A VERIFICATION OF A REMOTE MONITORING OF RESULTS OF BALLAST WATER MANAGEMENT SYSTEM

Goran Bakalar¹, Myriam Beatriz Baggini²,
¹Bonum Mare Consulting LLC, 148 Young Ave, Cocoa Beach, 32931, FL, USA
²Bonum Mare Consulting LLC, 148 Young Ave, Cocoa Beach, 32931, FL, USA

Abstract:
Remote monitoring of BW (ballast water), after being treated by any BWTS (Ballast Water Treatment System) on board ships is the only autonomous detection system for this purpose suggested at this time. The experience from ships indicated operational problems with the treatment of ballast water on board the ships. Another problem, confirmed by scientists, is re-growth of microorganisms after the treatment. Automated monitoring of treated BW on ships is a solution. It was specified, described and mathematically proved and verified in this article. Sophisticated part of this system, flow cytometer, needs some specific conditions for the operation. Important pressure reduction is an obligation and was explained and suggested the procedure and possibility of implementation. Remotely operated from land, this system improves traffic environment. Result of this study is a verification that brings up more trust in this automated system that verifies contents of ships’ ballast water before a ship enters a port.

Keywords: remote operations, monitoring devices, ballast water management, flow cytometer

1. Introduction

After and during the cargo loading from commercial ships, water is taken to ensure ship's strength and stability. This water is called ballast water. Non-native marine species arrive in ports via ballast water which is being discharged while the cargo is loaded. The BWMC (Ballast Water Management Convention) 2004 protects the sea environment through regulations regarding ballast water treatment (Bakalar, 2011). Therefore, most of ships will have to treat ballast water once the Convention comes into force. Regulations and standards established in D-2 regulation (Globallast, 2016) of the Convention, by the IMO (International Maritime Organization), require treatment limits to be met independently and calls for vessels to carry out monitoring themselves (Albert et al., 2013). Many successful, type approved technologies have been suggested for ballast water treatment (EPA, 2011; Lloyd's, 2014), such as disinfection with chlorine (Simpson, 2011), injecting chemicals (La Carbona et al., 2010), adding biocides to ballast water for the neutralisation of harmful microorganisms, sterilisation with ozone (Perins et al., 2006), filtration with UV (ultraviolet) light (Suherland et al., 2003), electro-ionization (Aliotta et al., 2001), exposure to cavitation (Cvetković et al., 2015; Cvetković et al., 2016), and magnetic separation (Ren et al., 2016). Some of the suggested type approved systems are more effective in neutralizing microorganisms such as bacteria and zooplankton and other systems cannot treat them so well. No system can inactivate all microorganisms in ballast water. Some states require implementation of sampling of treated ballast water before they approve and sign the Convention. The solution verified by authors in this article is a monitoring system that could be implemented in the maritime industry. A shipping company would make an additional confirmation of high quality of their operations if they implement this automated remote autonomous system in their fleet.

2. Materials and methods

Certain systems for detection of ballast water were suggested by scientists (Bakalar and Baggini, 2016; Bakalar and Baggini, 2016a; Bakalar and Tomas, 2011). It can be indication monitoring or compliance monitoring within required treatment limits. Indication means that the detection result proves that a treatment was performed. Compliance monitoring results show the exact amount of certain microorganism in a sample of ballast water. Some of the indication monitoring technologies work with enzymes and total energy detected in a sample. Another technologies, like Pulse-Amplitude-Modulation (PAM) fluorometry, measure fluorometric character of a particle (Schreiber, 2004). The amount of remaining energy or enzimes is a proof of whether a ballast was treated at all or not. Flow cytometer is a detection sensor device of compliance monitoring and needs an operator just to calibrate it using a computer after each completed detection (Bakalar, 2014). The time of DNA detection in laboratories has been shortened from days in the past down to three hours (Asai et al., 2003). Flow cytometer is capable to scan 10,000 different particles per second (Bakalar, 2013). It detects all different DNA of the smallest microorganisms. That is needed because the smallest microorganisms were not included in BWMC 2004 (van Der Star et al., 2011). Also, regrowth of treated microorganisms (Grob et al., 2016; Liebich et al., 2012; Macintyre et al., 2016) would be controlled in this way. It is important that this detection sensor is capable to be operated autonomously and remotely. All other detection methods and their devices need significant operational assistance by humans (Bakalar and Tomas, 2016).

