Shipboard Demonstrations of Ballast Water Treatment to Control Aquatic Invasive Species

Matson Navigation Company
and
Ecochlor, Inc.

ABSTRACT

Matson Navigation Company (Matson) has maintained a long and successful partnership with the California State Lands Commission (CSLC) to address the issue of invasive species introductions from ships. Matson is currently involved in a partnership with CSLC and Ecochlor, Inc. (Ecochlor) to demonstrate Ecochlor's chlorine dioxide ballast water treatment system onboard the *ITB Moku Pahu*. Chlorine dioxide is unique in its effectiveness against all organisms. Chlorine dioxide does not form unwanted chlorinated by-products even in heavily contaminated water. Most importantly, chlorine dioxide can be safely and economically generated as a dilute solution on board commercial vessels. This presentation will include an industry perspective on being at the forefront of ballast treatment technology innovation, review of the vessel specifics, the results of shipboard testing conducted by the University of Rhode Island, Graduate School of Oceanography, comparison to IMO and U.S. Coast Guard (USCG) treatment standards, and the status of the USCG Shipboard Technology Evaluation Program (STEP) application.

INTRODUCTION

Matson: A History of Environmental Stewardship

Because Matson believes it has a responsibility to protect the environment of the communities it serves, the company is committed to meeting or exceeding environmental regulatory requirements as an integral part of its business. Matson has adopted several innovative environmental management practices, such as its industry-leading zero discharge policy, and has partnered with regulatory agencies and engineering firms to test innovative environmental technologies aboard its ships. All of Matson's vessels have received the American Bureau of Shipping's Safety, Quality and Environmental (SQE) certification, which requires a documented environmental management system focused on continuous improvement, and Matson's offices and terminals are certified to the ISO 14000 environmental management system standard. For its work to protect the environment, Matson received the USCG's prestigious Benkert Environmental Award for Excellence in June 2006.

Matson has maintained a long and successful partnership with the CSLC to address the issue of invasive species introductions from ships, and has worked closely with the CSLC since the adoption of the California Ballast Water Management for Control of Nonindigenous Species Act in 1999. Most recently, Matson representatives actively participated on the CSLC's ballast water performance standards advisory committee, as well as the hull fouling technical advisory committee. In addition, Matson has allowed two of its vessels to be used as a test platform for a new ballast water treatment technology.

In August 2000, the CSLC was awarded a $150,000.00 grant from the U.S. Fish and Wildlife Service (USFWS) to implement the West Coast Regional Applied Ballast Management Research and Demonstration Project. This project was an inter-agency pilot program to acquire and distribute information regarding applied alternatives for ballast water management. In December 2000, the Port of Oakland agreed to match the USFWS funds, doubling the income resources available for this project, making it possible to evaluate the efficacy of ballast water treatment systems onboard at least two vessels. Additionally, the State Water Resources Control Board (SWRCB) received $150,000 from the Exotic Species Control Fund to evaluate alternatives for treating and managing ballast water.

Matson's *R.J. Pfeiffer* became one of the vessels to have an OptiMar® treatment system installed for the demonstration project. This system treats ballast water with a 2-step process beginning with a cyclonic separation chamber followed by ultraviolet irradiation. Full-scale engineering designs for the *R.J. Pfeiffer* were previously funded by the Great Lakes Ballast Technology Demonstration Project and made available for the West Coast Demonstration Project. The original system was installed in early 2002, however propulsion vibrations from the engine caused quartz tubes to break inside the UV chamber. After multiple adjustments, a new design was installed in February 2003 and the research team performed evaluation tests during July 2003. The CSLC concluded that the project produced not only valuable information on the OptiMar® system, but also raised compelling questions for future ballast water treatment studies.

Matson has now formed a partnership with the CSLC and Ecochlor, Inc. to demonstrate a chlorine dioxide treatment system for ballast water aboard the bulk carrier *Moku Pahu*. The agreement with CSLC provides funding to offset the cost of retrofitting the *Moku Pahu*. In return, Matson is allowing a research team to gather data on the biological effectiveness and provides CSLC with information regarding the installation and system effectiveness, as well as operational and maintenance requirements.

TECHNOLOGY

Chlorine dioxide has been used to safely and economically control microorganisms in industrial and municipal applications for over 50 years, and it is unique in its effectiveness against all organisms. Unlike elemental chlorine, it does not form unwanted chlorinated by-products even in heavily contaminated water, and ballast water treated with chlorine dioxide is environmentally acceptable at discharge. Most importantly, chlorine dioxide can be safely and economically generated in dilute solutions on commercial vessels.

