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Rapid Compliance Monitoring using Indicative Tools

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ABSTRACT

There is an ongoing question as to how ships will demonstrate their ballast water is in compliance with regulations when they pull into ports as well as how port State control might check this. Making a direct measurement of compliance can be a long process requiring skilled scientists and resulting in costly delays. Several companies have developed rapid compliance tools which make indicative measurements based on well-established scientific methods. The question is – what is being done in the maritime industry to show these indicative measurements are truly a good indication of compliance with the ballast water regulations? This paper presents why the 10-50 µm sample size is being used for these indicative measurements, the types of data presented by indicative tools, an overview of the various instruments being developed, and then most importantly, what organisations are validating compliance monitoring and what is the current status of their validations. In addition, some organisations who have already adopted using compliance monitoring in their processes and how they are using it will be included.

Key words: Indicative monitoring, Rapid compliance, Variable fluorescence, PAM fluorescence, Fluorometry, Ballast Water compliance, Phytoplankton, Indicative tools, Meteor

1. Introduction

There is an ongoing question as to how ships will demonstrate their ballast water is in compliance with current regulations when they pull into ports, prior to discharge, and how port State control will check for compliance. Making a direct measure can be a long process requiring skilled scientists and resulting in costly delays. Several companies developed rapid compliance tools which make indicative measurements based on well-established scientific methods. The question is – what is being done in the maritime industry to show these indicative measurements are truly a good indication of compliance with the ballast water regulations?

2. The Basics of Upcoming Ballast Water Regulations

Under the regulations, ships will be required to manage their ballast water and sediments to the D-2 standard and maintain a ship-specific ballast water management plan (BWMP). Ships will also have to carry a ballast water record book (BWRB) and an international ballast water management certificate (IBWMC). Ballast water management standards will be phased in over a period of time. Eventually most ships will need to install an on-board ballast water treatment system and meet the D-2 standard (Figure 1) for discharged ballast water.

Figure 1. IMO/USCG D2 standard for discharged Ballast Water

	Micro organism Category	Control Limit
1	Viable/living organisms, size > 50 µm	< 10 cells/m3
2	Viable/living organisms, size 10-50 µm	< 10 cells/ml
3	Toxicogenic Vibrio Cholerae	< 1 Colony Forming Unit/100ml
4	Escherichia Coli	< 250 Colony Forming Unit/100ml
5	Intestinal Enterococci	< 100 Colony Forming Unit/100ml

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Tiered Monitoring Approach

Port State control guidelines indicate a tiered approach to check for ballast water non-compliance. Level 1 is a simple initial inspection of documentation and crew knowledge. If satisfied, the port State control process could stop at this point. However, if not, level 2 involves a more detailed inspection looking at the equipment operation and the self-monitoring indicators. If satisfied, port State control processes could again stop at this point or, if not, continue to level 3, an indicative measurement of non-compliance. If an indicative measurement cannot be made or if it fails, port State control could then insist on level 4, a direct measure of compliance which would result in a substantial delay to the ship. Accordingly, a lot of work is being done to gain confidence in the different indicative measures in development and in use.

3. Why Phytoplankton for Indicative Monitoring?

As indicated in Figure 1, there are several different size classes of organisms in the D-2 specification. Rapid, indicative tests have mostly been focused on phytoplankton – organisms in the 10-50 µm size class. There are several reasons for this and all of them focus on feasibility of sample analysis. Although zooplankton greater than 50 µm may be easier to see, a cubic meter of ballast water is too large a volume for quick analysis, especially if replicates are desired. There is more flexibility when selecting an appropriate volume for the 10-50 µm test; as small as a few milliliters allows for very rapid analysis with multiple replicates, if desired. Also, there are very well-established scientific methods used for quickly estimating the number of organisms in a sample and identifying the activity or "health" of those organisms. These methods are highly attractive in that they are easy to run and require no reagents – ideal for field work by non-scientists. Fluorescence is one of the more well-established methods used for estimating abundance and the photosynthetic efficiency or "viability" of phytoplankton. The challenge is finding the correct fluorometer or tool to fit the application requirements which are: fast, easy to use, and low maintenance. Regardless of which instrument is selected, it is important to remember that all of these tools provide *indicative* measurements – algae are living, mobile cells and even the established methods for detailed analyses are not considered absolute; all methods have some degree of uncertainty.

Abundance of Algae

Abundance, in this regard, represents the cells/ml concentration of the 10-50 µm organisms in ballast water and can be determined using specific fluorescence. Light from the fluorometer is shined into a sample of water. Algae absorb the light and instantaneously fluoresce, giving off multiple wavelengths of light termed bulk fluorescence. Typically, the bulk fluorescence is quantified and correlated with count estimates; however, the method used here utilises specialised filters to select a specific band of wavelengths from the overall fluorescence detected. This specific band of wavelengths is quantified, converted to a digital number, and displayed as an abundance (cells/ml) estimate. The selection of this specific band of wavelengths has been shown to provide a good correlation with microscopic quantification. Factors such as light or nutrient stress, hysteresis, algal phases, speciation, etc. will affect the absorption cross section of the cells ultimately impacting the amount of fluorescence output, but the impacts can be minimized and stabilized to some extent using wavelength filtering as explained above.