2 Corresponding author: Goran.Bakalar@xnet.hr
2.1. Automated autonomous remote system of detection of ballast water contents

Flow cytometer has been suggested by certain scientists to monitor chemical pollution from the ships in coastal areas (Bakalar et al., 2011). In Fig. 1 is a drawing of a system that has been suggested for early discovery of unwanted ballast water contents, using fixed flow cytometer, filtration of scanned data and communication sub-system that automatically transfers data from the ship to a land office. This system includes sub-systems and remote operation from the shore side office, autonomous from ship's crew. Flow cytometer could be fixed onto the ballast water pipeline system at the location that is available for detection of all ballast water tanks on board ship.

![Diagram of a system with land office, satellite communications, ship's computer, and flow cytometer](image)

This system has been applied for a patent and it was presented in scientific and IMO conferences and published in scientific journals (Bakalar, 2015; Bakalar, 2016). The main purpose of this detection system is to timely, automatically and autonomously from ships' crew members, sample treated ballast water and send the information of ballast water status on a ship, to the land office. This system includes sub-systems and remote operation from the shore side office, autonomous from ship's crew. It is a remotely operated ship's ballast water detection system from land-based office. Remote communication of sensor data in ballast water treatment systems was researched (Kim et al., 2014) and trend analysis and diagnosis for BWTS remote monitoring of proper dosage in neutralization unit was analyzed (Choi et al., 2014). A fixed flow cytometer on the ship is remotely run that analyses treated ballast water with recirculation (Bakalar, 2012). The data of the flow cytometry scans are transmitted by an INMARSAT satellite communication system. Flow cytometer detects data after the dosing pump (inside the flow cytometer unit) takes on and off the samples. The software filters detected data after that. Software is programmed to filter and archive just needed information (related to D-2 regulation of BWMC 2004) (Bakalar, 2013). INMARSAT communication system transfers data on time, tunneling privacy with firewall network protection. The operator in land office performs remote control of ballast water. Remote operation is already in use in maritime industry for remote maintenance and supervision of some other processes on ships (Bakalar, 2012a). The control of contents of ballast water is remotely operated by the automatic detection of ship’s ballast water via satellite communication from land. It commences before the ship enters the port in which cargo will be loaded, in a manner agreed upon by the staff from the office located on land and the staff that is located on ship. Remote operation in this system includes opening valves of ballast water tanks, operation of ballast pump and operation of flow cytometer detection. Once the detection with negative results is completed, the operator in land office grants permit for the ship to enter port with confirmed clean ballast. If the result of detection was positive, the operator will not grant permit to ship to enter the port since flow cytometer detected discrepancy to D-2 regulation of the Convention. In Fig. 2, the pipelines flow cytometer unit are adjusted to reduce the pressure that has been driven from main ballast water pipeline into the flow cytometer detection unit.
One of the most important conditions for flow cytometer, that needs to be verified, is the flow pressure of sampling water. The pressure cannot be higher than 2 bars, otherwise a flow cytometer would not be in proper operation (Bakalar, 2015). Verification of possibility of pressure reduction, in accordance with the drawing and suggestion in Fig. 2, is in following section.

3. A verification of the automated autonomous remote system of detection of ballast water contents

In following calculation is confirmed a pressure loss in flow cytometer unit. The pressure has to be lowered below 2 bars. That is a basic working condition for flow cytometer operation. As an example is taken a ship long L= 250 m, with width B= 50 m, height of bulhead deck D= 25.

Inner diameter $d_u$ is defined as follows:

$$d_u = 1.68 \sqrt{L \times (B + D)} + 25 \text{ mm}$$  \hspace{1cm} (1)

and calculated diameter of ballast water pipeline is:

$$d_u = \sqrt{250 \times (50 + 25)} + 25 \text{ mm} = \sqrt{18750} \text{ mm} = 161.93 \text{ mm}$$  \hspace{1cm} (2)

Ballast water flow through the pipeline is, in this case, stationary because the water fills whole inner diameter in the pipeline pressurised and driven by ballast pump maximum capacity of $2000 \frac{m^3}{h}$ ili $0.555 \frac{m^3}{s}$.

