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US Navy Approach to Seawater Systems Biofouling Control

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The US Navy has a long history in the control and prevention of the growth of biological organisms or "biofouling" both on ship hulls and interior ships spaces, namely seawater systems such as auxiliary seawater (ASW) supply and fire main systems. The leading solution to seawater system fouling control has been electrolytic halogenation, which has been utilized and evaluated by the US Navy for over 20 years and its effectiveness is reflected by its usage amongst current and future USN ship classes. This experience has lead to a large volume of practical know-how with regards to installation and operational requirements, the effects on corrosion of marine materials and the salient overboard discharge issues. The current document seeks to discuss electrolytic halogenation including, the chemical reactions, equipment design and requirements, and the methodologies for neutralization of residual oxidants prior to overboard discharge. Furthermore, the following discusses recent advances by the Naval Research Laboratory in the construction of a Ballast Water Treatment Facility in which electrolytic halogenation techniques and equipment may be validated on a land-based, shipboard-volume scale, as well as any other ballast water treatment technique available form industry.

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Stopping the Ballast Water Stowaways – The Global Ballast Water Management Programme Initiative

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Marine species are being carried around the world in ships ballast water. When discharged into new environments, they may become invasive and severely disrupt the native ecology, impact economic activities such as fisheries and cause disease and even death in humans. Invasive marine species are one of the four greatest threats to the world's oceans and the other three are land based sources of marine pollution, over exploitation of living marine resources and physical alteration and destruction of coastal and marine habitat. A problem may arise when ballast water taken by a ship contains unwanted marine organisms. Once established, it is virtually impossible to control an invasive marine species. Impacts are usually irreversible. International Maritime Organization (IMO) has joined forces with Global Environment Facility (GEF) and the United Nations Development Programme (UNDP) to assist countries to reduce the transfer of invasive marine species in ballast water. The Global Ballast Water Management Programme (GloBallast) is working through six initial demonstration sites (Brazil, China, India, Ir. Iran, South Africa and Ukraine) to prepare for the new International regulatory regime. Activities carried out under GloBallast include: education and awareness, ballast water risk assessments, port baseline surveys, ballast water sampling, training port and shipping personnel in ballast water management practices, assistance with laws and regulations and self financing mechanisms. An overview of this initiative is presented.

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Preventing Aquatic Nonindigenous Species in the United States Through Regulation, Research, and Management

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Aquatic nuisance species (ANS) are increasingly viewed as a global environmental problem with large and long-lasting ecological and economic impacts. Introduced into habitats where they are not native, ANS can degrade ecosystems, resulting in billions of dollars of direct and indirect costs annually, as well as adverse effects on human health and lifestyles.

The Coast Guard's ANS Program focuses on ballast water management (BWM) options that can prevent the introduction of ANS via ballast water. Two pieces of Federal legislation, the Non-indigenous Aquatic Nuisance Prevention and Control Act of 1990 and the National Invasive Species Act (NISA) of 1996, require the Coast Guard to promulgate regulations and guidelines that establish BWM practices to meet this objective.

Four regulatory projects are in progress and listed below.

- Establishing penalties for vessels failing to report BWM practices.
- Require all vessels to conduct active BWM.
- Allow for shipboard testing and evaluation of treatment technologies.
- Establish a quantitative ballast water discharge performance standard.

A key hurdle to developing accepted ballast water treatment (BWT) technologies is the absence of a standard by which proposed technologies can be evaluated. The Coast Guard is leading a coordinated effort to develop this standard.

The Coast Guard has established a formal engineering test program (Environmental Technology Verification Program) with the Environmental Protection Agency to accelerate development and commercialization of BWT technologies.

The Coast Guard leads US participation in negotiations at the International Maritime Organization to establish a legally binding international instrument to regulate ballast water discharges.

We are seeing the early stages of these efforts and are optimistic that they will grow and bear fruit. We use the phrase "scientifically supportable, biologically meaningful, and verifiable" to characterize what we want in our domestic BWM program.

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The Development of the International Convention for the Control and Management of Ships' Ballast Water and Sediments

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The threat of introductions of harmful aquatic organisms and pathogens from the discharge of ship's ballast is an international issue that is appropriately being addressed by the International Maritime Organization (IMO), the United Nations specialized agency that deals exclusively with marine matters. The IMO's Marine Environment Protection Committee (MEPC) has identified addressing the ballast water issue as its number one environmental priority.

The IMO first developed guidelines on the management and control of ballast water in 1991 and, since 1994, has been working on the drafting of mandatory regulations. The process was interrupted in the late 1990s when it was recognized that an update to the guidelines was necessary.

In attempting to reach consensus on the contents of the regulations, many issues have been debated, such as a global vs. regional approach, the continued acceptance of ballast water exchange and requirements for new ships vs. existing ships, but the greatest challenge has been to develop treatment and discharge standards. When the Working Group developing the regulations met in March 2002, they considered 14 possible ballast water treatment standards, which they have since reduced to just one performance standard, but the parameters for the standard remain undecided.

