

## EMERGING BALLAST WATER TREATMENT TECHNOLOGIES: A REVIEW

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**Abstract:** Ballast water-shifts across the globe have been a major cause of ecological imbalance. The International Maritime Organisation (IMO) has actively taken regulated measures to minimise the species shift by adopting the International Convention for the Control and Management of Ships' Ballast Water and Sediments in 2004. Since then, vessels have been increasingly practising water exchanges. Exchanges are seen to be not completely effective. This regime has to give way for effective Ballast Water Treatment to keep up with IMO requirements as also the stricter requirements stipulated by some US ports. As full ratification of the Treaty is pending, many treatment technologies have been emerging. A review of some representative systems is presented in this paper. Brief analyses of the systems available on date and those awaiting approval have been carried out. Most of these systems use a pre-treatment employing physical filtration and in the later part treat the ballast water with physical and chemical disinfection methods. An effective method for species reduction has been to employ chemicals. In terms of capital cost, foot print and power requirements, chemical solutions fare better than the physical disinfection methods. However, it is feared that chemicals might cause greater harm to the environment. Physical disinfection methods have lesser issues than the usage of chemicals. Considering the long-term harm of chemicals, a filtration system in combination with heat treatment is suggested. Such an attempt might even emerge as a viable option before the IMO deadline of 2016.

**KEYWORDS:** Ballast Water Treatment Technologies, Chemical Disinfection, Physical Disinfection, Costs, Filtration, Heat Treatment

### Introduction

Ballast water from ships has been established as a potential vector for transference of various species around the world. The shifts will have negative impacts on the environment through factors such as competition for food, altered substrate/ambient temperature and light availability (Sutherland et al, 2001). Cholera infections could result from discharge of ballast water (McCarthy and Khambaty, 1994). According to many reports, the shifts have been increasing. An Australian study indicates a shift of more than 200 species (Hewitt, 2000) and another estimate indicates that, on a daily average, over 3000 species are carried on board ships (Pereira et al., 2010; Carlton, 1995). The consequences could be extinction of species, ecological imbalance, damages to port structures etc.

According to the Ballast Water Convention, the International Maritime Organisation (IMO) has set Ballast Water Exchange Standard, D1 and Ballast Water Performance Standard (BWPS), D2. From 2009, vessels follow D1 or D2, though the Regulations are not in full effect. As of February, 2010, 22 countries representing 22.65% of world's merchant shipping tonnage had ratified the ballast water treaty (Carlton, 2010). As of 31 January 2011, this has increased to 27 countries representing 25.32% of world tonnage (IMO), whereas a minimum number of 30 countries representing not less than 35% of the gross tonnage are required for ratification. The steady increase in ratifications implies urgency in effecting the ballast-water management practices.

Initial research had proposed management of ballast water with precautionary practices (Carlton et al., 1995). Such practices are: mini-

missing ballasting where specified species are present, restricting ballasting to daytime when species densities could be less and avoiding ballasting in areas where likelihood of industrial effluents exist. Other practices include avoiding ballast intake in shallow ports and dredging areas and also confining the ballast carriage in specified tanks (Rigby and Taylor, 2000). Presently, Ballast Water Exchange (BWE) has been the main recourse for ships in operation but, with the emphasis on D2 regulations getting stronger, Ballast Water Treatment (BWT) is the next stage for adoption.

Though water exchange is a simple procedure for ships with existing resources, its efficiencies for organism removal have been low, particularly considering the sediments left over in the ballast-water tanks (Buck, 2004). The exchange process requires time and repeated filling and removal of sea water. To achieve the exchange criteria laid down by IMO, which is at least 95% water exchange, the ballast tanks need to be emptied and filled about thrice their full volume (Rigby and Hallegraef, 1994). Further, a 95% exchange does not necessarily assure 95% organism removal as homogeneous distribution might not be present, but at times it could exceed 95% also (Murphy et al., 2002). Propeller emergence, extra working hours for the crew, higher stresses, damage risk due to sloshing etc., are other issues which are unfavourable for the exchange method as a solution. Further, exchanges are not always possible given the weather conditions and the hull-girder stress considerations (Karaminas et al., 2000). Operational limitations apart, organism removal efficiencies were also reported to be low (Ruiz and Hines, 1997; Taylor and Bruce, 2000). Some reports concluded insufficient exchanges as a reason for presence of species (Harvey et al., 1999). Reports varied from 87% to 48% (Zhang and Dickman, 1999) and the vast variations of species efficiencies were attributed to the ages of ships considered for survey. Comparisons were difficult as quantitative measurements were not available (Rigby and Taylor, 2000). Moreover, water exchanges are seen as operative measures till effective treatment systems are developed and regulations are in full effect. Presently,

two primary methods of exchanges are being practiced, namely, the sequential method and the flow-through method, objectively replacing the original ballast water.

