Ballast Water Management Systems for Vessels

Matej David and Stephan Gollasch

Abstract In this chapter we focus on ballast water management systems (BWMS) which are currently in use as well as treatment approaches manufacturers have chosen for the development of future BWMS. The main purpose of this review is to identify the current availability of BWMS technologies worldwide. Until January 2014 we brought together information of 104 different BWMS. To achieve the ballast water discharge standards, different water treatment technologies are used, mostly in combination, and applied in different stages of the ballasting process. In general, the treatment processes can be split in three stages, i.e., pre-treatment, treatment and residual control (neutralisation). Among the 104 BWMS identified, 100 apply their treatment at the uptake, some of those BWMS require also a treatment during ballast water discharge (in-line treatment) and three BWMS apply treatment only during the voyage (in-tank treatment). The majority of BWMS use filtration or a combination of hydrocyclone and filtration as pre-treatment separation step. The dominating treatment processes are to use an active substance, mostly generated on board by electrolysis/electrochlorination. The second most frequent treatment process is UV. BWMS to be installed for operation on vessels need to be type approved by a state. By the writing of this chapter more than 30 BWMS were type approved. It should be noted that the development of BWMS is a very dynamic market with newly proposed BWMS appearing almost on a monthly basis. The chapter also outlines how BWMS are applied on vessels, their capacities and installation requirements, which BWMS were type approved, and what projected global market for BWMS may exist. A recent calculation on the estimated value of the global market for purchasing and installing BWMSs resulted in an estimated turnover of possibly $50–74 billion. The chapter ends with a list of manufacturers, commercial names of their BWMS, applied treatment technologies used and links to BWMS web pages where available.

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Introduction

As the entry into force of the *International Convention for the Control and Management of Ships' Ballast Water and Sediments* (BWM Convention; IMO 2004) is approaching rapidly the industry is more and more aware and considers ballast water management a good business. This becomes obvious when noting the high number of vessels which need to be equipped with treatment systems.

This comprehensive review of ballast water management systems (BWMS) was conducted until January 2014. In this chapter we focus on BWMS which are currently in use as well as treatment approaches the manufacturers have chosen for future BWMS.

The main purpose of this review is to identify the current availability of BWMS technologies worldwide, to briefly introduce these and their use on vessels, identify their timely availability in relation to the BWM Convention requirements, and to identify the prospects of the global BWMS market. At the beginning of this chapter the requirements that BWMS need to comply with are presented, followed by an introduction of BWMS identified, which technologies different BWMS use, how are BWMS applied on vessels, what are BWMS capacities and their installation requirements, what is the situation with BWMS testing and approvals and what is the foreseen global market for BWMS. At the end, names of manufacturers, commercial names of their BWMS, treatment technologies used and links to BWMS web pages are provided, where available (see Table 2).

IMO Requirements

With the *Guidelines for Approval of Ballast Water Management Systems* (*G8*) (G8 Guidelines), IMO has in 2008 adopted requirements for a comprehensive test programme to evaluate the performance and suitability of BWMS. This includes performance tests in larger scale on land under controlled conditions as well as shipboard tests to show the efficiency and seaworthiness of BWMS. Noting some shortcomings in these test requirements some countries have developed their own requirements and test protocols, which set more stringent standards than the G8 Guidelines. One example is the USA with its Environmental Technology Verification (ETV) Program developed for the U.S. Environmental Protection Agency and the U.S. Coast Guard Shipboard Technology Evaluation Program (STEP) (NSF International 2010; STEP 2010).

At present there are many different treatment technologies available, and most of those were previously developed for municipal and other industrial applications. However, when applying those without modifications and improvements to the ballast water treatment purpose, none of these technologies have shown the capability to treat the ballast water to the level required by the BWM Convention D-2 *Ballast Water Performance Standard* (see chapter "Ballast Water Management Under the Ballast Water Management Convention").

The setting of these proposed regulations is an important driving force for ballast water treatment technology developments worldwide. As a result, it was expected that the development and implementation of these systems will proceed at a greatly accelerated rate. However, the ambitious phase-in of the D-2 standard as shown in chapter "Ballast Water Management Under the Ballast Water Management Convention" was modified at MEPC65 (in May 2013) and approved by the IMO Assembly in December 2013. The required starting times were now set as in maximum 5 years after the entry into force of the BWM Convention because the time limits as agreed earlier (see chapter "Ballast Water Management Under the Ballast Water Management Convention") are valid for so many vessels that timely retrofitting may become very difficult or impossible because of BWMS manufacturing and dockyard limitations (IMO 2010g, h; IMO 2011a, z).

