BALLAST WATER TREATMENT TECHNOLOGY

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Contents

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1. Introduction

Ballast water contains a variety of organisms including bacteria and viruses and the adult and larval stages of the many marine and coastal plants and animals. While the vast majority of such organisms will not survive to the point when the ballast is discharged, some may survive and thrive in their new environment. These 'non-native species', if they become established, can have a serious ecological, economic and public health impact on the receiving environment.

The International Maritime Organization (IMO) has developed international legislation, the International Convention for the Control and Management of Ships' Ballast Water and Sediments, to regulate discharges of ballast water and reduce the risk of introducing non-native species from ships' ballast water.

The requirement for ballast water treatment has arisen from the requirements of regulation D-2 of the Convention. In response to this, a number of technologies have been developed and commercialised by different vendors. Many have their basis in land-based applications for municipal and industrial water and effluent treatment, and have been adapted to meet the requirements of the Ballast Water Management Convention and shipboard operation. These systems must be tested and approved in accordance with the relevant IMO Guidelines.

This revision of the guide provides updated information on suppliers and the solutions that they provide, and indicates the status of systems in relation to the approval process. An outline description of water treatment processes and an appraisal of commercially available and developing technologies for ballast water treatment are also provided.

A summary both of the governing regulation that ultimately makes ballast water treatment mandatory forms Section 2 and water treatment technology as it relates to ballast water management, Section 3. These sections then provide the background knowledge and context for an assessment of the commercial technologies either currently commercially available or projected to be market-ready by 2009/2010 with reference to their efficacy, technical and economic viability and testing and approval status (Section 4). Full data, referenced against individual suppliers, are provided in the Annex.

The revisions to this publication, undertaken by the Institute for the Environment at Brunel University, update the 2007 guide produced for Lloyd's Register by the Centre for Water Science at Cranfield University in conjunction with the consultants Vale Water Services and Whitewater Limited. The continued assistance of the technology suppliers who contributed much of the information published herein is gratefully acknowledged.

2. Regulation

Ballast water quality and standards

Regulation D-2 of the Ballast Water Convention sets the standard that the ballast water treatment systems must meet (Table 1). Treatment systems must be tested and approved in accordance with the relevant IMO Guidelines.

Table 1 IMO 'D2' standards for discharged ballast water

Organism category	Regulation
Plankton, >50 μm in minimum dimension	< 10 cells / m^3
Plankton, 10-50 μm	< 10 cells / ml
Toxicogenic Vibrio cholera (O1 and O139)	< 1 cfu* / 100 ml
Escherichia coli	< 250 cfu* / 100 ml
Intestinal Enterococci	< 100 cfu* / 100 ml

* colony forming unit

Ships will be required to treat ballast water in accordance with the timetable shown in Table 2. According to this table, a key milestone arises in 2009, when ships under construction in or after that date having less than 5000 m^3 ballast water capacity must have ballast water treatment installed to meet the D2 Standard in the Convention. This is likely to apply to around 540 ships estimated to be commencing construction in 2009.

Table 2 Timetable for installation of ballast water treatment systems

Ballast capacity	Year of ship construction*			
	Before 2009	2009+	2009-2011	2012+
< 1500 m^3	Ballast water exchange or treatment until 2016 Ballast water treatment only from 2016	Ballast water treatment only		
1500 – 5000 m^3	Ballast water exchange or treatment until 2014 Ballast water treatment only from 2014	Ballast water treatment only		
> 5000 m^3	Ballast water exchange or treatment until 2016 Ballast water treatment only from 2016		Ballast water exchange or treatment until 2016 Ballast water treatment only from 2016	Ballast water treatment only

* *Ship Construction* refers to a stage of construction where:

- The keel is laid or construction identifiable with the specific ship begins; or
- Assembly of the ship has commenced comprising at least 50 tonnes or 1% of the estimated mass of all structural material, whichever is less; or
- The ship undergoes a major conversion.

Major conversion means a conversion of a ship:

- which changes its ballast water carrying capacity by 15 percent or greater or which changes the ship type, or
- which, in the opinion of the Administration, is projected to prolong its life by ten years or more, or
- which results in modifications to its ballast water system other than component replacement-in-kind.

Conversion of a ship to meet the provisions in the Convention relating to ballast water exchange ('regulation D- 1') does not constitute a major conversion in relation to the above requirements.

The approval processes

Technologies developed for ballast water treatment are subject to approval through specific IMO processes and testing guidelines designed to ensure that such technologies meet the relevant IMO standards (Table 1), are sufficiently robust, have minimal adverse environmental impact and are suitable for use in the specific shipboard environment.

A company offering a treatment process must have the process approved by a Flag Administration. In general the manufacturer will use the country in which it is based to achieve this approval, although this is not a specific requirement and some companies may choose to use the Flag State where the testing facility is based or the Flag State of a partner company. In general the Flag State will probably choose to use a recognised organisation - such as a classification society - to verify and quality assure the tests and resulting data.

The testing procedure is outlined in the IMO's Guidelines for Approval of Ballast Water Management Systems[1] (frequently referred to as the 'G8 guidelines'). The approval consists of both shore based testing of a production model to confirm that the D2 discharge standards are met and ship board testing to confirm that the system works in service. These stages of the approval are likely to take between six weeks and six months for the shore based testing and six months for the ship based testing.

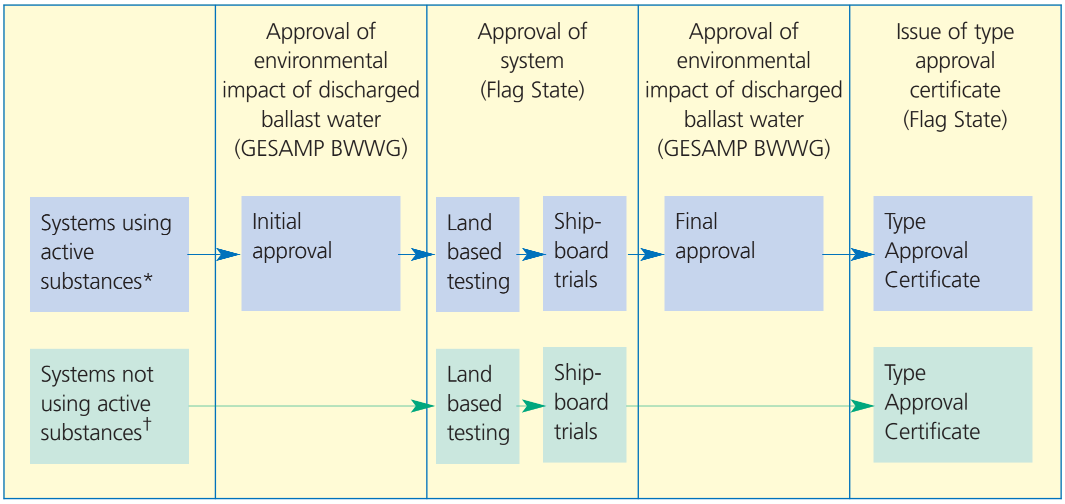

Fig 1. Summary of approval pathway for ballast water treatment systems

* Includes chemical disinfectants, e.g. chlorine, ClO_2, ozone

† Includes techniques not employing chemicals, e.g. deoxygenation, ultrasound

Further requirements apply if the process uses an 'active substance' (AS). An AS is defined by the IMO as 'a substance or organism, including a virus or a fungus that has a general or specific action on or against harmful aquatic organisms and pathogens'. For processes employing an AS, basic approval from the GESAMP[2] Ballast Water Working Group (BWWG), a working committee operating under the auspices of IMO, is required before shipboard testing proceeds. This is to safeguard the environment by ensuring that the use of the AS poses no harm to the environment. It also prevents companies investing heavily in developing systems which use an active substance which is subsequently found to be harmful to the environment and is not approved.

The GESAMP BWWG assessment is based largely on data provided by the vendor in accordance with the IMO approved Procedure for Approval of Ballast Water Management Systems that make use of Active Substances[3] (frequently referred to as the 'G9 Guidelines').

1 Guidelines for approval of ballast water management systems (G8) IMO resolution MEPC125(53)

2 Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection. An advisory body established in 1969 which advises the UN system on the scientific aspects of marine environmental protection.

3 Procedure for approval of ballast water management systems that make use of active substances (G9) IMO resolution MEPC126(53).

Basic Approval is the first step in the approval process when using an active substance. In most cases Basic Approval has been granted with caveats and the request for further information for the purposes of Final Approval. Basic Approval is thus an ‘in principle’ approval of the environmental impact of an active substance, which may then expedite inward strategic investment or marketing within the supplier’s organisation and allow testing of a system at sea. After Basic Approval for active substances, treatment systems can be tested both on land and onboard ship according to the IMO Guidelines for Approval of Ballast Water Management Systems (‘G8 guidelines’). Final Approval by the GESAMP BWWG will take place when all testing is completed. Once final approval is granted by GESAMP the Flag Administration will issue a Type Approval certificate in accordance with the aforementioned guidelines. If the process uses no active substances the Flag Administration will issue a Type Approval certificate without the need for approval from the GESAMP BWWG.