Proactive with IMO, some US Ports have established standards which in parts are stricter than the IMO's BWPS. A comparative projection is shown in Table 1. Californian Standards are taken from the updated report prepared by the California State Lands Commission (Dobroski et al., 2009). Apparently, the stricter performance standards shown in Table 1 cannot be realised with exchange procedures. Only effective treatment of ballast water can bring down the species to innocuous levels. Research has resulted in treatment technologies based on various concepts and more vessels are opting for treatment installations. This paper attempts to review some of the type-approved technologies, while suggesting a combination system. The principles of ballast-water management strategies which are currently being employed are shown in Table 2.

### ***Emerging Treatment Technologies***

The technologies which may be considered are those which are type-approved and awaiting approvals. The current status report of Lloyds Register, groups the treatment processes generically under physical solid-liquid separation and disinfection. Most of these systems have been adapted to meet IMO requirements (Regulation D-2 Standards) from land-based waste-water applications (Lloyds' Register, 2010). The systems which are getting ready for commercial use are grouped in Table 3.

Of the technologies listed under the broad categories of physical and chemical methods, the major methods are briefly reviewed below. Efficacies, costs, comparative merits and demerits are highlighted.

### ***Physical Disinfection Technologies***

Amongst the technologies, most of the solutions employ a pre-treatment with filtration followed by a form of disinfection. Disc stack and cartridge-type filtration systems, removing organisms

Table 1. Ballast-water Performance Standards. Source: IMO; (Dobroski *et al.*, 2009)

Organism Size Class	California Standards	IMO D2 Standards
Organisms greater than 50 $\mu\text{m}$ in minimum dimension	No detectable living organisms	<10 cells/m <sup>3</sup>
Organisms 10 – 50 $\mu\text{m}$ in minimum dimension	< 0.01 living organisms per ml	<10 cells/ml
Living organisms less than 10 $\mu\text{m}$ in minimum dimension	< 103 bacteria/100 ml < 104 viruses/100 ml	
<i>Escherichia coli</i>	< 126 cfu/100 ml	<250 cfu/100 ml
Intestinal enterococci	< 33 cfu/100 ml	<100 cfu/100 ml
Toxicogenic <i>Vibrio cholerae</i>	< 1 cfu/100 ml or < 1 cfu/gram wet weight zoological samples	< 1 cfu/100 ml or < 1cfu/gram wet weight zoological samples

1. BWT systems must meet the IMO D-2 Standards.
2. California Performance Standards: No living organisms by 1 Jan 2020.
3. California Performance Standards to be effected between 2010 and 2016 based on ballast water capacities varying between <1500 to >5000 metric tons.
4. cfu: Colony Forming Unit. A measure of viable bacteria numbers.
5.  $\mu\text{m}$ : One millionth of a metre

between 10-50 $\mu\text{m}$  have been employed. The efficiencies of such physical filtration have been >91% (Parsons, 2003). Physical separation technologies of filtration, hydrocloning and UV have been reported for efficiencies from 95% while testing dinoflagellates to 8.3% for Nauplius larvae (Tsolaki and Diamadopoulos, 2009). Filtration techniques are the simplest in approach for typical organism sizes ranging from 25-50 $\mu\text{m}$  (Taylor and Rigby, 2001) and footprints are as low as 3.5 m<sup>2</sup> to 18 m<sup>2</sup> for combination systems such as filtration-UV (Lloyds' Register, 2010).

Hydrocloning is a method projected as a cost-effective alternative to filtration (Taylor and Rigby, 2001). The method achieves organism removals similar to filtration but efficiencies are much lower (Parsons, 2003). As hydrocloning depends on the density difference between the organisms to be removed and the fluid in which it is carried, larger biota removal becomes difficult (Parsons and Harkins, 2002).

