Shipboard Ballast Water Treatment Systems on Seagoing Ships

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This review paper summarizes the legislative framework and the available technologies for ballast water treatment with regard to the approval process and relevant issues. The International Maritime Organization (IMO) sets the limits of organism concentration in ballast water allowed to be discharged into the sea. The 2004 *International Convention for the Control and Management of Ships Ballast Water and Sediments* is the first international document that introduced obligatory ballast water management and control. Even though ballast water treatment systems are not 100 % effective, they significantly reduce the risk of spreading of invasive species through ballast water exchange. An increased manufacturer interest in the system's approval or development of new technologies is not expected in future because the procedure is time-consuming and expensive. The final choice of optimal ballast water treatment system depends on the ship owner or operator taking into account the price, type of the ship, whether it is a newbuilding or an existing ship, ballast system capacity and the seas where ships ply as well as harbours at which they call.

KEY WORDS

~ Ballast water
~ Treatment systems
~ Ballast Water Convention
~ Marine environment
~ Pollution

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1. INTRODUCTION

In the modern sea traffic ballast water is recognized as a possible source of serious and dangerous ecological, economic and health issues, which can result from the transfer of organisms in ship's ballast water tanks. It has recently been estimated that 4 billion tons of ballast water are used around the world every year (Tsolaki and Diamadopoulos, 2010). The concentration of organisms per liter of ballast water is estimated as follows: 100-102 zooplankton, 103-106 phytoplankton, 108-109 bacteria, and 109-1010 viruses (Ruiz and Reid, 2007).

In 1903 an alga *Biddulphia sinensis* originating from the seas of Asia was discovered, which foreshadowed the effect of organism transportation between different ecosystems. However, it was not until the 1970s that the problem became subject of extensive research. In 1991 **Resolution 50 - *International Guidelines for Preventing the Introduction of Unwanted Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges*** (http://www.imo.org/blast/blastDataHelper.asp?data_id=15624&filename=50(31).pdf) was published by the Marine Environment Protection Committee as the first important document which dealt with the issues of organism transportation in ballast water.

The next important step was to establish the guidelines set on the 20th IMO assembly. The guidelines are described in the **Resolution A.868 - *Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens*** (http://www.imo.org/blast/blastDataHelper.asp?data_id=22649&filename=A868.pdf). According to the guidelines from 1997 all ships that carry ballast water have to have ballast water management plan. The guidelines also contain recommendations for port authorities in order to provide adequate facilities to receive or process ballast water. The receiving ports are also responsible for providing information on their requirements to ships, as well as the information on the availability, capacities and applicable relevant fees of ballast water and sediment reception facilities.

2. INTERNATIONAL CONVENTION FOR THE CONTROL AND MANAGEMENT OF SHIPS' BALLAST WATER

The 2004 *International Convention for the Control and Management of Ships' Ballast Water and Sediments* is the first international document that introduced obligatory ballast water management and control (http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships%27-Ballast-Water-and-Sediments-(BWM).aspx). The legal basis for the Convention is: *the United Nations Convention on the Law of the Sea* (UNCLOS, 1982), *Convention on Biological Diversity* (CBD, 1992), *IMO Convention Resolution IV/5* (COP 4, CBD, 1998), *IMO Convention Resolution VI/23* (COP 6, CBD, 2002), *Rio Declaration on Environment and Development* (IMO assembly Resolution MEPC 67/37, 1995), *IMO assembly Resolution A 774* (1993) and *A 868* (1997) (Briski, 2014).

The Convention consists of two parts: the main part (22 articles) and the rules for the control and management of ships' ballast water and sediments (Sections A-E). The convention includes two attachments: the examples of *Ballast Water Management Certificate and Form of Ballast Water Record Book*.

In Section D of the Convention there are two types of standards for Ballast Water Management: *Ballast Water Performance Standard* D-2 regulation (Table 1), and *Ballast Water Exchange Standard* D-1 regulation.

Table 1.
IMO D-2 Standard for ballast water discharge.

Microorganism category	**IMO Standard**
>50 µm Zooplankton	< 10 viable cells / m^3
10-50 µm Phytoplankton	< 10 viable cells / ml
Vibrio Cholerae bacterium	< 10 cfu /[1] 100 mL or <1 cfu/1 gram (wet weight) zooplankton samples
E. Coli bacterium	<250 cfu/100 ml
Intestinal enterococci bacterium	<100 cfu/100 ml

Table 2.
Timeframe for introducing the Convention Ballast Water Treatment Standards (modified from: http://www.lr.org/en/marine/consulting/environmental-services/ballastwatermanagement.aspxfrom).