Whilst there is a considerable amount of published information concerning the efficacy of the commercially available or developing ballast water treatment technologies, these data have not all been generated under the same conditions of operation, scale and feedwater quality. This makes appraisal of the technologies difficult. The IMO ‘G8’ Guidelines for Approval of Ballast Water Management Systems are therefore designed to create a level playing field for assessment of technological efficacy. The stipulated testing regime and protocols are prescriptive in nature and costly to undertake. The sea-based test alone requires six months of testing based on a triplicated trial, with biological analysis to be completed within six hours of sampling. The land-based testing is based on specific organisms which therefore have to be either indigenous in the water or cultured specifically for the test. The land based and shipboard testing is overseen by the Flag Administration or a recognised organisation (generally a classification society).

Generally it is taking up to two years from submitting an application for Basic Approval for an active substance to completion of testing. As of July 2008, three systems have received type approval certificates, two of which have been required to go through the full 'G9' active substance approval procedure.

3. Treatment Process

Background

The technologies used for treating ballast water are generally derived from municipal and other industrial applications; however their use is constrained by key factors such as space, cost and efficacy (with respect to the IMO discharged ballast water standards).

There are two generic types of process technology used in ballast water treatment: solid-liquid separation and disinfection (Fig. 2).

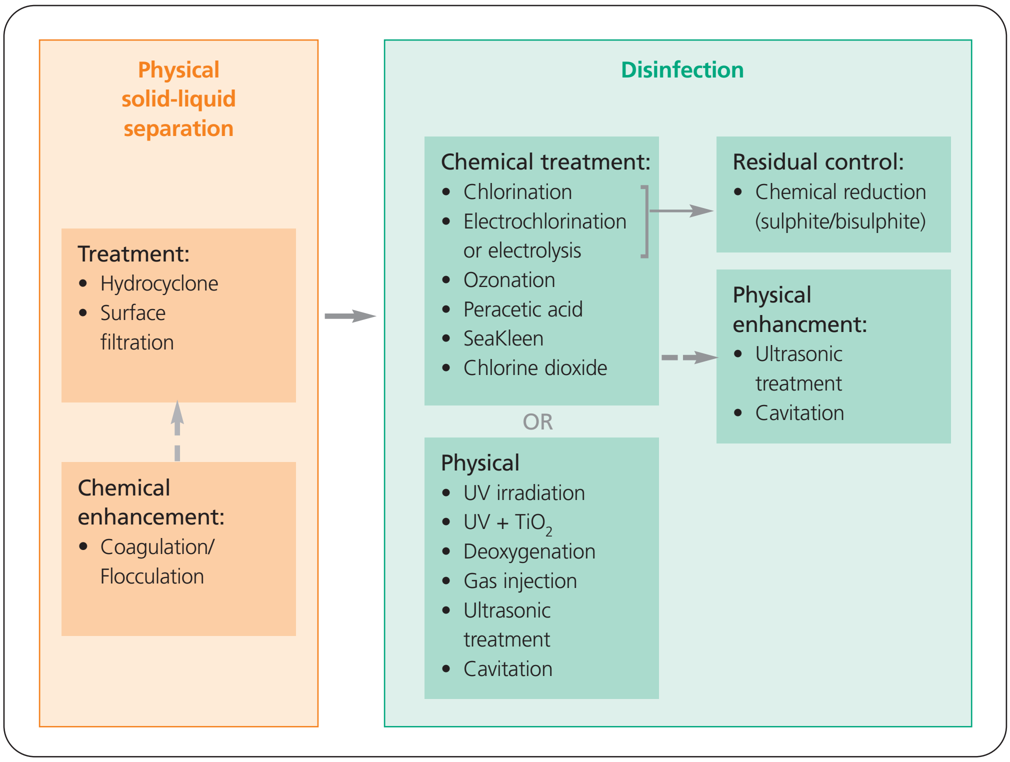

Fig. 2
Generic ballast water treatment technology process options

Solid-liquid separation is simply the separation of suspended solid material, including the larger suspended micro-organisms, from the ballast water, either by sedimentation (allowing the solids to settle out by virtue of their own weight), or by surface filtration (removal by straining; i.e. by virtue of the pores in the filtering material being smaller than the size of the particle or organism).

Disinfection removes and/or inactivates micro-organisms using one or more of the following methods:

- chemical inactivation of the microorganism
- physicochemical inactivation by irradiation with ultraviolet light, which denatures the DNA of the micro-organism and therefore prevents it from reproducing. Ultrasound or cavitation (termed 'micro-agitation' for the purposes of this publication) are also physico-chemical disinfection methods
- deoxygenation either by displacement of the dissolved oxygen with an inert gas injection or stripping it by means of a vacuum and thereby asphyxiating the micro-organism.

All of the above disinfection methods have been applied to ballast water treatment, with different products employing different unit processes. Most commercial systems comprise two stages of treatment with a solid-liquid separation stage being followed by disinfection (Fig. 2), though some disinfection technologies are used in isolation. One ballast water treatment technology also employs chemical enhancement (ie coagulation/ flocculation) upstream of solid-liquid separation; another employs titanium dioxide (TiO_2) to intensify ultraviolet irradiation.

Separation processes
As previously stated, the chemical or physicochemical unit processes used for disinfection are usually preceded by physical solid-liquid separation, by either filtration or hydrocyclone technology.

The filtration processes used in ballast water treatment systems are generally of the automatic backwashing type using either discs (Fig 3a) or fixed screens. Since the standards relating to treated ballast water are size-based, technologies capable of removing materials above a specific size are most appropriate.

Removal of larger organisms such as plankton (Table 1) by filtration requires a filter of equivalent mesh size between 10 and 50μm. Such filters are the most widely used solid-liquid separation process employed in ballast water treatment, and their effective operation relates mainly to the flow capacity attained at a given operating pressure. Maintaining the flow normally requires that the filter is regularly cleaned, and it is the balance between flow, operating pressure and cleaning frequency that determines the efficacy of the filtration process. In principle, surface filtration can remove sub micron (i.e. less than 1μm in size) micro-organisms. However, such processes are not viable for ballast water treatment due to the relatively low permeability of the membrane material.

Hydrocyclone technology is also used as an alternative to filtration, providing enhanced sedimentation by injecting the water at high velocity to impart a rotational motion which creates a centrifugal force (Fig. 3b) which increases the velocity of the particle relative to the water. The effectiveness of the separation depends upon the difference in density of the particle and the surrounding water, the particle size, the speed of rotation and residence time.

Since both hydrocylcones and filters are more effective for larger particles, pre-treatment with coagulants to aggregate (or 'flocculate') the particles may be used upstream of these processes to increase their efficacy. However, because flocculation is time dependent, the required residence time for the process to be effective demands a relatively large tank. The processes can be advanced, however, by dosing with an ancillary powder of high density (such magnetite or sand) along with the coagulant to generate flocs which settle more rapidly. This is sometimes referred to as 'ballasted flocculation', and is used in some municipal water treatment installations where space is at a premium and has been used in one of the systems included in this publication.

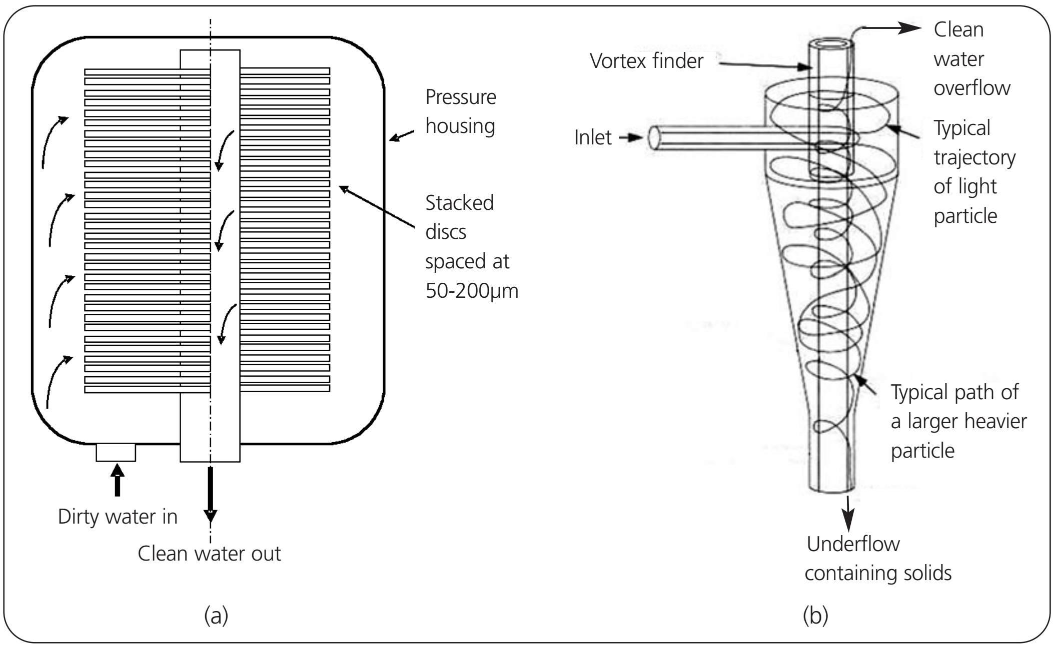

Fig. 3
(a) Filtration, and (b) Hydrocyclone processes

Disinfection

Chemical disinfection

A number of different chemicals or chemical processes have been employed in the ballast water treatment systems reviewed including:

- Chlorination
- Electrochlorination
- Ozonation
- Chlorine dioxide
- Peracetic acid
- Hydrogen peroxide
- Menadione/Vitamin K

The efficacy of these processes varies according to the conditions of the water such as pH, temperature and, most significantly, the type of organism. Chlorine, whilst relatively inexpensive is virtually ineffective against cysts unless concentrations of at least 2 mg/l are used. Chlorine also leads to undesirable chlorinated byproducts, particularly chlorinated hydrocarbons and trihalomethanes. Ozone yields far fewer harmful byproducts, the most prominent being bromate, but requires relatively complex equipment to both produce and dissolve it into the water. Chlorine dioxide is normally produced *in situ*, although this presents a hazard since the reagents used are themselves chemically hazardous.