Ballast Water Management Systems

World-wide available information about 104 different BWMS was collected and is presented in this chapter (IMO 2005a, b, 2006a, b, c, d, e, f, g, h, i, j, 2007a, b, c, d, e, f, g, h, i, j, 2008a, b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, r, s, t, u, v, w, 2009a, b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, r, 2010a, b, c, d, e, f, g, h, i, j, k; 2011a, b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, r, s, t, u, v, w, x, y, z, za; 2012a, b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, r, s, t, u, v, w, x, y, z, za, 2013a, b, c, d, e, f, g, h, i, j, k; Mesbahi 2004; Köster 2010; Shiferaw 2012, Stephan Gollasch pers. comm.). Some of these systems are in the (early) development stage, hence information about these is limited or not available due to confidentiality reasons or patents pending. It is further assumed that not all systems listed will reach full commercially ready development and some manufacturers have stopped the further development of the systems under consideration or withdrawn the system from the market. It should be noted that the development of BWMS is a very dynamic market with newly proposed BWMS appearing almost on a monthly basis.

Ballast Water Management Systems Treatment Technologies

To be able to achieve the requirements of the ballast water discharge standards, different water treatment technologies are used, mostly in combination, and applied in different stages of the ballasting process. In general, the treatment processes can be split

Table 1 Generic treatment process and some main BWMS technologies

	Treatment			
Pre-treatment	Chemical	Physical	Biological	Residual control
Filtration	Chlorination	UV radiation	Bioaugmentation with microorganisms	Chemical reduction (Neutralisation)
Hydrocyclone	Electrochlorination	Deoxygenation		
Coagulation	Ozonation	Inert gas or Nitrogen injection		
Flocculation	Chlorine dioxide	Ultrasonic treatment		
	Peracetic acid	Cavitation		
	Other active substances	Fine filtration		
		Heat		

in three stages, i.e., pre-treatment, treatment and residual control (neutralisation). In the pre-treatment stage the main focus is to exclude as much as possible solid material and bigger organisms, and with this helping the other treatment process(es) to be more effective, e.g., UV efficacy is limited if there are many solid particles in suspension because organisms survive when being in shadows of such particles, and the more solids and organisms are in the water, the more active substances are needed to achieve the same lethal effect. The residual control stage (neutralisation) is needed if there are any substances left in the ballast water after the treatment process is completed that could cause harm when being discharged from a vessel, e.g., residual toxicity from the use of active substances and their by-products (see Table 1).

In the following paragraphs we describe some of the main working principles of BWMS components.

Filtration

Filtration of ballast water seems to be the most environmentally sound method, but the amounts of ballast water that have to be treated are immense. Different filter technologies are in use, e.g., disk filters, mesh and wedge-wire filters. Ultra-filtration methods have not yet been tested or proven to work with large volumes of ballast water and high loads of sediments. The efficacy of removing particles larger than the mesh-size of these filter units is with 95–98 % very effective. In addition some percentage of the smaller particles may also be removed. Some systems use a combination of two filters where the first removes very large particles, which enhances the efficiency of the second finer filter. However, although the organism removal rate is high the D-2 standard is unlikely to be met with filtration as a stand-alone technology. Most filters used include an automatic backwash mechanisms for self-cleaning to ensure continuous operation. Overboard disposal of the collected residues as filter backwash would occur at the location of ballasting rather than at the destination port, thereby avoiding the transfer of non-native species with the filter backwash.

Hydrocyclone

Cyclonic separation has been proposed as a relatively simple and inexpensive way of removing larger particles and organisms from ballast water. Water and particles enter the hydrocyclone tangentially, thus setting up a circular flow. They are then drawn through tangential slots and are accelerated into the separation chamber. Centrifugal action tosses particles heavier than the water to the perimeter of the separation chamber. The solids gently drop along the perimeter and end up in the calm collection chamber of the separator. Solids may be periodically purged or continuously extracted from the separator. However, cyclonic separation of organisms with a specific gravity similar to that of water is limited which is valid for many plankton taxa. Therefore, some BWMS use the hydrocyclone as a pre-separator which is followed by a filtration unit thereby enhancing the performance of the filtration unit.

Ultraviolet Radiation

Ultraviolet (UV) radiation is commonly used for sterilising potable or waste water and for the purification in aquaculture and fisheries. UV radiation operates by causing photochemical reactions of biological components such as nucleic acids (DNA and RNA) and proteins. The lower UV wavelengths are generally more effective. However, radiation at these wavelengths shows a lower transmission in water. It's performance may further be affected by organic material, particles or bubbles. The effectiveness of UV treatment depends also largely upon the pigmentation, size, morphology of organisms (surface/volume ratio). Viruses require similar dosages to bacteria. Algae require larger dosages than bacteria due to their size and their pigmentation. Disadvantaging is the effect that some smaller organisms could pass the UV unit in the shadow of larger organisms/particles with reduced treatment and the reduced transmission of UV-radiation in turbid waters. It was observed in tests that some organisms have a self-repair mechanism so that re-growth of organisms after UV treatment occurred. This is (partly) overcome by applying the UV exposure also during ballast water discharge. Another and unsolved problem is that the UV effect on organisms is not immediately observed (Liebich et al. 2012; Martínez et al. 2012) so that compliance with the D-2 standard is difficult to show when the water is treated during discharge.