Ballast tanks capacity (m3)	Year of ship construction	First next class review for renewing certificates - a year after ship's delivery								
		2009	2010	2011	2012	2013	2014	2015	2016	2017
< 1500	< 2009	D-1 or D-2								D-2
	in 2009	D-1; D-2 until the second annual class inspection, but not after 31st December 2011, or until the Convention takes effect, whichever comes later								
	> 2009	D-2 (at the time of ships delivery or when the Convention takes effect, whichever comes later)								
≥ 1500 or ≤ 5000	< 2009	D-1 or D-2						D-2		
	in 2009	D-1; D-2 until the second annual class inspection, but not after 31st December 2011, or until the Convention takes effect, whichever comes later								
	> 2009	D-2 (at the time of ships delivery or when the Convention takes effect, whichever comes later)								
≥ 5000	< 2012	D-1 or D-2								D-2
	> 2012	not applicable			D-2 (at the time of ships delivery or when the Convention takes effect, whichever comes later)					

D-1 regulation is applied during a transitional period until adequate conditions for the application of D-2 regulation are created (Table 2). According to D-1 regulation a ship must exchange at least 95 % of ballast water volume. Moreover, the Convention B4 regulation even prescribes the place of the exchange. The place should be at least 200 nautical miles away from the nearest land and at the minimum of 200 m depth. If by any chance these regulations cannot be complied with, the exchange should then take place at a distance of at least 50

1. CFU (Colony-Forming Unit), in microbiology, a number of units that form a colony.

nautical miles away from the nearest land and at the minimum depth of 200 m. It is the master's responsibility to make a decision on ballast water exchange taking into account the safety and stability of the ship and its crew members and/or passengers. The master should also take into consideration weather conditions and possible technical difficulties or extraordinary circumstances.

Marine Environmental Protection Committee (MEPC) is IMO technical body related to marine pollution issues. MEPC is assisted by IMO sub-committee for *Pollution Prevention and Response* (PPR). In order to adopt the Convention MEPC authorized an advisory committee *Group of Experts on the Scientific Aspects of Marine Environmental Protection* GESAMP in 1969. GESAMP provides scientific and technical support to undertake in-depth studies, analyses and reviews of specific topics (http://www.gesamp.org/). The GESAMP Ballast Water Working Group (GESAMP-BWWG) consists of independent experts who review proposals for Ballast Water Management systems. GESAMP-BWWG does not evaluate the operation or design of the systems, or their effectiveness but only environmental and human health risks. They report their reviews to MEPC and propose *Basic* or *Final Approvals* of the BWT system. These proposals are discussed on regular MEPC sessions.

BWT systems are approved in accordance with *Guidelines for Approval of Ballast Water Management Systems* - G8 Guidelines (IMO Resolution MEPC.174(58)) while systems that use active substances are approved in accordance with *Procedure for Approval of Ballast Water Management Systems that make use of Active Substances* - Procedure G9 (IMO Resolution MEPC.169(57)). Active Substance is an inorganic substance or organism that affects aquatic organisms or pathogens.

Methodology for information gathering and the conduct of work of GESAMP-BWWG (BWM.2/Circ.13/Rev.1.) defines *Basic Approval* as an approval of active substances and Ballast Water Management Systems in accordance with regulations of the Convention and it should inform about potential risks regarding the use of active substances. It is highly recommended that the residual toxicity of ballast water is measured in all types of water (sea, fresh water, brackish water) where ships navigate to clearly state the limitations of use. *Final Approval* involves an obtained Basic Approval and an approval of the use of active substances, or a preparation according to IMO Convention. It also gives an assessment of the whole *effluent toxicity* (WET). The testing is conducted as a part of the homologation procedure for granting type approval for a certain system in accordance with the conditions listed in MEPC 174(58). Final Approval is supposed to confirm any Basic Approval findings in all operating conditions within the set limits.

