter of water and only 25% of the light would pass the second centimeter (Figure 4).

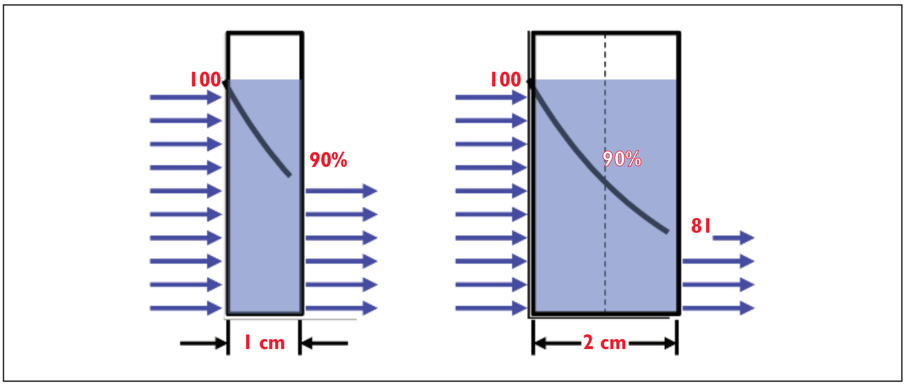

Figure 3. Water that absorbs less light, has a higher UVT. In this example, the water has 90%/cm UVT. The amount of incident light remaining at 2 cm is 81%.

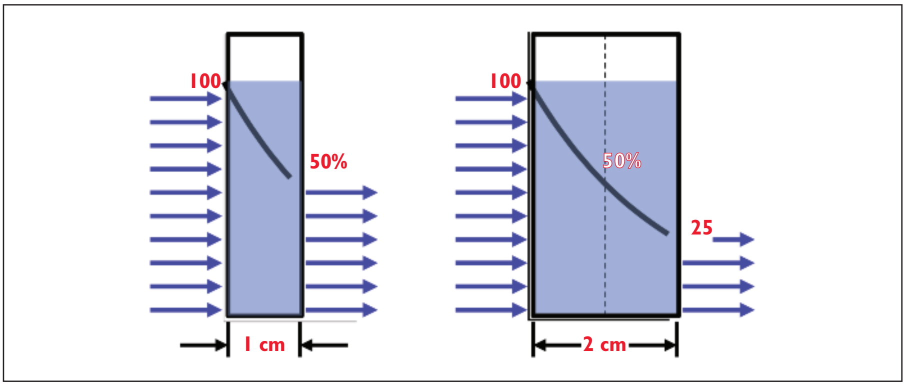

Figure 4. Water that absorbs more light, has a lower UVT. In this example, the water has 50%/cm UVT. The amount of incident light remaining at 2 cm is only 25%.

The lower the UVT of the water, the more energy that must be applied to achieve the desired inactivation of organisms. It should be noted that a typical secondary effluent from a municipal wastewater plant can range between approximately 50% to 65%, thus there is a great deal of experience designing UV equipment to treat water of a similar nature to ballast water. Ballast water treatment systems must of necessity address water from different sources, and the UVT of these source waters can be expected to vary dramatically from low values for sediment rich harbor waters (river run-off) to higher values for cleaner waters such as protected Mediterranean harbors that do not have a river inflow.

Impact of UV Transmittance on System Design

The UV transmittance of the water being treated must be taken into account when assessing the appropriate application of UV reactors for ballast water treatment. Two examples illustrate the importance of this statement. Example 1 is a BWTS that was designed for 50% UVT water. A system designed for this UVT will typically have lamps that are closely spaced together compared to a system designed for a higher UVT. The close spacing ensures that no water being treated gets in a low intensity or low 'dose' region. This is required as only 50% of the light emitted by the lamp will penetrate the first 1 cm of the fluid being treated (Figure 3). This system can be utilized for fluids with a much higher UVT (eg. 99%) because target organisms are receiving much more than their required minimum target dose at higher UVT levels. The system illustrated in Example 1 will be effective at treatment across the entire water quality range (50–99% UVT).

Example 2 is a BWTS system that was designed for 90% UVT water. As the design UV transmittance of the water being treated increases, lamps can typically be spaced further apart. In this scenario, 90% of the light emitted by the lamp will penetrate through the first cm of water being treated (Figure 3). This system will work for water with UVT greater than 90%, however, it will not work for water with UVT less than 90%. For example, at 50% UVT this system will have 'dark zones' or zones of inadequate UV intensity. If this is the case, the dose delivered in these dark zones will be greatly reduced. As a result, many organisms will not receive their required minimum target dose. Therefore, the system illustrated in Example 2 will not be effective at treatment across the entire water quality range (50–99% UVT), rather its effectiveness will be limited to the range greater than 90% UVT.

In summary, a UV system should be designed to be effective at the lowest UVT value of the waters to be treated. It should also be noted that filtration and separation technologies will likely impact UV system performance. Filtration may sometimes improve the UVT of the fluid, and the required dose levels will change depending on the filtration pore size utilized in the system.

UV Transmittance versus Turbidity

The unit of measurement of turbidity is NTU, or Nephelometric Turbidity Unit. The device that measures this value is a nephelometer. The nephelometer is oriented 90 degrees to the light source and measures the light scattered from the suspended solids in the water rather than measuring the percentage of light absorbed from the particulate matter in the water, or inversely, the percentage of light transmitted through the water. The particle colour, shape, and size can affect the NTU value. It is important to note that turbidity measurements are made using a light source with natural light wavelengths (ie. visible light), as apposed to light at the wavelength of 254nm that is used for UVT measurements. As discussed previously, UVT is the percentage of light passing through a water sample over a specified distance (typically 1 cm) relative to distilled water. Turbidity can influence UVT, but they are not linearly connected, or actually connected in any concrete way. For example, a fluid with a turbidity of 20 NTU could have a UVT of 60% or higher, or of 5% or lower. Conversely, a fluid with a turbidity of 1 NTU could have a UVT of 90% or greater, or 5% or lower. Fluid that is visibly clear to the human eye may have contaminants in solution that do not block the long wavelengths of light (ie. Visible light) that a nephelometer uses to make a measurements, but these contaminants may block a6 relatively short wavelength of light such a 254 nm. High NTU values can be an indicator that the water being evaluated may have a low UVT, but any further assumptions are very risky and possibly incorrect. Accurate UVT measurements are critical to properly assess the impact of water quality on UV system performance.

In addition to hydraulics and UV transmittance, other factors will impact dose delivery within a UV reactor. Figure 5 below outlines the various factors that impact the performance of the UV system.

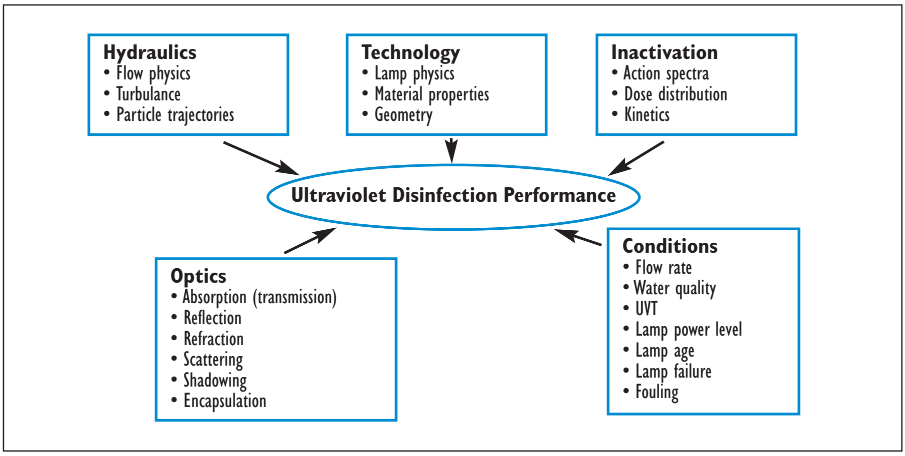

Figure 5. Factors Affecting UV Disinfection Performance

Bioassay Protocols

The non-ideal behavior of real UV reactors and the complexity of their designs prohibits reliance solely on theoretical calculations to reliably predict the UV dose delivered by the reactor, and requires that the dose delivered by the reactor be validated using an empirical testing protocol. The bioassay protocol is the standard approach provided by all current regulatory guidance, and is currently the globally accepted approach for validation of the dose delivery performance of a UV disinfection reactor. The bioassay protocol is divided into three parts: firstly, the development of a UV dose-response curve with an ideal laboratory reactor for a culture of challenge organism (bacterium, bacterial spore or virus); secondly, the passing of the challenge organism from the same culture through the reactor being validated while it operates under specified conditions of flow rate, lamp power level and water quality; and thirdly, a comparison of the inactivation of the challenge organism following passage through the reactor with the laboratory dose-response curve to determine which dose delivered by the ideal reactor gives the same challenge organism inactivation. For those specified conditions of operation, the reactor is thereby validated to deliver the Bioassay Equivalent Dose read from the dose-response curve. For more extensive validation under different operating conditions (flow rate and/or power level and/or water quality (UVT), the protocol is repeated from step two for each operating condition.