UV radiation, a tried, tested method in water/waste water management has been adopted,

accounting for almost 25% of the current installations (Lloyds' Register, 2010). As water clarity is important, UV is adopted as a secondary treatment to filtration etc., (Taylor and Rigby, 2001). In the listed systems, UV is supplemented with Ozone, Hydrogen peroxide or Titanium dioxide chemical disinfection systems. Inefficiencies due to suspended impurities and ineffectiveness in eliminating large organisms (NRC Report, 1996) withstanding, UV units have been the least complex in operation (Lloyds' Register, 2010).

Deoxygenation systems achieve removal of oxygen by using Nitrogen, chemicals and Venturi Oxygen Stripping. The technology has a complementing advantage as the de-aerated water is sealed off in the ballast tanks (Lloyds' Register, 2010). If an inert gas generator is installed, as in the case of crude oil tankers, the deoxygenation equipment need not be erected as a separate installation. A major advantage claimed is the reduction in corrosion levels due to reduced oxygen (Tamburri *et al.*, 2002). Chemicals for oxygen removal, monitoring of physical parameters like temperature, pH, salinity,

Table 2. Principles of Current Major Ballast-water Management Strategies.

System Principle	Remarks	References
Ballast Water Exchange: Emptying and refilling of ballast water from ship's tanks away from origin and destination ports so that original ballast is exchanged with water from other ocean areas. 1. Sequential Method: Ballast tanks are emptied and filled in a planned sequence. 2. Flow-through Method: Ballast water is replaced continuously by pumping in water and overflowing the tanks. 3. Dilution Method: Ballast water is pumped into the tank from top and at the same flow rate, water is simultaneously removed from the bottom of the tank.	The technique is based on the following premises: - Organisms from near shore areas do not survive in open, deep sea ambience. - Open, deep seas will have lesser density of organisms and so lesser amount of organisms will be loaded while refilling. - The open sea organisms will not survive the near shore ambience.	Zhang and Dickman, 1999; Karaminas et al., 2000;
Filtration: Porous screens/packed discs stop the particles by straining as the liquid flows through.	Solids-Liquid Separation. Physical action.	Parsons and Harkins, 2002; Matheickal et al., 2004; Lloyds' Register, 2010
Hydrocloning, Centrifugal Separators: As the water is subjected to high centrifugal forces, heavier elements are thrown to the periphery and removed then after.	Solids-Liquid Separation. Physical action.	Parsons and Harkins, 2002; Lloyds' Register, 2010
UV Radiation: Ultra-Violet radiation kills the organisms.	Physical action. Disinfection.	Raikow et al., 2007; Lloyds' Register, 2010
De-Oxygenation: Removal of Oxygen from water asphyxiates organisms.	Physical action. Disinfection.	Tamburri et al., 2002; Raikow et al., 2007; Lloyds' Register, 2010
Ultrasonics/ Cavitation: Sound energy with high amplitude and frequency causes mechanical stress disrupting cell membranes.	Physical action. Disinfection.	Sawant et al., 2008; Lloyds' Register, 2010
Electric pulse: Electrical field application kills organisms.	Physical action.	Lloyds' Register, 2010
Heat Treatment: Increasing the temperature would kill organisms.	Physical action	Raikow et al., 2007; Quilez-Badia et al., 2008; Lloyds' Register, 2010
Chlorination, Chlorine-di-Oxide, Electrolysis: Chlorine kills the organisms.	Chemical action. Disinfection.	Rigby and Taylor, 2000; McCracken, 2001; Lloyds' Register, 2010
Ozonation: Bromine resulting from Ozone reaction with bromide kills the organisms.	Chemical action. Disinfection.	Herwig et al., 2006; Lloyds' Register, 2010
Peroxyacetic acid, Peracetic acid + Hydrogen peroxide combination with brand name, Peraclean®: Oxidising action of the biocide kills the organisms.	Chemical action. Disinfection.	Kuzirian et al., 2001; Lloyds' Register, 2010
Vitamin K, Brand Name, Seakleen™: Toxic effect of Vitamin K3 (Menadione) kills the organisms.	Chemical action. Disinfection.	Wright et al., 2007; Lloyds' Register, 2010

Table 3. Ballast-water Technologies: Technology and Cost Comparison. (Source: Lloyd's Report, 2010)