Electrochlorination

The use of electrochlorination as a means of preventing marine growth is well known. Electrochlorination is used on board so that the active substances are generated from the ballast water taken on board (no storage tank of chemicals) and this may either be done in a side stream or in the full ballast water stream of a vessel. Electrolyzers usually consist of a number of reactor cells arranged in series.

A minimum salinity is needed for its efficient use, in freshwater and lower brackish ballast water uptake zones marine water may be pumped into the line from a previously filled ballast tank to reach the required minimum salinity.

Chemical Dosing

A large number of chemical disinfectants are commercially available. These have been used successfully for many years in land-based potable and wastewater treatment applications. For the purpose of ballast water treatment several substances and formulations were considered, e.g., Chlorine dioxide, PeracleanOcean and SeaKleen. These systems have in common that an on board storage is needed and it would be beneficial that a supply of additional such substances is available in all ports the vessel is calling which may be logistically challenging. Further, ozone, generated on board from ambient air, is used in several BWMS. Most chemicals are usually applied during ballast water uptake with a mixing device to allow efficient treatment.

Neutralisation

The vast majority of ballast water treatment systems which make use of active substances add a neutralization substance. Such a neutralization step may not always be needed as e.g. on longer voyages the active substance may be (bio-)degraded before the ballast water discharge occurs. It seems most useful to apply the neutralising substance during the ballast water discharge. Proper mixing should occur so that the neutralizer is well circulated in the ballast water and that its neutralizing power is applied before the ballast water has left the vessel. Our review has shown that Sodium Thiosulphate is the most frequently used neutralizer today (see Table 2).

Application of Ballast Water Management Systems Technologies on Vessels

Different vendors developed different BWMS combining different technologies. Different systems (or parts of these) have their application in different stages of the ballasting process, i.e., at the uptake of ballast water, during holding the ballast water in tanks during navigation, and/or at discharge.

Among the 104 BWMS identified (see Table 2), 100 apply some treatment at the uptake, of these four apply treatment at the uptake and during the voyage (Table 2, nr. 17, 61, 74 and 95), and three are known to apply the treatment only during the voyage (nr. 12, 38 and 58). 29 BWMS treat the ballast water at uptake and discharge.

Some pre-treatment technology is used by 80 BWMS, of these 70 use filtration, three use a combination of hydrocyclone and filtration (nr. 16, 28 and 32), one uses a combination of flocculation and filtration (nr. 39), four use a hydrocyclone (nr. 35, 90, 95, and 97), and the remaining two use different other methods (nr. 5 and 17). It is interesting to note that 24 systems do not have a pre-treatment separation step.

Most of BWMS identified are regarded as BWMS that make use of an active substance (58). The most frequently used technique seems to be electrolysis/electrochlorination (35), and is applied as stand-alone treatment method by 28 BWMS, and by seven in combination with other techniques. The remaining 24 BWMS use dosing of different active substances, e.g., chlorine, PeraClean, SeaKleen and Akrolein.

In the second place is UV treatment with 34 BWMS, 24 of these use UV as stand-alone treatment method, while ten systems use UV in combination with one or more other techniques, i.e., TiO_2, ultrasound, ozonation, electrolysis, plasma.

In total 26 BWMS use two or more treatment techniques in combination as the main treatment method, while 75 rely on one treatment technique, no information was available for three BWMS (see Table 2).

One BWMS (Table 2, nr. 74) is the only system which makes use of vacuum deoxygenation and bioaugmentation. Bioaugmentation is a mechanism to, e.g., start activated sludge bioreactors in municipal wastewater treatment plants. In this BWMS microorganisms will be used to treat living organisms.

The application of BWMS that make use of active substances may result in residual active substances above the maximum allowable level (TRO[1] 0.2 mg L^{-1}) when this is to be discharged into the surrounding waters, hence they need to neutralise these before the discharge. The BWMS without neutralization will depend on a longer holding time of ballast water in the tanks during which the chlorine will breakdown to uncritical substances. Chlorine dioxide has a half-life of approximately 6–12 h (according to the suppliers and Olivieri et al. 1986), but at the concentrations at which it is employed it can be safely discharged after a maximum of 24 h. However, this relates also to water salinity and temperature and both should be taken into account when evaluating the minimum retention time before discharge.

Thirty-four BWMS that make use of active substances have included also an obligatory neutralisation process at discharge, and further three have this as an option. The most frequently used neutralisation is by Sodium Thiosulphate (24 BWMS), Sodium Sulphite use five BWMS, three use Sodium Biosulphite, one uses Activated Carbon, one uses Thiosulphate, and for three BWMS the substance is unknown (see Table 2). Most chlorination systems are applying a dose which results in approx. 10 mg L^{-1} chlorine during treatment, which has proven to be effective to kill organisms, but less than 0.2 mg L^{-1} residual chlorine in the ballast water discharges has proven to be environmentally acceptable to the recipient waters (see various references of Final Approvals of BWMS and GESAMP BWWG reports (IMO 2005–2012)). Most ozonation suppliers are using an ozone dose of 1–2 mg L^{-1} which has proven to be effective (Lloyds Register 2011a).