As currently drafted the regulations would require ships to carry an approved Ballast Water Management Plan, to keep a Ballast Water Management Book, and to manage sediment and ballast. New ships would be required to discharge no detectable quantities of viable organisms above a certain size (proposed as 50 microns) and to discharge no other organisms above a certain concentration (to be determined). Existing ships conducting ballast exchange would have to do so with an efficiency of 95% volumetric exchange, but only those ships constructed before the entry into force of the Convention would be considered as conducting an equivalent exchange by using three times flow through. Issues such as the parameters for the performance standard, the definition of a new ship, the decision of whether or not ballast water exchange will be phased out for existing ships, whether special requirements are required in certain areas and whether special areas should be established are still significant items being debated.

The MEPC will further discuss the proposed ballast water convention when it meets again in July 2003. If issues can be resolved, it is expected that the Convention would be adopted at a Conference of Parties in early 2004. The Convention would then come into force when a sufficient number of countries ratify it after implementing its provisions in their national legislation.

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Ballast Water Management Practices of Foreign Flag Vessels

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The Shipping Federation of Canada is an association of ship owners, commercial operators and agents who represent 95% of Canadian-owned oceanic traffic moving to and from ports on the east coast, the St. Lawrence and the Great Lakes. The Federation has been an active player in the implementation of ballast water management regulations for the Great Lakes, and is keenly interested in the development of a regionally coordinated approach to ballast water management that is based on internationally accepted standards and practices. In 2000, the Federation developed a "Code of Best Practices for Ballast Water Management," which is a voluntary program used by oceans ships as a means of minimizing the risk of introducing non-indigenous aquatic organisms and pathogens into the Great Lakes. The code enumerates a variety of measures that ships agree to undertake in this respect, including the cleaning of tanks, commitments with regard to areas and periods for ballast water intake, and agreement to conduct ballast water management at every practical opportunity.

Oceanic shipping is an international activity by its very nature, with ships sailing many different routes throughout the world. The masters and crews of those vessels are subject to an increasing number of standards, procedures and regulations. As a result, it is important to ensure that such rules and regulations are as simple and user friendly as possible.

Foreign-going vessels rarely have to conduct full ballast exchange along the east coast (which would take 24 to 30 hours, or some 350 nautical miles, to complete). They more frequently exchange ballast from two or three tanks (which takes 8 to 9 hours). However, coastal vessels coming from ports along the east coast or the Atlantic provinces usually find it impossible to conduct a full exchange outside the Economic Exclusive Zone (more than 200 nm from shore) due to their trading limits. Thus, such vessels have, until now, been exempted from requirements to comply with Canadian and US ballast water guidelines.

We believe that the most viable means of addressing cases in which vessels are unable to exchange ballast water at sea (due to safety considerations or coastal trade limitations) is to define a clear alternative ballast water management option. Effective development and use of such a zone or procedure would, however, require bi-national coordination.

It is extremely important that any effort to develop new measures governing ballast water management be consistent with the guidelines and regulations that are either already in place or under development at the international and national level. Legislators should also bear in mind that frequently changing limits and reporting procedures over a short period of time would lead to confusion and a reduction in compliance. A common approach from the Atlantic provinces and the States on the East Coast is absolutely essential.

Ballast water treatment systems are probably the more promising tool for effective ballast water management. The Shipping Federation supports the development of efficient treatment options and some of its members have installed trial systems on their vessels. However, at this stage, none of the systems that are available on the market have proven to be sufficiently effective to be installed on a large scale. In addition, treatment systems represent major financial investments that ship owners are not likely to undertake until an international or national standard has been developed. It is also important to remember that the installation of treatment systems on board fleets could take several years given the extensive dry-docking that might be required. Thus, given the highly competitive environment in which shipping takes place, any effort to impose a treatment requirement on vessels calling at a particular state or region would result in a diversion of cargo to other ports and threaten the economy of the region as a whole.

The Great Lakes NOBOB Project: 38 Ships and 82 Tanks Later

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The majority of vessels arriving from overseas to the Great Lakes enter as NOBOBs (no-ballast-on-board). A major goal of the Great Lakes NOBOB Project is to assess whether these vessels are a potential vector for nonindigenous aquatic species introductions to the Great Lakes. Task 1 of the project is to characterize the amount, and biological and chemical content of sediment and water residuals within NOBOB ballast tanks. Over a two-year period, 82 ballast tanks were entered and sampled on 38 different vessels. Salinities of residual water ranged from 0 to 36 ppt, with approximately 50% in the fresh to brackish water range. In residual water samples we found: bacterial levels typical of environmental samples, occasional presence of pathogenic protozoa, Pfiesteria, and vibrio cholerae; live phytoplankton cells in all samples, including nonindigenous species, that exhibited various growth response during experimental grow-outs; and over 45 species of live zooplankton including nonindigenous species. In residual sediments we found: viable phytoplankton cysts in all samples, including nonindigenous species of diatoms and marine dinoflagellates (some HAB species); and zooplankton resting eggs in all samples, including nonindigenous species, at densities ranging from 100–10 000 eggs/m^2 with an average viability of 36% under experimental hatching studies.