The procedure of obtaining the necessary certificates for built-in ballast water treatment systems that use active substances is carried out in the following steps:

1. In accordance with *Procedure for Approval of Ballast Water Management Systems that make use of Active Substances* (G9) the manufacturer must be granted a recommendation by GESAMP-BWWG following the current BWM.2/Circ.13/Rev.1. Based on that recommendation MEPC grants a basic approval on its next regular session.
2. Type approval is part of the procedure for obtaining final approvals and it needs to be obtained in accordance with *Guidelines for Approval of Ballast Water Management Systems* (G8) and the instructions of the ships Flag Administration.
3. After its installation, system review is carried out by a recognized organization (RO), i.e. by a classification society, following the authorization and instructions of the ship's Flag Administration.

The procedure of obtaining the necessary certificates (Figure 1) for built-in ballast water treatment systems that do not use active substances is carried out in the following steps:

1. Type approval obtained in accordance with *Guidelines for Approval of Ballast Water Management Systems* (G8) and instructions of the ships Flag Administration.
2. System review, after its installation, is carried out by a recognized organization (RO), i.e. by a classification society, following the authorization and instructions of the ships Flag Administration.

IMO also requires the installation of sample collection system in order to verify the effectiveness of the system and its accordance with prescribed values after the installation or while operating. It should be situated as close to the discharge as possible. There are very detailed descriptions of ballast circulation sampling points and equipment allowed to use. The main condition is to disable shear strains or any disturbance in the stream while redirecting sample lines from the main stream. Its goal is to ensure that the samples are representative, i.e. to ensure that the redirection process does not destroy living organisms in the ballast and thus provide a false image of the systems effectiveness.

It is important to note that MEPC/GESAMP-BWWG issues a decision on environmental effect while the ship's Flag Administration assesses systems in accordance with the prescribed standards. A system approved by one state is not automatically approved by other states, which can pose a problem once the Convention officially takes effect. The best way to solve the problem is to fully standardize analysis and evaluation procedures as well as sample collection procedure. Compared with other IMO type testings this is by far the most extensive procedure in term of human resources, time and costs. In accordance with G8 guidelines, homologation testing of Ballast Water Treatment Systems needs to be carried out in a land-based facility and on board ships and it lasts for at least 6 months. Regulations established by the Convention have

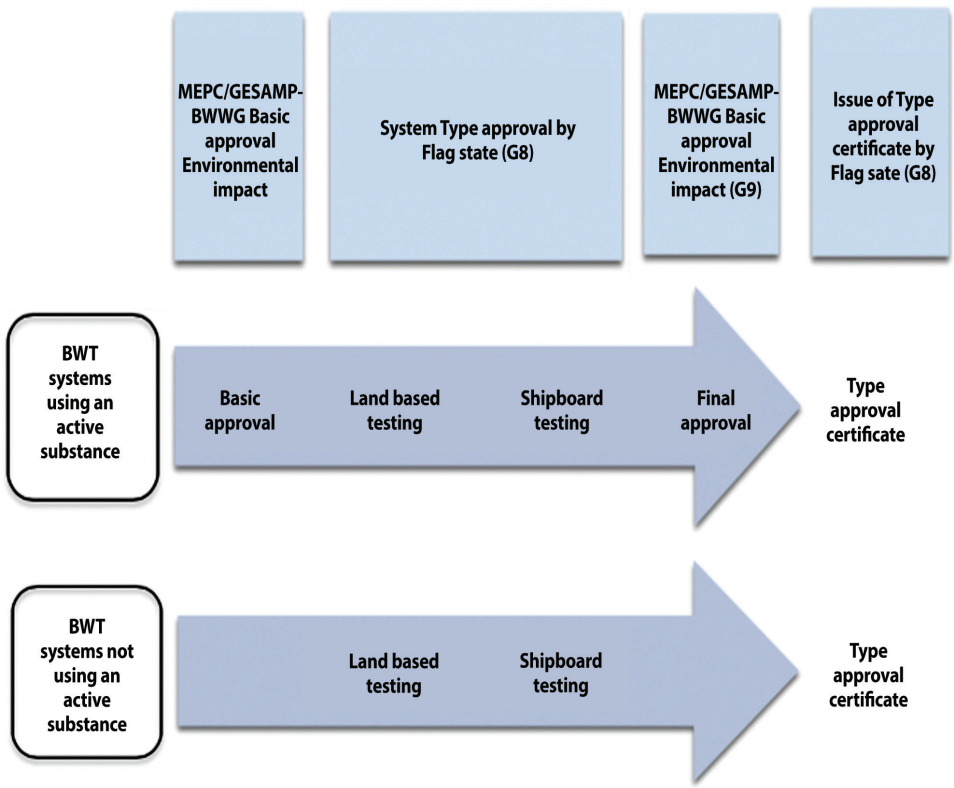

Figure 1.
The procedure of approval of Ballast Water Treatment according to the Convention.