Peracetic acid and hydrogen peroxide (provided as a blend of the two chemicals in the form of the proprietary product *Peraclean*) are infinitely soluble in water, produce few harmful byproducts and are relatively stable as *Peraclean*. However this reagent is relatively expensive, is dosed at quite high levels and requires considerable storage facilities.

For all these chemicals pre-treatment of the water with upstream solid-liquid separation is desirable to reduce the 'demand' on the chemical, because the chemical can also react with organic and other materials in the ballast water.

Post-treatment to remove any residual chemical disinfectant, specifically chlorine, prior to discharge using a chemical reducing agent (sodium sulphite or bisulphite) may be appropriate if high concentrations of the disinfectant persist. In potable water treatment this technique is routinely employed. When used in ballast water treatment, dosing to around 2 mg/l of chlorine can take place, leaving a chlorine residual in the ballast water tanks to achieve disinfection. The chlorine level is then reduced to zero ('quenching' the chlorine completely) prior to discharge. This technique is used in at least two of the ballast water treatment systems currently reviewed.

Menadione, or Vitamin K, is unusual in that it is a natural product (although produced synthetically for bulk commercial use) and is relatively safe to handle. It is marketed for use in ballast water treatment under the proprietary name *Seakleen*® by Hyde Marine. As with other disinfectant chemicals, it is not without a history of application elsewhere and has been used in catfish farming where it is liberally spread into water. Over three tonnes of menadione are used annually for this application alone.

Physical disinfection

Of the physical disinfection options ultraviolet irradiation (UV) is the most well established and is used extensively in municipal and industrial water treatment applications. The process employs amalgam lamps surrounded by a quartz sleeve (Fig.3) which can provide UV light at different wavelengths and intensities, depending on the particular application. It is well known to be effective against a wide range of microroganisms, including viruses and cysts, but relies on good UV transmission through the water and hence needs clear water and unfouled clean quartz sleeves to be effective.

The removal of water turbidity (i.e. cloudiness) is therefore essential for effective operation of the system. UV can be enhanced by combining with another reagent, such as ozone, hydrogen peroxide or titanium dioxide which will provide greater oxidative power than either UV or the supplementary chemical reagent alone.

The remaining physical disinfection processes do not inherently require use of pre-treatment. However, the efficacy of both processes is subject to limitations. Deoxygenation takes a number of days to come into effect due to the length of time it takes the organisms to be asphyxiated. However, most voyages will exceed this time period so this should not be a significant constraint.

Cavitation or ultrasonic treatment processes both act at the surface of the micro-organism and disrupt the cell wall through the collapse of microbubbles. These processes are currently not as well understood as the other more established disinfection technologies and some systems use these techniques with chemical disinfection to provide the necessary biocidal efficacy.

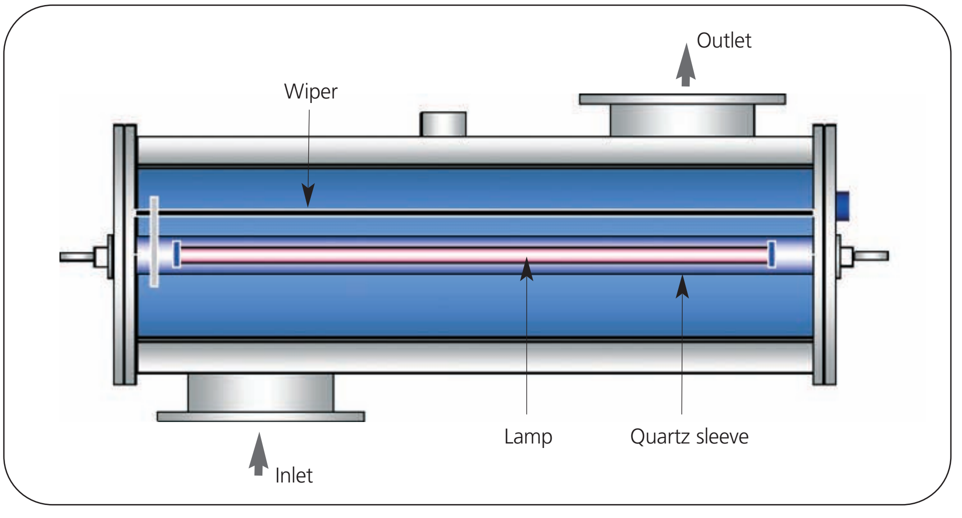

Fig. 4 UV tube and system

Ballast water treatment unit processes
The range of unit processes employed for ballast water treatment is shown in Table 3. The commercial systems differ mainly in the choice of disinfection technology and the overall system configuration (i.e. the coupling of the disinfection part with solid liquid separation, where the latter is used). Almost all have their basis in land-based systems employed for municipal and industrial water and wastewater and thus can be expected to be effective for the duty of ballast water, albeit subject to constraints in the precise design arising from space and cost limitations.

Table 3 Commercial technologies by generic unit operation type

ID Manufacturer	Solid-liquid sepn				Chemical disinfection and dechlorination						Physical disinfection			Micro-agitation		AO
	HC	Filt	None	Coag	O_3	Cl	EL/EC	PAA	SK	Res	UV	Deox	Heat	Cav	US	
1 Alfa Laval Tumba AB		X									X					TiO_2
2 ATG Willand		X									X					
3 Ecochlor Inc			X			X (as ClO_2)										
4 Electrichlor Inc		X					X									
5 Environmental Technologies Inc		X			X										X	
6 Gauss		X									X					
7 Greenship	X						X									
8 Hamann AG	X	X						X								
9 Hitachi		X		X[3]												
10 Hi Tech Marine Pty Ltd			X										X			
11a Hyde Marine Inc -Hyde Guardian		X									X					
11b Hyde Marine Inc -*Seakleen* ™			X						X							
12 JFE Engineering Corporation		X				X (as Cl_2)				X				X		
13 Marenco Technology Group Inc		X									X					
14 Mahle NFV GmbH		X									X					
15 MH Systems Inc			X									X				
16 Mitsui Engineering & Shipbuilding			X		X									X		
17 NEI Treatment Systems LLC			X									X		X		
18 Nutech 03			X		X											
19 Oceansaver AS												X		X		
20 Optimarin AS		X									X					
21 Panasia		X									X					$OH^\bullet$
22 Qwater		X													X	
23 Resource Ballast Technology		X			X		X							X		
24 RWO Marine		X					X									$OH^\bullet$
25 Severn Trent De Nora							X			X						
26 Siemens		X					X									
27 Techcross			X				X									
28 Toagosei Group		X				X (as OCl)				X						
29 Ferrate Treatment Technologies[1]																Fe^{6+}
30 Sincerus[1]			X				X									

[1]Data incomplete - did not return completed survey forms

HC Hydrocyclone Filt Filtration Coag Coagulant (with magnetic particles) UV Ultraviolet irradiation Deox Deoxygenation O_3 Ozonation Cav Cavitation Cl Chlorination

EL/EC Electrolysis/electrochlorination PAA Peracetic acid (as *Peraclean*) ClO_2 Chlorine dioxide SK *Seakleen* Res Residual Cl neutralisation US Ultrasound AO Advanced oxidation

4. Treatment technologies and suppliers

Suppliers
This publication considers only suppliers of complete systems for ballast water treatment rather than suppliers of unit operations, although individual proprietary unit operations (e.g. filters, electrochlorination devices, disinfectant chemicals and UV sterilisers) may be included as part of the systems reviewed.

Basic technical information is available from 30 companies, and 28 of these took part in the survey, and it is information from these 28 which forms the basis of this publication. Of these, 11 are part of a multi-billion dollar turnover international group of companies with significant activity in marine and/or engineering areas. The remainder appear to be SMEs (small to medium enterprises, generally defined as having less than 250 employees) all of which have been set up within the past 13 years and seven of which are no more than seven years old. Nine different countries are represented by these 28 companies, with the predominant nation being the US (Fig. 5).

Some companies have collaborated with unit process suppliers to produce a system. For example, RWO Marine (part of the multi-billion dollar turnover Veolia group of companies) originally partnered Permascand for its *Ectosys* system (and have since acquired the *Ectosys* product), the Mitsui Engineering system was originally developed by a number of partners led by the Japanese Association of Marine Safety; several companies employ proprietary filters. A number of the smaller suppliers, whilst having few employees in the core company, have partners, primarily licensees/distributors providing a global network to sell the technology.