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Ballast Management and the Control of Sediment Accumulation in Water Ballast Tanks

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Ballast water management, including the management of residuals, has been identified internationally as the only existing defense against the proliferation of aquatic nuisance species through the vector of international shipping, and is likely to remain so in the near term. In the context of protection of the Great Lakes, ballast management was initially viewed solely as open ocean exchange for ships proceeding on the transoceanic voyage in ballast. However the vast majority of ships entering the Great Lakes from overseas do so with cargo on board and with only unpumpable ballast residual in their tanks, which will eventually commingle with water ballast taken in and subsequently discharged within the Great Lakes basin.

For these ships, the other elements of ballast management become critical, as they can be ballasting at both ends of the transoceanic voyage in fresh or brackish water without the prophylactic effect of saline shock that open ocean exchange provides. Unpumpable ballast, the residual that cannot be stripped from the tanks, is as much a factor of commercial shipping as ballast water itself, as there are few ships, particularly in the dry bulk trades that can completely evacuate their ballast during the course of the deballasting/cargo loading cycle. Sediment intake during ballasting, particularly at berths in rivers and estuaries, may be unavoidable, and once precipitated can form a major component of that residual if not addressed promptly and regularly.

Significant efforts are being made by the industry for both commercial and environmental reasons to manage residuals. This presentation, based on field observations of the deep sea Great Lakes trade over a six year period in studies sponsored by Fisheries and Oceans, Canada, Sea Grant and the Great Lakes Protection Fund as part of their overall assessment of NOBOB ships, examines the management options available to the ship operator for limiting or eliminating these residuals, the technical and operational limitations that they currently deal with, and the overall application and effectiveness of sound management practice in the trade.

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Do Resting Eggs in Ballast Tanks Pose an Invasion Risk?

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Ship-mediated biological invasions continue to be recorded within the Great Lakes, despite the implementation of ballast water exchange regulations in 1993. We explore whether vessels declaring no ballast on board (NOBOB) status, being currently exempt from regulations, may be a vector for introduction of nonindigenous species (NIS) to the Great Lakes. These vessels potentially pose an invasion risk owing to the presence of viable invertebrate resting eggs contained in residual sediment. NOBOB ships that ballast and deballast Great Lakes water while in transit may deposit invertebrates or their resting eggs. To determine the possibility that NOBOB sediments act as a vector for NIS we investigated the density, diversity and viability of invertebrate resting eggs within residual sediments of 69 tanks on 39 vessels over two years. The density and viability of resting eggs varied widely, from 0.3 to 91.3 eggs/g sediment and 0 to 92%, respectively. Viability of resting eggs was explored under various day length and salinity conditions. Here, we report preliminary findings from hatching experiments, providing the first evidence that residual sediments can carry viable invertebrate resting eggs. Thirty-three species have been identified to date, seven of which are not currently established in the Great Lakes. In addition, we will present preliminary findings on the effect of saltwater exposure on viability of freshwater species' resting eggs.

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Ballast Tank Biofilms as "Seed Banks": Physicochemical and Microbiological Characterization