some disadvantages. For instance, the Convention defined a transitional period for the regulation implementation, new ballast water treatment technologies requires considerable financial investments and qualified staff. Those are possible reasons for slow application of standards set by the Convention.

In the past ten years many new systems for ballast water treatment and exchange were introduced on board in order to meet the standards. A small number of newbuildings are equipped with whole-scale ballast water cleaning systems. On most of the newbuildings there are space and electrical power supply planned before installing.

In some states (Argentina, Australia, Canada, New Zealand and the USA) legislature regarding ballast water is more restrictive than the Convention despite the fact that the Convention has not been ratified yet.

3. CRS CIRCULAR

Regardless of the fact that the Convention has not been adopted yet, the Republic of Croatia issued its own ordinance on ballast water management and control requiring the Ballast Water Management Plan and Ballast water reporting form. *Croatian Register of Shipping (CRS) Circular QC-T-189* gives an overview of basic requirements of the Convention. In further editions (1 to 5), it regularly keeps track of any changes and new documents regarding the Convention (http://www.crs.hr/Portals/0/docs/hrv/tehnicke_okruznice/QC-T-189%20rev%205.pdf). *CRS regulations on statutory certification of seagoing ships* will cover the Convention requirements as well as the content of the circulars regarding ships' ballast water and sediments management in Section 9. The ordinance took effect without Section 9 because the Ministry of Maritime Affairs, Transport and Infrastructure requested improvements to be made in the area of navigation III (international navigation in the Adriatic sea). A Committee was formed to find an acceptable solution.

4. BALLAST WATER EXCHANGE AND TECHNOLOGIES FOR BALLAST WATER TREATMENT

Regarding the requirements established in the Convention, all vessels conform to D-1 or D-2 regulation for ballast water management. At this moment, Ballast Water Exchange (BWE) is

Table 3.
Mechanical, physical and chemical methods for BWT.

Name of the system	Operating principle	Disadvantages
Mechanical methods		
Filtration	Porous barriers or small nets stop the particles	• low energy efficiency • dimensions of the system • problem with sediment discharge • problems with smaller particles
Cyclonic separation	Powerful centrifugal force separate heavier particles	• low energy efficiency • dimensions of the system • problem with sediment discharge • problems with smaller particles
Physical disinfection		
Cavitation and ultrasound	High amplitude sound energy and frequency destroys cell membranes	• risks for human health and safety • negative effect on ship hull
Heat treatment	High temperature kills organisms	low energy efficiency unless residual heat is used
Deoxygenation (inertization)	Organisms suffocate due to oxygen deficiency	ineffective in removing anaerobic microorganisms in short-range navigation conditions (less than 4 days)
UV radiation	Ultraviolet radiation kills microorganisms	• ineffective in removing suspension and larger organisms • low energy efficiency • dimensions of systems, • inability to discharge ballast by gravity
Chemical treatments		
Chlorination, chlorine dioxide, electrolysis	Chlorine kills organisms	• ineffective in areas of low salinity ineffective against cysts • produce unwanted chlorinated hydrocarbons and trihalomethane • can increase corrosion • inevitable secondary neutralization of residual hypochlorite during ballast discharge • difficulties with electrode maintenance and replacement • demanding system management
Ozonation	Bromine kills organisms	• low energy efficiency • reduced efficacy with larger particles, difficulties with ozone leakage detection • corrosion of the ballast system • neutralization during de-ballasting process
Peraclean® (peroxyacetic acid, peracetic acid, hydrogen peroxide)	Oxidation kills organisms	• relatively expensive • problem of global availability • necessity of storage space
Seakleen® (vitamin K, menadione)	Vitamin K3 kills organisms	• inevitable secondary neutralization • problem of global availability