Comparing Average (Ideal) Doses to Bioassay Doses

Bioassay determined dose versus average (ideal) dose for a UV reactor system under varying flow rates, UVTs and lamp power settings is plotted in Figure 6 (Petri and Olson 2001). Poor correlation exists between the ideal model and actual data, and using ideal dose calculations to size UV reactor systems is, therefore, inappropriate, for several reasons:

a. the spatial distribution of UV intensity is very difficult to model, especially since the absolute UV lamp output is difficult to quantify
b. hydraulic effects generally account for 20% to 50% of reactor inefficiency, meaning the ideal model could lead to undersizing by a factor of 2 or more.

A simple example illustrates the fallacy of using ideal dose for sizing. Consider a reactor delivering a dose of 100 mJ/cm2 for 99% of the flow and 0 mJ/cm2 for 1% of the flow.

Table 1. Comparison of Average (Ideal) Versus Bioassay Dose Calculation

Dose	**Value**	**Discussion**
Average (Ideal)	99 mJ/cm2	Average UV intensity within reactor multiplied by average residence time
Bioassay	40 mJ/cm2	99% of the reactor achieves 5 log inactivation of the target, while 1% of the reactor achieves 0 log inactivation. Only 2 log inactivation can be achieved overall (100,000/100 ml organisms to 1000.99/100 ml)

Ideal dose calculations would average out the dose to give dose delivered by the reactor as 99 mJ/cm2. Clearly, only 2 log inactivation can be achieved by such a reactor. However, the ideal dose of 99 mJ/cm2 leads one to believe that if the reactor were challenged with MS2 Phage, where a dose of approximately 20 mJ/cm2 is required for one log inactivation, nearly 5 log inactivation would be achieved. The preferred method to size UV reactor systems is through bioassays, or bioassay validated computational tools.

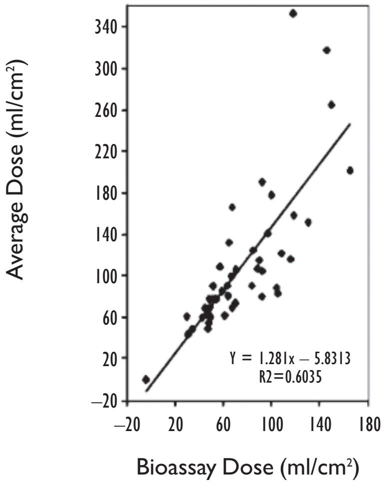

Figure 6. Comparison between bioassay dose versus average (ideal) dose for a UV reactor system

Filtration

A robust filtration system design is critical in ballast water treatment. The filtration system loading rates which are designed for use in the ballast water treatment market are among the highest in the filtration industry. This is done mainly to keep the size of the filtration equipment within reason so it can be incorporated into an already limited available space aboard an existing ship or a new build design.

Loading rate is key in filtration, especially in the simple screen filtration technologies which are used in ballast water treatment and which have no depth component to them. The higher the loading rate as measured in flow rate per area of filter media (e.g. GPM/FT2) the more differential pressure is produced. Higher differential pressure leads to degradation of filter performance (more available force to drive retained particles through the thin filter media, "particle shearing"). A filtration system not only has to catch the particles being removed, it also has to retain them throughout the filtration cycle as well.

It is very important to note that the filtration system must be matched with a UV equipment design to achieve an efficient overall ballast water treatment system. It is important to design systems in such a way as to optimize the strengths of both the separation and the disinfection technology. You do not want to size the filtration system to remove particles of the size that the UV system can easily inactivate and you do not want to oversize the UV system to inactivate particles that can be easily removed by the separation technology. It is equally important to align the two technologies so that there is no gap in performance between them as such a gap would lead to a non-compliant system. The balance between filtration system performance (particle size removal) and UV disinfection system performance (UV dose delivery to individual targets and smaller particles) is critical to developing a robust, cost effective, and efficient ballast water treatment system.

Discussion

For drinking water UV reactors, there are no convenient indicator organisms, like total coliforms, that are abundantly available for routine monitoring of UV disinfection system performance for wastewater applications. Therefore, it is important that the full scale reactor be bioassay validated to ensure delivery of the target UV dose whether the water being treated has the indicator or not. As a result, the practice of scaling UV reactors up and down is not permitted for drinking water applications in most jurisdictions around the world. To address higher flow drinking water applications, duplicate validated reactors can be used in parallel to increase total system capacity. In addition, duplicate validated reactors are sometimes employed in series to deliver higher doses.

Scaling up is permitted under specific conditions for water reuse applications according to the National Water Research Institute (NWRI) (USA) Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse. Such applications generally use modular systems where the units are scaled up by repeat units of identical geometry. For reclaimed-water application only (as they are of lower risk to the public), if the velocity field for both the test and full-scale reactors can be measured and the uniformity of the velocity field can be verified by empirical measurements then larger reactors can also be used in full-scale applications. The full-scale and test reactors must have identical lamp spacing. In addition, the full-scale reactor must be operated at the same velocity range and flow per lamp used for performance validation. The scale-up factor for a given reactor is limited to 10 times the number of lamps used in the test reactor.

Filtration technologies are scalable by either of two ways; the first is by adding more of the same model tested in a modular approach which could involve a header type arrangement or some other method. This approach while technically accurate can become difficult to install and manage depending on the number of overall units. The amount of plumbing, valves, connections, and control mechanisms increases making the maintenance of such a system cumbersome. The second way to scale a filtration technology is to extrapolate the important design factors into a larger size unit. Unlike scaling up a UV system, a filtration system's size can be typically increased within reason, without sacrificing the integrity of the design or system performance. One of the key design parameters to maintain throughout the scaling up of various models is filter media surface area. Maintaining the same filter loading rate (flow rate per unit of filter media area) from a smaller test unit tested should yield similar filtration performance in a larger model.

Recommendation

It is paramount that any validation protocol for a filtration-UV ballast water treatment system accounts for:

1. Overall system performance changes due to filter performance changes resulting from changes in:
   a. Hydraulic pressure and
   b. Loading rate per unit filter surface area.
2. Overall system performance changes due to UV system performance changes resulting from changes in:
   a. Flow rate
   b. UV transmittance of the water being treated
   c. Changes in lamp power setting

In addition, the interrelationship between the type of filtration system and UV dose must also be accounted for. A ballast water treatment system (BWTS) employing a smaller sized screen (e.g. 30 microns) in the filtration system is likely to require a lower delivered UV dose for the UV system than a BWTS employing a filter with a 50 micron screen. Therefore, the determination of dose values over which a system is validated should be related to the filtration system utilized in the overall system.

Scaling Filtration Systems

For filtration system scaling, if done within a reasonable factor and as long as best engineering practices are used in the extrapolation of the key design parameters, a small scale (250 M^3/hr) filtration system should perform similarly to a larger scale filtration system (1,250 M^3/hr).

For ballast water filtration systems it is recommended that testing to validate encompass a worst case scenario with respect to water quality. Typically, the types of filtration systems used 10 in ballast water filtration will work as well and in most cases better, in relativity clean water than they do in the most challenging waters. There are several water quality parameters that need to be tested such as turbidity, total suspended solids, particle counts and biological loading while monitoring and recording the differential pressure through out the filtration cycle. Each of these parameters needs to be tested at the pre and post filtration sample locations to determine overall filtration performance throughout the filtration cycle. A filtration cycle begins with a clean filtration system and continues until the differential pressure measured across the filtration system reaches the terminal head loss point as determined by the system manufacturer.

When scaling a filtration system, the test water should have turbidity influent levels of a NTU range that is representative of harbor waters. In addition, the test waters should have total suspended solids levels that are appropriate for a challenge. Influent particle counts should have an appropriate particle size distribution so as to challenge the filtration system and the effluent particle counts should be monitored. Biological loading should consist of organisms that are representative of the IMO guidelines with regards to numbers, size, and type. This filtration testing is to be done in conjunction with the UV system testing protocol to insure total system compliance.

Scaling UV Systems

In ballast water treatment, there are not necessarily going to be convenient indicator organisms universally and always present in the untreated ballast water, and therefore monitoring of the treated effluent is not currently a practical solution. For UV systems, the following approach is recommended. First, at least one system configuration (e.g. 250 m^3/h) should be bioassay tested at a specific set of operating variables (design flow, minimum UVT, power) in accordance with IMO testing protocols and requirements at an approved test facility.

To increase the flow capacity of the system, two approaches, multiplication and scaling may be utilized. First, unlimited multiples, ‘N’, of the tested system (e.g. 250 m^3/h) could be used in parallel to increase the total flow capacity of the system. In this example, a 1,000 m^3/h system may employ ‘N’ or four of the 250 m^3/h previous validated systems to attain this flow requirement. Again, there should be no limitation on the parallel multiples allowed given that the unit has been extensively performance tested. If a parallel arrangement is not appropriate, another option would be to use a scaled up higher flow system that may be more cost effective in treating the higher flows. The scaling should be limited to five times the flow of the validated unit as long as the following conditions are met:

1. The scaled up UV system has the same lamp spacing and hydraulic configuration of the bioassay tested validated unit.
2. The scaled up UV system employs the exact same lamp and power level as the bioassay tested validated unit.
3. The scaled up UV system has a similar flow/velocity per lamp.