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Lessons repeatedly learned from the past underscore the need for control of ship-surface biofouling and source ballast water. The probability of successful establishment of self-sustaining populations of exotic species is expected to increase with greater volumes of ballast water and reduced ship transit times. In addition to potential environmental and public health impacts caused by invasive species, modern aquaculture development in coastal zones is at risk of disease transfer from ballast water. More recently, the potential for ballast-tank biofilms to act as "vertical seed banks" during and after multiple ballast exchanges has become a specific concern. The overall goal of this multi-university collaboration is to assess the potential for ballast-tank biofilms to globally transport microorganisms and pathogens. Previous field experiments during transoceanic voyages demonstrated that biofilms form on multiple types of artificial surfaces deployed in ballast-water holds. When the substrata and associated biofilms were removed from the hold and submerged in sterile artificial seawater, they readily seeded secondary biofilms. In addition to bacterial populations, the primary biofilms contained a significant contingent of protista, which themselves may carry bacteria and viruses harmful to humans and other species. Continuing field experiments include deployment of controlled-surface sampling units in ships' ballast tanks, aseptic collection of biofilms from the walls of recently deballasted tanks, and laboratory experiments with a 260-gallon (1 m^3) model ballast tank supplied with sand-filtered Lake Erie water. Analyses of field biofilm samples have revealed the presence of potential pathogens, including Pseudomonas putrefaciens, Vibrio alginolyticus, and Vibrio cholerae. The Vibrio cholerae detected were not representatives of human-cholera serogroups. Dinoflagellate cysts recovered from field biofilm samples later germinated to swimming cells. Contrary to our expectation of biopolymer-rich films, biofilms collected from the walls of deballasted tanks were richer in silicates and silica, as indicated by infrared spectroscopy and supported by SEM/EDXray observations of sediments. An apparent lack of substantivity (lack of adhesion to the substratum) indicated that portions of ballast biofilms can be easily stripped from tank walls under modest shear. Although not surrounded by the usual slime components of biofilms from nutrient-rich systems, as detected by infrared spectroscopy, a thriving microbial community was revealed by light microscopic and immunofluorescence analyses of ballast biofilms. When replicates of these test plates were subjected to controlled shear conditions (stagnation point flow cell apparatus), much of the micro-particulate and microbial load was removed. Subsequent immunofluorescence analysis of the shear-challenged samples, however, showed that populations of target organisms were still present on the surface. These, more strongly retained, organisms can survive in the biofilm to produce new generations of cells for later release into the ballast water. In the model ballast tank containing Lake Erie water seeded with ballast-tank sediment, biofilms formed readily on all test surfaces. Preliminary light microscopic analyses of these biofilms revealed bacteria and protista. Species identifications are underway.

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Pathogen Organisms Arriving from Ships' Ballast Water in Cartagena Bay

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Considering that several species of bacteria, plants and animals can survive in the ballast waters transported by ships and the role of ballast water as a mean for propagating bacteria casing epidemics, a research study was initiated to identify the species of organisms present in this type of waters arriving in the Cartagena Bay. The analysis of pathogen bacteria, phytoplankton and zooplankton was made in the samples from ballast water tanks.

The samples were screened for the presence of *Vibrio cholerae* selecting yellow colonies on TCBS agar and performing the arginine dihydrolase and esculin hydrolysis tests using purified isolates. Isolates giving negative reactions in the both of the tests was presumptively considered *V. Cholerae*.

This research is the first study in ballast water in Colombia and is the first step to adequately define of the nature and extent of the problem in the country to develop in the future control and preventive measures.

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Evaluations of Deoxygenation as a Ballast Water Treatment to Prevent Aquatic Invasions and Ship Corrosion

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One of the most important mechanisms for the introduction of aquatic nuisance species is transport in ship ballast waters. Although several ballast tank treatments to prevent transport of aquatic organisms appear promising, all existing approaches will result in significant costs to the shipping industry. The implementation of ballast water treatment measures would be hastened by providing the shipping industry with economic incentives for doing so. Our initial work suggests that deoxygenation may be such a treatment with benefit for ship owners by reducing corrosion, while simultaneously limiting the number of aquatic organisms surviving transport in ballast tanks.

Purging of oxygen from ballast tanks with nitrogen gas was recently proposed by Sumitomo Heavy Industries to be a cost-effective technique for reducing corrosion and therefore extending ship life. An initial shipboard study found a 10-fold reduction in corrosion rates under hypoxic ballast tank conditions. In previous studies, we also tested both the oxygen tolerance of larvae from known invasive invertebrate species and conducted literature reviews on the ability of aquatic organisms to survive low oxygen environments. These investigations suggest that few organisms will be able to withstand extended periods of exposure to hypoxic ballast water.

While initial results are promising, several questions must be addressed before definitive conclusions can be drawn regarding the feasibility of deoxygenation as a ballast water treatment. In particular, issues of cost effectiveness, responses of natural planktonic communities, microbiologically influenced corrosion, and scaling up to shipboard applications require additional investigations.

We will discuss the potential of deoxygenation to prevent both invasions and corrosion by briefly reviewing our past work and reporting on our current investigations to: 1) optimize the oxygen stripping process (with particular emphasis on the ballasting flow rates and tank volumes of large vessels); 2) determine mortality levels of natural Chesapeake Bay planktonic communities (zooplankton, phytoplankton, and microbes) under hypoxia in mesocosm experiments; and 3) quantify corrosion rates and establish the mechanisms under deoxygenated conditions (with particular emphasis on microbiologically influenced corrosion). These steps will ultimately lead to a full-scale study to determine the efficacy of deoxygenation at removing ballast water organisms onboard active vessels.

