BALLAST WATER TREATMENT TECHNOLOGY

Current status

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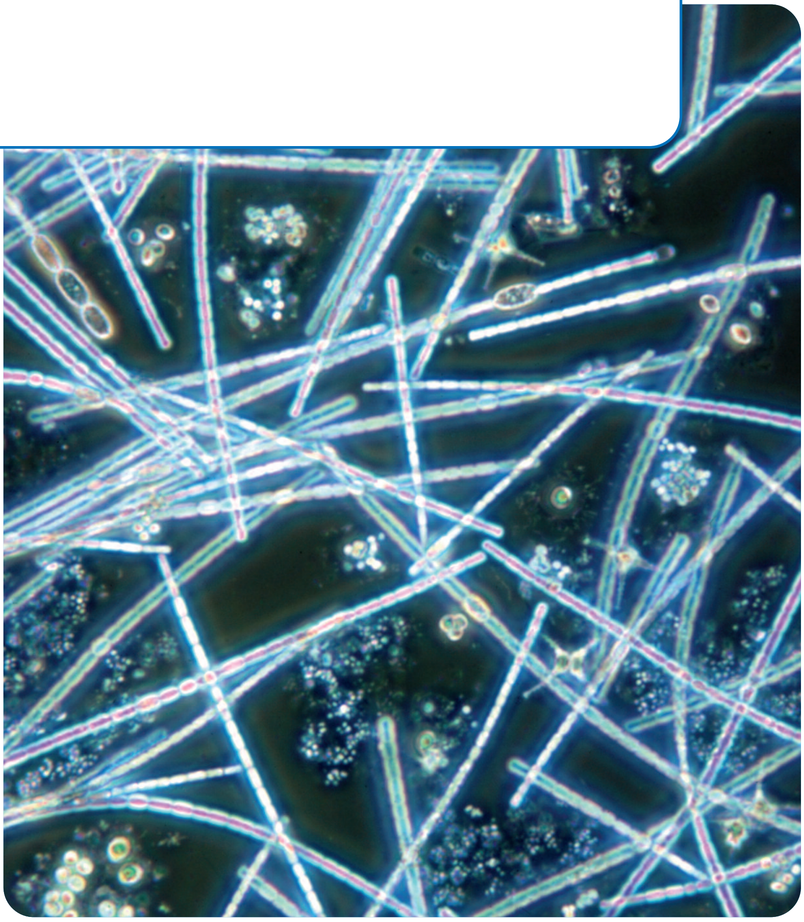

Lloyd's Register

LIFE MATTERS

Contents

BALLAST WATER TREATMENT TECHNOLOGY

1. Introduction

The requirement for ballast water treatment arises from the requirements of regulation D-2 of the International Convention for the Control of Ships Ballast Water and Sediments (BWM 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 BWM Convention and shipboard operation.

This publication comprises an outline description of water treatment processes and an appraisal of commercially available and developing technologies for ballast water treatment. It is the end deliverable of work conducted by the Centre for Water Science at Cranfield University in conjunction with the consultants Vale Water Services and Whitewater Limited on behalf of Lloyd's Register. The publication contains a summary both of the governing regulation that ultimately makes ballast water treatment mandatory (Section 2), and of 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 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 assistance and patience of the technology suppliers who contributed much of the information published herein are gratefully acknowledged.

2. Regulation

Ballast water quality and standards

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

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

Table 1 IMO 'D2' standards for discharged ballast water

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.

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

Table 2 Timetable for installation of Ballast Water Treatment systems

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 testing 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.