[1] TRO = total residual oxidants

According to the Lloyd's Register review of BWMS (Lloyds Register 2011a, b), technical features of the products are not necessarily common to all of them and are specific to generic types of process technologies. Deoxygenation is effective because the deoxygenated water is stored in sealed ballast tanks. However the process takes between 1 and 4 days to take effect, and thus represents the only type of technology where longer voyage length is a factor in process efficacy. This type of technology is also the only one where, technically, a decrease in corrosion propensity would be expected (and, according to one supplier, has been recorded as being suppressed by 50–85 %), since oxygen is a key component in the corrosion process. The water is re-aerated on discharge to avoid any unwanted effects to the recipient environment. However, the efficiency of deoxygenation is of concern as some organism can change their metabolism to another source than oxygen and other organisms are not dependent on oxygen at all.

Essentially most UV systems operate using the same type of medium pressure amalgam lamps. A critical aspect of UV effectiveness is the applied UV dose/power of the lamp. This information has not been given by all suppliers. Another aspect of UV effectiveness is the clarity of the water. In waters with a high turbidity or colloidal content, UV would not expected to be as effective as in very clear waters, but it was shown that UV systems also under these conditions meet the D-2 standard. Most of the busy ports in Europe (e.g., Rotterdam, Antwerp, Felixstowe and Hamburg) are located in estuaries with high sediment content.

Ballast Water Management Systems Capacities and Installation Requirements

Different BWMS have different capacities and technical profiles, which are mainly related to the aspects of appropriate capacity of the ballast water system of a vessel, as well as to the system space requirement and power consumption. For many BWMS the information available was very limited, and for some BWMS no information became known at all.

BWMS capacities range from 50 $m^3\ h^{-1}$ to more than 10,000 h^{-1}, while five manufacturers informed that their systems are (will be) able to treat 20,000 and more h^{-1}. In terms of footprint space requirements the systems with the capacity 200 h^{-1} could occupy from even less than 1 m^2 and up to 30 m^2, while the systems with the capacity 2,000 $m^3\ h^{-1}$ would occupy from 1 m^2 and up to 145 m^3. Systems operate also with no electricity requirement, and others may consume up to 200 kW per 1,000 $m^3\ h^{-1}$ water to be treated.

Chemical dosing systems such as PeracleanOcean, SeaKleen and chlorine dioxide have low capital costs because only a dosing/mixing pump is required but these systems require chemical storage facilities and availability of chemicals in all ports visited. Should the active substance be transported in higher concentrations, as during shipment to the vessel, some special regulations regarding the transport of dangerous goods may apply in certain ports due to safety concerns.

The biggest operating cost for most systems is power and for large power consumers (electrolytic, advanced oxidation processes and UV) the availability of shipboard power will be a factor which may limit its installation and operation. For chemical dosing systems, power consumption is very low and chemical costs are the major factor. For these reasons chemical addition may be better suited to treat small ballast capacities.

Although the BWMS operate at generally low pressure and thus do not require additional ballast water pumping pressure, those employing Venturi devices (for exerting shear forces and proper mixing of chemicals) incur pressure losses of up to 2 bar.

For most systems it is recommended that the installation takes place in the engine/machine room near the existing ballast water pumps, although installation on deck may also be possible if appropriate precautions are taken. If the location is in an explosion zone, then the installation will need explosion proofing. Some of the technologies can be provided as explosion-proof products, but there is a cost factor for this. The generation of hydrogen by the electrolytic technologies is not considered an issue, provided the gas is vented and diluted with air to safe levels.

Whilst disinfection by-products are an issue, and central to the approval of ballast water management systems that make use of active substances, suppliers are confident that the levels of active substances and by-products generated are unlikely to be problematic. There is a large amount of scientific and technical information on disinfection by-products formation that is likely to support this. However, all systems using active substances will be reviewed by an independent expert group of GESAMP to assess the environmental acceptability of the treated water at discharge.

Ballast Water Management Systems Testing and Approvals

All systems need to be type approved by a Flag state before being sold to a client. Systems that use Active Substances by the definition in the BWM Convention have to undergo a more thorough certification process and obtain Basic and Final Approvals by IMO MEPC. This process was initiated to proof the environmental acceptability of treated ballast water when discharged from a vessel.

All systems are tested in a land-based setting with challenging water conditions (different water parameters and high organism numbers) to show that the D-2 standard is met. Ten test cycles need to be carried out in minimum. In addition, at least three test cycles need to be undertaken over a period of at least 6 months on board of commercial vessels to document that they meet the D-2 standard and are seaworthy. These tests are addressed in the IMO Guidelines G8. Currently a harmonization of sampling methods and sample analysis options is ongoing with all test facilities and shipboard sampling teams being involved (GloBalTestNet) and in October 2013 a Memorandum of Understanding of these was signed to achieve these goals. Test facilities are located in China, Denmark, Germany (Stephan Gollasch for shipboard

BWMS	**BWMS approval according to G9 (GESAMP and MEPC)**	**BWMS approval according to G8 (Flag state)**		**BWMS approval according to G9 (GESAMP and MEPC)**	**BWMS Type Approval Certificate (Flag state)**
using active substance(s) →	Basic Approval →	Land based tests →	Shipboard tests →	Final Approval →	Type Approval
without using active substance(s) →	→	Land based tests →	Shipboard tests →	→	Type Approval

Fig. 1 The approval process of BWMS according to the IMO requirements

tests), Japan, Korea, The Netherlands, Norway, Singapore, Slovenia (Matej David for shipboard tests), UK and the USA, and others are further planned in India and South Africa (Gollasch 2010 and pers. comm.).