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Deoxygenating Ballast Water Using a Dry Biomass Process: A New Technique to Treat Ballast Water to Reduce Aquatic Invasive Species Transfer

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Following the suggestion by Tamburri et al. (2002) that deoxygenating ballast water may be an effective treatment method to minimize the risk of transferring invasive aquatic organisms, we developed and conducted preliminary testing of a new technology capable of generating rapid oxygen depletion and inducing significant mortality of organisms in ballast water tanks. The method is based on a biological process using dry multi-species biomass which rapidly depletes dissolved oxygen once in water solution. Preliminary tests done on large volumes of St. Lawrence River water showed that oxygen levels dropped from 12 mg/L to 0 mg/L in less than 24 hours. The effectiveness of this method is temperature-dependent and can yield significant positive results between 5 °C and 35°C. This technology is environmentally safe and could be easily implemented on board ships. Further testing conducted at pilot-scale is planned for assessing the application of this technology for ballast water treatment.

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Large-Scale Testing of Hydrocyclone, Screen and UV Radiation as Ballast Water Treatment Technologies

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Large-scale dockside experiments were undertaken to evaluate the treatment efficiency of commercially available unit processes for preventing the transfer of unwanted species via ships' ballast water. The project was undertaken with funds from the US Coast Guard Research and Development Center, and the treatment system was built at the University of Miami's Rosenstiel School of Marine and Atmospheric Science campus. The test water from Biscayne Bay, Florida, was pumped through the system at approximately 5.7 m^3 min^{-1} (1500 gpm or gallons per minute). The unit processes included a hydrocyclone (centrifugal force of approximately 13 X g at 5.7 m^3 min^{-1}), a self-cleaning 50 µm (micron) screen, and a UV (ultraviolet) treatment unit (100% transmittance = 60 000 µW s cm^{-2}). In addition to these unit processes, a mixing system, including a high pressure injection pump, was fabricated to add suspended solids (clay slurry) to the flowing Biscayne Bay water to enhance turbidity. The effect of increased suspended solids and enhanced water color on the unit processes was the main focus of this research.

A broad spectrum of biological and biochemical indices were monitored to evaluate treatment efficiency. During each experimental run, 760 L (200 gal) samples were collected and passed through 35 µm plankton nets for zooplankton collection. Water samples were also collected for phytoplankton, microbiological, ATP and protein analyses. After the initial samples were collected, a second set of samples was held for 18 hours (turbidity experiments) or 6 to 7 days (color experiments) to determine the effects of storage on the effectiveness of treatment processes. Statistical analyses showed that hydrocyclonic separation was not effective for treatment. The 50 mm screen, however, was effective at removing over 90% of the zooplankton species monitored, and a small percentage of the microphytoplankton in the natural water samples. Initially, UV treatment was able to reduce the count of viable microorganisms to an undetectable level; however, bacterial regrowth was observed in samples held for 18 hours. There was no regrowth in samples held for 6 to 7 days.

The main variable explored in this research was the effect of increased suspended solids (turbidity) or enhanced color on the unit processes. While the dose delivered by the UV system decreased due to the increased suspended solids loading, its reduced value (approximately 25 000 µW s cm^{-2} minimum dosage) was still sufficient to inactivate microorganisms, even with the increased turbidity. In subsequent experiments, a UV dose of 10 000 µW s cm^{-2} was found to be insufficient to inactivate microorganisms.

In general, it was observed that only the 50 mm screen contributed appreciably to removal of organisms, especially zooplankton in the test water of this facility. If organisms smaller than 50 mm are to be removed or killed however, then either a more efficient filtration process or a biocide will need to be added to achieve these treatment goals. It appears that UV treatment will not be effective at facilitating any meaningful treatment, especially against potential invading organisms such as large zooplankton or larvae of invertebrates.

Ship Ballast Water Treatment: The Closed-Loop Option

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A new Ballast Water Treatment (BWT) process option is presented that is potentially advantageous when applied to any number of treatment process configurations, but especially advantageous when used in processes that involve UV-based treatment. The new process option, the use of closed-loop treatment while in transit, is examined for its compatibility with a set of BWT process selection criteria, design options and strategic considerations that are outlined in the paper. The primary advantage of the closed-loop option when used with UV technologies is the ability to accommodate low water qualities in the equipment design without having to size the treatment technology to address the worst case water quality in a single pass. Advantage is taken of the in-transit time to build UV dose to whatever level is specified in the process design. En route treatment also takes advantage of the power availability. The closed-loop option configuration has the flexibility of being used in a single pass process when water quality permits, in a dual pass (ballasting and deballasting) when in-transit growth of organisms is a problem, in the patented closed-loop option while in transit from port to port when the ballast water quality is poor, and is compatible with Ballast Water Exchange (BWE) where it is deemed practicable and safe. The closed-loop process option is also examined for its potential to manage ballast tank sediments.

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The Natural Ballast Water Exchange Method

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The United States, Canada, Australia, and New Zealand have led the way by adopting strict guidelines for ballast water exchange, and the rest of the international shipping community is rallying to combat the threat of biological pollution. In fact, the International Maritime Organization (IMO) passed a resolution in November 1997 that identifies two methods for ballast water exchange: the sequential and flow-through methods. Both methods protect the aquatic environment but require a considerable amount of fuel and staff time.