the principal method of ballast water management. Regardless of its simplicity, BWE is not effective enough, so certain rules must be followed. Namely, after emptying the ballast tanks, residual sediment is often found, so the procedure needs to be carried out repeatedly for a longer period of time. Since current IMO criteria require the exchange of minimum 95 % of the water, it is necessary to find the best way of emptying the tanks. The tanks are usually emptied using two methods: the pumping-through method (flow-through exchange) and the sequential method. Both methods require the exchange of greater volume of water in the tanks over a longer period of time. There are some disadvantages related to these methods, e.g. increased mechanical strains of the ship's structure, propeller insufficient emergence during the procedures, additional working hours for crew members, increased risk of high pressures of pumped water damaging the tank walls, etc. BWE is sometimes hardly feasible, e.g. in adverse weather conditions. Furthermore, the concentration of coastal plankton organisms will be decreased only by 80-95 % using BWE if carried out by strictly following the guidelines and regulations (Ruiz and Reid, 2007).

5. BALLAST WATER TREATMENT TECHNOLOGIES

Even though ballast water treatment systems are not 100 % effective, they significantly reduce the risk of spreading of invasive species through ballast water exchange. In some states (Argentina, Australia, Canada, New Zealand and the USA) legislature regarding ballast water is more restrictive than the Convention despite the fact that the Convention has not been ratified yet.

The methods of ballast water treatment (Table 3) can be classified as:

- mechanical methods of particle separation (filtration, cyclon separation),
- physical methods of treatment (cavitation, ultrasound, heat treatment, deoxygenation, ultraviolet radiation),
- chemical treatment by active substances (chlorination. electrochlorination, ozonation, treatment with chlorine dioxide, hydrogen peroxide, menadione/vitamin K),
- various combinations of the above mentioned treatments.

Mechanical methods of BWT are filtration and cyclonic separation (hydrocyclones). In ballast water treatment systems, *filtration* is used to remove larger marine organisms and improve the efficacy of secondary treatment (Briski, 2014). By using this ecologically acceptable method of BWT based on the physical separation of solid phase (plankton and sediment) from liquid phase (sea water), the number of different organisms in filtered water significantly decreases, but not to the level required by the IMO standards established in the Convention. This procedure is usually used to remove organism size from 10 to 50 μm, with 91 % efficacy (Parsons, 2003). However, since this method of BWT does not have any by-products such as heat or chemical residue, filtration is found to be one of the ecologically most acceptable methods of water treatment. *Cyclonic separation* is a method similar to filtration regarding cost/benefit ratio. It uses hydrocyclones to create a vortex that drives organisms away in one direction and water in another. This method does not require significant pressure of water pumping like filtration (Tsolaki and Diamadopoulos, 2010). Unlike filtration, which requires regular check and replacement of filters that can be clogged with sediment, cyclone separation devices do not need to be significantly maintained since they do not have mobile parts (Jing et al., 2012). However, cyclone separation is less effective in separating the zooplankton, microalgae and bacteria from the water (Jing et al., 2012).

Physical disinfection. Systems that use *ultrasound* are also effective in organism removal. *Cavitation* is used as an additional treatment method in various systems, but difficulties are possible when water is pumped at a flow rate higher than 5,000 m^3/h. Potential health and safety risks must not be disregarded, as well as the potential effect of repeated exposure of ship hull to high-frequency waves. *Heat treatment* can use ship engines or backup heaters and it does not use any additional energy, which makes it energy efficient, especially in warm waters. Ballast water can also be heated by microwaves but it can significantly increase the temperature in the tanks (Tsolaki and Diamadopoulos, 2010). *Deoxygenation* methods use inert gases or a sudden drop in pressure. Since crude oil and product tankers already have inert gas systems, they can use it for deoxygenation. This method is ineffective in removing anaerobic microorganisms (Tamburri et al., 2002), but it kills about 99 % sea-water zooplankton (Tsolaki and Diamadopoulos, 2010). Oxygen removal from the tanks also prevents corrosion (Tamburri et al., 2002). ***Ultraviolet radiation*** is a very successful method of ballast water treatment (BWT). UVR efficiency depends on the dosage of UVR applied. Without further filtration, UVR is usually combined with mechanical cleaner, which can be separate or integrated in UVR equipment (Albert et al., 2010).