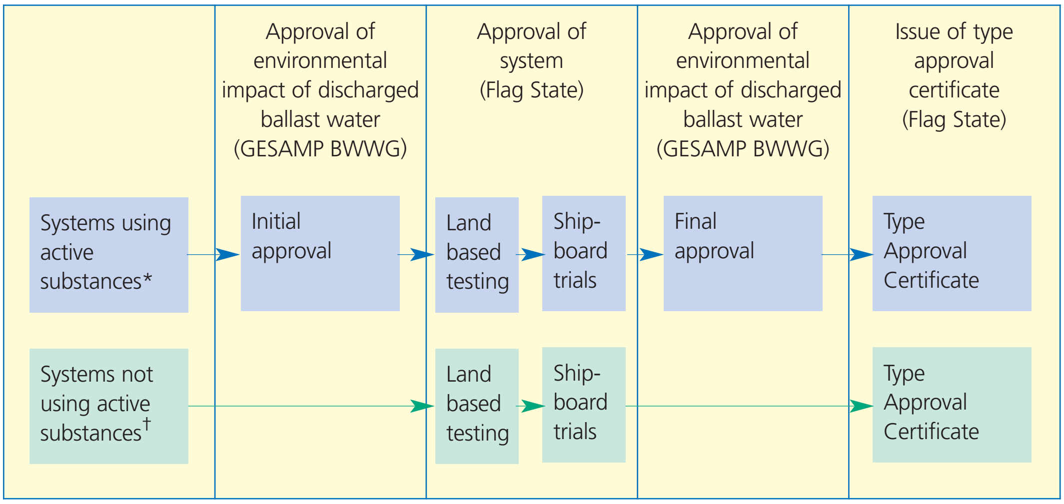

Fig 1. Summary of approval pathway for ballast water treatment systems

* 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'). The IMO Marine Environment Protection Committeee has, on the recommendation of the GESAMP BWWG, granted basic approval to four technologies as of June 2007.

[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 at May 2007, no systems have completed the final stages of the approval process under the ’G8’ Guidelines for Approval of Ballast Water Management Systems, although this may soon change.

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).

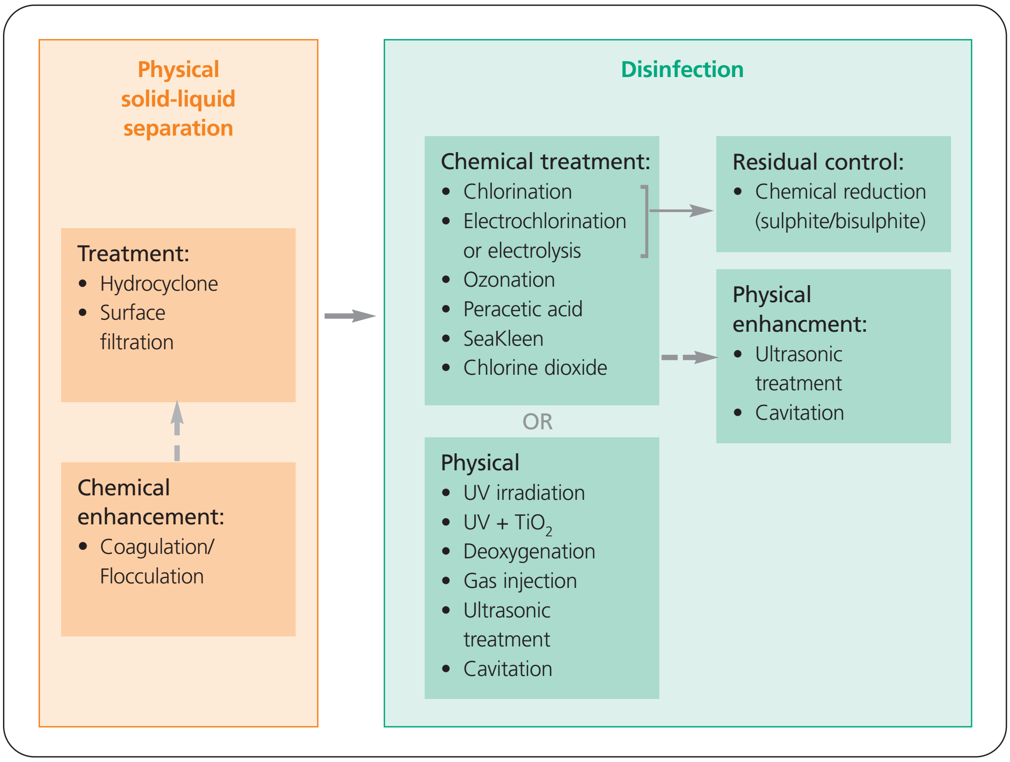

Fig. 2 Generic ballast water treatment technology process options

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.