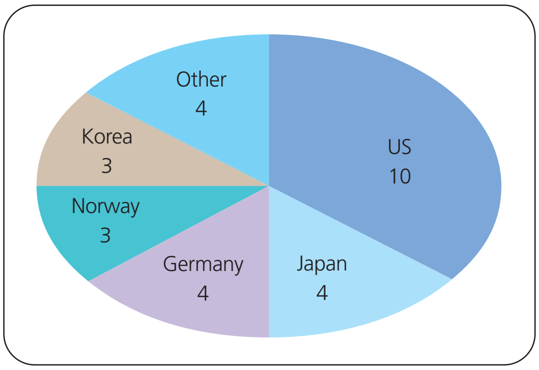

Fig. 5 Technology suppliers by country: 'Other' comprise Australia, Netherlands, South Africa and the UK

Technologies

Categories
The combination of treatment technologies utilised by the various suppliers are summarised in Table 3; since one supplier Hyde Marine offers two systems, there are 31 systems in total. All of the 29 products for which information is available, other than those based on gas injection, are either modular or can be made so.

All of the systems reveiwed have undergone preliminary pilot trials. The published data from these trials has shown the systems to be generally effective with reference to the IMO treated water standards applicable to discharged ballast water shown in Table 1. There has been debate as to whether systems using UV as a disinfection technique require active substance approval; nevertheless, two such systems, GloEn-Patrol and PureBallast, have, as of April 2008, undergone Basic Approval under the G9 Guidelines (and Final Approval in the case of PureBallast).

There has also been debate as to whether free hydroxyl radicals produced by electrolysis (eg RWO Marine's process) or advanced oxidation are considered to be active substances by the GESAMP WG. The MEPC 57 (April 2008) revision of its Procedure for Approval of Ballast Water Management Systems that make use of Active Substances (G9) clarified "Active Substance means a substance or organism, including a virus or a fungus that has a general or specific action on or against harmful aquatic organisms" and furthermore that "Any system which makes use of, or generates, Active Substances, relevant chemicals or free radicals during the treatment process to eliminate organisms in order to comply with the Convention should be subject to this Procedure". It is consequently now clear that all such systems are to be subject to the G9 approval procedures.

Of the systems considered the majority employ upstream filtration for solid-liquid separation (Fig. 6a), with the filter pore size primarily in 30-50 μm range. Only one supplier (Hitachi) employs a sub-10 μm rated filter, which would be expected to provide good disinfection capability against the larger micro-organisms and reduce the loading on the downstream processes. However, filters of smaller pore ratings demand commensurately higher operating pressures, and thus higher energy demands, and also more rigorous cleaning. One supplier (Marenco) uses cartridge filters which are not backwashable. Three suppliers employ hydrocyclones. Only one system (Hitachi) employs pre-coagulation upstream of the filter. This particular system employs magnetic particles to accelerate the clarification process ('enhanced flocculation').

All solid-liquid separation processes produce a waste stream containing the suspended solids. This waste stream comprises the backwash water from filtering operations or the underflow from the hydrocyclone separation. These waste streams require appropriate management. During ballasting they can be safely discharged at the point where they were taken up. On deballasting, the solid-liquid separation operation is generally by-passed.

Whilst there are a range of disinfection processes used for ballast water treatment, the majority of the systems are based on either electrolytic treatment (electrolysis or electrochlorination) or UV irradiation (Fig. 6b). In one case (Alfa Laval system), the UV irradiation is supplemented with titanium dioxide (TiO_2) to intensify the oxidative power of the UV light (Section 3.3).

The electrolytic treatment products have different design features but all essentially employing a direct current to electrolyse the water. Electrolytic technologies provided for ballast water treatment may be designed to generate either chlorine, as in the classic electrochlorination process, or other oxidative products. Those designed for chlorine generation rely on the salinity of the feedwater for effective chlorine generation; supplementary brine is necessary when the abstracted ballast water is fresh. This is not an issue for classical chlorine dosing using hypochlorite solution, of which there is only a single example (JFE). There are only single examples of the use of *SeaKleen* or chlorine dioxide for disinfection. This may be due to licensing constraints or patenting issues.

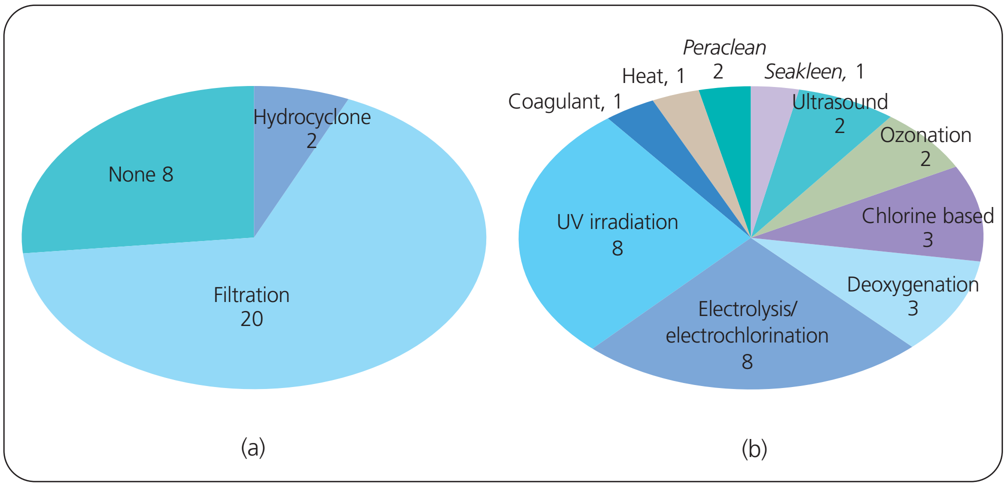

Fig. 6 Summary of treatment technology options for (a) physical pre-treatment, and (b) disinfection

Process configurations

With regard to overall process configuration, that is the way in which the unit operations are combined to produce a treatment technology (Fig 7). Of the products surveyed, eight are filtration followed by UV, five are filtration followed by electrolytic treatment and one is hydrocyclone separation followed by electrolysis/electrochlorination. The use of filtration upstream of a UV process is essential for removing solid particles, and in particular fine particles which inhibit the effective operation of the UV due to their impact on light transmission (Section 3). The UV tubes appear to be mainly medium pressure type as is appropriate for the system capacities of these shipboard applications.

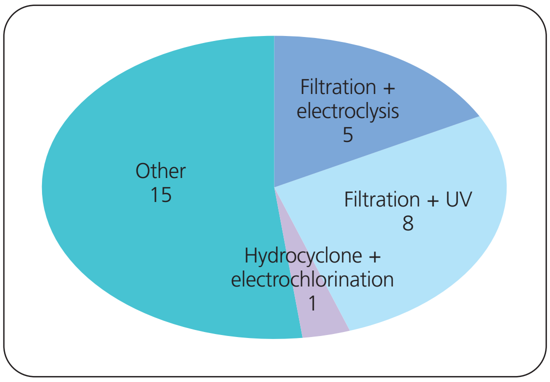

Fig. 7 Treatment process configurations

As with UV disinfection, upstream solid-liquid separation ahead of chemical treatment is required mainly to reduce the solids loading on the disinfection process. This reduces the risk of fouling and clogging of the disinfection unit, but also reduces the load on the chemical; the chemical is thus used primarily for disinfection rather than chemically oxidising other essentially innocuous dissolved matter in the ballast water. However there are systems where no pre-treatment is used ahead of chemical disinfection. In some systems the impact of the disinfectant chemical is enhanced by the use of micro-agitation, i.e. cavitation or ultrasonic treatment. As already stated (Section 3), the use of micro-agitation for disinfection - either in combination with a classical chemical disinfectant or, more unusually, in isolation - is not widespread. Existing examples for water and wastewater treatment appear to be limited to cooling tower waters. There is one example (Qwater) of ultrasonic treatment being used in the absence of a disinfection chemical. Three systems use a proprietary biocide chemical such as *Peraclean* or *Seakleen* or *TG Ballast Cleaner*.

Of the remaining systems, one uses heat, the others are based on deoxygenation using injection of an inert gas (nitrogen), in some cases combined with carbon dioxide to displace the dissolved oxygen. This method is particularly attractive when a supply of nitrogen gas exists on board, as when transporting flammable or explosive materials such as liquid fuel. Of the three examples, two employ cavitation – presumably to enhance the solubility of the gas in water. These systems are not modular but are scaled according to the desired capacity.

Almost half of the systems reviewed treat the ballast water both during ballasting and discharge (Table 5). If filtration is used with backwashable filters then the filters are by-passed during discharge to avoid discharging non native organisms and other material into the receiving water. The majority of the other technologies treat only during ballasting. Of the remainder, two treat during discharge and two during ballasting and during the voyage.

Cost and footprint

The key technical features of the system with respect to ballast water treatment are the flow capacity, footprint, overall size of the system and costs, the latter comprising capital expenditure (capex) and operating expenditure (opex). Most of the technologies have been developed for a flow rate of about 250m^3/hr, considered to be the flow rate required for the first phase of ships required to be equipped with ballast water treatment technology. Since the systems are largely modular in design (other than the gas injection type), there is no technical limit to the upper flow rate other than that imposed by size and/or cost. In some cases there are examples of systems already installed for flows above 5000 m^3/hr.