After all these tests the system gets eventually type approved by a Flag state. This comprehensive approval process usually takes 1.5 years or longer. The duration of a type approval depends on many factors, including the test requirements, the availability of land and shipboard test facilities, the success of BWMS performance test runs and whether or not a system makes use of active substances. When active substances are used comprehensive basic and final approval dossiers need to be prepared, which requires additional tests. These dossiers are evaluated by the Ballast Water Working Group of GESAMP (see Fig. 1).

At present BWMS are in different stages of development, testing and approval processes, while 33 were already type approved by different administrations (IMO 2013k, see grey shading in Table 2). The authors have further obtained information that German authorities have issued an additional certificate for the Aquaworx BWMS (nr. 6) (Clason, personal communication) which brings the total number of type approved BWMS to 34. We expect this number to rise soon as several other BWMS are in the final phase of the approval process.

The Global Market for Ballast Water Management Systems

Japanese experts calculated the number of vessels to which Regulation D-2 would have applied if it would have been implemented as originally planned from 2009 to 2020. The number of vessels would have totalled to more than 75,000 vessels, with the highest annual number in 2017, i.e., more than 16,000 vessels. Divided by 365 this results in an installation demand of ca. 45 BWMS per day. The number of vessels required to install BWMS was expected to rapidly increase in 2015 and sharply drop in 2020, because the vessels constructed before 2009 should have installed BWMS between 2015 and 2019. The number of existing vessels that would need to retrofit would be in total approximately 34,000 vessels and the number of vessels, which are required to retrofit BWMS is estimated at 2,500 vessels in 2015 and 2016, 11,000 vessels in 2017, and 9,000 vessels in 2018 and 2019. The phase-in of the vessels to meet the D-2 standard was recently time-wise relaxed (see chapter "Ballast Water Management Under the Ballast Water Management Convention"), which will likely result in a longer high demand of BWMS to be installed on board vessels (IMO 2010g, h).

A recent calculation on the estimated value of the global market for purchasing and installing BWMSs was conducted by IMarEST (IMO 2011a, z) and the estimations resulted a turn-over between 2011 and 2016 of possibly $50–74 billion.

As per the original IMO requirements more than 21,000 vessels were subject to the first round of BWMS retrofits. This would have included vessels with a ballast water capacity of 1,500–5,000 m^3. With 16,000 out of these 21,000 vessels, the majority of those vessels would have been general cargo ships. IMarEST analysed the "delivered" vessels by type and it was estimated that more than 68,000 vessels would need to install on board BWMS before 2020 (IMO 2011a, z).

Fishing vessels are a special case and only those of >300 gross tons were included in the analysis of IMarEST (IMO 2011a, z). Considering the tight profit range of especially smaller fishing vessels, it is unlikely that they will include the installation of BWMS in their business plans. Other limitations for those vessels may be the lack of space to install BWMS so that those vessels may have to find another way to comply with ballast water management regulations.

According to IMarEST estimates the cost range of BWMS across system types and categories of ship was estimated to be between $640,000 and $947,000 per vessel, however the authors in direct contact with BWMS vendors received information that the system prices would start from approximately 250,000 Euro. It should also be noted that installation costs will vary to a great extend which is related to the BWMS and ship characteristics and the footprint and other requirements. In some cases, depending on the number of ballast pumps aboard, more than one BWMS may have to be installed.

BWMS manufacturers and shipowners assume that minimal or even no lost profit may occur due to the retrofitting of BWMS provided the installation time does not extend the normal shipyard time. Alternatively the BWMS may be installed during navigation, but cabin and lifeboat limitations may occur when planning to accommodate the installation crew (IMO 2011a, z).

Ballast Water Management Systems Information

Table 2 BWMS manufacturers (in alphabetical order), commercial names of their BWMS, technologies used and available web pages (last accessed January 2014). Type approved BWMS are shown with grey shading

