Biological Analysis of Type-Approved Ballast Water Management Systems Installed on Vessels Operating in US Waters

Summary Report
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INTRODUCTION

In an effort to better understand the capabilities of type –approved Ballast Water Management Systems (BWMS) on operational vessels and to demonstrate the practicableness of collecting ballast discharge samples for compliance testing, the Golden Bear Research Center (GBRC) sampled and analyzed treated ballast water. This project will allow CSLC to assess the biological efficacy of various treatment technologies and models currently being used across the United States and help guide their own developing compliance assessment program. To ensure high confidence in the results of sample enumeration, detailed analyses (i.e. microscopy) were used for both ≥10 μm and <50 μm and ≥50 μm size class organisms. This data summary is specific to the ten vessels sampled as per the GBRC agreement with the California State Lands Commission's Marine Invasive Species Program (MISP), however a larger dataset of IMO D2 Commissioning Tests will be shared for the purposes of developing a peer-reviewed manuscript.

An additional aspect of this project was to develop and deliver to MISP staff, two sample collection devices that could be used for future sample collections and compliance efforts.

METHODS

Sample Collection

Discharge samples were collected during ballast water discharge after full treatment and hold time were applied, which were based on the particular BWMS sampled. Samples were taken in accordance with GBRC Standard Operating Procedures (SOP-GBF-OPS-13_Commissioning Testing), which incorporates the *Guidelines on ballast water sampling* (G2) and the European Maritime Safety Agency (EMSA) Guidance for best practices on sampling. The samples used in the analyses were taken from the vessel installed sample port on the discharge ballast line. For ≥50 μm size class organism enumeration, a minimum of 1 m^3 of treated discharge water was concentrated through a 35 μm plankton net to 60 mL, with the entire contents of the cod end being counted under a dissecting microscope. Organisms in the ≥10 μm and <50 μm size class were collected sequentially as whole water samples (~1 L) at time points (Beginning, Middle, and End) throughout the sample collection.

The total volume sampled was measured throughout sample collection with a flow meter installed in-line in the sample collection device (Figure 1).

For BWMS that used active substances to kill organisms in ballast water, measurements were made prior to sampling (HACH DR300 Chlorine or Palintest Kemio ClO_2 meter) to ensure that the active substance was below the relevant Minimum Allowable Discharge Concentration (MADC).

When possible, crew records were reviewed to verify correct operation and hold time of the BWMS prior to sampling.

Sample Analysis

Sample analysis of the two largest organism size classes enumerated in this study, was done using detailed analysis methods as per GBRC SOPs and summarized here. For ≥10 μm and <50 μm size class organisms, unconcentrated sample water was dosed with a combination of fluorescein diacetate (FDA) and chloromethylfluorescein diacetate (CMFDA) as cellular tags for viable cells. Triplicate 1 mL samples were then loaded into Sedgwick Rafter counting chambers and examined under an epifluorescent microscope. For ≥50 μm size class organisms, the entirety of the final volume through the plankton net was concentrated in the cod end (60 mL). The entire contents of the cod end were then counted under a stereo microscope for live organism counts.

Sample Collection Device

As part of a previous project, a sampling tool designed by Glosten, the Mark II, was designed and fabricated with the intent to be the standard BWMS sampling device for California State Lands Commission staff. The design incorporated a “hot tap” feature that would allow the device’s pitot and return flow tubes to be inserted into a vessel’s ballast piping without the need to drain and depressurize the pipes, a timely and labor intensive function. Connecting the sampling device to the vessel's piping requires a very specific sized flange and type of valve to be installed by the vessel in order to work. At the time of design, it was believed that the international standards dictating the sample port design in vessels would be standardized to the collection device's specifications. Given this did not occur, finding vessel's with compatible fittings became nearly impossible and makes it very difficult to depend on it as a useable device. Additionally, the tool itself is relatively heavy, being constructed out of stainless steel, weighing approximately 100 pounds in total. The size of each of the component pieces are fairly large and cumbersome, requiring at least two operators to transport and assemble for each sampling event. The assembly and breakdown of the apparatus is also significantly more time-consuming than the following sampling unit.