Manufacturer	Treatment Technology	Capital Costs \$'000 per 200- 2000m <sup>3</sup> /h r	Operating Costs \$ Per 1000m <sup>3</sup> /hr	Remarks
Alfa Laval Tumba AB	Filtration + UV. Additional oxidation with TiO <sub>2</sub>	n.a	n.a	TA;CA;NUI-5
atg UV Technology	Filtration + UV	n.a	n.a	CA;NUI-1
Atlas-Danmark	Filtration + Electrolysis/ Electrochlorination	180/850	n.a	
Auramarine Ltd.	Filtration + UV	n.a	40	
Brilyant Marine	Electric Pulse	300/2000	n.a	
Coldharbour	Deoxygenation + Cavitation	n.a	n.a	
DESMI Ocean Guard A/S	Filtration + Ozonation + UV	n.a	n.a	
Ecochlor Inc	Chlorine-di-oxide	500/800	80	CA;NUI-2
Electrichlor Inc	Filtration + Electrolysis/ Electrochlorination	350/n.a	19	CA;NUI-3
Environmental Technologies Inc	Filtration + Ozonation+ Ultrasound	n.a/500	n.a	
Erma First SA	Hydrocloning + Electrolysis/ Electrochlorination	n.a	200	
Hamann AG	Filtration (2 step) + (Peraclean®Ocean)	n.a	n.a	TA;CA;NUI-2 Peracetic acid and Hydrogen peroxide combination.
Hamworthy Greenship	Hydrocloning + Electrolysis/ Electrochlorination	n.a	n.a	CA;NUI-2
Hi Tech Marine Pty Ltd	Heat Treatment	150/1600	Nil	CA; Assumes utilisation of waste heat available onboard.
Hitachi	Filtration + Coagulants	n.a/400	n.a	Pre-coagulation by magnetic particles.
Hyde Marine Inc	Filtration + UV	230/1200	15-20	TA;CA;NUI-15
Hyundai Heavy Industries – Eco Ballast	Filtration + UV	n.a	n.a	NUI-1
Hyundai Heavy Industries - HiBallast	Electrolysis/ Electrochlorination Residual Cl <sub>2</sub> neutralisation	n.a	n.a	NUI-1
JFE Engineering Corporation	Filtration + Chlorination + mixing / agitation + Residual Cl <sub>2</sub> control	n.a	53	NUI-1
Mable NFV GmbH	Filtration + UV	n.a	n.a	NUI-1
Marengo Technology Group Inc	Filtration + UV	145/175	0.6-1	CA;NUI-1



Mexel Industries	Biodegradable non-oxidising biocide	2/5	n.a	NUI-2; Biocide details not known.
MH Systems Inc	Deoxygenation with inert gas and CO <sub>2</sub>	500/1500	60	
Mitsui Engineering and Shipbuilding	Hydrodynamic shear, Cavitation and Ozonation	n.a	n.a	NUI-1
NEI Treatment Systems LLC	Deoxygenation + Cavitation	249/670	130	TA;CA;NUI-6
NK Co., Ltd.	Ozonation	250/1000	7	TA;CA;NUI-4
Nutech 03	Ozonation	250/450	n.a	CA;NUI-4
Oceansaver AS	Filtration + Deoxygenation + Cavitation	288/1600	n.a	TA;CA;NUI-6 Not clear if the manufacturer has electrolysis/Electrochlorination system also.
Optimarin AS	Filtration + UV	290/1280	n.a	TA;CA;NUI-11
Panasia	Filtration + UV		n.a	CA;NUI-2
Pinnacle Ozone Solutions	Filtration + Ozonation + Electrolysis/ Electrochlorination	200/500	13	
Qingdao Headway Technology Co Ltd	Filtration + Electrocatalysis + Ultrasound	n.a	1.8	CA;NUI-1
Qwater	Filtration + Ultrasound	n.a	n.a	CA; Little information available.
Resource Ballast Technology / Unitor BWTS	Cavitation, ozone, Electrolysis and filtration	275/700	n.a	NUI-4
RWO	Filtration + Electrolysis/ Electrochlorination	n.a	n.a	CA;NUI-16
Sea Knight Corporation	Vacuum De-Oxygenation + Bio-Remediation	165/275	n.a	
Severn Trent De Nora	Filtration + Electrolysis/ Electrochlorination + residual control	600/700	20	NUI-2
Siemens	Filtration + Electrolysis/ Electrochlorination	500/1000	8.5-10	Operating Cost based on HFO cost at \$480/ton.
Techcross	Electrolysis/ Electrochlorination	200/600	3	TA;CA;NUI-13 Fuel costs considered for Operating cost projections.
TG Corporation	Filtration + chlorination + mixing / agitation	n.a	53	NUI-1
Vitamar, LLC- Seakleen™	Menadione / Vitamin K3 ( Seakleen™)	n.a	n.a	