Activity of Algae (Viability)

Most indicative tools in development use some form of Pulse Amplitude Modulated (PAM) fluorometry to estimate photosynthetic efficiency, or Activity, of algae in the 10-50µm size

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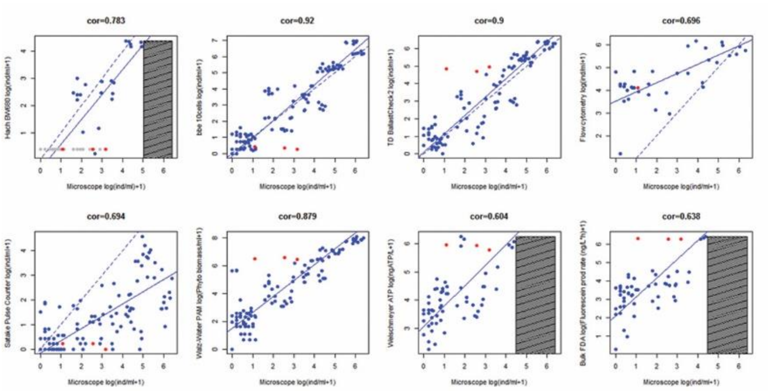
class. First, the sample is monitored using a very low level intensity of light so as to not induce a change in the algal state, specifically the chlorophyll reaction centers. While continuously monitoring the sample using the low intensity light, high intensity light is introduced to saturate the sample, effectively closing the chlorophyll reaction centers, stopping photosynthesis, and bringing the algal cells to a maximum fluorescence state. Activity is then calculated using the fluorescence responses from these two fluorescence states. The Activity represents the photosynthetic capability of the algal cells in the sample termed “health” or, with respect to discharge standards, “viability” of algae.

4. Data from Rapid Compliance Tools

Rapid compliance tools typically provide an easy-to-identify risk assessment expressed in words or colours and, although they utilise similar approaches, they result in slightly different responses. Some assess risk based on a combination of both the quantity and the photosynthetic efficiency of cells. This approach provides a cell count independent of the viability measurement and risk is assessed using both parameters measured. In this case, more detailed information is being reported, allowing for more accurate counts as opposed to methods that are solely based on the photosynthetic efficiency of cells for assessing risk in response to UV treatments. Whether that detailed information is required or preferred has yet to be determined. Regardless, several of these approaches have shown good correlations as detailed in Figure 2.

Figure 2: METEOR data showing 10-50µm Indicative Tools correlation with Microscopy
Data belongs to METEOR participants. Funding by BSH and DFO



A key feature of the indicative tools is that they respond to all treatment types as they reflect both a reduction in cells and also a reduction in viability or health of algae.

5. Continuous or Discrete Indicative Monitoring Tools

Both continuous and discrete indicative monitoring tools are being developed with each approach offering distinct benefits. An advantage of continuous systems is that they are sampling continuously meaning they can sample large volumes of water to generate large data sets. An advantage of discrete tools is that they offer an independent verification of the ballast water treatment system which can be performed when desired. Also, discrete tools require very little or almost no maintenance or cleaning. Both continuous and discrete tools provide documentation that a port state officer might request during an inspection.

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6. Validating Indicative Tools

Regulatory agencies as well as scientists have been working to validate as to whether indicative tools provide a good indication for risk of non-compliance. Some regulatory agencies involved in validations include United States Coast Guard (USCG), German Federal Maritime and Hydrographic Agency (BSH), and California State Lands Commission (CSLC).

The USCG worked with Naval Research Lab (NRL) and Alliance for Coastal Technologies (ACT) to validate six different indicative tools. They performed one set of laboratory-based experiments and three sets of field-based experiments in three different locations offering fresh, brackish, and marine water in mesotrophic, oligotrophic and eutrophic conditions. Reports are expected in spring of 2017 but preliminary results were reported as promising. BSH funded a two week sampling voyage aboard the RV Meteor led by the Department of Fisheries and Oceans out of Canada (DFO) which included 19 researchers from 10 different countries performing 28 experiments with multiple analytical tools and sampling devices. They used 10 different instruments specifically focused on the 10-50 µm samples alone. Figure 2 shows several indicative tools correlating well with microscopic analyses.

CSLC is striving toward even tighter regulations than the USCG and has been validating indicative tools. Their results are also promising and they plan to include a compliance monitoring step in their protocol expected to be issued in early 2017. The International Maritime Organization is proposing collection of compliance data for several years to determine the best path forward.

As mentioned, oceanographers & aquatic biologists have utilised fluorometry techniques for decades when attempting to detect or quantify chlorophyll in marine or freshwater environments. It is considered a standard assay and an important parameter in almost any research effort. Consequently, those scientists now involved with ballast water quickly looked to fluorometry and have been performing validation work for many years. They are doing both land-based and shipboard tests, comparing results from indicative tools with microscopic cell counting – the established “ground truth” method for direct measurement.

7. Using Indicative Tools

The use of indicative tools is expanding – companies providing testing services, ballast water treatment system manufacturers, sampling system manufacturers, and ship operators; all have used indicative tools. Testing services use them as an indication of whether detailed analysis is required, treatment system manufacturers use them to ensure challenge conditions are adequate before beginning system testing as well as an initial indication of the treatment system effectiveness, sampling system manufacturers use them coupled with their samplers to provide complete sampling and analysis, and ship operators have started using indicative tools to get a quick indication of their risk of non-compliance.

8. Conclusion

The uptake and discharge of ballast water is a dynamic process. Regulatory bodies and scientists are investigating how best to monitor and test ballast water to demonstrate compliance. Portable devices utilizing fluorometric techniques are of high interest and are currently the leading technology. Although no regulatory agency has officially endorsed any indicative measurement tool, fluorometry is gaining acceptance and being used worldwide.

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