Nr.	Manufacturer	System name	Pre-treatment	Treatment	Residual control	Web site
1	21st Century Shipbuilding Co., Ltd	ARA Ballast (Blue Ocean Guardian BOG)	Filtration	Plasma+UV	–	www.21csb.com/eng /sub04_02.html
2	Akballast	Akballast	Filtration	UV	–	–
3	Alfa Laval Tumba AB	PureBallast (3.0)	Filtration	UV + TiO_2	–	www.alfalaval.com /campaigns/pureballast3/Documents/index.htm
4	Alfa Laval Tumba AB	PureBallast (3.0 Ex)	Filtration	UV + TiO_2	–	www.alfalaval.com /campaigns/pureballast3/Documents/index.htm
5	Aquaeng Co. Ltd.	AquaStar BWMS	Smart pipe unit	Electrolysis/electrochlorination	Sodium thiosulphate	www.aquaeng.kr
6	Aquaworx ATC GmbH as original developer, now with GEA Westfalia	AquaTriComb, new name: BallastMaster ultraV	Filtration	UV + ultrasound	–	www.westfalia - separator.com/applications/marine /ballast-water-treatment/gea - westfalia -separator-ballastmaster - ultrav.html
7	atgUVTechnology (ATG Willand)	–	Filtration	UV	–	www.atguv.com /marine-shipping
8	ATLAS-DANMARK	ATLAS-DANMARK ABTS	Filtration	Electrochemical (Anolyte)	–	www.atlas -denmark.com
9	Auramarine	CrystalBallast	Filtration	UV	–	www.auramarine.com/news/auramarine-_new_challenger_in_the_market_for_ballast_water_treatment_systems
10	Azienda Chimica Genovese	ECOLCELL BTs	Filtration	Electrolysis/electrochlorination	Sodium thiosulphate	www.acgmarine.com/en/products/ecolcell -bts
11	BaWaPla (stopped development)	–	Filtration	Electrolysis/electrochlorination	–	www.bawapla.com
12	Bawat	–	–	Inert gas+heat	–	www.bawat.dk
13	Bio-UV	Bio-SEA	Filtration	UV	–	www.ballast -water-treatment.com
14	Brillyant Marine	–	–	Elelctric pulse	–	www.brillyantinc.com
15	Cavipure (old name: Jetsam)	–	Filtration	UV+ultrasound	–	–
16	China Ocean Shipping Company (COSCO)	Blue Ocean Shield	Hydrocyclone + Filtration	UV	–	www.cosco.com/en
17	Coldharbour Marine	Coldharbour BWT	Cavitation	Deoxigenation	–	www.coldharbourmarine.com
18	Dalian Maritime University	DMU OH BWMS	Filtration	hydroxyl radicals, ozone and hydrogen peroxide	Sodium thiosulphate	www.dlmu.edu.cn
19	DESMI OceanGuard AS	DESMI OceanGuard BWMS	Filtration	Ozonation+UV	–	www.desmioceanguard.com
20	Dow Chemical Pacific (Singapore) Pte Ltd.	Dow-Pinnacle BWMS	Filtration	Ozonation	Sodium thiosulphate (optional)	–
21	Ecochlor Inc	Ecochlor	Filtration	Chlorination (ClO_2)	–	www.ecochlor.com
22	Ecologiq	BallaClean	Filtration	Electrolysis/electrochlorination	–	www.ecologiq.us
23	Electrichlor Inc	Electrichlor	Filtration	Electrolysis/electrochlorination	–	www.electrichlor.com
24	EltronWaterSystems	PeroxEgen	–		–	www.eltronwater.com
25	Environmental Technologies Inc	ETI	Filtration	Ozonation+ultrasound	–	www.tlmcos.com
26	Envirotech and Consultancy PTE ltd.	BlueSeas BWMS	Filtration (microsized strainer)	Electrochemical disinfection	Sodium thiosulphate	www.blueseas.com.sg (under construction)
27	Envirotech and Consultancy PTE ltd.	BlueWorld BWMS	Filtration (microsized strainer)	Electrochemical disinfection	Sodium thiosulphate	www.blueseas.com.sg (under construction)
28	Erma First SA	Erma First BWMS	Hydrocyclone	Electrolysis/electrochlorination	Sodium bisulphite	www.ermafirst.com /ballast-water
29	Ferrate Treatment Technologies (stopped development)	Ferrator BW	–	Fe6+	–	www.ferratetreatment.com /ballast water.htm
30	Gauss (stopped developement)	–	Filtration	UV	–	–

(continued)

Table 2 (continued)