GBRC was only able to sample a single vessel using the Mark II sampling device, but at great cost to the vessel, who was willing to invest in retrofitting their piping to fit the Mark II in order to receive the data on their BWMS performance.

After several failed attempts to identify additional vessels with the proper installed piping to use the Mark II, GBRC constructed and built two collection devices designed to the specifications as requested by MISP staff (Figure 1). The collection devices are based off of GBRC's current IMO D2 Commissioning Testing sampling device and consist of a flexible hose to attach to the vessel sampling port, a means to meter the flow rate and total volume of sample collected, a diaphragm valve to control the flow rate, and distribution tubes for collection of whole water samples and to pass sample water through a 35um net. The electronic flow meter/totalizer is built and certified to ATEX standards for Intrinsically safe instruments for use in hazardous locations. Where practical, the device was built using 304 stainless steel to minimize the risk of static build-up within the unit.

Figure 1 – Diagram and photo of the sample collection device

As water passes through the flow meter/totalizer, the technician ensures the sample collected is passed through the sample net and into a container of at least 33 gallons to provide a “soft landing” which reduces potential mortality of organisms. In most cases, vessel crew provides a means to either remove the treated ballast water after collection from the container (diaphragm pump / syphon), or a place for dumping the water (vessel deck or bilge). The sampling device is lightweight and easily can be disassembled into two pieces for ease of transport and storage.

RESULTS

A total of ten vessels were sampled for this project, with nine having observed organism concentrations below current state, federal, and international Ballast Water Discharge Standards (BWDS) of <10 live organisms/mL for ≥10 μm and <50 μm organisms and <10 live organism/m³ for the and ≥50 μm organisms (Table 1).The one test that failed was a compliance test and exceeded the BWDS for organisms ≥50 μm.

In all sampling events, observed BWMS showed no significant alarms or issues during the treatment process and all ballast water hold times, as defined in the system's USCG Type Approval Certificate, were met. For the three sampled BWMS sampled that utilized active substances as their treatment method, pre-discharge samples showed the oxidant had fallen to levels below the Minimum Allowable Discharge Concentration (MADC) of <0.1 mg/L TRO (Sunrui BWMS) and <0.2 mg/L ClO_2 (Ecochlor BWMS).

Table 1. Ballast Water Management Systems tested and the concentration of live organisms found in each size class (>50µm and between 10-50µm). All tests except on vessels 7, 9 and 10 were performed during Commissioning testing.

Vessel	Ballast Water Management System Model	Technology Type	Source Water Location	Live Organisms >50 µm/m^3	Live Organisms 10-50 µm/mL Average [a] ± SD
1	Alfa Laval PureBallast 3.1	Ultraviolet	Seattle, WA	1.8*	0.3 ±0.6
2	Alfa Laval PureBallast 3.1	Ultraviolet	Selby, CA	6.0	7.7±2.1
3	Sunrui BalClor BC 1500	Electrochlorination	Tampa, FL	0.7*	0.3*±0
4	Ecochlor Series 200	Chlorine Dioxide	Long Beach, CA	0.5*	0.3±0.6
5	Ecochlor ET-5700-5.0	Chlorine Dioxide	Long Beach, CA	1.0*	4.7±1.2
6	Alfa Laval 3.2 Compact Flex 500	Ultraviolet	Nova Scotia, Canada	1.0	0.3*±0
7[b]	Sunrui BC3000	Ultraviolet	Stockton, CA	1.0*	3.3±1.5
8	Desmi CompactClean 500	Ultraviolet	San Francico Bay, CA	1.0*	6±1.7
9[b]	MIURA CO. LTD HK-(E)R	Ultraviolet	Benicia, CA	4.0	0.3*±0
10[b]	1500 TYPE JFE BallastAce	Chlorine	Pacific (Open Ocean)	<1.0*	24.3±6.7