Chemistry:

Chlorine dioxide (ClO_2) is a gas with strong oxidation properties and a high antimicrobial activity over a wide pH range. This gas does not occur in nature. It is used as an effective disinfectant in drinking water treatment facilities (from 0.07 to 2.0 mg L^{-1}), in various applications of the food and beverage industries, in bleaching of textiles, pulp and paper as well as in industrial cooling systems, waste water treatment facilities, in sterilizing manufacturing and laboratory equipment and in treating medical wastes (2). Unstable as a gas, ClO_2 requires on-site generation prior to its easy dissolution in water. Generation of ClO_2 proceed either by reduction of the chlorate ion (ClO_3^-) in an acidic medium or by oxidation of the chlorite ion (ClO_2^-), the former being more economical (3). This ballast water treatment system uses hydrogen peroxide as the reducing agent is found in Equation (1) and this process is safe as it directly produces neutral sodium sulfate and no chlorine.

$$2\ NaClO_3 + H_2O_2 + H_2SO_4 \dashrightarrow 2\ ClO_2 + O_2 + 2\ H_2O + Na_2SO_4 \qquad (1)$$

The mechanism of action of ClO_2 on organisms is not entirely deciphered. Given the very high affinity of ClO_2 for reduced sulfur compounds and the ability of ClO_2 to penetrate into organics due to its non-polar property, it is believed that ClO_2 goes across the cell wall and inactivates organisms by oxidizing the sulfhydryl group on sulfur-containing amino acids (cysteine and methionine) with direct effect on the function of proteins, including enzymes (4). The concentration of ClO_2 rapidly decreases when mixed with water. This decrease, known as the initial oxidant demand, is dependent on the specific characteristics of the water mass. Effective disinfection is thus the result of the combination of the concentration of residual ClO_2 and the time of exposure until the point when residuals are no longer detectable. This value is expressed as CxT (mg min L^{-1}). Many organisms are inactivated quickly, namely bacteria (5) and some protozoan (*Giardia* cysts) (7). The residuals provide contact time for action against more resistant microorganisms and metazoans, such as mollusks (8,9,10). As an example, treatment of sewage contamination in a water system with initial ClO_2 residuals between 0.85 and 0.95 mg L^{-1} lead to 2.8-log inactivation of total coliform and 4.4-log inactivation of viruses (11). CxT values required for inactivation by ClO_2 fall at or below 35 mg min L^{-1} for *Giardia* cysts and viruses depending on water temperature.

A plot of the concentration-time product vs. temperature obtained from treatment of ballast water with an initial dosage of 5 mg L^{-1} ClO_2 indicates a decrease of the CxT product with increasing temperature, as expected (12). The lowest available CxT value obtained at 24 ^oC, 171 mg min L^{-1}, is nearly five times the CxT value required to eradicate *Giardia* cysts and viruses, thus demonstrating the available conditions for efficient disinfection using ClO_2. Time to non-detectable residuals varied between 6 and 50 hours.

The product of residual ClO_2 concentration and time as a function of temperature in ballast water over the course of one year is found in Figure 1. The different ballast waters originated from three different ports on the east coast of USA and one from Halifax (Canada) for a range of temperatures between 1 and 24 ^oC.

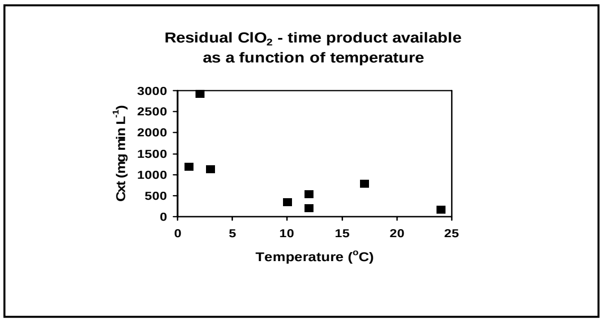


Figure 1. **Product of Residual**

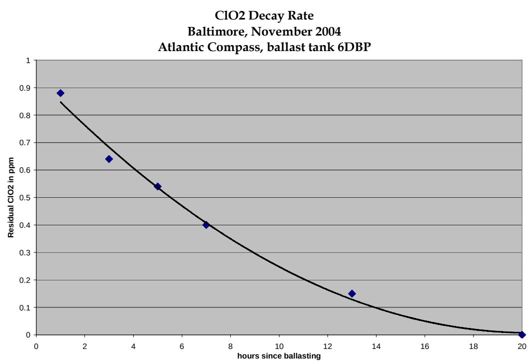
To be a viable approach to the control of invasive species, the treatment of ballast water with a biocide such as ClO_2 must be effective, affordable, non-disruptive to ship operations and commercial activities and safe to human health as well as the environment.