Nr.	Manufacturer	System name	Pre-treatment	Treatment	Residual control	Web site
31	GEA Westfalia	BallastMaster ecoP	Filtration	Electrolysis/electrochlorination	Sodium thiosulphate	www.westfalia-separator.com/applications/marine/ballast-water-treatment/gea-westfalia-separator-ballastmaster-ecop.html
32	Hamann AG (Degussa) (withdrawn from market)	Sedna using Peraclean Ocean	Hydrocyclone + Filtration	Paracetic acid	–	www.haman nag.com
33	Hamworthy	Aquarius UV	Filtration	UV	–	www.wartsila.com/en/ballast-water-management-system/hamworthy/aquarius-uv
34	Hamworthy	Aquarius EC	Filtration	Electrolysis/electrochlorination	Sodium bisulphite	www.wartsila.com/en/ballast-water-management-system/hamworthy/aquarius-ec
35	Hamworthy Greenship (stopped development)	Greenship Sedinox	Hydrocyclone	Electrolysis/electrochlorination	–	–
36	Hanla IMS Co., Ltd.	EcoGuardian	Filtration	Electrolysis/electrochlorinationc	Sodium thiosulphate	www.hanlaims.com/
37	Headway Technology Co., Ltd.	OceanGuard	Filtration	Electrolysis/electrochlorination +ultrasonic treatment (EUT)	Sodium thiosulphate (optional)	www.headwaytech.com/en
38	Hi Tech Marine Pty Ltd	Ballast water disinfection	–	Heating	–	www.htmarine.com.au
39	Hitachi	ClearBallast	Flocculation (magnetic particles) + Filtration		–	www.hitachi-pt.com/products/es/ballast
40	HWASEUNG R&A Co., Ltd.	HS-Ballast	–	Electrolysis/electrochlorination	Sodium thiosulphate	www.hsrna.com/eng/main
41	HyCa Technologies Pvt. Ltd.	HyCator	Filtration	Electrolysis/electrochlorination	Sodium thiosulphate	www.hycator.com/index.php/ourproduct/hycator-bwt
42	Hyde Marine Inc	Hyde Guardian Gold	Filtration	UV	–	www.hydemarine.com/ballast_water
43	Hyde Marine Inc	Seakleen ™(Vitamar)	–	SeaKleen	–	www.hydemarine.com/ballast_water
44	Hyundai Heavy Industries	EcoBallast	Filtration	UV	–	http://english.hhi.co.kr
45	Hyundai Heavy Industries	HiBallast	Filtration	Electrolysis/electrochlorination	Sodium thiosulphate	http://english.hhi.co.kr
46	JFE Engineering Corporation	JFE BallastAce BWMS (uses TG Ballastcleaner)	Filtration	Chlorination+residual Clorine+cavitation (TG BallastCleaner)	Sodium sulphite (TG Environmental guard)	www.jfe-eng.co.jp/en/products/machine/marine/mar01.html
47	JFE Engineering Corporation	JFE BallastAce BWMS (uses NEO-CHLOR MARINE)	Filtration	Chemical injection (Neo-Chlor Marine)	Sodium sulphite	www.jfe-eng.co.jp/en/products/machine/marine/mar01.html
48	Jiujiang Precision Measuring Technology Research Institute	OceanDoctor	Filtration	UV+photocatalytic reaction	–	–
49	Kashiwa Kuraray Co.Ltd. (ref doc 61/2/6)	Microfade	Filtration	Chlorination (Cl_2)	Sodium sulphite	www.kuraray.co.jp
50	Katayama Chemical inc.	Sky-System using PeracleanOcean	–	PeracleanOcean	Sodium sulphite	www.nipponyuka.jp
51	Knutsen Ballast Vann AS	KBAL	–	vacuum+UV	–	www.knutsenoas.com/knutsen-technology/knutsen-ballast-water-treatment-technology-kbal%C2%AE/
52	Korea Top Marine (KT Marine) Co., Ltd.	KTM-BWMS (Plankill pipe™)	–	Electrolysis/electrochlorination	Sodium thiosulphate	–
53	Kwang San Co., Ltd.	En-Ballast	Filtration	Electrolysis/electrochlorination	Sodium thiosulphate	www.kwangsan.com
54	Mahle NFV GmbH	Ocean Protection System OPS	Filtration	UV	–	www.mahle-industrialfiltration.com
55	Marenco Technology Group Inc	Marenco BWTS	Filtration	UV	–	–
56	Maritime Solutions Inc.	–	Filtration	UV	–	www.maritimesolutionsinc.com
57	Mexel Industries	–	–	Chemical treatment	–	www.mexelusa.com
58	MH Systems Inc	MH Systems BWTS	–	Deoxigenation	–	www.mhsystemscorp.com
59	Mitsui Engineering & Shipbuilding	FineBallast® OZ (Special Pipe SP-Hybrid BWMS with ozone)	–	Ozonation+cavitation	Activated carbon	www.mes.co.jp/english/business/ship/ship_13.html

(continued)

Table 2 (continued)