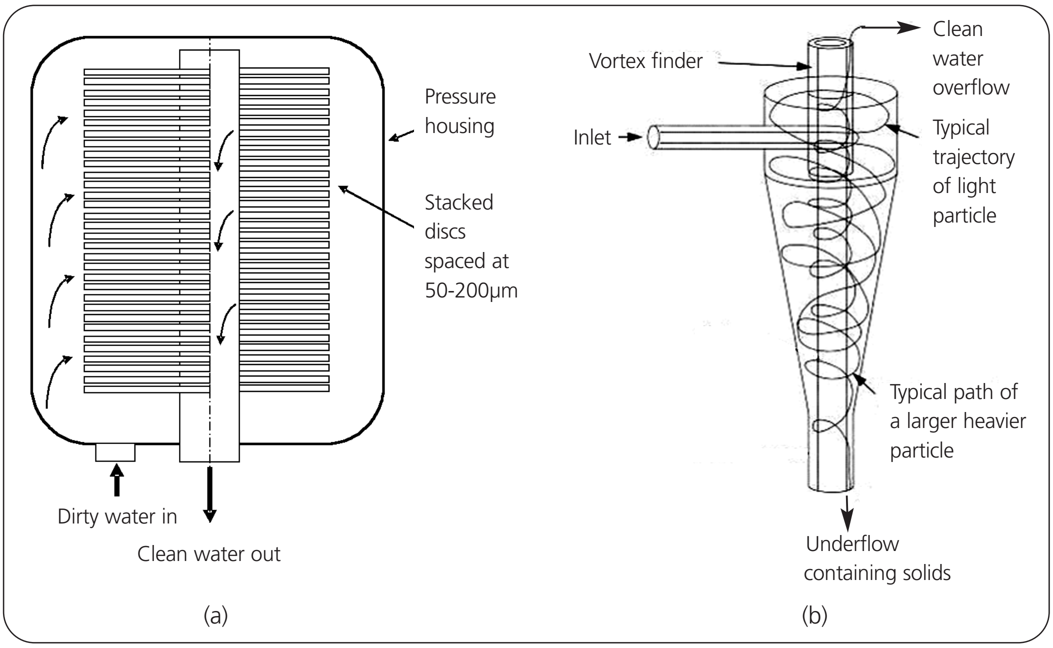

Fig. 3
(a) Filtration, and (b) Hydrocyclone processes

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 awaiting US FDA and EPA approval which should be granted in 2008. 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.

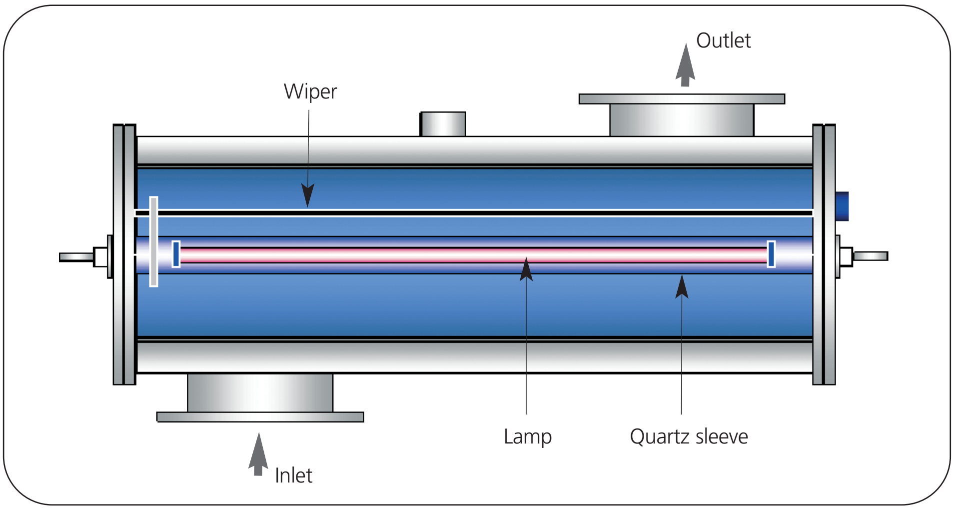

Fig. 4 UV tube and system

Ballast water treatment unit processes

Taking account of all of the technologies surveyed, there are currently 16 individual unit processes used in ballast water treatment (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	Active substance	Solid-liquid sepn				Chemical disinfection and dechlorination							Physical disinfection		Micro-agitation		AOP
			HC	Filt	None	Coag	O_3	Cl	EL/EC	PAA	ClO_2	SK	Red	UV	Deox	Cav	US	
1	Alfa Laval Tumba AB	X[4]		X										X				TiO_2
2	Ecochlor Inc	X			X						X							
3	Electrichlor Inc	X		X					X									
4	RWO Marine	X[4]		X					X									
5	Environmental Technologies Inc	X			X		X										X	
6	Gauss			X										X				
7	Greenship	X	X						X									
8	Hamann AG	X	X	X						X								
9	Hitachi	X		X		X[4]												
10	Hyde Marine Inc	X[3]		X								X[3]		X[3]				
11	Mitsui Engineering & Shipbuilding	X		X			X									X		
12	JFE Engineering Corporation	X		X				X					X			X		
13	Marenco Technology Group Inc			X										X				
14	Oceansaver AS				X										X	X		
15	MH Systems Inc				X										X			
16	Mitsubishi Heavy Industries	X		X					X									
17	NEI Treatment Systems LLC				X										X	X		
18	Nutech 03	X			X		X											
19	Optimarin AS			X										X				
20	Qwater			X													X	
21	Resource Ballast Technology	X		X					X							X		
22	Severn Trent De Nora	X		X					X				X					
23	Techcross	X			X				X									
24	ATG Willand		X[2]	X[2]										X				
25	Sincerus Water Treatment[1]	X	X						X									
26	DNV Maritime Solutions[1]	X		X						X				X				