When the sequential method is used, water is pumped out of the ballast tank until suction is lost and clean ballast water is pumped in. The flow-through method involves pumping ballast water into the tank until the dirty water overflows through the openings on top of the ballast water tank. Both methods rely on the use of an electric or steam-driven ballast pump and a diesel generator or a boiler. Careful monitoring of deballasting and ballasting operations is essential, and both methods create extra work for the duty engineer.

The Natural Ballast Water Exchange method takes into consideration the well-being of seafarers and the environment. The method relies on natural forces of pressure and gravity to achieve ballast water exchange. Unlike the sequential and flow-through methods, the new method does not require extra personnel to operate and monitor auxiliary machinery. Instead, clean water enters the ballast tank main line through a water inlet at the ship's bow. The pressure from the water flowing into the tank forces the biologically tainted water out through an opening located at the forward bottom end of the ballast water tank. To complete the operation, a limited amount of power is required to pump in enough clean ballast water to meet the initial water level.

When the ship is in forward motion, the pressure of the water acting on the hull is greater than the pressure of the water in the ballast tank. Simply put, this process uses the pressure differential to force the ballast water from the ballast tank, thereby replacing the water automatically. Overall, the new method saves on fuel costs and offers certain safety advantages.

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Kill Harmful Microorganisms in Ships' Ballast Water Using Hydroxyl Radical

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A physics method is studied that the electrons are accelerated and then the gas molecules are aroused using a strong dielectric barrier discharge. With this method, the strong electric field ($E_d \geq 400$Td, 1Td=10^{-17}Vcm^2) is formed with the thinner α-Al_2O_3 dielectric layer in the narrow discharge gap at a high pressure ($P \geq 0.1$Mpa or n=2.6x10^{-19}/cm^3). The electrons achieve the average energy of above 12eV. The ionization potential of O_2 and H_2O molecules is12.5 eV and 12.6eV respectively. The ionization numbers of O_2 in strong ionization discharge is 12 769 times higher than that of O_2 in other gas ionization discharge at normal pressure. As a result, O_2 in air and H_2O in seawater are ionized and dissociated into a number of activate particles such as OH, O_2^+, O (^1D), HO_2 radical and so on. High dissolved hydroxyl radical (OH*) concentration of more than 10mg/L is achieved by the activate particles dissolved into seawater (a part of ballast water) with high mass transfer efficiency. 1.0 t dissolved hydroxyl radical is enough to treat about 10.0 t ballast water. The hydroxyl radical is a "green" ideal medicament without any toxin and residues, which is possible to be decomposed into H_2O and O_2 after 20 minutes.

The principles of organisms killed by hydroxyl radical are as follows:

1) Oxidization and decomposition of amino acids of introduced organism. The activated groups such as -OH, -NH_2 guanidino etc in amino acids of protein play an important action on maintaining proteinic configuration and catalytic activity of enzyme. When the hydroxyl radicals react with the activated groups, the chemical damage of protein further the death of introduced organisms occur.
2) The hydroxyl radical reacts with Deoxyribonucleic Acid (DNA) to produce DNA adducts resulting in a chemical damage without any restoration.
3) Hydroxyl radicals acts on the lateral chain of phosphatide polyunsaturated fatty acid of cell membrane to lead to the fast degradation of polyunsaturated fatty acid further to the damage of cellularity and then to cells death. In a world, the hydroxyl radical has a broad-spectrum deadly characteristic that is possible to kill microorganisms meanwhile bleaching and deodorization. The hydroxyl radicals act on the introduced microorganisms belonging to a dissociative radical reaction with a fast reaction rate.

When the dissolved hydroxyl ratio concentration is 0.15mg/L, the kill efficiency of bacteria sum is 99%. When the ratio concentration is 0.25mg/L, the kill efficiency of bacteria sum reaches 100%. After 5 minters of reaction, the hydroxyl ratio concentration to kill Ba. *Navicula*, Ch. *Dunaliella*, P. *Subcordiformis* is in range of 0.6~0.8 mg/L respectively, and the kill efficiency is above 99.0%. When the ratio concentration is 0.9 mg/L, 1.16mg/L, 1.12mg/L, the kill efficiency reaches 100%. The algae chlorophyll-a change after 24 hours of hydroxyl reaction is shown in Fig.4. The hydroxyl ratio concentration of suppressing chlorophyll-a increase is in the range of 0.21~0.34mg/L, the ratio concentration of all chlorophyll-a decomposed is in the range of 0.55~0.68mg/L. Therefore the dissolved hydroxyl value to kill microorganisms is 0.8mg/L.