Treatment Methodology:

Ecochlor's treatment system injects a dilute solution of chlorine dioxide into the ballast water piping as ballast water is loaded. The chlorine dioxide solution strength is determined by operational parameters (flow rate, target dosage) and adjusted automatically during the ballasting operation. The Ecochlor™ System can also be electronically setup to measure residuals of chlorine dioxide.

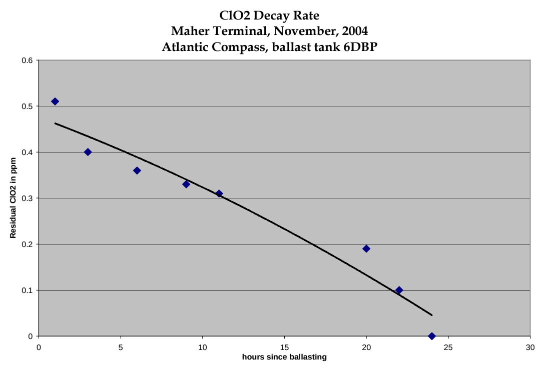
The chemical concentration is sufficient to neutralize any invasive species in the ballast water entering the system and also will remain active for a period of time to neutralize any biofilm in the ballast water tanks. The biofilm is a source of re-inoculation of the ballast water and must be neutralized for proper control of invasive species.

Chlorine dioxide will remain active for several hours in the ballast tanks but will decay over time. There will be no chlorine dioxide residual in the ballast water at the time of discharge. The graphs below show the decay of chlorine dioxide in selected ports of call — Baltimore, Newark, and Djibouti, Africa.



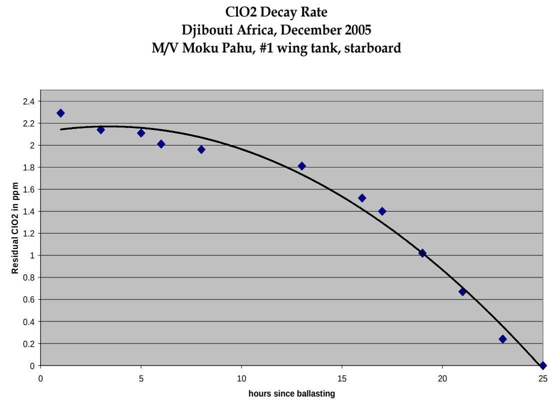
Decay in Baltimore, Initial dosage of 5.0 ppm

November, water temp 12^0 C

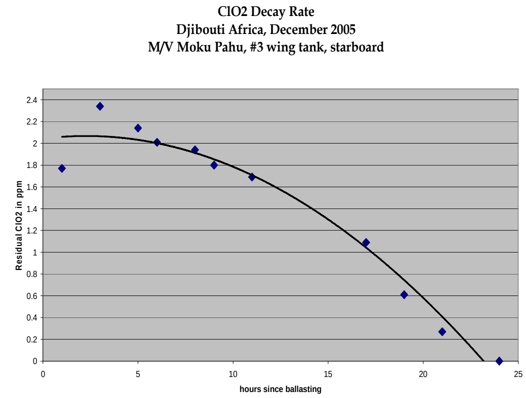


Decay in Newark, Initial dosage of 5.0 ppm

November, water temp 10^0 C



Decay in Djibouti, Initial Dosage of 8.0 ppm
December, water temp 25^0 C



Decay in Djibouti, Initial Dosage of 8 ppm
December, water temp 26^0 C

MOKU PAHU

The *Moku Pahu* is a U.S. flagged, Integrated Tug/Barge (ITB) bulk carrier that was built in 1982. The combined tug and barge have an overall length of 209 meters, a beam of 25.6 meters and a maximum deadweight of 37,107 long tons at the 11 meter maximum draft.

The vessel is managed and operated by Matson and was designed to carry sugar from Hawaii to California. The vessel also operates on the spot market and has carried U.S. World Food Aide to Russia, North Korea and Africa.

The *Moku Pahu* has 13 ballast tanks and can carry up to 17,000 metric tons of ballast. The vessel performs the flow-through method of ballast water exchange when calling on ports in the USA. This technique consumes considerable manpower and increases greatly the operational hours on the two ballast water pumps. In order to reduce the labor requirements and save money, Matson began investigating alternatives to ballast water exchange.

BALLAST WATER TREATMENT SYSTEM

The ballast water treatment system selected by Matson was designed, fabricated and installed by Ecochlor. Overall, the system has the capacity to treat a maximum ballast water flow rate of 2,500 metric tons per hour.