Pressure drop in a ballast water pipeline is in depend to inner resistance. Inner resistance is in depend of kind of flow, temperature and speed, and, the most important for this study, numerous kinds os narrowings in a pipelines system. The first pressure loss can be on T-connection, as shown on Fig. 2. That is the first connection of flow cytometer unit and ship's ballast water pipeline system. Next pressure reduction point is at inlet non-return valve of cytometer unit. Loss factor used for pressure loss in T-connection is $\xi = 0.11$, added to pressure loss because of narrowing the space in the pipe of (calculated in 2nd equation) $161.93 \text{ mm}$ into $120 \text{ mm}$ in relation $\xi = \frac{120}{162}$. Pressure drop $\xi$ of the narrowing at the valve is in relation to human operator and his decision or it was automatically ordered. Automatic valve can be narrowed of 30% of inner diameter in relation $\xi = \frac{80}{120}$ and pressure could be lowered down to required pressure by pump capacity that also can be regulated automatically or by operators' decision. Important factor is ballast water velocity:

$$v = \text{ballast water flow velocity} \frac{m^3}{s}$$  \hspace{1cm} (3)

$\xi$ of T-connection and narrowing of inner diameter of flow cytometer pipeline is
Redundancy and a known malfunction index for these types of devices in maritime industry, marketing, reputation of shipping companies, ballast water treatment system performance of BWTS on ships. Experience in operational ballast water treatment systems on board the ships, the trust in this subsystem has been proven. The computing part of the subsystem in the system with two parallel subsystems, one of which is redundant, will be regularly maintained by operator and by self-diagnosing automatic function errors removal (Bakalar, 2016; Bakalar and Tomas, 2016). In this way, the possibility of malfunction of some ballast water treatment systems on board the ships is lowered. Malfunction index or failure for maintenance which is impossible to be diagnosed and automatically removed for this type of device of reliability for 1000 hours of work. Reliability of this type of sophisticated systems on ships was calculated in previous certain research and it was \( R(t) = 0.704688 \) (Bakalar, 2013). Total reliability of the whole computing subsystem as a part of some ballast water treatment systems on board the ships was 3.37642. The measured pressure in main ship’s ballast pipeline, at the beginning of this calculation, was 5 bar. The pressure was reduced down to 1.62358 bar and required pressure < 2 bar was verified. That pressure is good enough for proper flow cytometer function.

Malfunction index in this system is the relation between malfunctioning components and proper components:

\[
\lambda = \frac{1}{P_c} \frac{dP_f}{dt}
\]

where \( P_c \) is the number of components which remained in proper functionality after a specified time, and \( P_f \) is the number of components which remained malfunctioning after the specified time of function.

Reliability of sophisticated part of the system is:

\[
R(t) = P_c(t) = e^{-\lambda t}
\]

which means that reliability in the function of time depends on probability of proper function and failures in specified time.

4. Discussion

Redundancy is the characteristic of computing system quality that ensures failure avoidance when a part of the system fails. This is most commonly ensured with additional spare software, by reliability of the two systems working parallelly with achieved redundancy and a known malfunction index for these types of devices in determined on board the ships conditions. It has been assumed in previous researches that the computing part of the subsystem in the system with two parallel subsystems, one of which is redundant, will be regularly maintained by operator and by self-diagnosing automatic function errors removal (Bakalar, 2016; Bakalar and Tomas, 2016). In this way, the possibility of malfunction of some ballast water treatment systems on board the ships is lowered. Malfunction index or failure for maintenance which is impossible to be diagnosed and automatically removed for this type of device of reliability for 1000 hours of work. Reliability of this type of sophisticated systems on ships was calculated in previous certain research and it was \( R(t) = 0.704688 \) (Bakalar, 2013). Total reliability of the whole computing subsystem as a part of some ballast water treatment systems on board the ships which consists of the two units of which one is software redundant is \( R(u) = 0.93097 \) (Bakalar, 2013). After the analysis of the reliability of the computing system, which is a subsystem of certain ballast water treatment systems on board the ships, the trust in this subsystem has been proven. The computing subsystem reliability with eventual use of redundant software is 0.931 or 93.1%. That reliability also has to be proven in the operations on board the ships. There were reported experienced operational problems with BWTS on ships (Bakalar, 2016a) and it was suggested action similar to suggestion in certain previous research (Bakalar, 2011a). System reliability of mechanical parts and system software reliability of 93.1% means that 6.9% of the operational time of any of the mentioned systems could be in failure or under repair. That is a high risk for the operation of BWTS and detection system verified in this study will be of great help in verification of results of performance of BWTS on ships.

5. Conclusion

Experience in operational ballast water management is hidden back data today. That is reasonable because of the profit in the maritime industry, marketing, reputation of shipping companies, ballast water treatment system
inventors and institutes where the systems were tested and certified. Accidents data or malfunction and failure data of installed ballast water treatment systems are not available except to owners, classification companies or insurers. The only way for scientists to confirm proper performance of BWTS is to suggest control and supervision. Verification in this study helps to better understand a supervision system suggested in a previous research.

**References**


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