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Technology Policy Implications for Ballast Water Introductions of Non-indigenous Species

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The problem of non-indigenous species introductions only escalates, as the world becomes a global economy. Increased trade between different locations provides new vectors of introduction for many non-indigenous species. The most common method of introduction has been identified as ballast water from ships. The scientific community is currently trying to evaluate the economic, ecological, and human impacts of these introductions, but it is increasingly important that policy analysts become involved in the research. There is currently not a model that can determine the likelihood that an introduced species will become invasive. It therefore is necessary to evaluate the potential of reducing the risk factors that lead to introductions. Policy makers at the national and international level are currently struggling to formulate and implement policies that will effectively reduce the risk of introductions to coastal waters. The proposed policies advocate a global standard that may not adequately protect the environment and may impose unnecessary restrictions or financial burdens on the shipping industry.

The risk reduction model developed through this research evaluates both the likelihood of invasions from oceanic voyages as well as coastwise shipping introductions. The model characterizes three elements: 1) the port of origin environment (e.g., salinity, temperature); 2) the voyage factors (e.g., treatment method, length of voyage, volume of ballast, and ballasting events); and 3) the port of destination environment to determine the risk reduction potential of technology policy combinations. This work evaluates the risk of species being introduced and then extrapolates to produce an estimate of invasion risk.

The model will be applied to a variety of ports in the United States, representative of geographic location, vessel type, cargo volume, and ecological conditions. The model is intended to evaluate the available policy and technology solutions to determine the most effective combination to reduce the risk of introduced species to individual port environments. The model will illustrate the dominant factors of introduction and the areas of greatest concern. Information from the model will enable policy makers to implement policies that address specific factors and trade routes, instead of the broad issue of invasions.

The risk reduction model can be applied to any port to determine which policy and technology combination will most effectively combat the risk of introduction of invasive species. The model developed by this research will inform the policy making process by evaluating the factors that are controllable by regulations, technology and policy requirements. Previous research and models in this area have address the biological conditions necessary for invasion, these cannot be changed by regulations, therefore it is necessary to develop a model that involves the ports and ships, the two areas that can be regulated. This presentation will discuss the development of the model and explain the factors evaluated by the model, and preliminary results from the Port of Houston, Texas.

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Quantification of Risks of Alien Species Introductions Associated with Alternative Areas for Ballast Water Exchange in the Laurentian Channel of the Gulf of St. Lawrence

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Canada has one of the longest navigable coastlines in the world, bordering the Atlantic, Arctic and Pacific Oceans, as well as the Great Lakes. Shipping is important to the Canadian national and international trade. Our coastal waters receive yearly over 52 million tonnes of ballast water from foreign ports around the world (Gauthier & Steel 1966). Millions of tonnes of ballast water are discharged into the Estuary and Gulf of St. Lawrence each year. Ballast water has been identified as one of the pathways by which alien aquatic species are introduced outside of their normal range. Under the current Canadian voluntary guidelines, all ships entering Canadian Waters are expected to exchange ballast water outside of the Exclusive Economic Zone (EEZ). The 2001, Transport Canada survey has shown that 77% of all ships entering the Gulf of St. Lawrence have exchanged ballast water in mid-ocean. Of the remainder, 8.5 % are ships, which declared that as they are coming up the North American coastline they are exempt from the need to exchange. Additional 13% do not have a clear reason for not exchanging and may in fact also be part of the coastal trade. Less then 1% of all ships surveyed declared safety as a reason for not doing the exchange.

The current guidelines make provisions for ballast water exchange in “back-up areas”, if exchange is not feasible offshore for safety reasons. Incoming foreign ships may exchange their ballast waters within the Gulf of St. Lawrence, in the Laurentian Channel southeast of Anticosti Island, where depth exceeds 300 m. The magnitude of the risk such ballast water exchanges pose, compared to risk from ballast water discharge in other areas of the Gulf of St. Lawrence was evaluated using a Probabilistic Risk assessment model. The risk was measure in terms of quantity of alien species introduced into various parts of the Gulf, including the Laurentian Channel, giving current shipping patterns and practices.

This presentation will discuss the results of the study and propose that the model employed could be used to simulate a number of “what if” scenarios. Such approach could help test the impacts of any new shipping guideline or regulations on the risk of alien introduction into the Gulf of St. Lawrence.

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A Pilot-Scale System for the Treatment of Ships' Ballast Water Using Hydroxyl Medicament

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The high dissolved hydroxyl concentration is formed using the strong dielectric barrier discharge and its kill principles are introduced in paper, the title "Kill Harmful Microorganisms in ship's Ballast Water Using Hydroxyl Radical". In this paper, a pilot-scale system for the treatment of ship's ballast water and its experimental results are discussed.

High-concentration hydroxyl radical is produced in Hydroxyl generator 3, and then is injected into dissolved unit 8 to form high dissolved hydroxyl medicament. The ratio concentration of OH* medicament reaches the threshold value of 0.65mg/L in the main pipeline of the ballast water. The introduced microorganisms are killed along a 6 m long main pipe, 10 m long is enough. In this system, the flow rate of ballast water is 20 t/h, the flow velocity is1.6 m/s, the sample point is along 6 m long of main pipe.