[1]Did not return completed survey forms; [2]Physical pre-treatment options under consideration; [3]Two disinfection options offered [4]Technology may be considered as using 'active substancies'

HC Hydrocyclone; Filt Filtration; Coag Coagulant (with magnetic particles); UV Ultraviolet irradiation
Deox Deoxygenation; O_3 Ozonation; Cl Chlorination; EL/EC Electrolysis/electrochlorination; PAA Peracetic acid (as *Peraclean*)
ClO_2 Chlorine dioxide; SK *Seakleen*; Red Reduction; Cav Cavitation; US Ultrasound; AOP 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. Very many companies may consider their product(s) to be appropriate for ballast water treatment but it is not necessarily the case that shipboard applications exist. Moreover, a few companies appear to have withdrawn from this market altogether, following an initial assessment of the technology and market potential. These have been excluded from the survey.

Whilst basic technical information is available from 26 companies, only 24 of these took part in the survey, and it is information from these 24 which forms the basis of this publication. Of these 24, nine are part of a multi-billion dollar turnover international group of companies with significant activity in marine and/or engineering areas, whilst 14 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. The remaining one is a governmental organisation. Eight different countries are represented by these 24 companies, with the predominant nation being the US (Fig. 5).

Some companies have collaborated with unit process suppliers to produce a system. For example, Alfa Laval use the Wallenius UV-based advanced oxidation process; 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.

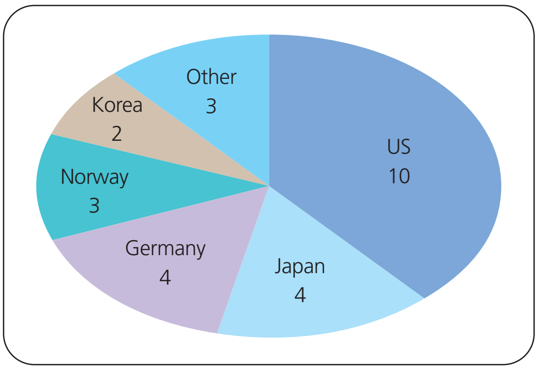

Fig. 5 Technology suppliers by country: 'Other' comprise the Netherlands, South Africa and the UK

Technologies

Categories

Treatment technologies offered by the 26 suppliers are summarised in Table 3; since one supplier Hyde Marine offers two technologies, there are 27 technologies in total. All these systems 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. However, these data are based on test protocols which largely do not comply with those stipulated under the IMO 'G8' Approval of Ballast Water Management Systems and such approval is still required.

All of the 27 products for which information is available, other than those based on gas injection, are either modular or can be made so. Ten of the technologies do not employ chemicals for the main flow and disinfection and may be considered to have no active substance. However there is ongoing debate as to whether free hydroxyl radicals produced either by electrolysis or advanced oxidation will be considered to be active substances by the GESAMP BWWG.

Of the 27 technologies considered 17 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. Four suppliers employ hydrocyclones as pre-treatment and the remainder use no solid-liquid separation at all. One supplier (Hamann) uses both hydrocyclones and filtration. Only one system (Hitachi) employs pre-coagulation upstream of the filter. This particular system employs magnetic particles to accelerate the clarification process ('ballasted 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 total of eight disinfection processes used for ballast water treatment, the majority of the systems provided (15 of the 27 reviewed) are based on either electrolytic treatment (electrolysis or electrochlorination) or UV irradiation (Fig. 6b). In one case (the Wallenius process employed by Alfa Laval), the UV irradiation is supplemented with titanium dioxide (TiO_2) to intensify the oxidative power of the UV light (Section 3.3). Electrolytic treatment is used the most extensively, with products having 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.