The intent of the above conditions is to ensure that the scaled up UV system has a similar UV dose distribution as the base validated unit. By ensuring that the scaled up system has the same lamp and lamp spacing, an attempt is being made to ensure that the light intensity is similar between units. In addition, the requirement to have a similar flow/velocity per lamp attempts to manage hydraulic flow patterns in the UV system. It should be noted that this suggested approach falls between the accepted drinking water validation approach of extensively bioassaying each model of UV system and that of the grey water approach for scaling that is used by NWRI in North America.

To manage the above factors, Computational Fluid Dynamics and Light Intensity modeling may be used. Over a decade of experience exists in using these models to manage the above factors. Specifically, ballast water treatment system manufacturers should be required to submit this modeling to demonstrate the proper scaling of different configurations.

These models may also be used to scale system pipe diameters or other components that affect the inflow or outflow of the BWTS so as to correlate the scaled up design to the performance tested validated configuration.

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The Use of Mesocosms in Risk Assessment of Active Substances in Ballast Water Treatment

N.H.B.M. Kaag, A.C. Sneekes and E.M. Foekema*
IMARES Wageningen UR

Abstract

As a consequence of the adoption of the IMO Ballast Water Convention, several companies have developed ballast water management systems (BWMS). When a BWMS makes use of active ingredients, toxicity should be assessed according to MEPC guideline G9 in order to establish the ecological risk of the substance and the treated ballast water that is discharged. Acute and chronic laboratory tests (bioassays) are being used to assess the ecological risks of substances and treated ballast water. Bioassays are single species tests that give information on the direct effects on the individuals of the organism tested. Ecosystems, however, consist of several interacting species and, as a community, may react differently to a toxic substance and show recovery after exposure declines. Moreover, in most cases the exposure conditions in a field situation strongly deviate from a laboratory test beaker. Dissipation/degradation is, for instance, hardly addressed in laboratory toxicity tests. This is recognized in the legislation process of pesticides, where data collected under more field relevant conditions is used for what is called the 'higher tier risk assessment'. For this type of testing, mesocosms, or experimental ecosystems, are applied. Organisms from different taxonomic and functional groups are exposed simultaneously in outdoor ponds under realistic environmental conditions and exposure regimes. This allows for the assessment of direct and indirect toxic effects on a suit of organisms (the ecosystem) present in the test systems. Over the last decade, we have tested several pesticides in outdoor freshwater mesocosms for legislation purposes.In 2008 and 2009, we have conducted marine mesocosm experiments, in order to investigate the applicability of these systems for higher tier risk assessment of for instance active substances used in BWMS and the residue risk of treated ballast water at the moment of discharge. The results of these studies will be presented and

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* IMARES Wageningen UR, Dept. Environment. P.O. Box 57, 1780 AB Den Helder, The Netherlands.

compared to results of freshwater pond studies. Possibilities for improving the accuracy of the risk assessment of BWMS will be discussed.

Key words: Ballast Water, Marine Mesocosms, Community, Risk Assessment

1 Introduction

In 2004, the International Maritime Organization (IMO) adopted the "International Convention for the Control and Management of Ship's Ballast Water and Sediments" (IMO 2005), which would enter into force 12 months after ratification by at least 30 states representing 35% of world's merchant shipping tonnage. To guide the development of Ballast Water Management Systems (BWMS), the IMO has published a number of guidelines stating the requirements for performance and use of BWMS. For BWMS using active ingredients the Guideline G9 (MEPC 169/57) is especially important. It describes the procedures for ecological risk assessment for the receiving waters by evaluating the ecotoxicity of active ingredients and treated ballast water.

2 Risk Assessment Procedures

The procedure for the risk assessment that is applied for BWMS that make use of active ingredients, is basically similar to procedures adopted elsewhere (see for instance EU-TGD Part II, ECB 2003). It is based upon the PEC/PNEC ratio: When the PEC (Predicted Environmental Concentration) is larger than the PNEC (Predicted No Adverse Effect Concentration) an ecological risk is indicated. The PEC is based on calculations using biodegradation data and a dilution model. The PNEC is based upon toxicity data from literature or laboratory tests. The risk of underestimating the actual environmental impact by following this approach is acknowledged and uncertainty (assessment) factors are derived on bases of assumptions made concerning extrapolation from single-species short-term toxicity data to complex ecosystem effects. It is assumed that the most sensitive species determines the ecosystem sensitivity and that protection of the ecosystems structure will protect the community function.

For marine risk assessment, more conservative assumptions are made compared to freshwater risk assessment in order to protect the higher phylogenetic diversity in the marine ecosystem (Table 1). Reducing uncertainty by collecting more information on the toxicity of a substance, will result in a lower assessment factor. The usual way to reduce assessment factors is to produce data about the toxicity of the active ingredient for more species, representing more phylogenetic groups, and/or by performing chronic toxicity tests, and preferably use these data to calculate the species sensitivity distribution and to predict the hazardous concentration that leads to a potentially affected fraction of 5% of the species (Aldenberg & Jaworska 2000). Based on the reliability of the dataset that is used for this approach, the assessment factor could be reduced to 5 or even 1.

Table 1. Overview of assessment factors to derive a PNEC for aquatic and marine ecosystems (ECB 2003)

Data Set	**Aquatic**	**Marine**
Lowest short-term LC50 from algae. crustacean, fish	1,000	10,000
Lowest short-term LC50 from algae. crustacean, fish + 2 additional marine groups	.	1,000
1 long-term NOEC from crustacean or fish	100	1,000
2 long-term NOECs from algae and/or crustacean and/or fish	50	500
Lowest long-term NOEC from algae, crustacean, fish	10	100
2 long-term NOECs from algae and/or crustacean and/or fish + 1 NOEC additional marine group	.	50
Lowest long-term NOEC from 3 fresh water or marine species + 2 NOECs additional marine groups	.	10
Species sensitivity distribution (SSD) method	5-1	5-1
Field data or mesocosms	case by case	case by case

The draw-back of this method is that the basic data is still based upon single-species laboratory experiments, which do not incorporate species interactions and recovery potential. Typically, the active ingredients used in BWMS are chemicals with a very short residence time. Chronic testing of these substances at a constant exposure concentration of the active ingredient is, therefore, not appropriate to study the environmental impact of the residue toxicity of discharged treated ballast water.

The same is the case for modern, rapidly degradable pesticides. In the legislation of pesticides this gap between laboratory and field is recognized and results from the 'first tier risk assessment' can be overruled when "it is clearly established through an appropriate risk assessment that under field conditions no unacceptable impact on the viability of exposed species occurs -directly or indirectly- after use of the plant protection product according to the proposed conditions of use" (ECB 2003). For this 'higher tier assessment' under more realistic conditions, mesocosms, or experimental ecosystems, are applied.

3 Mesocosms as Tool for Risk Assessment

Each mesocosm study is designed to answer specific questions, nonetheless various guidance documents have been drafted that describe the basic principles of this kind of studies when performed for risk assessment. The most recent guidelines are the recommendations from the 'HARAP' (Campbell *et al.* 1999) and the 'CLASSIC' (Giddings *et al.* 2002) workshops. In De Jong *et al.,* (2008) guidance is given about the evaluation of mesocosm studies for risk assessment. In principle, organisms from different taxonomic and functional groups are exposed simultaneously in outdoor ponds under realistic environmental conditions and exposure regimes. This allows for the assessment of direct and indirect toxic effects on a suit of organisms (the ecosystem) present in the test systems, including recovery of the community once the toxic stress has disappeared (Figure 1).

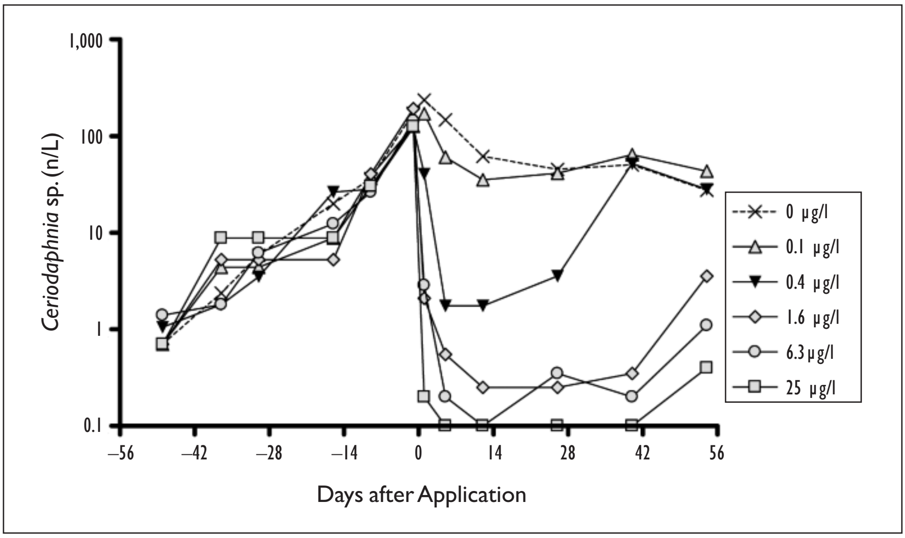

Figure 1. Impact of a single application (on day 0) of a rapid degradable insecticide in freshwater mesocosms on a zooplankton group. Presented are the average values of the duplicated treatments. The grey field indicates the range of the observations in the triplicated control (0 µg/l) mesocosms. Treatment level 0.1 µg/l has no impact, treatments 0.4 µg/l shows severe impact with recovery after 40 days. Higher treatment levels show indication of recovery at the end of the study. Example from a mesocosm study conducted in 2000 by IMARES.