1. TA: Type Approved as per Lloyds' Report; CA: Commercially Available date earlier to 2010; NUI: Number of Units Installed; n.a: not available
2. Primary technology mentioned first.
3. 7 more manufacturers listed with incomplete information in the Lloyds' Report have been omitted.
4. Capital costs and operating costs are quoted as provided in the Report.

dissolved oxygen etc., might be required to ensure the effectiveness.

NRC Report (1996) expresses doubts in effectiveness of deoxygenation against anaerobic

bacteria etc., and projects this to be a partial solution for organism removal. Later research supports deoxygenation with evidence showing significant mortality rates of many organisms,

though deoxygenation may be less effective on some taxa which are adapted to low-Oxygen environments (Tamburri et al., 2002). However, the mortality efficiencies on typical marine zooplankton have been around 99% (Tsolaki and Diamadopoulos, 2009). Currently 5 units are projected using this technology (Lloyds' Register, 2010). A drawback of any deoxygenation system is that the treatment process requires time in the range of one-to-four days based on time to significant mortality (Lloyds' Register, 2010). In most of the ocean going vessels, however, the ballast voyage period would be in excess of the required period and this treatment phase requirement is expected not to pose a problem for the treatment process. In a study on typical vessel movements, the average period for which vessels are on ballast works is seven days (Endresen et al., 2004).

Ultrasound systems have shown good organism removal efficiencies, depending on wave amplitudes and residence times. Cavitation methods are employed as supportive treatments in a few systems. Cavitation technology might cause problems for pumping rates higher than 5000m<sup>3</sup>/hr, especially in single-pump installations as also on health and safety requirements and hull integrity on repeated high wave exposure (Gregg et al., 2009).

#### *Chemical Disinfection Technologies*

Use of oxidising and non-oxidising biocides has been adopted from water and waste-water treatment experience. The effectiveness of chemicals is attributed to their fundamental actions: alteration of cell permeability/colloidal nature of protoplasm/organism DNA or RNA, cell wall damage and by inhibition of enzyme activity (Tsolaki and Diamadopoulos, 2009).

Amongst the chemical disinfection methods, chlorination has been the most preferred. Chlorine can be generated from Sodium Hypochlorite, electrolysis etc., and dosages are around 2mg/l. Chlorine disinfection is an effective method employed in potable water systems. Bacteria elimination efficiencies of 85.2 % for *Escherichia Coli* and 99.85% for anaerobic bacteria have

been recorded (Zhang et al., 2003) from ballast-water tests using hypochlorite. Electrolysis of sea water dissociating Sodium and Chlorine is also employed in many systems. Efficiency testing of one such system has recorded 99% results for bacteria, phytoplankton and mesoplankton (Matousek et al., 2006). Effectiveness of Chlorine depends on temperature, reaction time and residual Chlorine (Tsolaki and Diamadopoulos, 2009) as also pH level (Armstrong, 1997). High residual levels of Chlorine and toxic by-products might require post-treatment (Rigby and Taylor, 2000; Bolch and Hallegraeff, 1993; Rigby et al., 1993), as evident from residual treatment of Sodium Sulphite or bisulphite in some systems.

Other oxidising chemicals in use are Chlorine-di-oxide, Ozone, Bromine and Hydrogen peroxide.

Chlorine-di-oxide tests have recorded 98% organism removal (Bolch and Hallegraeff, 1993). Residual levels of Chlorine-di-oxide have to decline prior to discharge and would safely require 24 hours (Lloyds' Register, 2010).