Chemical treatments. Chemical treatment efficiency depends on pH, temperature and types of organisms. Systems that use biocides must be designed to avoid discharging of unwanted concentrations of residual biocide (Albert et al., 2010). Despite low costs, *chlorine* is relatively ineffective against cysts unless it is used at a concentration of at least 2 mg/l. The usage of ozone (Perrins et al., 2006), hydrogen peroxide (Kuzirian et al., 2001) or titanium dioxide (TiO_2) (Wu et al., 2011) is not effective in waters with suspension or larger organisms. *Chlorine dioxide* is normally produced in situ by sulfuric acid (H_2SO_4), or combination of sodium chlorite ($NaClO_2$) and hydrogen peroxide (H_2O_2). The reactants are very dangerous for human health. In *electrochlorination*, chlorine disintegrates into hypochlorite acid and hypochlorite ion is added to ballast water system in order

Table 4.
The list of available ballast water treatment systems.

Name	Treatment method	Website
PureBallast 1.0	filtration, UV, advanced oxygenation (TiO_2)	www.alfalaval.com
PureBallast 2.0	filtration, UV, advanced oxygenation (TiO_2)	www.alfalaval.com
PureBallast 3.0	filtration, UV, advanced oxygenation (TiO_2)	www.alfalaval.com
PureBallast 3.1	filtration, UV, advanced oxygenation (TiO_2)	www.alfalaval.com
AquaStar	electrolysis/electrocatalysis, cavitation	www.aquaeng.kr
CrystalBallast	UV	www.auramarine.com
Bawat BWMS	deoxygenation	www.bawat.com
BIO-SEA	filtration, UV	www.ballast-water-treatment.com
Cathelco BWT System	filtration, UV	www.cathelco.com
GLD	deoxygenation, cavitation, ultrasound	www.coldharbourmarine.com
OxyClean BWTS	filtration, ozonation, UV	www.desmioceanguard.com
RayClean BWTS	filtration, UV	www.desmioceanguard.com
Ecochlor	electrolysis/electrocatalysis	www.ecochlor.com
BlueSeas BMWS	filtration, electrolysis/electrocatalysis	www.blueseas.com.sg
Erma First	filtration, hydrocyclones, electrolysis/ electrocatalysis	www.ermafirst.com
AVITALIS BWTS	filtration	www.evonik.com/peraclean-ocean
Seacure	filtration, electrolysis/electrocatalysis	www.evoqua.com/seacure
BallastMaster EcoP	filtration, electrolysis/electrocatalysis	www.westfalia-separator.com
BallastMaster UltraV	filtration	www.westfalia-separator.com
OceanGuard	filtration, electrolysis/electrocatalysis, ultrasound, advanced oxygenation (OH·)	www.headwaytech.com
Hyde GUARDIAN	filtration, UV	www.hydemarine.com
EcoBallast	filtration, UV	www.hhi.co.kr
HiBallast	filtration, electrolysis/electrocatalysis	www.hhi.co.kr
JFE Ballast Ace	filtration, chlorination	www.jfe---eng.co.jp
KBAL	UV, pressure/vacuum	www.knutsenoas.com
MICROFADE	filtration, chlorination	www.kuraray.co.jp
Ocean Protection System (OPS)	filtration, UV	www.mahle-industrialfiltration.com
	deoxygenation, carbonation	www.mhsystemscorp.com www.ballastwatersolution.com
FineBallastMF	filtration	www.mes.co.jp
Fineballast OZ	ozonation, cavitation	www.mes.co.jp
MMC Green Technology BWMS	filtration, UV	www.mmcgt.no
BioVioletTM	filtration, UV	www.kwangsan.com
VOS	deoxygenation, cavitation	www.nei-marine.com

BlueBallast	ozonation	www.nkcf.com
MKII	filtration, electrolysis/electrocatalysis, deoxygenation, cavitation	www.oceansaver.com
Optimarin Ballast System (OBS)	filtration, UV	www.optimarin.com
GloEn-PatrolTM	filtration, UV	www.worldpanasia.com
CleanBallast	electrolysis/electrocatalysis, advanced oxygenation (OH·)	www.rwo.com
Purimar TM	filtration, electrolysis/electrocatalysis	www.shipcs.com/eng
Balpure ®	filtration, electrolysis/electrocatalysis	www.balpure.com
BalClor	filtration, electrolysis/electrocatalysis	www.sunrui.net
Electro-Cleen System	electrolysis/electrocatalysis, advanced oxygenation (OH·)	www.techcross.com
Trojan Marinex	filtration, UV	www.trojanmarinex.com
Aquarius UV	filtration, UV	www.wartsila.com
Aquarius EC	filtration, electrolysis/electrocatalysis	www.wartsila.com
BSKY	hydrocyclones, UV, ultrasound	www.bsky.cn