The expert group that discussed the application of mesocosm data for risk assessment of pesticides during the HARAP workshop concluded that "If a field study (outdoor micro- or mesocosms) has been properly designed, executed, analysed and interpreted, the results may be used in risk assessment without applying an uncertainty factor" (Campbell *et al.* 1999). This conclusion was adopted by the European Commission in 2002 (Sanco 2002).

In mesocosm studies, agricultural pesticides are usually applied one or more times in a scheme representative of agricultural usage practise. Several test concentrations are created in duplo or triplo, as well as untreated controls. The experiment is then continued until at least 8 weeks after the last application in order to be able to specify the effect classes that are related to recovery of the most sensitive endpoints (De Jong *et al.* 2008). A similar approach would be applicable for testing of the active ingredients of BWMS, simulating one or more discharges resulting in specified concentrations of the active ingredient in an ecosystem.

For testing the impact of the discharge of treated ballast water on a receiving ecosystem, a specific experimental design will be necessary, as it would require replacement of a variable amount of water in the mesocosms. In some way this should also be applied to the controls, in order to be able to separate the impact of dilution from possible toxic effects.

4 Practical Experiences

During the past 20 years we gained broad experience with various types of mesocosms. Besides the standard stagnant ponds, work was done with flow through systems to study the chronic impact of complex effluents, tidal marine systems, enclosures of planktonic communities and mesocosms consisting of two connected compartments representing a pelagic surface system and a (dark) deep water benthic system (Bowmer *et al.* 1994; Foekema 2004; Foekema *et al.* 1998; Jak *et al.* 1998; Kaag *et al.* 1994, 1997, 1998; Kuiper 1977, 1984; Scholten *et al.* 1987). The fresh water mesocosms were constructed both as stagnant ponds and as flow-through systems, depending on the research questions. Until recently, for marine mesocosms stagnant systems were only used when a benthic compartment was not part of the study. In the studies with a benthic compartment, the research question was focused on the environmental impact of contaminated sediments, and it was believed that a stagnant system would be strongly affected by the organic enrichment that often accompanies contaminated sediments. However, for studying the fate of active ingredients in an ecosystem stagnant systems are most appropriate. For this reason, we have started experiments with stagnant marine mesocosms including a benthic compartment in 2008.

The mesocosms used, are circular glass-fibre basins with a diameter of approx. 180 cm, partly buried to buffer the systems from fluctuations in air temperature, as well as for practical reasons. On the bottom a 20 cm layer of clean sediment (medium-fine sand) is created, after which the mesocosms are filled with a layer of 60 to 140 cm of natural water including phytoplankton and zooplankton. The water is 2 mm filtered to remove larger (predatory) species, but to maintain the natural plankton community. Specific macrofauna species are added to create a test community. In freshwater mesocosms, vascular plants may be introduced; in marine systems macro-algae. Subsequently, all mesocosms are interconnected through an overflow basin and the water is circulated amongst all mesocosms during one month to ensure a homogeneous water quality and plankton communities in all systems. Before applying a test substance, the circulation is ended and the mesocosms are isolated from each other. Internal circulation is created when necessary. Based on our expertise and experience we have described procedures that ensure a good replication of our mesocosms.

Water quality parameters (oxygen content, pH, nutrients, chemistry, etc.) and phytoplankton and zooplankton development are monitored on a regular basis.

Macrofauna is mostly sampled at the end of the test to assess survival, growth and, depending on the species, population development.The first stagnant marine mesocosm test ran from December 13th, 2007 to August 25th, 2008. Macrofauna was introduced on January 11th, 2008. Four shallow (water depth 60 cm) and four deep (water depth 140 cm) mesocosms were installed. Two of each were ended on April 21st, 2008 to assess development in winter and early spring. Water temperatures declined to near zero during December, but were 6°C in January when macrofauna was introduced. The temperature fluctuated between 4 and 8°C until the end of March, after which it continuously increased to more than 22°C early July.

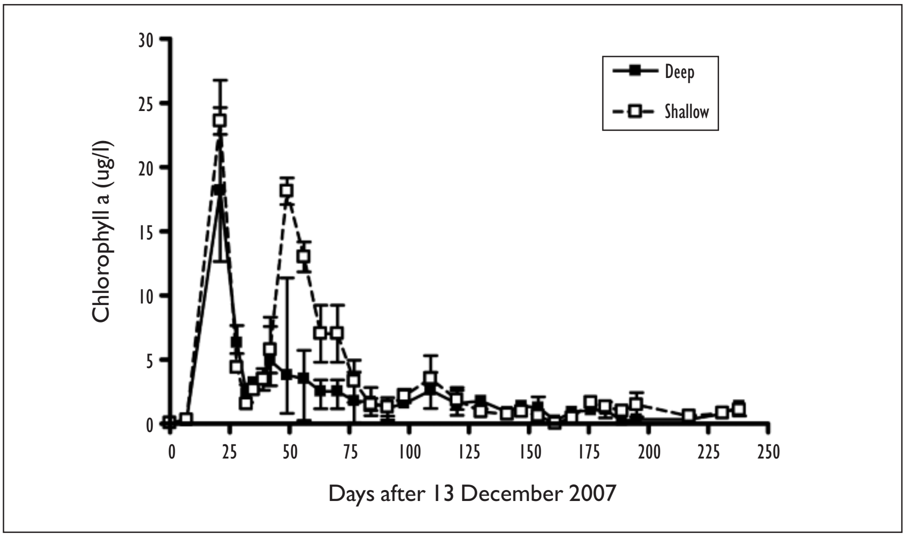

Figure 2. Development of phytoplankton in marine mesocosms based upon chlorophyll-a measurements. Presented is the mean and standard deviation of 4 (until Day 110) or 2 replicates.

Macrofauna species showed good survival (>90%) throughout the experimental period. Growth was mainly observed between April and August. Populations of the mudshrimp *Corophium volutator* developed from approx. 80/m^2 in January, to 500 (shallow) and 2,000 (deep) in April and 125,000 (deep) and 350,000 (shallowp)/m^2 in August. An exception was the lugworm *Arenicola marina*, which lost considerable weight between April and August. Most likely, the systems could not supply enough food to sustain 20 lugworms/m^2. This is a remarkable difference with flow-through mesocosms, in which we can introduce at least 80 lugworms/m^2 (Kaag *et al.* 1997). In the second experiment that ran from early April to early August 2009, only 8 lugworms/m^2 were introduced, allowing growth during summer.

Typically, after installation of mesocosms, enhanced phytoplankton development is observed (algal bloom), the magnitude of which depends on the nutrient status of the systems. Once the zooplankton and other grazing animals are established, the phytoplankton community falls back to a lower level. This development is shown in Figure 2 for the first experiment using two types of stagnant marine mesocosms.

Experiment 1 was started in winter, when production is low and nutrient levels are relatively high. This rapidly resulted in a pronounced bloom of the phytoplankton, followed by a second bloom in shallow mesocosms. Later in the season, when the temperature increased, grazing by zooplankton (Figure 3) and macrofauna and competition of periphyton resulted in a lower standing stock of phytoplankton.

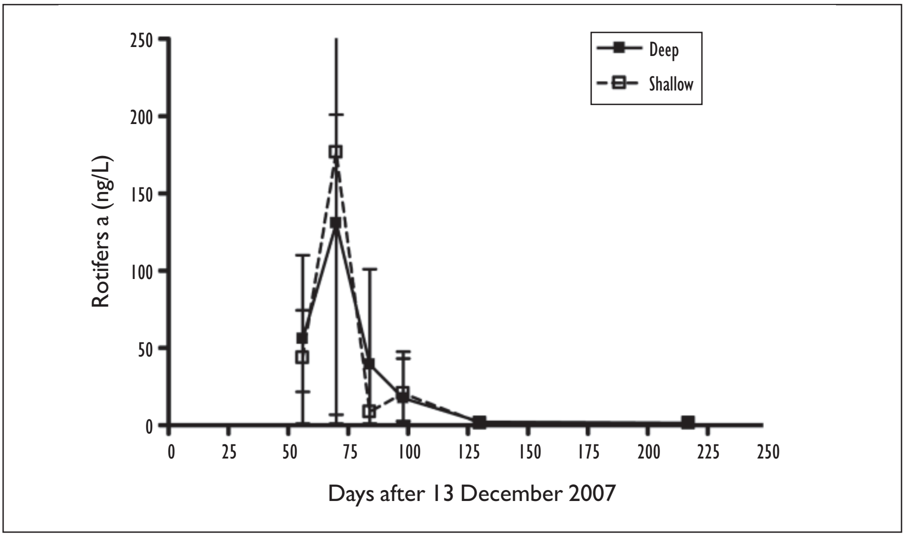

Figure 3. Number of adult copepods per liter in marine mesocosms. Presented is the mean and standard deviation of 4 (until Day 110) or 2 replicates.

Application of a toxicant may initiate a new and at higher concentrations persistent bloom of phytoplankton. At intermediate concentrations, the bloom may be transient due to recovery of the grazing by zooplankton.