NRC Report (1996) negatively-rated Ozonation methods given the concerns for corrosion, deterioration of seals and crew safety. Oemcke and van Leeuwen (1998, 2004) considers Ozonation unsuitable due to high-dosage requirements (current systems dose 1-2mg/l which is considered low), corrosion and high costs. Further tests on spores and dinoflagellates with four systems (Ozonation, UV, Ultrasonics and Hydrogen peroxide) resulted in >99% removals (Oemcke and van Leeuwen, 2005). Shipboard trials have been favourable showing effective elimination of hetrotrophic bacteria (Herwig et al., 2006).

Of the labile substances, Peracetic acid (Peraclean®Ocean) is supported for its biodegradable nature (Veldhuis et al., 2010) and for absence of undesirable by-products (Gregg et al., 2009). Comparative studies of three commercial chemicals (Peraclean®Ocean, Seakleen™ and Vidrex®) were carried out by Gregg et al., (2007). Peraclean®Ocean exhibited biodegradability in 2-6 weeks (from 200ppm concentrations) and effective inactivation of dinoflagellates and control some bacteria like

*Escherichia Coli*. Similar elimination efficiencies were observed for Seakleen™. Menadione or Vitamin K (Seakleen™) is considered relatively safe to handle (Lloyds' Register, 2010) and its high degree of toxicity reduces the amount of chemical required (approx. 1kg/1000 ltr) (Wright et al., 2007).

## Discussion

The production, storage and use of chemicals raises questions on long-term harm to the environment and personnel. Firstly, disinfection by-products (DBPs) such as Trihalomethanes (THMs) could be causing environmental and health harm, as in the case of Chlorine, Chlorine-di-oxide and Ozone (Tsolaki and Diamadopoulos, 2009). Some chemicals like Chlorine dioxide require time to be discharged in a harmless state as its DBPs of chlorites and chlorates are potentially toxic. Chlorine-based systems require neutralisation or some form of control. With Ozone usage, brominated and non-brominated DBPs need control. Apprehensions about accumulation of mutagenic and carcinogenic chemicals as also affectations of the aquatic webs have been expressed in NRC Report (1996). The next issue is the over-effectiveness of chemicals. While trying to eliminate harmful organisms, many harmless organisms also will be terminated. Chemical discharges apart, effectiveness against some target organisms and compliance with discharge regulations at various ports are other issues against chemical usage (Tsolaki and Diamadopolulos, 2009).

Physical disinfection methods have issues similar to chemical methods on species elimination, but their intensities are comparatively less. Production, storage and harm to personnel appear to be non-issues. Of the isolated technologies, only one heat-treatment solution is projected in the Lloyds' Report, 2010. Heat treatment is projected as an effective method in earlier studies (NRC Report, 1996; Rigby and Taylor, 2000) where, sustaining a temperature range of 35°–45° C ensures elimination of organisms. NRC Report (1996) favours heat treatment as a promising solution while observing that length of voyages,

sea water temperatures and water volumes can affect the heat application as also the discharged hot water. Species mortality has been proven if temperatures are sustained for extended periods (Quilez-Badia *et al.*, 2008). Heat-treatment technologies singly and in combination with microwave and ultrasound have been tested with various organisms and efficiencies of 100% has been reported (Tsolaki and Diamadopoulos, 2009). Energy costs for heating, impacts of storage and discharge are issues of concern (Quilez-Badia *et al.*, 2008), but the solution provider in the Lloyds' Report (2010) quotes nil operating cost for a heat-treatment system based on waste-heat utilisation. This is advantageous on the amortisation front. In this light, heat treatment technology, utilising the available heat resources might be an economical choice.

Lloyd's Report projects a mean of 7m<sup>2</sup> footprint for treating water at the rate of 200m<sup>3</sup>/h and 21m<sup>2</sup> for 2000m<sup>3</sup>/h considering the available technologies. Significantly, heat-treatment unit has the maximum footprint of 145m<sup>2</sup>. Footprints are expected to be larger for physical disinfection solutions due to the equipment requirements.

The Lloyd's Report analyses costs based on limited information provided by technology suppliers. On an average, the operating costs average \$30 per 1000 m<sup>3</sup>/hour of treated water, with a maximum of \$130. Operational costs of chemical systems might remain more-or-less steady due to regular consumption of chemicals, whereas physical disinfection systems might fare better in the long term (*ibid*). Operational costs in general relate to the installed power and the consumption. Cost quotes have been projected as quoted by the manufacturer. A comparison based on technologies becomes difficult as in some cases similar technologies have large differences. For example, it can be seen from Table 3 that capital costs of Filtration/UV Technology provided by one manufacturer is in the range of US\$230000-1200000, whereas a similar combination solution is quoted by another in the range of US\$145000-175000.