The mean key data for costs and footprint for all the technologies are summarised in Table 4 and Figures 8 and 9. Full data are provided in Table 5. The mean quoted estimated or projected operating cost of the systems, on the basis of the 13 sets of data provided is $47 per 1000m^3, within a broad range of values from no cost (when waste heat is used) to $200 per 1000m^3 treated water. Seven of the 13 suppliers who provided operational expenditure information quoted costs below $20 per 1000m^3, and variation may be due to methods of calculating opex. Some suppliers indicated that extra water head on ballast pumps may be required. There is a tendency, where data is available, for larger units to be more efficient in terms of power requirements, which for the 14 systems for which data was available ranged from 4 to 220 kW per 1000m^3 of treated ballast water. In most cases (except for the few technologies that use stored chemicals and the gas injection units that use fossil fuel) the majority of the opex relates to the power required to operate the process (UV irradiation, electrolysis or ozonation).

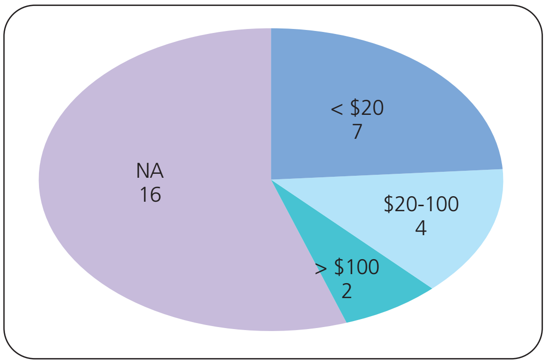

Fig. 8 Estimated plant operating cost per 1000m^3 of treated water: 29 products; information not available or not provided for 16 systems

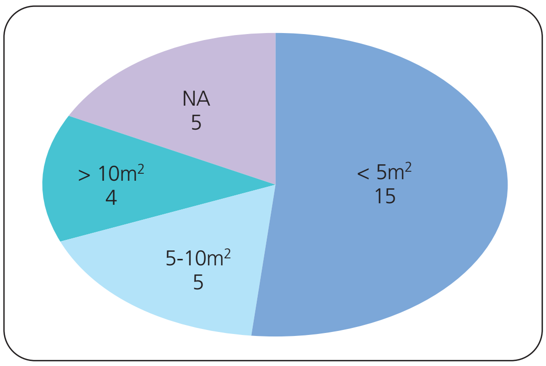

Fig. 9 Estimated footprint of a 200m^3/h plant: 29 products; information not available or not provided for five systems.

Table 4 Summary of plant footprint, height and capital and operating expenditure

	Footprint, m^2		Height	Capex $'000		Opex	Power
	200 m^3/h*	2000 m^3/h*	m	200 m^3/h*	2000 m^3/h*	$/1000 m^3	kW/1000m^3
Mean	7	26	2	379	875	47	67
Data points	24	21	25	14	15	13	14
Min	0.25	1	1.38	145	175	0	4
Max	25	145	4.3	780	2000	200	220

*System flow rate

Capital cost information is more widely available in 2008 compared to 2007, however, almost half of the suppliers regard this information as confidential. From the 14 sets of data provided, the capital cost of a 200 m3/h plant ranges from $145k to $780k, with a mean value of around $380k. For a 2000 m^3/h plant, the equivalent values are $175k to $2000k with a mean of $875k. As with the opex, from the limited information provided there appears to be no correlation between the quoted capex and the configuration of the process, and variations in prices arise from differences in assumptions made by the various suppliers regarding inclusion or exclusion of specific components. Prices quoted must be regarded as tentative since some of these products are still under development and the price is to some extent determined by the marketplace.

The footprint of the systems reviewed varies between 0.25 and 25 m^2 for a 200 m^3/h unit, with a mean value of 7 m^2, according to the data provided by suppliers in relation to 24 systems. For a unit of ten times this flow capacity, there is less information, since some suppliers do not provide units of this size, and the minimum, maximum and mean values are 1, 145 and 21 m^2 respectively. One supplier (Hamann) indicated that they had included pipework in their footprint, and Optimarin stated that their system may be suspended under the deck, giving a zero footprint. Thus, whilst the units may be predominantly modular, this does not imply that the footprint increases proportionately with flow capacity. The height quoted, or calculated from total volume space occupied, is between 1.38m and 4.3m for the 23 technologies for which information was provided.

Table 5 System key data: capacity, footprint and costs

Manufacturer	Treatment protocol	Capacity* 000's m^3/h	Estimated Footprint		Estimated Capex $'000 (installed cost)		Estimated Opex $/1000 m^3
			200 m^3/h	2000 m^3/h	200 m^3/h	2000 m^3/h	
Alfa Laval Tumba AB	A+B+D	5	3	12	NA	NA	NA
ATG Willand	A+B+D	>10	25	NA	NA	NA	NA
Ecochlor Inc	A	0.25-10	6.8	9.5	500	800	80
Electrichlor Inc	A+B+D	>10	3	-	350	NA	19
Environmental Technologies Inc	B	>10	NA	15	NA	500	5
Gauss	NA	NA	NA	NA	NA	NA	NA
Greenship	A+B+D	>10	1.6	15	300	2300	NA
Hamann AG	A	0.05-2	4.3	64**	NA	NA	200
Hitachi	A	>10	20	100	NA	400	NA
Hi Tech Marine Pty Ltd	A+C	5	7.3	145	780	1600	nil***
Hyde Marine Inc - Hyde Guardian	A+B+D	>10	3.5	25	NA	NA	10
Hyde Marine Inc - *Seakleen*™	A	>10	0.25	1	NA	NA	NA
JFE Engineering Corporation	A+B+D	2.1	NA	12	NA	NA	40
Marenco Technology Group Inc	B	1	1.2	NA	145	175	0.6-1.0
Mahle NFV GmbH	A+B+D	25	4	NA	NA	NA	NA
MH Systems Inc	C	>10	5	9	650	950	60
Mitsui Engineerg. & Shipbuilding	A	NA	15	NA	NA	NA	NA
NEI Treatment Systems LLC	A	NA	3	6	360	690	150
Nutech 03	A	>10	22	40	288	150	320
Oceansaver AS	A+B	0.5-5	NA	NA	NA	1600	NA
Optimarin AS	A+B+D	>10	0-3	0-11	430	1800	NA
Panasia	A+B+D	4	1.8	148	NA	NA	NA
Qwater	A+B+D	NA	15	30	NA	NA	NA
Resource Ballast technology	A	0.2-5	2	4	200	500	NA
RWO Marine	A+B+D	>10	3	20	NA	NA	NA
Severn Trent De Nora	A+B+D	>10	8	11	350	500	13
Siemens	A	>10	3.3	4.1	400	600	20-30
Techcross	A	>10	2	4	297	559	3
Toagosei	A+B+D	NA	NA	NA	NA	NA	NA

A ballasting, B discharging, C during voyage, D bypass filter on deballasting

*Maximum treatment flow currently available (>10m^3/h indicates no stated maximum) **includes pipework

*** Assumes waste heat utilised

Other system characteristics
Other technical features of the products are not necessarily common to all of them and are specific to generic types of process technology. These process-specific facets can be summarised as follows:

- Deoxygenation is the only technology specifically developed for ballast water treatment and is effective because the de-aerated water is stored in sealed ballast tanks. However the process takes between one and four days to take effect, and thus represents the only type of technology where 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.

- Systems in which chemicals are added normally need to be neutralised prior to discharge to avoid environmental damage in the area of discharge. Most ozone and chlorine systems are neutralised but some are not. Chlorine dioxide has a half life in the region of 6-12 hours, according to the supplier, but at the concentrations at which it is employed it can be safely discharged after a maximum of 24 hours.

- 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 be expected to be as effective.

- Most chlorination systems are applying a dose in the region of 2 mg/l residual chlorine which has proven to be effective.

- Most ozonation suppliers are using an ozone dose of 1-2 mg/l which has proven to be effective.

- UV systems are the least complex treatment plants to operate. Electrolysis and electrochlorination plants are the most complex.

- Deoxygenation plants are relatively simple devices if an inert gas generator is already installed on the ship and in the latter case would take up little additional space.

- Chemical dosing systems such as *Peraclean*, *SeaKleen* and chlorine dioxide have low capital costs because only a dosing pump is required but require chemical storage facilities and availability of chemicals in the ports visited.

- The biggest operating cost for most systems is power and for large power consumers (electrolytic and advanaced oxidation processes) availability of shipboard power will be a factor.

- For chemical dosing systems, power is very low and chemical costs are the major factor. For these reasons chemical addition may be better suited to small ballast capacities.

- Although the systems operate at generally low pressure and thus do not require additional ballast water pumping pressure, those employing venturi devices (for exerting shear) incur pressure losses of up to 2 bar.

- For most systems it is recommended that 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 penalty for this. The generation of hydrogen by the electrolytic technologies is not considered an issue, since 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 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.

Commercial availability

At the time of publication, 21 of the 28 companies participating in the review had installed systems, and one (MH Systems Inc.) was involved in the late stages of system design. A total of 56 ballast water treatment systems had been installed by these suppliers as of July 2008. UV based systems, from Alfa Laval, Hyde Marine and Optimarin account for just over one third of installations.