5 Conclusions

Mesocosms can form a valuable tool for ecological risk assessment of discharged treated ballast water. Especially when the Ballast Water Treatment System is based on the application of rapidly degradable active substances. A carefully conducted mesocosm study will not only yield NOEC and LOEC values at the population level for a suit of organisms, but also at community level. Moreover, if the duration of the test is sufficient and recovery is observed, it is also possible to assess a NOEAEC (No Observed Ecological Adverse Effect Concentration). In accordance with pesticide regulations this NOEAEC could be applied as PNEC (Predicted No Adverse Effect Concentration) for risk assessment without using an assessment factor.

Agricultural pesticides are usually applied one or more times in a scheme representative of agricultural usage practise. Several test concentrations are created in duplo or triplo, as well as untreated controls. The experiment is then continued until at least 8 weeks after the last application in order to be able to specify the effect classes that are related to recovery of the most sensitive endpoints (De Jong *et al.* 2008). A similar approach would be applicable for testing of the active ingredients of BWMS, simulating one or more discharges resulting in specified concentrations of the active ingredient in an ecosystem. Test procedures for such studies are already available.

However, the most realistic scenario is the discharge of treated ballast water in an ecosystem, as will occur in/near international harbours. Even without causing an effect, in the mesocosms this will result in a dilution of the plankton community that is present. In order to separate the toxicological effects from this dilution effect, a comparable dilution should be achieved in the control mesocosms. Appropriate test procedures have to be developed to cope with these scenarios.

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Global R&D Forum on Emerging Ballast Water Management Systems-Closing Remarks

Miguel Palomares
DIRECTOR, MARINE ENVIRONMENT DIVISION, IMO

Ladies and Gentlemen,
Distinguished participants,

It is indeed a great pleasure for me to be back in Malmö, to close this Global R&D Forum on Emerging Ballast Water Management Systems. I am humbled to stand in front of such a body of knowledge and wisdom.

Although IMO has been arranging R&D conferences on Ballast Water Management since 2002, this R&D Forum marks something of a new departure. When proposed by the Global Industry Alliance Task Force at its first meeting in December 2008, it was envisaged as a forum to take stock of where we are today in terms of our capacity to meet the requirements of a Convention that seems more and more likely to enter into force in a near future. But, and perhaps more interestingly, it was also intended as a much needed opportunity to showcase and discuss **alternative** options to Ballast Water Management, what the Convention calls "Other Methods of Ballast Water Management".

This forum also emphasises an important aspect that continuous innovation and collaborative R&D efforts are key to the success of the global efforts to address marine biosafety issues in general and ballast water issues specifically. With this in mind, it is thus very encouraging to note that the majority of the world's expertise on Ballast Water Management, from the shipping industry, academia and administrations, have chosen to come to Malmö for this Forum. This is indeed a vote of confidence for our determination to meet the challenges ahead of us.

I have been advised that it has been three days of cutting-edge presentations and challenging discussions, and I am confident that these will continue even after we have left this room and returned to our respective home bases. During the Forum, you have heard about technical and regulatory aspects of several innovative ballast water management options. In addition to this, you have engaged in a stock-taking exercise of the progress made on conventional ballast water treatment systems. This has included some challenging thoughts on what we have actually learnt so far, both in terms of developing solutions to treat ballast water, but also when it comes to testing, verifying and monitoring.

Those of you who attended the pre-conference workshop on equivalency between G8/G9 approved treatment systems and alternative management options, were also part of an important discussion on how to provide a scientific and regulatory framework for the approval of these systems, in a manner that is consistent with what is applied to the traditional treatment systems. All these discussions will, in one way or another, feed into the discussions between Administrations that takes place at IMO, and will, I am sure, prove most valuable in our combined efforts to provide a range of solutions to combat the transfer of harmful aquatic organisms and pathogens through ships' ballast water and sediments.

This R&D Forum could not have come at a better time. With more than 50,000 ships to equip, survey and certify, we can not sit idle. All solutions and innovations that meet the standards set out in the Convention, should be welcomed.

As you know, over the last couple of months, Sweden, the Marshall Islands and the Republic of Korea have deposited their instruments of ratification, thus bringing the total number of Contracting States to 21 and the aggregated gross tonnage to almost 23 per cent. To enter into force, a total of 30 signatories are needed, representing 35 per cent of the world's merchant tonnage. With many countries at an advanced stage in their ratification process, the entry into force seems to be imminent, which puts pressure on all parts of the shipping sector, to ensure that we are prepared to meet the requirements of the Convention in a timely manner. Of course, this does not mean that we should not look beyond the Convention and address the new challenges and opportunities that lay ahead.

As most of you know, IMO has been actively involved in seeking a solution to the ballast water issue since the late 1980s, an effort that culminated in the adoption of the Ballast Water Management Convention at the IMO Headquarters in London in February 2004. But the work and commitment of the Organization certainly did not end there, it continues relentlessly through its committees and sub-committees, its Integrated Technical Cooperation Programme, the Biosafety Section of the Secretariat itself, as well as the GloBallast Programme and the Global Industry Alliance.

Ladies and Gentlemen, allow me to conclude by thanking those that have been involved in the preparations and coordination of this very busy week of activities, and I know that you are many. As I mentioned, the seeds for this Forum were actually planted more than a year ago and, since then, a number of people in several organisations have worked together to guarantee a successful conclusion. Their efforts have not been in vain and I am glad that I have had the opportunity of witnessing first hand the closing stages of the Forum.

First of all, allow me to thank the members of the Global Industry Alliance – APL, BP Shipping, Daewoo Shipbuilding and Vela Marine International – for having the vision to support and promote this extremely important and timely forum.

I would also like to thank the City of Malmö for welcoming us to this magnificent city and for the much appreciated conference dinner in the Town Hall. Malmö has always been a very engaging and active host to the World Maritime University, and we are pleased to see that this commitment extends to highly technical activities such as this.

We have been very fortunate to have several other sponsors as well, including Wilhelmsen Ships Equipment, who kindly provided all the coffee breaks and lunches during this Conference, and Respartner, who has provided travel assistance to the participants.

I would also like to thank the dedicated GloBallast Partnerships team at IMO for all their hard work – my colleagues Jose, Fredrik and Bob and also Dandu for keeping a firm hand on the biosafety helm at IMO. They have worked on this Forum since its inception, and their valuable contribution should be acknowledged by all.

Last but not least, I would like to extend a sincere thank you to Dr. Björn Kjerfve and the Wold Maritime University, over which he so ably presides, for an extremely efficient and successful cooperation. To all of those who have been involved from your part, Professors Olof Linden and Neil Bellefontaine, Ms. Mia Hedin, Ms. Hong Vo, Mr. Erik Ponnert, and many more – Thank you!

As I now officially close this Forum, I urge all of you to ensure that the momentum that has been built during this week is maintained and built upon. The world’s oceans and the peoples whose lives depend on them, like our friend the Caspian fisherman, need your commitment and determination if we are to succeed in our efforts to stem the threat posed by invasive aquatic species through an effective ballast water management international regime. The alliances and partnerships we have seen in action this week will, I am sure, continue working together to make this noble pursuit a reality.

With that I would like to sincerely thank you all for your active participation in the R&D Forum and the pre-conference workshops and wish you a safe journey back home.

GLOBAL R&D FORUM ON

Emerging Ballast Water Management Systems

26–29 January, 2010
St Gertrud's Conference Centre,
Malmö, Sweden

Programme

Tuesday 26 January

Pre-conference workshop on providing equivalency between IMO Guidelines G8/G9 approved treatment systems and alternative management options

Wednesday 27 January

MORNING SESSION

Chair Person. Mr Andrew Hudson, Principal Technical Adviser, UNDP, International Waters and Cluster, Water Governance Programme

Welcome address
Dr Björn Kjerfve, President, World Maritime University

Welcoming remarks
Dr Jose Matheickal, Chief Technical Advisor, GloBallast Partnerships, IMO

Keynote address
Ballast Water Management – an overview of the regulatory process
– Mr Dandu Pughiuc, Head, Biosafety Section, IMO

BWM hurdles and the need for innovative approaches: An industry perspective
– Captain Tey Yoh Huat, Chairman of the IMO-GloBallast Global Industry Alliance Task Force, Vice President, APL CO. Pte. Ltd.