***** Minimum detection limit, no live organisms observed; [a] n=3; [b] Compliance Test

CONCLUSION

The adoption of BWMS to combat the spread of AIS has increased over the past few years as federal, state, and international regulations come into force. Despite the widespread and increasing use of BWMS to manage ballast water, there are currently few regulations in place to assess the biological efficacy and compliance of these systems while in use. The IMO mandated D2 Commissioning Testing is providing some of the first data into how BWMS are being operated, however these tests are generally done shortly after installation and with clean ballast tanks, so likely aren't true representations of the efficacy of a BWMS that has been in service for any amount of time. Furthermore, while there are sampling guidelines, there aren't yet robust standard methods for sample collection and analysis for the labs conducting the sampling, potentially making some of the available data questionable.

Fortunately, for the vessels sampled in the study, the failure rate remained low at 10%. Out of the ten ships sampled, there was only one observed exceedance of the BWDS in the ≥10 μm and <50 μm organism size class. A meta-analysis by the nongovernmental organization (NGO) Global TestNet observed a failure rate of 20% when it came to commissioning and compliance testing of BWMS with the majority of failures occuring in the ≥50 μm size class category (Global TestNet, 2021).

It is also important to note that seven of the ten samplings that occurred were during IMO Commissioning. Commissioning Testing is currently required by the IMO (BWM.2/Circ.70/Rev.1) to ensure a newly installed BWMS is working properly. These tests differ from compliance tests in several important ways. First, the vessel's crew are typically trained by the BWMS manufacturer shortly before the test occurs, ensuring system operation and instruction are followed closely. Second, before a Commissioning Test begins, it is recommended that the vessel clean its ballast tanks. Ballast tank cleaning removes accumulated sediments, where live organisms can potentially escape treatment. Compliance tests are intended to ensure a BWMS is functioning properly after repeated use on a working vessel. Cleaning of tanks and other pre-test measures likely will not be carried out before a compliance test, which will likely provide a better assessment of how the BWMS is functioning. It is also expected that the potential for human error in system operation will be higher as the time increases from initial crew training and BWMS installation.

The successful treatment of ballast water is a product of both a properly working BWMS and a properly trained crew. There will be ongoing challenges for vessel management to ensure that a BWMS is maintained and serviced to the manufacturer's specifications and that all personnel receive regular training to ensure proper operation. By doing so, risk of failure to effectively treat ballast water will hopefully remain low.

RECOMMENDATIONS

Based on the results of this study and from past sampling experiences, GBRC makes the following recommendations for sample collection during compliance checks of BWMS:

- Inspectors/Samplers must communicate with vessel's crew before sampling takes place to receive ballasting operation schedule, pump room layout, and sample valve design.
- The correct fitting required by the discharge sample valve should be determined before boarding the vessel. By doing so, an inspector/sampler will be able to plan accordingly on what compatible adaptor is needed to connect their sampling device.
- Inspectors/Samplers should be prepared for shifting schedules and other delays, which frequently occur in commercial shipping.
- To properly analyze the ≥50 μm organism size class, ≥1 m^3 of treated ballast water needs to be concentrated. It should be agreed prior to arrival how the vessel will accommodate this water, whether by spilling into the vessel's bilge or be siphoned into a nearby holding tank. Sample volume for the ≥10 μm and <50 μm organism size class can be limited to 1L and should be collected from the drip sampler during the length of the sampling event. If that is not

possible, it is recommended to collect the 1L sample in thirds at the beginning, middle, and end of the event.

- Any person collecting or analyzing samples should be trained in Good Laboratory Practices (GLP) to ensure samples are handled and analyzed properly (e.g. per the ETV 2010). Once a sample is collected, it is recommended that analysis occur as soon as possible to limit artificial organism mortality.

REFERENCES

Global TestNet. Submission of the Information concerning the Experience Building Phase of the IMO from members of the Global TestNet. 2021

NSF International. Generic Protocol for the Verification of Ballast Water Treatment Technology. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-10/146, 2010