The ship's ballast water in this system is taken from the Dalian port, Liaoning Province, P.R. China. The Phytoplanktons, Zooplanktons and Germs are as follows. Phytoplankton: Chloreua Pyrenoidesa, Chaetocers, Peridinium. Zooplankton: Euplotes. Germ: Pseudomonas, Flarobacterus, Vibrio, Acinetobacter, Escherichia, Alcaligenes, Staphyloccus.

Because of low content of the monoplast algae and germs in ship's ballast water, 2216E liquid nutrient medium is injected into a glass tank of $1.5m^3$ for the enrichment culture of the algae and germs which are enriched into 2°¡$10^{12}/m^3$ and 4°¡$10^6/m^3$ respectively. When the ratio hydroxyl

concentration is 0.65 mg/L, the germs, monoplast algae and Zooplanktons are not tested in the water sample of 150 mL. The introduced microorganisms can be killed within 4.1 s also along the main pipe of the ballast water.

The conclusions that hydroxyl radical kills the introduced microorganisms is as follows.

1) Lipide peroxidation degree of monoplast algae increases 2 times in the experiment resulting in death.

2) Hydroxyl radical has a strong destruction effect on monosaccharide, amylose, protein, DNA and RNA in the plankton cell.

3) Hydroxyl radical has a obvious destruction to the activity of CAT, POD and SOD in antioxidase system of Plankton. Therefore, the first is the loss of enzyme activity. And then, the enzyme as a protein is oxidized and decomposed by hydroxyl radical. Especially, antioxidase system is destroyed, which effect vital activity of the cells so that the cell die.

The content of phosphate and nitrate has a little raise of 11.5% and 17.4% respectively. The content of nitrite and ammonium salt has a obvious decrease from 66.6 ug/L to 1.1 ug/L and 79.8 ug/L to 0.4ug/L respectively, which are oxidized and decomposed by hydroxyl radical. The products have Nitrate to lead to a little increase of Nitrate. Nitrite and ammonium salt have a harmful effect on aquatic, especially Nitrite can oxidized the low-iron hemoglobin into the high-iron hemoglobin resulting in the loss of function to carry oxygen. Therefore the water quality is obviously improved after the treatment of hydroxyl radical.

The decrease of 50% turbidity, no COD tested, 2 times raise of TOC indicated that hydroxyl radicals oxidize and decompose the organics in water into COD and OC is difficult to be tested. In addition, The oxygenolysis of hydroxyl radicals to the cell remains also contributes to the increase of TOC content.

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Cost Analysis of Mandatory Ballast Water Exchange in the United States

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The United States Coast Guard is currently engaged in a rulemaking effort to make the provisions of the Ballast Water Management regulations of 33 CFR 151:2000 – 2065 mandatory for all vessels entering US waters. The poster presentation will document the cost analysis for the cost born by the shipping industry to implement these mandatory provisions.

Previous studies of ballast water as a vector for the introduction of aquatic invasive species have taken various approaches to characterizing the amount of ballast water entering the US waters as a result of cargo operations. This analysis attempts to capture the amount of ballast water that would need to be exchanged by vessels to which these new federal regulations would be applicable. In contrast to previous work, this analysis does not restrict itself to a representative sampling of commercial vessels, nor is it a characterization of activity confined to a particular US port zone.

Specifically, the poster will present an analysis based on vessel arrival data for all commercial vessels inbound to the US. All of these arrivals are assigned a vessel type, based on its size, and service. Data published in Lloyd's Register of Shipping is used to characterize each arrival in terms of vessel particulars in order to establish on average, how much ballast water is on board and the capacity of ballast pump likely to be used for exchange. In addition, arrival data is used to determine the vessel's transit and whether the transit takes the vessel more than 200 nautical miles from any land, permitting the exchange of mid-ocean water. If the transit does permit an exchange of ballast water, the probability of performing an exchange is applied based on wave height data published for specific sea areas. Wave height is being used in this analysis as a lower limit estimate of the sea states permissible for completing exchanges as determined by either flag or class societies based on vessel type. The hour-cost of operating the ballast pump for the required volume exchange is calculated for all of the vessel entries for each of two years of arrival data. Pump hours are influenced both by the size of the vessel, as well as whether the vessel is more suited to exchange by the sequential method or the flow-through method. In addition, a annual repair/maintenance cost that is a fraction of the ballast pump's capital cost is added for the wear and tear inflicted on the pump by the additional operating time. Finally the one time cost, per vessel, of the development of a vessel-specific ballast water management plan is added to complete the analysis.

The poster presentation will present all the assumptions used to develop the analysis as well as the vessel-type specific average costs for ballast water exchange, both on a per-trip basis and an annual basis for vessels trading in the US.

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