Ballast Water Treatment Systems: 'Old' and 'new'ones
– Dr Marcel Veldhuis, Senior Scientist, Royal Netherlands Institute for Sea Research

AFTERNOON SESSION

Emerging Ballast Water Management Concepts

Technical Aspects
Chaired by Captain Ahmed Al Babtain, Vela Marine International

Keynote address
The Variable Buoyancy Ship: A Road to the Elimination of Ballast
– Professor Michael Parsons, University of Michigan

Ballast water replaced with fresh water – why not?
– Captain Valter Suban, Professor Matej David, Professor Peter Vidmar, and Marko Perkovič
Faculty of Maritime Studies and Transportation, Slovenia

A study of ballast water treatment applied on iron ore ports in Brazil using discrete simulation
– Newton Narciso Pereira, Hernani Luiz Brinati, Rui Carlos Botter, University of São Paulo,
Department of Naval Architecture and Oceanic Engineering, Brazil

Regulatory Aspects

Chaired by Dr Kai Truempler, Federal Maritime & Hydrographic Agency of Germany

Keynote address

Ballast water technology availability – an update
– Captain Graham Greensmith, Lead Specialist, External Affairs, Lloyd's Register

Ballast water treatment ashore brings more benefits
– Associate Academic Dean Patrick Donner, World Maritime University

Ballast water management in the Baltic Sea
– Mr Markus Helavuori, Maritime Inspector, Finnish Maritime Administration

Alternative ballast water management options for Caspian region shipping:
Outcomesof a recent CEP/IMO/UNOPS Study
– Dr R. W. Hilliard, InterMarine Consulting Pty Ltd, Australia and Dr J. Matheickal,
International Maritime Organization

Thursday 28 January

MORNING SESSION

Progress on conventional Ballast Water treatment systems

Chaired by Professor Neil Bellefontaine, WMU

Keynote address

Evaluating, installing and testing a Unitor BWT system
and some reflections about industry challenges ahead
– Mr Iver Iversen, Business Development Director, Wilhelmsen Ships Equipment AS

Microwaves + Ultraviolet + Ozone Ballast Water Treatment
– Dr Alex Taube, R&D Director, Technical Solutions and Innovations P/L, Australia

Thermal Aqua-Filtration (TAF) system: A new concept of environment-friendly BWMS
applying "retrieved heat" to eliminate the living organisms
– Kazuhiko Koike (Hiroshima University), Nobuhiko Fujiki (Taiko Sangyo Co., Ltd.), Kenji Yamane
(National Maritime Research Institute, Osaka), Yoshiyuki Inohara, Izuo Aya (Taiko Sangyo Co.,Ltd.)

Development of Novel VUV photocatalysis system for ballast water treatment
– Yansheng Yin, Lihua Dong, Li Zhang, Chunhua Fan, Tao Liu, Yun Zhou, Dongsheng Wang, Yunlian
Xu, Baojia Xiao. Institute of Marine Materials Science and Engineering, Shanghai Maritime
University and Shanghai Haida Assets Management Co.Ltd

Beyond-Ballast: Integrating shipboard environmental technologies:
Ozone as a single-source system for treating multiple waste streams including ballast
– Sung-Jin Park, Jung-In Bin, Ki-Wook Kim, Seung-Je, Yoon NK Co. Ltd Busan, Republic of Korea.
– Presented by Steve Raaymakers, Eco-Strategic

Applicability of approved ballast water management systems that make use of active substances
or preparations under the Ballast Water Regulations in Victoria, Australia
– Dr Marlos De Souza, Program Leader – Ballast Water & MARPOL 73/78
Environmental Strategies Unit, EPA Victoria, Australia

AFTERNOON SESSION

Testing, Verification and Monitoring of Ballast Water

Chaired by Professor Olof Lindén, WMU, and Mr Fredrik Haag, IMO

Keynote address

A summary of findings from the first 35 ballast water treatment evaluations
– are we on the right track?
– Dr Tim Bowmer, Chairman, GESAMP

Monitoring of bacteria in ballast water
– Helge Liltved, Norwegian Institute for Water Research (NIVA)

Ballast water treatment testing and discharge toxicity
– Mario Tamburri, Greg Ziegler, Dan Fisher, Lance Yonkos and Kitae Rhie, Maritime Environmental Resource Center, University of Maryland and Kyung Hee University

A novel approach to determine ballast water vitality and viability after treatment
– Peter Paul Stehouwer, Frank Fuhr and Marcel Veldhuis,
Royal Netherlands Institute for Sea Research

New data experiments using viability stains ontreated ballast water for IMO compliance monitoring
– Kent A. Peterson, Chief Executive Officer, Fluid Imaging Technologies, Inc., USA

How to take a representative ballast water sample?
– Dr Stephan Gollasch (GoConsult) and Matej David, University of Ljubljana,
Faculty of Maritime Studies and Transport

Factors influencing organism counts in ballast water samples and their implications
– Frank Fuhr, Jan Finke, Peter Paul Stehouwer, Swier Oosterhuis & Marcel Veldhuis,
Royal Netherlands Institute for Sea Research

Validation protocols for performance testing and scaling
ballast water treatment systems employing UV disinfection and filtration
– Jim Cosman, Manager, Regulatory Affairs TROJAN UV

The use of mesocosms in risk assessment of active substances in ballast water treatment
– Klaas Kaag, Wageningen Imares Afdeling Milieu, Netherlands

Friday 29 January

Report from the pre-conference workshop

PLENARY SESSION

Moderator Dr Jose Matheickal

Panel Discussion on Ballast Water Management: What have we learned and the way forward
– Dr Tim Bowmer, Chairman, GESAMP
– Mr Iver Iversen, Wilhelmsen Ships Equipment AS
– Mr Jan Linders, RIVM
– Professor Michael Parsons, University of Michigan
– Mr Dandu Pughiuc, IMO
– Mr Marcel Veldhuis, NIOZ
– Mr Chris Wiley, Chariman of the IMO MEPC Ballast Water Working Group

Conference Conclusions and Recommendations
– Mr Miguel Palomares, Director, Marine Environment Division, IMO

List of Conference Participants

First Name	Last Name	Organisation	Country
Abraham	Martinez	Panama Maritime Authorithy	Panama
Adanma Ifeoma	Ezedinma	World Maritime University, SM	Sweden
Aditya Trisandhya	Pramana	World Maritime University, MSEA	Sweden
Ahmed	Al Babtain	Vela International Marine Ltd.	United Arab Emirates
Alberto Antonio	Bengue	World Maritime University, PM	Sweden
Alex	Taube	TS Innovations	Australia
Allegra	Cangelosi	Great Ships Initiative	United Stated of America
Ana	Skara	LLM Lund Universty	Sweden
Andreas	Zipperle	Technical University Hamburg	Germany
Andrew	Hudson	UN Development Programme (UNDP)	United Stated of America
Anna	Orchard	Shell Int. Trading & Shipping Co Ltd	United Kingdom
Anna Malin	Petré	LLM Lund Universty	Sweden
Arief Kurnia	Risdianto	World Maritime University, MLP	Sweden
August	Tobiesen	NIVA	Norway
Barbara	Werschkun	Safety of Transports and REACH Coordination Federal Institute for Risk Assessment	Germany
Bart	Boosman	Wagenborg Shipping B.V.	The Netherlands
Bev	Mackenzie	IMarEST	United Kingdom
Birger	Hahn	MAHLE Industriefiltration GmbH	Germany
Birte	Clason	Aquaworx GmbH	Germany
Björn	Kjerfve	World Maritime University	Sweden
Bram	van Weerdenburg	CytoBuoy	The Netherlands
Brian	Elliott	EMSA	United Kingdom
Brigitte	Behrends	Marena Ltd	Germany
Camilla	Nöjdh	Respartner	Sweden
Carla	Escalante – Fischer	World Maritime University	Sweden
Caroline Maria	Okeijn	World Maritime University, MLP	Sweden
Carolyn	Junemann	US DOT Maritime Administration	United Stated of America
Cato C.	ten Hallers-Tjabbes	Royal NIOZ	The Netherlands
CDR Agneta	Dahl	USCG at WMU	Sweden
Cecilia	Denne	World Maritime University	Sweden

Cees	van Slooten	Royal NIOZ	The Netherlands
Cheng	Zhang	World Maritime University, PM	Sweden
Chris	Wiley	Chariman of the IMO MEPC Ballast Water Working Group	Canada
Chris	Hoebeke	World Maritime University	Sweden
Christian	Ingvorsen	DESMI Ocean Guard A/S	Denmark
Christodoulos	Dimas	TBP BV-Burgas Alexandroupolis Pipeline	Greece
Claus	Jørgensen	DHI	Denmark
Clive	Cole	World Maritime University	Sweden
Craig	Eason	Lloyd's List	United Kingdom
Cristian Leonel	Martis Aravena	World Maritime University, MET	Sweden
Dandu	Pughiuc	International Maritime Organization	United Kingdom
Daniel S.H.	Moon	World Maritime University	Sweden
Dario	Ercolani	ILF Beratende Ingenieure GmbH	Germany
David	Köröndi	LLM Lund Universty	Sweden
David	Smith	Plymouth Marine Laboratory	United Kingdom
David Kugwayire	Songotu	World Maritime University, PM	Sweden
Dewi	Susanti	World Maritime University, SM	Sweden
Diana	Veigule	LLM Lund Universty	Sweden
Dick	Brus	Ministry of Transport	The Netherlands
Didin	Alfiani	World Maritime University, MET	Sweden
Domyoung	Hyoun	World Maritime University, MLP	Sweden
Don	Huh	DSME(Daewoo Shipbuilding & Marine Engineering Co.)	Republic of Korea
Dong Hyun	Shon	Techcross Inc.	Republic of Korea
Dong Min	Seo	World Maritime University, MSEA	Sweden
Dorota	Chmielewska	LLM Lund Universty	Sweden
Duc Minh	Pham	World Maritime University, SM	Sweden
Edmund	Hughes	Coast Guard Agency (UK)	United Kingdom
Edyta	Białowąs	Port of Gdynia Authority S.A.	Poland
Egon	Walzer	Evonik Degussa GmbH	Germany
Eka	Rukhadze	BP Exploration Caspian Sea Ltd	Georgia
Elsa	Lacladere	BP Shipping	United Kingdom
Emmanuel Jinah	Bailor	World Maritime University, SM	Sweden
Enrico	D'agostini	World Maritime University, SM	Sweden
Eric	van Alphen	Alfa Laval	Sweden
Erik	Ponnert	World Maritime University	Sweden
Etienne	Brutel de la Rivière	NIOZ – Royal Netherlands Institute for Sea Research	The Netherlands
Eun-Chan	Kim	KORDI, Korea	Korea
Eva	Nilsson	World Maritime University	Sweden
Eva	Höltén	World Maritime University	Sweden
Faleh Abdulrahman M.	Alfaleh	World Maritime University, MLP	Sweden