to prevent growth of aquatic organisms. Free chlorine and its derivatives will kill almost all aquatic organisms and their final concentrations will satisfy IMO D-2 regulation. When discharging ballast the rest of hypochlorite is neutralized by adding a neutralizing chemical that removes all of the remaining oxidants that could be harmful. *Ozone* use involves much less harmful ingredients, mostly bromate. The production equipment is very complex. *Peracetic acid and hydrogen peroxide* (Peraclean) are completely soluble in water. They produce very small amounts of harmful by-products and are relatively stable. *Menadione or vitamin K* is a natural biocide and it is relatively safe to handle.

When using chemicals for ballast water treatment it is necessary to apply a mechanical ballast treatment first in order to remove larger solids and thus reduce expensive chemicals' consumption. In order to remove residual chemical disinfectants (especially chlorine), before unloading into the seawater the discharge needs to be treated with additional chemical reducing agents, sodium sulfite or bisulfite.

Considering the fact that none of BWT methods listed above is efficient, the combination of various methods is necessary. There are currently 46 water treatment systems on the market (Table 4). Most water treatment systems use two or more different treatment methods, e.g. physical separation is followed by the use of biocide or a UVR treatment. In reality, some systems, especially the UVR, work during ballast loading and unloading (Albert et al., 2010).

HiBallast is an example of a system that combines mechanical filtration for removing organisms and particles larger than 50 µm and electrolysis which produces high concentrations of sodium hypochlorite (NaOCl). The disinfectant is added into the ballast during ballast loading, while sodium thiosulfate ($Na_2S_2O_3$) neutralizer is added during ballast discharging. The concentration of the neutralizer is measured by TRO (*Total Residual Oxidant*) sensor and automatically regulated by the control system that includes system vent pipes, electrolysis, neutralization and filter unit. During an electrochemical chlorine generation, explosive hydrogen is released and continuously de-aired (http://www.hyundai-engine.com/).

In systems with active substances various chemicals are added into the ballast water in order to reduce the number of microorganisms below the prescribed limits regardless of their presence. There is no system that can measure the amount of microorganisms and simultaneously regulate the amount of active substance added, nor is there a technology that can measure the number of microorganisms in the ballast water after the process is finished. In the current systems the amount of active substance and neutralization substances can be controlled during ballast discharge. The system efficacy in preventing microorganism transfer has not been tested yet, and it is impossible to guarantee that the sample will pass the port authority testing. This is the reason for some states not to ratify the Convention.

5. SELECTION OF BALLAST WATER TREATMENT SYSTEM

Ship owners are often faced with difficulties in the process of reaching a decision on which ballast water treatment system fits best a certain ship. Several factors have to be taken into account in order to make the right decision. The final choice of optimal ballast water treatment system depends on the ship owner or operator taking into account the price, type of the ship, whether it is a newbuilding or an existing ship, ballast system capacity and seas where ships ply as well as harbours at which they call.

The selection of ballast system depends more on flow-rate capacity of the system and less on the size of the ship. The price of installation is an inevitable factor. Capital investment and operational expenses (OPEX) increase proportionally with the capacity for UVR-based systems, while it is not the case for smaller electrochlorination systems with the ballast capacity lower than 2,000 m^3/h.

Currently, the most common ballast water treatment systems are two-stage electrochlorination for high-capacity systems and UVR systems for low-capacity systems, both combined with mechanical filtration method (filtration or cyclonic separation for the necessary initial treatment) for the removal of organisms and particles bigger than 20 µm. Mechanical filtration uses usually self-cleaning filters. Initial separation of larger organisms and particles significantly improves the treatment efficacy and helps in the system maintenance.