Table 6 System status: commercial development and approval

Manufacturer	Active substance approval (if applicable)		System approval		Test site	Approval Certificate[1]	Commercially available[2]	Units installed[3]	Projected production
	Basic	Projected final	Shipboard	Landbased					Units/y
Alfa Laval Tumba AB	07/2007	07/2007	04/2008	04/2008	NIVA	06/2008	2006	5	No limit
ATG Willand	-	-	-	-	-		Yes	1	NA
Ecochlor Inc	10/2008*	07/2009*	Ongoing	06/2008	NIOZ		2006	2	100
Electrichlor Inc	-	-	-	-	-		2006	3	240
Environmental Technologies Inc	-	-	-	-	-		NA	0	NA
Gauss	-	-	-	-	-		NA	0	NA
Greenship	10/2008**	07/2009*	06/2008	10/2007	Harlingen		2006	2	No limit
Hamann AG - SEDNA	03/2006	04/2008	06/2007	06/2007	NIOZ	06/2008	2006	2	65
Hitachi – Clear Ballast	04/2008	-	-	-	-		2009	0	50
Hi Tech Marine Pty Ltd	-	-	-	-	-		Yes	–	
Hyde Marine Inc –Hyde Guardian	-	-	11/2008*	11/2008*	NIOZ		2000	7	600
Hyde Marine Inc –Seakleen TM	-	-	-	-	-		2009	0	1000
JFE Engineering Corporation	10/2008*	07/2009*	10/2009	10/2009	-		2009	1	300
Marenco Technology Group Inc	-	-	2007	2007	MLML		2008	3	240 -360
Mahle NFV GmbH	-	-	2009	2009	NIOZ		2010	1	No limit
MH Systems Inc	-	-	07/2009	12/2008	SIO		2006	1[4]	300
Mitsui Engineering & Shipbuilding	10/2006	07/2009*	03/2009	02/2008	JAMS		2009	1	40 – 100
NEI Treatment Systems LLC	-[5]	-[5]	-[5]	-[5]	NOAA	10/2007	2006	5	200
Nutech 03	07/2007	10/2008*	2008	2008	-		2008	4	168
Oceansaver AS	04/2008	10/2008*	08/2008	10/2007	NIVA		2008	2	>200
Optimarin AS	-	-	01/2009	05/2008	NIVA		Yes	8	300 – 600
Panasia Co Ltd – GloEn Patrol	04/2008	-	03/2009	10/2008	KORDI		2009	1	NA
Qwater	-	-	-	-	-		04/2009	0	NA
Resource Ballast Technology	04/2008	2009*	2008	2008	Cape Town		2009	2	2000+
RWO Marine – Clean Ballast	10/2006	07/2009*	03/2009	09/2007	NIVA		2008	2	No limit
Severn Trent De Nora	2008*	2009*	2009	01/2007	UNSRL		2007	1	100
Siemens	-	-	-	-	-		2009/10	NA	NA
Techcross – Electro-Clean	03/2006	10/2008**	08/2007	08/2007	KORDI		2007	2	1200
Toagose Group – TG Ballastcleaner	10/2008**	-	-	-	-		NA	NA	NA

*dates projected by manufacturer
**Recommended for approval at MEPC 58 October 2008

1 Guidelines for approval of ballast water management systems (G8) IMO resolution MEPC.125(53)
2 Year commercialised or anticipated for commercialisation for ballast water treatment;
3 refers to existing installations;
4 system design for R/V Melville, a Scripps ship, almost complete
5 tests comparable to IMO 'G8' ballast water management systems testing protocol stated to have been completed prior to introduction of 'G8' protocol;

Approval status

The regulatory framework requires that a key distinction is to be made between those systems employing active substances (primarily disinfectant chemicals) and those which do not. Non-AS systems would appear to have less regulatory hurdles to overcome as they do not require GESAMP G9 approval. However, Alfa Laval have successfully demonstrated that it is possible to obtain full type approval certification ahead of systems which do not require GESAMP approval.

According to information provided by the suppliers, most of the technologies reviewed are progressing towards approval, though the scheduling of the testing differs between the different suppliers and thus the projected date for final approval. To date ten of the active substance systems have received basic approval from the MEPC, however, a further three are expecting basic approval by the end of 2008. At present, two systems have final active substance approval, although by the end of 2008 this is likely to be five.
It is clear, however, that many systems are undergoing 'G8' ballast water management systems approval without having received basic approval for the active substances. Indications are that up to twelve companies are or will be undertaking testing of ballast water management systems at test facilities in during 2008 and 2009.

By July 2008, three systems (Alfa Laval, Hamann HG and NEI Treatment Systems) have been issued with type approval certificates, and others are progressing through the approval process. It is expected that the number of systems with type approval certificates will significantly increase over the next 12 - 18 months.

5. Concluding remarks

Most of the products included in this publication are either commercially available or are to be commercialised in the near future. Almost all should be commercially available by 2010, according to approval schedules provided and manufacturing capability detailed by the technology suppliers. However, these estimates may be optimistic and will be reviewed in an update to this publication.

Most technologies have their basis in known water and wastewater treatment unit operations used in the municipal and other industrial sectors, the exception being deoxygenation which is specific to ballast water treatment. There is a great deal of evidence supporting the efficacy of most of the technologies with respect to the ballast water quality standards, though this is subject to testing under the stipulated IMO conditions. To date, there are three systems which have been awarded full type approval certificates, two of which use active substances (Alfa Laval and Hamann AG), and one using deoxygenation / cavitation (NEI Treatment Systems).

There is strong commitment towards approval from most companies. Most companies have indicated that `G8' and if necessary `G9' ballast water management systems testing will be carried out by the end of 2009. Only one or two of the 26 companies or organisations surveyed are not in a position to commercialise their products.

Annex – Listing by supplier

Supplier **Alfa Laval Tumba AB**
Process *Pureballast*: Filtration + Ultraviolet/TiO_2
System used Ballasting + discharging
Partner(s) Wallenius
Country Norway
Web site www.alfalaval.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
07/2007*	07/2007*	04/2008	04/2008	NIVA	27/06/2008	2006	5	**
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of:** 200 m^3/h	2000 m^3/h	**Maximum height** m	**Capex, $k** 200 m^3/h	2000 m^3/h	**Opex** $per 1000 m^3/h	**Company formed**	**No. employees**
5	3	12	3	NA	NA	NA	1883	9500
Power requirement kW / m^3/ h		**Additional services**		**Comments**	*Basic and final approval granted MEPC 56 **According to an evaluation of potential growth to 2016, manufacturing not seen as a limiting factor			
NA		Air, water (rinsing)						

Supplier **ATG Willand**
Process Filtration + ultraviolet
System used Ballasting + discharging
Country United Kingdom
Web site www.atgwilland.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
-	-	-	-	-	-	Yes	1	NA
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of:** 200 m^3/h	2000 m^3/h	**Maximum height** m	**Capex, $k** 200 m^3/h	2000 m^3/h	**Opex** $per 1000 m^3/h	**Company formed**	**No. employees**
>10	25	NA	2.2	NA	NA	NA	1885	20
Power requirement kW / m^3/ h		**Additional services**						
NA		none						

Supplier **Ecochlor Inc.**
Process ClO_2
System used Ballasting
Partner(s) Rolls-Royce Marine; Proflow Inc.; Eka Chemicals
Country US
Web site www.ecochlor.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
10/2008*	07/2009**	Ongoing	06/2008	NIOZ		2006	2***	100****
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of:** 200 m^3/h	2000 m^3/h	**Maximum height** m	**Capex, $k** 200 m^3/h	2000 m^3/h	**Opex** $per 1000 m^3/h	**Company formed**	**No. employees**
0.25-10	6.75	9.5	2.5	500	800	80	2001	6
Power requirement kW / m^3/ h		**Additional services**		**Comments**	* Basic approval expected at MEPC 58 ** projected for MEPC 59, July 2009 *** plus 4 pending **** projected for 2010			
NA		Water						

Supplier **Electrichlor Hypochlorite Generators Inc.**
Process Filtration + electrolysis/electrochlorination
System used Ballasting + discharging
Country US
Web site www.electrichlor.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
-	-	-	-	ND		2006	3	240
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
>10	3	NA	2	350	NA	19	2000	19
Power requirement kW / m³/ h		**Additional services**						
>10		NA						

Supplier **Environmental Technologies Inc**
Process Filtration + ozone + ultrasound
System used Discharging
Country US
Web site www.tlmcos.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
-	-	-	-	NA		NA	0	NA
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
>10*	NA	15	2.4	NA	500	5	1994	3
Power requirement kW / m³/ h		**Additional services**		**Comments**	*Modular system treats 227-1360 m³ ballast water/h per module			
70		Water (cooling)						

Supplier **Gauss**
Process Filtration + ultraviolet
System used NA
Partner(s) MWB AG, AWI
Country Germany
Web site www.gauss.org

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
-	-	-	-	ND		NA	0	NA
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
NA	NA	NA	NA	NA	NA	NA	1996	10
Power requirement kW / m³/ h		**Additional services**		**Comments**	Research organization. Progress in product development dependent on securing funding			
NA		NA						