Fanny	Granskog	LLM Lund Universty	Sweden
Farshad	Shamgholi	LLM Lund Universty	Sweden
Fathima Rusniya	Mohamed Haris	World Maritime University, SM	Sweden
Fatma Iddi	Ali	World Maritime University, MLP	Sweden
Frank	Fuhr	Royal NIOZ	The Netherlands
Fredrick Stephano	Sadyalunda	World Maritime University, MET	Sweden
Fredrik	Ahlqvist	LLM Lund Universty	Sweden
Fredrik	Norén	N-Research	Sweden
Fredrik	Haag	International Maritime Organization	United Kingdom
Frode	Tangen	BOLLFILTER Nordic Aps	Denmark
Gitte	Petersen	DHI	Denmark
Graham	Greensmith	Lloyds Register	United Kingdom
Gus	van der Veen	CytoBuoy	The Netherlands
Helge	Liltved	Norwegian Institute for Water Research (NIVA)	Norway
Henrik	Ramstedt	Swedish Transport Agency	Sweden
Henrik	Oksfeldt Enevoldsen	IOC of UNESCO	Denmark
Henrik	Nilsson	Region Blekinge – Baltic Master II	Sweden
Herbert Wellington	Bain	World Maritime University, MSEA	Sweden
Hong	Vo Diem	World Maritime University	Sweden
Iara	Costa Conrado	LLM Lund Universty	Sweden
Ibrahim Loniel Hamid	Wurie	World Maritime University, MSEA	Sweden
Ilmar	Reepalu	City of Malmö	Sweden
Isabel	van der star	Royal NIOZ	The Netherlands
Ismail	Aydin	LLM Lund Universty	Sweden
Iver	Iversen	Wilhelmsen Ships Equipment AS	Norway
Jad	Mouawad	Det Norske Vertitas AS (DNV)	Norway
Jakub	Piotrowicz	Maritime Institute in Gdansk	Poland
Jan	Horck	World Maritime University	Sweden
Jan	Linders	RIVM	The Netherlands
Jan-Åke	Jönsson	World Maritime University	Sweden
Jean Edmond	Randrianantenaina	World Maritime University, MLP	Sweden
Jennifer	Gerardi	Trojan Technologies	United Kingdom
Jens-Uwe	Schröder	World Maritime University	Sweden
Jesús Antonio	Menacho Pierola	World Maritime University, MSEA	Sweden
Jim	Cosman	Trojan Technologies	United Kingdom
Jolanda	Matthijssen	Cofely West Industrie	The Netherlands
Jonas	Pålsson	World Maritime University	Sweden
Jose	Matheickal	International Maritime Organization	United Kingdom
José Manuel	Correro	LLM Lund Universty	Sweden
Josephine Olaso	Castillo	World Maritime University, MLP	Sweden

Juan Pablo	Fábrega	Panama Maritime Authorithy	Panama
Jurrien	Baretta	Cofely West Industrie	The Netherlands
K.R. Deepak	Kumar	World Maritime University, MEOM	Sweden
Kai	Truempler	Federal Maritime and Hydrographic Agency of Germany	Germany
Karin	Schröder	Federal Maritime and Hydrographic Agency of Germany	Germany
Katarina	Kepplerus	LLM Lund Universty	Sweden
Katarzyna	Hlebowicz-Stanisławska	Port of Gdynia Authority S.A.	Poland
Katja	Slobben	Exmar Marine nv	Belgium
Kazuhiko	Koike	Hiroshima University	Japan
Kent	Peterson	Fluid Imaging Technologies	United Kingdom
Kim	Gustavsson	DHI	Denmark
Kitae	Rhie	Kyung Hee University	Korea
Klaas	Kaag	IMARES	The Netherlands
Kolbjørn	Liland	Strømme Group AS	Norway
Kristina	Larsson	LLM Lund Universty	Sweden
Kyoung Soon	Shin	Korea Ocean Research & Development Institute	Korea
Lars	Nyman	RWO GmbH	Sweden
Lars-Erik	Larsson	World Maritime University Visiting Lecturer	Sweden
Li	Zhang	Shanghai Maritime University	China
Lihua	Dong	Shanghai Maritime University	China
Liondy Rhadames	Nunez Aquino	World Maritime University, SM	Sweden
Lisa	Drake	Naval Research Laboratory	United Stated of America
Malin	Faraasen	Region Blekinge – Baltic Master II	Sweden
Mandana	Mansoorian	World Maritime University, MSEA	Sweden
Manuel	Ramos Gomes	World Maritime University, PM	Sweden
Marcel	Veldhuis	Royal NIOZ	The Netherlands
Marcie	Merksamer	Ecochlor Inc.	United stated of America
Margot	Bik	Royal NIOZ	The Netherlands
Mario	Tamburri	Alliance for Coastal Technologies Chesapeake Biological Lab, UMCES	United Stated of America
Mark	Kalhøj	DESMI Ocean Guard A/S	Denmark
Markus	Helavuori	Finnish Transport Safety Agency	Finland
Marlos	De Souza	Environment Protection Authority of Victoria (EPA)	Australia
Martin	Andersen	DHI Water & Environment (S) Pte Ltd	China
Martin	Schabert	Lloyds Register EMEA	Denmark
Masashi	Sugomori	World Maritime University, MET	Sweden
Mats	Björkendahl	Hyde Marine Inc	United Stated of America
Mattias	Rust	WWF	Sweden
Maurya	Falkner	California State Lands Commission	United Stated of America
Max	Mejia	World Maritime University	Sweden

Mehmet Hanifi	Guler	World Maritime University, PM	Sweden
Meindert C.	Vink	Netherlands Shipping Inspectorate	The Netherlands
Mia	Steinberg	Naval Research Laboratory	United Stated of America
Mia	Hedin	World Maritime University	Sweden
Michael	Leach	Trojan Technologies	Canada
Michael	Parsons	University of Michigan	United Stated of America
Michael	Baldauf	World Maritime University	Sweden
Michelle	Aulson	Naval Sea Systems Command	United Stated of America
Miguel	Palomares	International Maritime Organization	United Kingdom
Mikhail Alexandrovich	Konoplev	World Maritime University, SM	Sweden
Mohammed Ashraf Karim	Chowdhury	World Maritime University, PM	Sweden
Mohd Khairul Tazril	Tarmizi	World Maritime University, MLP	Sweden
Mohd Nazwan Hafeez	Hashim	World Maritime University, MET	Sweden
Mojgan	Momeni Farahani	LLM Lund Universty	Sweden
Molly	Olsson	LLM Lund Universty	Sweden
Naveen Kumar	Gunasekaran	World Maritime University, SM	Sweden
Neil	Bellefontaine	World Maritime University	Sweden
Nicolas	Carette	Marin	The Netherlands
Niklas	Rönnberg	Shipowners Association	Finland
Nilam	Permatasari	World Maritime University, SM	Sweden
Ola	Westling	Arc Aroma Pure	Sweden
Olof	Lindén	World Maritime University	Sweden
Omar Hassn O.	Badokhon	World Maritime University, MET	Sweden
P.K.	Mukherjee	World Maritime University	Sweden
Pablo Rodolfo	Perez Lavallen	World Maritime University, MSEA	Sweden
Panicker Aji	Vasudeva	World Maritime University, MSEA	Sweden
Patrick	Donner	World Maritime University	Sweden
Peilin	Zhou	University of Strathclyde	United Stated of America
Pervez Iqbal	Mughal	World Maritime University, MET	Sweden
Peter	Hallin	LLM Lund Universty	Sweden
Peter	Nielsen	AlfaWall	Sweden
Peter	Säbom	HYDAC Fluidteknik AB	Sweden
Peter	Park	DongMoon ENT Co., Ltd	Korea
Peter	Lundahl Rasmussen	BIMCO	Denmark
Peter Paul	Stehouwer	Royal NIOZ	The Netherlands
Pierre	Cariou	World Maritime University	Sweden
Pontus	Karlsson	LLM Lund Universty	Sweden
Prayudi Budi	Utomo	World Maritime University, MEOM	Sweden
Rajashree Kashinath	Dabke	World Maritime University, PM	Sweden
Rajendra	Chaturvedi	Shreepati Group of Companies	India