The problem with the current UVR systems is related to the transparent tubes' cleaning in order to keep the transparency of the tubes and radiation intensity and range. While some manufacturers use strong light and high water turbulence, others use wiper that mechanically removes sediment. The cleaning is carried out by ultrasound micro-cavitation or mechanical scraping. The next problem is the efficiency of UVR in turbid water. Some systems adjust radiation intensity based on the measured light that penetrates through turbid water. Light penetration testing continually monitors the emission and it adapts monitoring when necessary making the system energy efficient. The advantages of UVR system are robustness and simplicity of use and maintenance, while power consumption is the main disadvantage, especially if the system is installed on board afterwards. It is often necessary to modify ship power supply and electricity distribution system in order to install an adequate UVR system.

The most significant downsides of UVR systems are low energy efficiency and the system dimensions but they do not require additional space for storing chemicals, do not produce toxic gases or harmful chemical agents, do not depend on seawater salinity and they are simple to use and maintain.

Combined ballast water electrochlorination treatment systems redirects small stream of water on electrolytic cells where sodium hypochlorite is produced and injected into the ballast before entering the tanks. The treatment leaves behind a reserve of sodium hypochlorite in the tanks and thus prevents growing of organisms during navigation. The cleanliness of the tank can be significantly improved by adequate control of sodium hypochlorite. An advantage of electrochlorination over UVR is that only one treatment is sufficient for achieving the satisfactory low number of organisms in the tank. The disadvantages are the complexity and the aggressiveness of sodium hypochlorite. When it is needed to stop operation or during the discharge, those systems use neutralization because sodium hypochlorite is an unwanted substance in clear water. Another disadvantage is the salinity of sea water necessary for producing hypochlorite and sometimes an additional tank is required in order to keep the adequate salinity of seawater.

The re-growth of phytoplankton can indicate the risks of introducing a new species, even after ballast water treatment is completed in accordance with IMO standards. A recent research conducted on six ballast water cleaning systems (3xUV, 2xEC, 1xCD) recorded a re-growth of phytoplankton after each of the six treatments (http://www.hyundai-engine.com/). The three tested UVR systems showed decrease in phytoplankton concentration, but it increased again later. In some systems the concentration of phytoplankton was higher due to the re-growth than in untreated ballast tanks. Re-growth of phytoplankton species differed in UVR and chemical systems, which indicated that none of the plankton species was resistant to all the treatments. All systems showed significant decrease in phytoplankton concentration below the IMO limits, which signified a reduced risk of transferring aquatic species, but it also confirmed the need for a better investigation of phytoplankton re-growth in the ballast water system. From the ship owner perspective, UVR systems have an advantage over EC BWTS systems because they do not use or store dangerous chemical agents. In case of emergency, ballast can be discharged at any time with no harm to the environment, but larger capacity and additional filtration are required for UVR systems (Stehouwer et al., 2015).

6. CONCLUSION

Even though ballast water treatment systems are not 100 % effective, they significantly reduce the risk of spreading of invasive species through ballast water exchange. In some states (Argentina, Australia, Canada, New Zealand and the USA) legislature regarding ballast water is more restrictive than the Convention despite the fact that the Convention has not been ratified yet.

The main problem with the Convention ratification is the inconsistency between the requirements for the system approval and future standards regarding the minimum discharge limits in ports. As regards systems with active substances, there is no system that can measure the amount of microorganisms and simultaneously regulate the amount of active substance added, nor is there a technology that can measure the number of microorganisms in the ballast water after the process is finished. The system efficacy in preventing microorganism transfer has not been tested yet and it is impossible to guarantee that the sample will pass the port authority testing. This is the reason for some states not to ratify the Convention.

In the past ten years many new systems for ballast water treatment and exchange were introduced on board in order to meet the standards. A small number of the newly built vessels are equipped with whole-scale ballast water cleaning systems. On most of the newly built vessels there are space and electrical power supply planned before installing.

Currently, the most common ballast water treatment system is two-stage electrochlorination for high-capacity systems and UVR systems for low-capacity systems, both combined with filtration or cyclonic separation for the necessary initial treatment. The most significant downsides of UVR systems are low energy efficiency and the system dimensions but as regards the design, they do not require additional space for storing chemicals, do not produce toxic gases or harmful chemical agents, do not depend on seawater salinity and they are simple to use and maintain.

An increased manufacturer interest in the systems' approval or developing new technologies is not expected in future because the procedure is time-consuming and expensive. The final choice of optimal ballast water treatment system depends on the ship owner or operator taking into account the price, the type of the ship, whether it is a newbuilding or an existing ship, ballast system capacity and seas where ships ply as well as harbours at which they call.

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