The *Moku Pahu* system is located in a converted spare parts storage area and did not require a full enclosure. The size of the *Moku Pahu* system is about 7.5 square meters (see Figure 2).

Figure 2. ***Moku Pahu* System**

INSTALLATION SUMMARY

Matson provided the following guidelines for the installation of the ballast water treatment system on the *Moku Pahu*:

- Install the system safely
- Protect the crew, the vessel, subcontractors and the vendor during the process
- Abide by the American Bureau of Shipping (Classification Society) recommendations and guidance
- Be prepared to install the system in China, Singapore or California (depending on charters won on the spot market
- Do not interfere with the vessels ability to bid or commit to potential charters
- Complete the installation as soon as possible

The ballast water treatment system was designed and fabricated in Connecticut while ABS reviewed and approved the installation plan. A tentative installation date was set 60 days later for late July or early August 2005. Meanwhile, Matson was bidding on several charters that could potentially take the vessel near China or Singapore. If one of these charters were won, Matson was willing to lay up the vessel for a few days to take advantage of these ports for the installation. The China/Singapore installation option would have required the ballast water treatment system to be sent via airfreight. All necessary arrangements were made to respond if this was necessary.

Once the system was fabricated and ABS had approved the installation plans, all were ready to respond to the first opportunity to install the system. Site preparation and preliminary piping and electrical work were done while the vessel performed normal cargo unloading in Crockett, California. Given the uncertainty of charters on the spot market, none of the bids to Asia were awarded. In light of this, Matson decided that the vessel would be laid up in San Francisco between sugar shipments and while waiting for a charter.

The most significant portion of the installation during this lay-up was the exterior skin penetration that was necessary to place the system in the desired location. Dockside scaffolding was necessary to support the hull penetration and a dockside crane was used to lift the system. US Labor Union members in accordance with Union shop rules performed the work.

During hydro testing of the system, a small leak was noticed in the fill line of one of the precursor chemicals. The loading of that chemical was delayed until a replacement fill line could be secured and installed.

Other repairs and vessel improvements were made on the *Moku Pahu* while the vessel was laid up in San Francisco. Once these activities were completed, the vessel sailed on schedule to Hawaii.

PREVIOUS SHIPBOARD TEST RESULTS

Prior to the Matson installation, Ecochlor had installed its first system in 2004 on Atlantic Container Line's *Atlantic Compass*. Testing of that system was conducted by researchers at the University of Rhode Island, Graduate School of Oceanography in July 2005.

In July 2005, over a 4-day period, the University of Rhode Island (URI) team established and tested an experimental protocol to sample and analyze a variety of biological parameters aboard the *Atlantic Compass*, where generation of ClO_2 was provided by the Ecochlor ballast water treatment system. Although only two tanks were available for testing on this roll-on/roll-off (RO/RO) container ship (one for control and one for treatment), other characteristics made the vessel an ideal setup for preliminary testing; namely the very predictable port-to-port schedule, the fast filling and emptying of the tanks (less than one hour), the relatively easy and protected access to the tanks and the availability of onboard laboratory space. This preliminary testing allowed evaluation of sampling constraints, logistics and experimental design in addition to providing data on the efficiency of the biocide against natural communities under real shipping conditions.

URI demonstrated with water from Newark Bay that an initial ClO_2 concentration of 5 mg L^{-1} was as effective at eliminating bacterial and planktonic populations as was found in prior laboratory phases of the technology development. With water temperature at 24 ^{o}C and 350 µm dissolved organic carbon, chlorine dioxide residuals lasted for ca. 6 hours, for a CxT value of 171 mg min L^{-1}. The application of 5 mg L^{-1} ClO_2 reduced bacteria abundance to non-detectable levels within the first 24 hours, whereas bacteria still proliferated in the control tank (Figures 3, Figure 4 and Figure 5). After two days, some bacterial growth was observed. Phytoplankton biomass was virtually eliminated in all size fractions, by comparison to the observed biomass in the control tank (Figure 6). In contrast to the control tank, there was immediate and near 100% mortality of zooplankton (>50 µm) in the treatment tank (Table 1).