Supplier **Greenship**
Process Hydrocyclone and Electrolysis/electrochlorination
System used Ballasting + discharging
Country Netherlands
Web site www.greenship.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
10/2008*	07/2009**	06/2008	10/2007	Harlingen	***	2006	2	NA#
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
>10	1.6	15	1.8	300	2000	NA	1994	5
Power requirement kW / m³/ h		**Additional services**		**Comments**	*Basic approval expected at MEPC 58 – based on GESAMP 6th meeting recommendation **final approval projected MEPC 59, July 2009 ***Target date of 10/2009 # Manufacturing not seen as a limiting factor			
30		none						

Supplier **Hamann AG**
Process 2 step filtration and peracetic acid (Peraclean®Ocean)
System used Ballasting
Partner(s) EVONIC Industries
Country Germany
Web site www.hamannag.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
03/2006*	04/2008**	06/2007	06/2007	NIOZ	10/06/2008	Since 2006	2	65
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
0.05-2	4.3	64#	2.2-2.9	NA	NA	200	1970	94
Power requirement kW / m³/ h		**Additional services**		**Comments**	* Basic approval 24/03/06 (MEPC 54/2/12 annex 5) **Final approval 04/04/2008 (MEPC 57/2/10 annex 7) #Footprint includes pipework			
NA		NA						

Supplier **Hitachi**
Process Filtration + pre-coagulant (enhanced flocculation)
System used Ballasting
Partner(s) Mitsubishi HI
Country Japan
Web site www.hitachi.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
04/2008*	-	07/2008	06/2008	ND		2009	0	50
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
>10	20	100	NA	NA	400	NA	1929**	9256,000
Power requirement kW / m³/ h		**Additional services**		**Comments**	*Basic approval granted MEPC 57 **As Hitachi Plant Technologies; original company formed in 1910			
NA		NA						

Supplier **Hi Tech Marine Pty Ltd.**
Process Heat
System used Ballasting or during voyage
Country Australia
Web site www.htmarine.com.au

Active substance approval (if applicable)		System approval		Test site	Type approval certificate	Commer-cially available	Units installed	Projected production
Basic	Final	Shipboard	Landbased					Units/y
-	-	-	-	-		Yes	-	-
Capacity	Footprint, m² for unit capacity of:		Maximum height	Capex, $k		Opex $per	Company formed	No. employees
1000 m³/h	200 m³/h	2000 m³/h	m	200 m³/h	2000 m³/h	1000 m³/h		
0.1-5000	7.3	145	4.3	780	1600	nil*	1986	Outsourced
Power requirement kW / m³/ h		Additional services		Comments: *assuming waste heat utilised				
5.8		Designed to use waste heat						

Hyde Guardian
Supplier **Hyde Marine - (Lamor Corporation, LLC)**
Process Filtration + ultraviolet
System used Ballasting + discharging (filter bypassed on discharging)
Country US
Web site www.hydemarine.com

Active substance approval (if applicable)		System approval		Test site	Type approval certificate	Commer-cially available	Units installed	Projected production
Basic	Final	Shipboard	Landbased					Units/y
-	-	11/2008*	11/2008*	Coral Princess NIOZ		2000	7	600
Capacity	Footprint, m² for unit capacity of:		Maximum height	Capex, $k		Opex $per	Company formed	No. employees
1000 m³/h	200 m³/h	2000 m³/h	m	200 m³/h	2000 m³/h	1000 m³/h		
>10	3.5	25	2	NA	NA	10	1969	20
Power requirement kW / m³/ h		Additional services		Comments: *dates projected by manufacturer				
75		Air (80psi)						

Seakleen™
Supplier **Hyde Marine - (Lamor Corporation, LLC)**
Process Menadione / Vitamin K (as Seakleen™)
System used Ballasting
Partners Garnett Inc., Vitamar, LLC
Country US
Web site www.hydemarine.com

Active substance approval (if applicable)		System approval		Test site	Type approval certificate	Commer-cially available	Units installed	Projected production
Basic	Final	Shipboard	Landbased					Units/y
-	-	NA	NA	NA		2009	0	1000
Capacity	Footprint, m² for unit capacity of:		Maximum height	Capex, $k		Opex $per	Company formed	No. employees
1000 m³/h	200 m³/h	2000 m³/h	m	200 m³/h	2000 m³/h	1000 m³/h		
>10	0.25	1	2	NA	NA	NA	1969	20
Power requirement kW / m³/ h		Additional services		Comments SeaKleen is still being developed and should be available during 2009				
NA		NA						

Supplier **JFE Engineering Corporation**
Process Filtration + chlorination + cavitation + residual control
System used Ballasting + discharging (filter bypassed on discharging)

Partners TG Corporation
Country Japan
Web site www.jfe-eng.co.jp
http://www.jfe-eng.co.jp/product/environment/environment2271.html

Active substance approval (if applicable)		System approval		Test site	Type approval certificate	Commercially available	Units installed	Projected production
Basic	Final	Shipboard	Landbased					Units/y
10/2008*	07/2009**	10/2009	10/2009	ND		10/2009	1	300
Capacity	Footprint, m² for unit capacity of:		Maximum height	Capex, $k		Opex $per	Company formed	No. employees
1000 m³/h	200 m³/h	2000 m³/h	m	200 m³/h	2000 m³/h	1000 m³/h		
2.1	NA	12	2.6	NA	NA	40	1975	1500
Power requirement kW / m³/ h		Additional services		Comments	*projected for MEPC 58 (approved at the sixth meeting of the GESAMP-Ballast Water Working Group 14/07/2008) **projected for MEPC 59 *** additional 15m water head increase in ballast pump also required, or booster pump equivalent			
7.7***		Air and water						

Supplier **Marenco Technology Group, Inc.**
Process Filtration + ultraviolet
System used Discharging

Country US
Web site www.marencogroup.com

Active substance approval (if applicable)		System approval		Test site	Type approval certificate	Commercially available	Units installed	Projected production
Basic	Final	Shipboard	Landbased					Units/y
-	-	2007*	2007*	MLML		2008	1	240-360
Capacity	Footprint, m² for unit capacity of:		Maximum height	Capex, $k		Opex $per	Company formed	No. employees
1000 m³/h	200 m³/h	2000 m³/h	m	200 m³/h	2000 m³/h	1000 m³/h		
**	1.165	NA	1.38	145	175	0.6-1.0	1999	NA
Power requirement kW / m³/ h		Additional services		Comments	*testing may not be strictly to IMO standards **modular system able to service most ranges of ballast water flow			
60		none						

Supplier **Mahle NFV GmbH**
Process Filtration + ultraviolet
System used Ballasting and discharge

Country Germany
Web site www.nfv-gmbh.de

Active substance approval (if applicable)		System approval		Test site	Type approval certificate	Commercially available	Units installed	Projected production
Basic	Final	Shipboard	Landbased					Units/y
-	-	2009	2009	NIOZ		2010	1	50*
Capacity	Footprint, m² for unit capacity of:		Maximum height	Capex, $k		Opex $per	Company formed	No. employees
1000 m³/h	200 m³/h	2000 m³/h	m	200 m³/h	2000 m³/h	1000 m³/h		
2.5	4	NA	2.5	NA	NA	NA	1965	45
Power requirement kW / m³/ h		Additional services		Comments	*manufacturing not seen as a limiting factor			
60		Control air and water						

Supplier **M H Systems**
Process Deoxygenation with inert gas and CO_2 *
System used During voyage

Country US
Web site www.mhsystemscorp.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
-	-	07/2009	12/2008	SIO		2006	0**	300

Capacity 1000 m³/h	Footprint, m² for unit capacity of: 200 m³/h	2000 m³/h	Maximum height m	Capex, $k 200 m³/h	2000 m³/h	Opex $per 1000 m³/h	Company formed	No. employees
10-18	5	9	1.8	650	950	60	1989	12

Power requirement kW / m³/ h	Additional services
10-18	NA

Comments *an "in-tank" or batch process system
**one system under preparation

Supplier **Mitsui Engineering and Shipbuilding Co. Ltd.**
Process Hydrodynamic shear, cavitation and ozonation
System used Ballasting

Partner(s) Japanese Association of Marine Safety; Marine Technology Institute; Laboratory of Aquatic Science Consultant Co; Shinko Ind..; M.O. Marine Consulting.; Mitsui O.S.K. Lines.
Country Japan
Web site www.mes.co.jp

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
10/2006*	07/2009**	03/2009	02/2008	JAMS		2009	1	40-100

Capacity 1000 m³/h	Footprint, m² for unit capacity of: 200 m³/h	2000 m³/h	Maximum height m	Capex, $k 200 m³/h	2000 m³/h	Opex $per 1000 m³/h	Company formed	No. employees
0.3***	15	NA	2.8	NA	NA	NA	1917	3,700

Power requirement kW / m³/ h	Additional services
70	Air and cool water

Comments *Basic approval given 13/10/06,MEPC 55/2/16 annex 5
**Final approval projected for MEPC 59, 07/2009
***larger capacity may be possible

Supplier **NEI Treatment Systems LLC**
Process Deoxygenation + cavitation
System used Ballasting

Partner(s) Mitsubishi Kakoki Kaishi Ltd (Japan)
Samgong Co. (Korea)
Country US
Web site www.nei-marine.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
-	-	-	-	NOAA	10/2007	2006	5	200