Nr.	Manufacturer	System name	Pre-treatment	Treatment	Residual control	Web site
60	MMC Green Technology AS	MMC	Filtration	UV	–	www.mmcgt.no/
61	NEI Treatment Systems LLC (two independent type approvals, i.e., Marshall Islands and Malta)	Venturi Oxygen Stripping	–	Cavitation+deoxigenation	–	www.nei-marine.com/en/about-us
62	NK Company	NK-03 BlueBallast	–	Ozonation	Sodium thiosulphate	http://nk-eng.nkcf.com
63	Nutech 03	Mark III	–	Ozonation	–	www.nutech-o3.com
64	Oceansaver AS (MetaFil AS)	OceanSaver	Filtration	Cavitation+electrolysis/electrochlorination+deoxigenation	Sodium thiosulphate	www.oceansaver.com
65	Oceansaver AS (MetaFil AS)	OceanSaver with optional N2 supersaturation	Filtration	Electrolysis/electrochlorination	Sodium thiosulphate	www.oceansaver.com
66	Optimarin AS	OptiMarin Ballast System OBS	Filtration	UV	–	www.optimarin.com
67	Panasia	GloEn-Patrol	Filtration	UV	–	www.pan -asia.co.kr
68	Panasia	GloEn-Saver	Filtration	Electrolysis/electrochlorination	Sodium thiosulphate	www.pan -asia.co.kr
69	Qwater	–	Filtration	Ultrasound	–	www.qwatercorp.com
70	REDOX Maritime Technologies (RMT) AS	REDOX AS	Filtration	ozone+UV	Sodium thiosulphate	www.redoxmaritime.no/uk/index.html
71	RWO GmbH Marine Water Technology	CleanBallast	Filtration	Electrochlorination+OH	Substance unknown	www.rwo.de /en/technologies_products_and_Solutions/Ballast_Water_Treatment/
72	Samsung Heavy Indistries	PuriMar	Filtration	Electrolysis/electrochlorination	Sodium thiosulphate	www.shi.samsung.co.kr/Eng/default.aspx
73	Samsung Heavy Indistries	NEO-PuriMar	Filtration	Electrolysis/electrochlorination	Sodium thiosulphate	www.shi.samsung.co.kr/Eng/default.aspx
74	Sea Knight Corporation	Insitu™	–	Chemical tr.+vacuum deoxigenation + bioaugmentation	–	www.seaknight.net
75	Sea Reliance Marine Services	–	Filtration	UV	–	–
76	Seair	–	Filtration	Ozonation	–	www.seair.ca
77	Sembawang	Semb-Eco	Filtration	UV incl. LED-UV	–	www.sembship.com
78	Severn Trent De Nora	BalPure	optional	Electrolysis/electrochlorination +residual Clorine	Sodium bisulphite or Sodium sulphite or Sodium thiosulphate	http://www.severntrentdenora.com/Products-and-Services/Ballast-Water-Treatment-Systems/
79	Shanghai Cyeco Environmental Technology Co. Ltd.	Cyeco	Filtration	UV	–	www.cyecomarine.com/product2.html
80	Siemens (now as Evoqua Water Technologies)	SiCURE	Filtration	Electrolysis/electrochlorination	Sodium sulphite (optional)	www.water.siemens.com
81	Sincerus	Sincerus maritime	Filtration	Electrolysis/electrochlorination	–	–
82	SPO System	Special Pipe Hybrid BWMS with PeracleanOcean	–	Cavitation+peracleanOcean	–	–
83	STX Metal Co. Ltd.	Smart Ballast	–	Electrolysis/electrochlorination	Sodium thiosulphate	www.stxmetal.co.kr
84	Sumetomo Electric Industries Ltd.	Ecomarine	Filtration	UV	–	http://global-sei.com/news/press/11/11_35.html
85	SUNBO Industries Co., Ltd.	Blue Zone	–	ozone	Thiosulphate	http://sunboind.en.ec21.com
86	Sunrui Corrosion and Fouling Control Company (Sunrui CFCC)	BalClor BWMS (Sunrui BWMS)	Filtration	Electrolysis/electrochlorination	Sodium thiosulphate	www.sunrui.net /Products/BalClorTMBallastWaterManagementSystem/
87	Techcross	Electro-Cleen System ECS	–	Electrolysis/electrochlorination	Sodium thiosulphate	www.techcross. com /new/main/main.asp

(continued)

Table 2 (continued)

Nr.	Manufacturer	System name	Pre-treatment	Treatment	Residual control	Web site
88	The Ship Stability Research Centre (SSRC), University of Strathclyde	ClearBal	–	–		www.sumobrain.com/patents/wipo/Ballast -water-treatment-system/WO2010086604.html
89	Trojan	Trojan Marinex	Filtration	UV	–	www.trojanmarinex.com
90	University of Dubrovnik, Croatia	–	Hydrocyclone	High pressure	–	–
91	Van Oord B.V.	VO-BWMS	–	Drinking water+chlorine	Sodium bisulphite	www.vanoord.com/
92	Wilhelmsen Technical Solutions/Resource (withdrawn from market, relaunch planned)	Unitor Resource BWTS	Filtration	Cavitation+electrolysis/electrochlorination+ozonation	–	www.resource-technology.com
93	Wuxi Brightsky Electronic Co., Ltd.	BSKY	Filtration	UV	–	www.bsky.cn
94	Confidential	Thermal Aqua Filtration (TAF)	Filtration	Heat	–	–
95	Confidential	–	Hydrocyclone	–	–	–
96	Confidential	–	Filtration	Cavitation+Electrochemical treatment	–	–
97	Confidential	–	Hydrocyclone	Chlorination	–	–
98	Confidential	–	Filtration	Akrolein	Not decided	–
99	Confidential	–	Filtration?	Electrolysis/electrochlorination	–	–
100	Confidential	–	Filtration	UV	–	–
101	Confidential	–	Filtration	Electrolysis/electrochlorination	Substance unknown	–
102	Confidential	–	Filtration	UV+microwaves+ozone	–	–
103	Confidential	–	Filtration	UV	–	–
104	Confidential	–	Filtration	UV	–	–

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