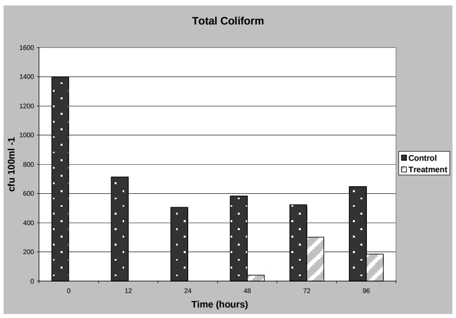


Figure 3. Time Course of Coliform Bacteria

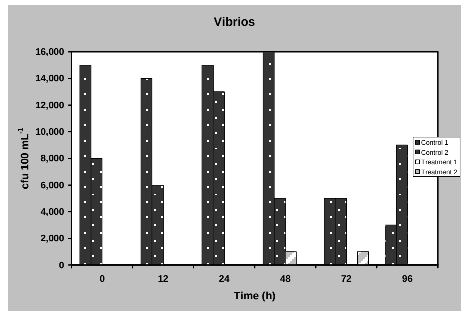


Figure 4. Time Course of Vibrio Colonies

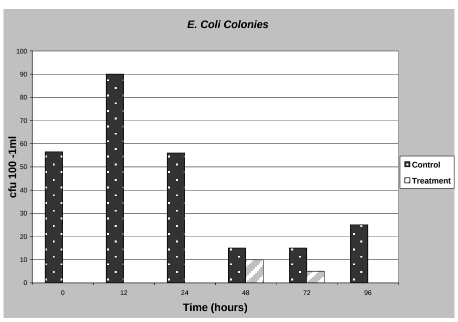


Figure 5. Time Course of E. coli Colonies

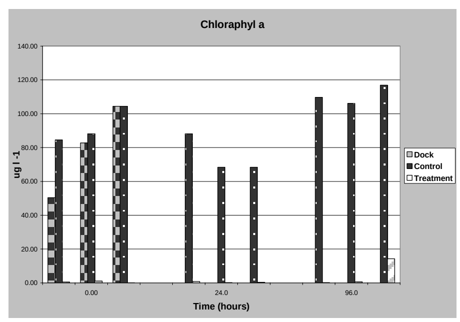


Figure 6. Time course of Chlorophyll-a Concentration

	Time =0	12 hr	24 hr	48 hr	72 hr	96 hr
Control	7121	5703	6615	2945	2846	1901
Treatment	0	0	0	5	0	0

Table 1. Total Zooplankton Abundance (Number m^{-3})

Although some minor but statistically significant recovery occurred in coliform bacteria five days after treatment and to a very minor extent in the autotrophic plankton, the system was deemed very effective at controlling potentially invasive species by comparison to the non-treated control tank. It is possible that biofilm in the tanks provided refuge for the organisms that survived. Laboratory experiments conducted in more controlled conditions (no biofilm) showed no such regrowth.

CONCLUSION

The installation aboard the *Moku Pahu* was performed safely, on schedule and without interruption of the vessels operational performance, and, the first round of testing on the *Atlantic Compass* showed the effectiveness of chlorine dioxide for controlling aquatic invasive species ranging from zooplankton to phytoplankton and pathogens.

In summary:

- The Ecochlor systems and the installations have been reviewed and approved by two Classification Societies (Lloyd's Register and ABS)
- The system has been safely installed, commissioned and operated on two commercial vessels
- The two installations were completed with out any interruption of normal vessel operations
- The preliminary results from the *Atlantic Compass* demonstrate the systems ability to quickly control aquatic invasive species in ballast water

The URI team will continue their testing on the *Atlantic Compass* in 2006 through a NOAA grant and will supervise the testing on the *Moku Pahu* in 2006 and 2007 with partial funding from the CSLC.

ACKNOWLEDGEMENTS

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12. M. D. Hasson, Ecochlor, Inc.

BIOGRAPHIES

Matson Navigation Company: Lisa Swanson

Ms. Swanson has been the Environmental Affairs Manager for Matson since 2005. Prior to that, she worked as an environmental consultant and Environmental and Safety Manager for a variety of shore-based industries. Ms. Swanson is responsible for developing and promoting environmental initiatives in support of Matson's ISO 14000 environmental management system certification.

Ms. Swanson is very proud of the fact that Matson was recently presented with the USCG's prestigious Benkert environmental excellence award.

Ms. Swanson received her Bachelor of Science degree in chemical engineering from the University of California, San Diego and is a registered professional engineer.

Ecochlor, Inc.: Tom Perlich

Mr. Perlich is currently the President of Ecochlor, a company he co-founded in 1999.

Mr. Perlich has over 20 years of progressive management experience in the field of specialty water treatment. Prior to founding Ecochlor, Mr. Perlich was the Corporate Sales Manager for Vulcan Performance Chemicals. Mr. Perlich was also a Regional Sales Manager for Exxon Chemicals and an Account Manager for Nalco Chemical. He has experience in all forms of water treatment including microbiological control in industrial and municipal water sources.

Mr. Perlich holds an Industrial Engineering degree from Rochester Institute of Technology.