In general, electric pulse, heat treatment and deoxygenation solutions are quoted high



for capital costs. This could be due to the fact that these technologies need elaborate erections of pipelines, heat exchangers, chambers and associated controls etc. UV combination systems may be grouped under mid-range capital costs. If capital costs alone are considered, the quoted rates are very high, varying from \$287000 to \$779000, depending upon the flow rates (Lloyds' Report, 2010). This could be attributed to the advent of these technologies and also as an attempt to recover research costs. The costs may be expected to diminish in the coming times as competition and installations increase.

The power requirements average about 68kw. As this translates into extra vessel operating costs, technologies with lesser power requirements would find preference in the long term. Power requirements for chemical systems are low and so operating costs are lower. For small-ballast capacities, chemical methods appear suitable (Lloyds' Register, 2010).

Most of the technologies are designed for flow rates of approx. 250 m<sup>3</sup>/hour targeting the first phase of ships expected to be fitted with treatment technologies. Maximum rates of 5000-10000 m<sup>3</sup>/hour are also projected. In the mid-range, about 16 technologies assure flow rates in the range of 1000-5000 m<sup>3</sup>/hour. So, any currently-available method may be assumed to cater to a wide range of water flow rates.

A total of 41 manufacturers are listed. Apart from the combining methods, in most cases, the treatments are also effected in combination. Treatments are mostly designed to be carried out during ballasting, while discharging and during voyages. Treatment during ballasting is identified for 36 counts, 21 during discharging and 6 during the sea passage, singly or in combination. If single treatment protocols are counted, 14 systems treat while ballasting, 2 during discharging and 1 during the sea passage. Of the systems employing filtration, the systems are bypassed during deballasting as a general rule. It may be safely assumed that treatment prior to taking the water in tanks is the preferred mode. This is supposed to overcome the organism-retention problems in the tank sediments.

Almost all the approved systems and those awaiting approval are employing combination technologies. In terms of organism and species elimination, all the methods show similar efficiencies. Significantly, there appears to be no large baseline data on actual harm of marine organisms and also typical benchmark organisms that may be considered for testing treatment solutions. Another critical issue in assessing treatment efficiencies is that no typical, comprehensive sample testing method has emerged.

However, Lloyds' Report could well be considered as the reference for ballast-water treatment solutions under the purview of IMO. In terms of readiness to address the IMO requirements, it may be said that treatment technologies are available for the industry. While filtration is found to be the favoured primary treatment, chemical disinfection has a slight preference over the physical disinfection methods. Treatment systems reported in considerable numbers have been projected in Figure 1.

In terms of capital costs, power requirements and footprint, chemical solutions appear better. Industry preference also shows a greater number of chemical system installations. The number of units installed totals 122 but Lloyds' Report mentions 106. It may be assumed that these are the shipboard installations. However, of the 122 installations, 49 installations are chemical dependant. Further, 16 units employ filtration/electrolysis/Electrochlorination, 14 are based on deoxygenation/Inert Gas/Carbon-di-oxide combinations, 11 units are based on filtration/UV combination and 13 are based on pure electrolysis/Electrochlorination systems. The remaining 68 installations include various treatment methods but with less than 10 installations. About 9 manufacturers are yet to install any units.

Rigby *et al.*, (2003) had projected an emergence of chemical treatments which will be costly and expressed concerns over environment, health and safety. The trends are not much deviant but the concerns are yet to be supported as user feedbacks will only be available in the coming years. It may be said that a working system

which is safe, cost-effective and environmentally-acceptable envisaged by IMO appear unrealistic (Rigby and Taylor, 2000). The threat to crew safety and the impact of releasing the residual chemicals into the environment makes use of chemicals unfavourable with advisory bodies such as the Australian Research Advisory Group (Rigby et al., 2003). Placing environmental concern above all, systems which are least polluting and disturbing to the environment have to be preferred.