Capacity 1000 m³/h	Footprint, m² for unit capacity of: 200 m³/h	2000 m³/h	Maximum height m	Capex, $k 200 m³/h	2000 m³/h	Opex $per 1000 m³/h	Company formed	No. employees
>10	3	6	2.6	360	690	150	1997	5

Power requirement kW / m³/ h	Additional services
25	Air and water

Supplier **Nutech O_3**
Process Ozonation
System used Ballasting
Country US/Republic of Korea
Web site www.nutech-o3.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
7/2007*	10/2008**	2008	2008	Korea		Late 2008	4	168

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 200 m^3/h	2000 m^3/h	Maximum height m	Capex, $k 200 m^3/h	2000 m^3/h	Opex $per 1000 m^3/h	Company formed	No. employees
>10	22	40	2	250	450	***	1997	4

Power requirement kW / m^3/ h	Additional services	Comments
10	Air and water	* Basic approval MEPC 56, MEPC 56/2/2 annex 6 ** Final approval projected October 2008 *** Manufacturer states "$0.007 per treatment"

Supplier **Oceansaver AS**
Process Filtration + deoxygenation + cavitation
System used Ballasting + discharging (filter and cavitation only)
Country Norway
Web site www.oceansaver.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
04/2008*	10/2008**	08/2008	10/2007	NIVA		2008	2	>200

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 200 m^3/h	2000 m^3/h	Maximum height m	Capex, $k 200 m^3/h	2000 m^3/h	Opex $per 1000 m^3/h	Company formed	No. employees
0.5-5	NA***	NA***	NA***	288	1600	NA	2003	13

Power requirement kW / m^3/ h	Additional services	Comments
80-100	Cooling water	* Basic approval MEPC 57, MEPC 57/2/10 annex 8 ** Final approval projected October 2008 *** System footprint difficult to estimate, since several sub-components and the largest of these can be located anywhere

Supplier **Optimarin**
Process Filtration + ultraviolet
System used Ballasting + discharging
Country Norway
Web site www.optimarin.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
-	-	01/2009	05/2008	NIVA		Yes	8	300-600

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 200 m^3/h	2000 m^3/h	Maximum height m	Capex, $k 200 m^3/h	2000 m^3/h	Opex $per 1000 m^3/h	Company formed	No. employees
>101	3*	6-11*	0.6-3.3	430	1800	-	1995	6

Power requirement kW / m^3/ h	Additional services	Comments
220	Air	* Installation may be suspended under deck for reduced footprint

Supplier **Panasia Co Ltd Korea – GloEn Patrol™**
Process Filter and medium pressure UV
System used Ballasting + discharging
Country Republic of Korea
Web site www.pan-asia.co.kr

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
04/2008*	-	03/2009	10/2008	KORDI	Expected 2009	2009	1	NA
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of:** 200 m^3/h	2000 m^3/h	**Maximum height** m	**Capex, $k** 200 m^3/h	2000 m^3/h	**Opex $per** 1000 m^3/h	**Company formed**	**No. employees**
4	1.8	14.8	2.3	NA	NA	NA	1989	70
Power requirement kW / m^3/ h		**Additional services**		**Comments**	* Basic approval given 04/04/2008, MEPC 57/2/10 annex 6			
194		Air						

Supplier **Qwater**
Process Filtration + ultrasound
System used Ballasting + discharging
Country US
Web site www.qwatercorp.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
-	-	NA	NA	NA		04/2009	0	NA
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of:** 200 m^3/h	2000 m^3/h	**Maximum height** m	**Capex, $k** 200 m^3/h	2000 m^3/h	**Opex $per** 1000 m^3/h	**Company formed**	**No. employees**
NA	15	30	2.4	NA	NA	NA	2002	NA
Power requirement kW / m^3/ h		**Additional services**						
NA		NA						

Supplier **Resource Ballast Technology**
Process Cavitation, ozone, electrolysis and filtration
System used Ballasting
Parter(s) Wilhelmsen Ships Equipment AS (Norway)
Country South Africa
Web site www.resource-technology.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
04/2008*	2009**	2008	2008	Cape Town		2009	2	2000+
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of:** 200 m^3/h	2000 m^3/h	**Maximum height** m	**Capex, $k** 200 m^3/h	2000 m^3/h	**Opex $per** 1000 m^3/h	**Company formed**	**No. employees**
0.25-5	12	4	2	200	500	NA	2001	3
Power requirement kW / m^3/ h		**Additional services**		**Comments**	*Basic approval given 04/04/2008, MEPC 57/2/10 annex 5 ** Final approval projected for 2009 *** Range is for 3000 – 500 m^3/h systems			
13-20***		NA						

Supplier **RWO GmbH Marine Water Technology, Veolia Water Solutions & Technologies (VWS)**
Process Filtration + EctoSys® (electrolysis / electrochlorination + AOP) **Country** Germany
System used Ballasting + discharging (filter bypassed on discharging) **Web site** www.rwo.de

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
10/2006*	07/2009**	03/2009	09/2007	Bremen 2007 NIVA 2008		2008	2	no limit***
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
>10	3	20	2.5	NA	NA	NA	1975	60
Power requirement kW / m^3/ h		**Additional services**		**Comments**	*Basic approval given 13/10/06, MEPC 57/2/10 annex 5 ** Projected for MEPC 59 *** Manufacturing not seen as a limiting factor (part of Veolia Water)			
80 (seawater) 120 (freshwater)		NA						

Supplier **Severn Trent De Nora**
Process Filtration + electrolysis/electrochlorination + residual control **Country** US
System used Ballasting + discharging **Web site** www.severntrentservices.com/denora

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
2009*	2009*	2009	01/2007*	UNSRL		2007	1	100
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
>10	8	11	2.5	350	500	13	1923	125
Power requirement kW / m^3/ h		**Additional services**		**Comments**	* Projected			
113		none						

Supplier **Siemens**
Process Filtration + electrochlorination **Country** USA, UK, Germany
System used Ballasting **Web site** under construction

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
-	-	-	-	NA		2009/10	NA	NA
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
0.2>10	3.3	4.1	2.5	400	600	20-30	1847	400,000
Power requirement kW / m^3/ h		**Additional services**		**Comments**	* larger units more efficient			
60-130*		Air and water						

Supplier **Techcross**
Process Electrolysis/electrochlorination
System used Ballasting
Country Republic of Korea
Web site www.techcross.net

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
03/2006*	10/2008**	08/2007	08/2007	KORDI		2007	2	1,200
Capacity 1000 m³/h	Footprint, m² for unit capacity of: 200 m³/h	2000 m³/h	Maximum height m	Capex, $k 200 m³/h	2000 m³/h	Opex $per 1000 m³/h	Company formed	No. employees
>10	2	6.5	2.0	297	559	3	2005	45
Power requirement kW / m³/ h		Additional services		Comments	* Basic approval given 24/03/06, MEPC 54/2/12 annex 6 **Final approval expected MEPC 58 (approved at the sixth meeting of the GESAMP-Ballast Water Working Group 14/07/2008)			
60 (seawater) 100 (freshwater)		NA						

Supplier **Toagosei Group – TG Ballast Cleaner**
Process Filtration + sodium hypochlorite + residual control
System used Ballasting + discharging
Parter(s) Tsurumi Soda Co. Ltd
Country Japan
Web site www.toagosei.co.jp

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
10/2008*	-	-	-	NA		NA	NA	NA
Capacity 1000 m³/h	Footprint, m² for unit capacity of: 200 m³/h	2000 m³/h	Maximum height m	Capex, $k 200 m³/h	2000 m³/h	Opex $per 1000 m³/h	Company formed	No. employees
NA	NA	NA	NA	NA	NA	NA	NA	2735
Power requirement kW / m³/ h		Additional services		Comments	* Basic approval projected at MEPC 58 – based on GESAMP 6th meeting recommendation No further information available at time of going to press			
NA		NA						

Glossary of terms and abbreviations

BALLAST WATER TREATMENT TECHNOLOGY

Technologies

AOP	Advanced oxidation
Cav	Cavitation
Cl	Chlorination
Clarif	Clarification
ClO_2	Chlorine dioxide
Coag	Coagulant (with magnetic particles)
Deox	Deoxygenation
EL/EC	Electrolysis/electrochlorination
Filt	Filtration
HC	Hydrocyclone
O_3	Ozonation
PAA	Peracetic acid (as Peraclean)
Red	(Chemical) Reduction
SK	Seakleen
US	Ultrasonic treatment
UV	Ultraviolet irradiation

Terms

capex	Capital expenditure
opex	Operating expenditure

Organisations, test sites

AISA	Agricultural Institute of South Africa
AWI	Alfred Wegener Institut
FDA	Federal Drug Administration
JAMS	Japan Association of Marine Safety
KORDI	Korean Ocean Research and Development Institute
MLML	Moss Landing Marine Laboratories
MWB	Motorenwerke Bremerhaven
NIOZ	Royal Netherlands Institute for Sea Research
NIVA	Norwegian Institute for Water Research
SAMSA	South African Department of Transport
SIO	Scripps Institution of Oceanography
USEPA	US Environment Protection Agency
USCG	US Coast Guard
USNOAA	US National Oceanic and Atmospheric Administration
USNRL	US Naval Research Laboratory

NA	Information not available or not made available
ND	Not determined by the supplier

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