Ralf	Sternberg	MAS – maritime assembly systems	Germany
Ralph	Michael	MAHLE Industriefiltration GmbH	Germany
Refaat Sabry Habib Azer	Armanios	World Maritime University, MSEA	Sweden
Rhea Rhenese	Rogers	World Maritime University, MLP	Sweden
Ricardo Jose	Cimino	World Maritime University, MSEA	Sweden
Rien	de Meij	Marin	The Netherlands
Rita	Essel	World Maritime University, PM	Sweden
Rizal Javier	Victoria	World Maritime University, MSEA	Sweden
Robert	Macciochi	International Maritime Organization	United Kingdom
Robert	Jellinggaard	BOLLFILTER Nordic Aps	Danmark
Robert	Hilliard	InterMarine Consulting	Australia
Roger	Sayegh	World Maritime University, SM	Sweden
Roger	Jones	World Maritime University	Sweden
Rona	Riantini	World Maritime University, MSEA	Sweden
Ross	Wakelin	Northern Research Institute Narvik A.S.	Norway
Rowan	Connelly	HF scientific	United Stated of America
Safaa Abdulhussein Jaiyz	Al-Fayyadh	World Maritime University, PM	Sweden
Salah Mohamed Hadhood	Alhadhood	World Maritime University, PM	Sweden
Samuel Mulatu	Habtemichael	World Maritime University, MLP	Sweden
Sebastian	Magnusson	LLM Lund Universty	Sweden
Seog Bae	Yun	World Maritime University, MEOM	Sweden
Seong Do	Park	Daewoo Shibuilding & Marine Engineering Co.,ltd	Korea
Shinichi	Maruta	Ministry of Land, Infrastructure, Transport and Tourism	Japan
Shinji	Usui	World Maritime University, MSEA	Sweden
Shuo	Ma	World Maritime University	Sweden
Silja	Snäll	LLM Lund Universty	Sweden
Sjur	Tveite	NIVA	Norway
So Hyun	Jo	World Maritime University, MSEA	Sweden
Song Jin	Na	World Maritime University, MSEA	Sweden
Stefan	Kacan	Federal Maritime and Hydrographic Agency of Germany	Germany
Stefan	Kools	Grontmij (AquaSense)	The Netherlands
Stephan	Gollasch	GoConsult	Germany
Stephanie	Delacroix	NIVA	Norway
Steve	Raaymakers	Ecostrategic	Australia
Stig	Strömkvist	Sydsvenskan	Sweden
Sung-Jin	Park	NK CO., LTD	Korea
Susanna	Perlheden	World Maritime University	Sweden
Takeshi	Nakazawa	World Maritime University	Sweden
Tammam	Hassan	World Maritime University, MSEA	Sweden
Thanh Tung	Le	World Maritime University, MSEA	Sweden

Therese	Nilsson	Baltic Master II, Region Blekinge	Sweden
Thi Huong Giang	Dang	World Maritime University, SM	Sweden
Thi Phuong Thao	Le	World Maritime University, MET	Sweden
Tim	Fileman	Plymouth Marine Laboratory	United Kingdom
Timothy	Carey	LLM Lund Universty	Sweden
Timothy	Bowmer	TNO – The netherlands Organization for Applied Scientific Research	The Netherlands
Tom	Vance	Plymouth Marine Laboratory	United Kingdom
Tom	Perlich	Ecochlor Inc.	United stated of America
Torben	Madsen	DHI	Denmark
Tracy	McCollin	Marine Scotland Science	United Kingdom
Tuomas	Asplund	LLM Lund Universty	Sweden
Uk	Kim	World Maritime University, MEOM	Sweden
Valter	Suban	University of Ljubljana	Slovenia
Viola	Liebich	NOIZ	The Netherlands
Virendra Jagannath	Mehta	Sea Reliance Marine Services PVT. LTD	India
Vivien Jane Evangelio	Cay	World Maritime University, MLP	Sweden
Volodymyr	Vitko	LLM Lund Universty	Sweden
Wenzheng	Wu	World Maritime University, MSEA	Sweden
Xiaolu	Yan	LLM Lund Universty	Sweden
Yasunobu	Araki		Japan
Yasuwo	Fukuyo	University of Tokyo	Japan
Yin	Yang	LLM Lund Universty	Sweden
Ying	Fang	World Maritime University, MLP	Sweden
Yo Ill	Song	DongMoon ENT Co., Ltd	Korea
Yoh Huat	Tey	APL CO. Pte. Ltd.	China
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Young-Soo	Kim	Korea Marine Equipment Research Institute	Korea
Yuki	Ueda	Mitsui Zosen Europe Ltd.	United Kingdom
Zhenzhou	Jiang	LLM Lund Universty	Sweden
	Thida Win	World Maritime University, MET	Sweden
	Swe Swe Zin	World Maritime University, SM	Sweden

World Maritime University

The World Maritime University is a graduate United Nations university, offering the degrees of MSc and PhD. Over the last quarter-century, WMU has educated almost 3,000 managers from 158 countries who now hold senior positions in maritime administrations, companies and training institutions, and make up a network of unparalleled influence and scope that stretches across the maritime world.

WMU offers MSc degree programmes in Sweden and in China, as well as PhD degrees based both in Sweden and in the UK. A postgraduate diploma is also offered by distance learning. In addition to the academic programmes, the University has a wide range of Professional Development Courses – short courses lasting for up to a month – that offer professional updating in areas across the field and can be tailor-made for a specific client.

WMU is active in research that is influencing the development and future directions of the maritime sector. From the effects of climate change on the future of shipping, to maritime safety, security and piracy, from port state control to engine room simulators, WMU's research teams are signalling the developments that will impact across the maritime world in the future.

WMU is fully engaged with the global maritime world, at a multitude of levels. To find out more about what we can do for you, please visit our web site (www.wmu.se) or email info@wmu.se

MSc programmes:
Maritime Affairs (in Malmö, Sweden), with specialisations in:

- Maritime Safety & Environmental Administration
- Maritime Law & Policy
- Marine Environmental & Ocean Management
- Port Management
- Shipping Management
- Maritime Education & Training

International Transport & Logistics (in Shanghai, China)
Maritime Safety & Environmental Management (in Dalian, China)

PhD programmes:
Maritime Administration (in Malmö, Sweden)
Maritime and International Commercial Law (jointly with Swansea, UK)

Postgraduate Diploma:
Marine Insurance (by distance learning)

Professional Development Courses:
In Malmö and at client locations worldwide

GloBallast Partnerships

Following the success of the original Global Ballast Water Management Project, known as 'GloBallast', The International maritime Organization (IMO) has again joined forces with the Global Environment Facility (GEF), the United Nations Development Programme (UNDP), Member Governments and the shipping industry to implement a five-year follow-up project, to sustain the global momentum in tackling the ballast water problem and to catalyze innovative global partnerships to develop solutions.

The main aim of **GloBallast Partnerships (GBP)** is to assist developing countries to reduce the risk of aquatic bio-invasions mediated by ships' ballast water and sediments. The project is being implemented by UNDP and executed by IMO, under the GEF International Waters portfolio, using a multi-component, multi-tiered approach involving global, regional and country-specific partners, representing government, industry and non-governmental organizations (NGOs):

- A global component, managed through a Programme Coordination Unit at IMO in London, providing international coordination and information dissemination, including the development of toolkits and guidelines, and establishing a strong co-operation with industry and NGOs.
- A regional component, providing regional coordination and harmonization, information sharing, training, and capacity building in the application of ballast water management tools and guidelines.
- A significant country component to initiate legal, policy and institutional reforms to address the issue and to implement the International Convention for the Control and Management of Ships' Ballast Water and Sediments. In fact, 13 countries, from 5 high priority regions, are taking a lead partnering role focusing especially on legal, policy and institutional reform. All told, more than 70 countries, in 14 regions, across the globe are directly or indirectly participating and benefiting from the project.

The "Global Industry Alliance" (GIA) is an alliance of maritime industry leaders working together with the GEF-UNDP-IMO GloBallast Partnerships Programme on ballast water management and marine biosecurity initiatives. The objective is to reduce the transfer of harmful organisms via ships, and to maximize global environmental benefits from addressing this issue in a sustainable and cost-effective manner.

The current GIA members include four major shipping companies; BP Shipping, Vela Marine International, Daewoo Shipbuilding & Marine Engineering Co., Ltd., and APL. It is expected that new members will be added to the GIA to increase the representation from various maritime sectors.

For further information on GloBallast Partnerships and the GIA, please contact:

GloBallast Partnerships PCU • International Maritime Organization, 4 Albert Embankment
London SE1 7SR, United Kingdom • Tel: +44 (0)20 7587 3279 • Email: jmatheic@imo.org • http://globallast.imo.org

International Maritime Organization

The International Maritime Organization (IMO) is the specialized agency of the United Nations with responsibility for ensuring that lives at sea are not put at risk and that the environment is not polluted by international shipping. The Convention establishing IMO was adopted in 1948 and IMO first met in 1959. IMO's 168 member States use IMO to develop and maintain a comprehensive regulatory framework for shipping. IMO has adopted more than 50 Conventions, covering safety, environmental concerns, legal matters, technical co-operation, maritime security and the efficiency of shipping. IMO's main Conventions are applicable to almost 100% of all merchant ships engaged in international trade.

For more information about IMO please contact us or refer to our website below:

International Maritime Organization
4 Albert Embankment
London SE1 7SR
United Kingdom
Tel: +44 (0)20 7735 7611
Fax: +44 (0)20 7587 3210
Email: info@imo.org
Web: www.imo.org

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