Secondly, the economics of energy and cost, effective design and easy installation are the factors to be considered. Cost burden due to combination systems has been predicted earlier showing increases in voyage costs (Rigby et al., 2003). If any treatment solution is to be considered, both capital and operating cost increases are inevitable, probably water exchange might appear to be most economical. With the current water-exchange practices, a steady substitution of or a combination with treatment methods is inevitable, as emphasised by IMO. The IMO time frame for treatment adaptation is projected in Table 4. While establishing the time frame for BWT, the terms of ship construction and major conversion etc., have also been defined by IMO but are not reflected in Table 4.

Though chemical solutions appear promising, in the long term, environmental harm might be significant, the mitigation costs also proving expensive. For this reason, treatment systems involving active substances are required to obtain initial and final approvals, after being assessed for environmental impact. Moreover, the land-based testing and the sea-based test for type approvals would involve an extended period of time. A system not involving active substances would require land and sea-trial validations only, for obtaining the type approval from Flag State etc.

So, keeping aside a chemical treatment option, a choice of physical filtration combined with physical disinfection using heat treatment could be probed into. Utilisation of waste heat from ship's engines is projected as a favourable option, especially for ships on voyages greater than 10 days (Rigby and Taylor, 2000). Considering that there is only a single heat-treatment option in the available technologies, heat treatment may be researched upon further as shipboard heat resources are readily available. As the IMO deadline is around 2016, such research might prove timely.

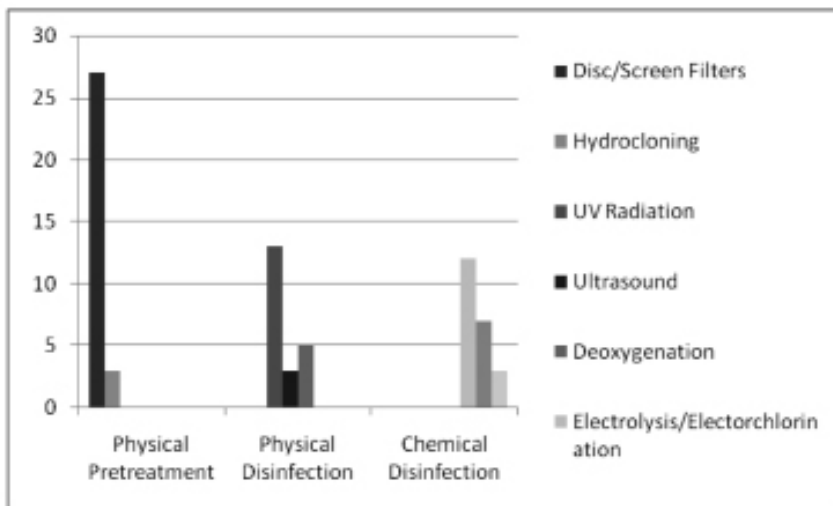


Figure 1. Comparison of Physical and Chemical Disinfection Treatment Technologies.

Table 4. Installation of Ballast-water Treatment Technologies: IMO Time frame. (Source: Lloyd's Report, 2010)

Ship's Ballast Capacity, m <sup>3</sup>	Year of Ship Construction			
	Earlier than 2009	After 2009	2009-2011	After 2012
<1500	-BWE or BWT until 2016 -BWT only from 2016	BWT Only		
1500-5000	-BWE or BWT until 2014 -BWT only from 2014	BWT Only		
>5000	-BWE or BWT until 2016 -BWT only from 2016		-BWE or BWT until 2016 -BWT only from 2016	BWT Only

## Conclusion

For a shift from exchange practices to treatment, it can be concluded that ship owners will have a number of options. The efficacies of methods are also promising. Technologies are proving compliance to D-2 Performance Standards and may be approved for stricter US standards. As the technologies are put into operation, significant demerits of systems will be realised, which may determine the choice of a favoured option. Presently, capital and operating costs would be the major determinants. The ratification of the Ballast Water Convention will increase the number of Ballast WT installations. The high costs of these technologies will increase freight costs also.

Considering the costs, environmental impacts of chemicals and the deadlines, a rational review of ballast-water management practices ought to be considered concurrently with treatment methods. Research on no-ballast ships, shore-based treatments and softer applications for species termination must be pursued. An approach to optimising the ballast management would be to combine technologies in an economical way. A method such as heat treatment which can harness the easily available shipboard resources combined with another physical disinfection method such as filtration and/or deoxygenation can be worked upon. This would be seen as a well-considered optimisation in shipboard ballast-water management.

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