Ten of the technologies do not employ chemicals for disinfection and may be considered to have no active substance. However there is a debate as to whether free hydroxyl radicals produced either by electrolysis (such as in the RWO Marine process) or advanced oxidation will be considered to be active substances by the GESAMP BWWG. Debate on this issue is on-going at the time of publication of this Publication. Of these ten technologies which do not use chemicals, six employ UV disinfection, one uses ultrasound with prefiltration and three gas injection for deoxygenation.

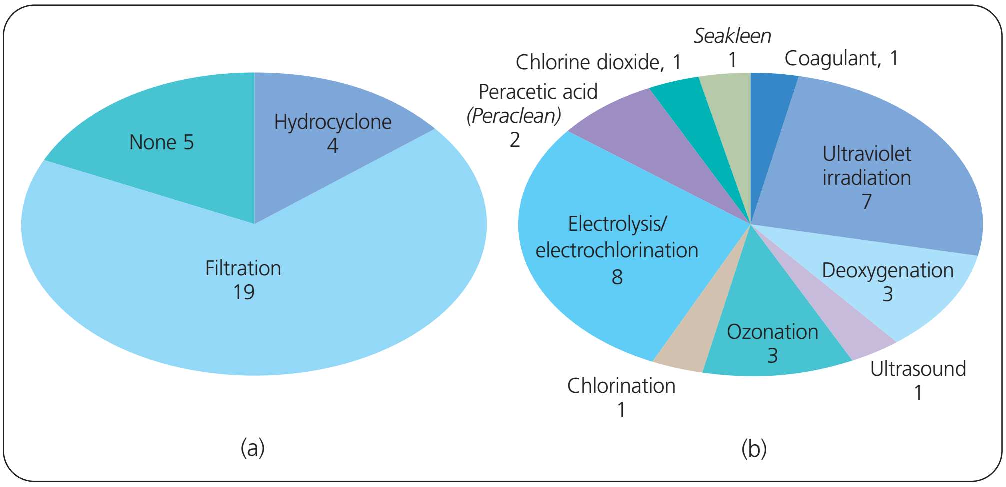

Fig. 6 Summary of treatment technology options for (a) physical pre-treatment, and (b) disinfection

Note: One supplier employs both hydrocyclones and filtration.

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), over half of the products surveyed (14 out of 27) are either filtration followed by UV (six), filtration followed by electrolytic treatment (five) or hydrocyclone separation followed by either electrolytic treatment or UV (three). 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.

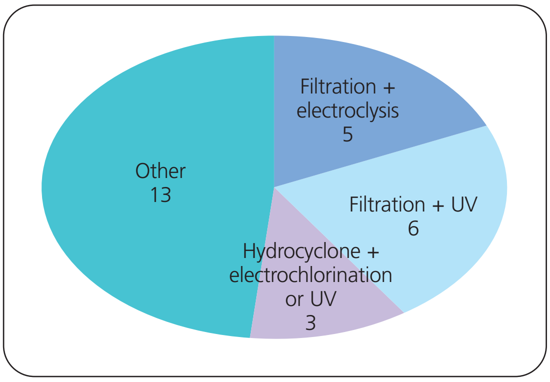

Fig. 7 Treatment process configurations: combinations of filtration or hydrocyclone followed by electro-chlorination/ electrolysis or UV irradiation

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 three products (Ecochlor, Nutech–O3 and Techcross) where no pre-treatment is used ahead of chemical disinfection, two of which relate to non-chlorine based chemical disinfection (ozonation and chlorine dioxide). The impact of the disinfectant chemical is, in four cases (ETI, JFE, Mitsui Engineering and Resource Ballast Tecnology), 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 technologies (Hyde marine, Hamman and DNV Maritime Solutions) use a proprietary biocide chemical such as *Peraclean* or *Seakleen*.

The remaining three technologies (NEI Treatment Systems, Oceansaver and MH Systems) 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.

Eleven of the technologies treat the ballast water both during ballasting and discharge (Table 5), effectively treating the ballast water twice. 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. Nine of the technologies treat only during ballasting and two only during discharge. A further two companies treat 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 \$0.1 per m^3, within a broad range of values from \$0.01 up to \$0.35 per m^3 treated water. Nine of the 13 suppliers who provided operational expenditure information quoted costs below \$0.08 per m^3; the mean value is skewed by two anomolously high values. There is no correlation between the quoted opex and the type of system. 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).

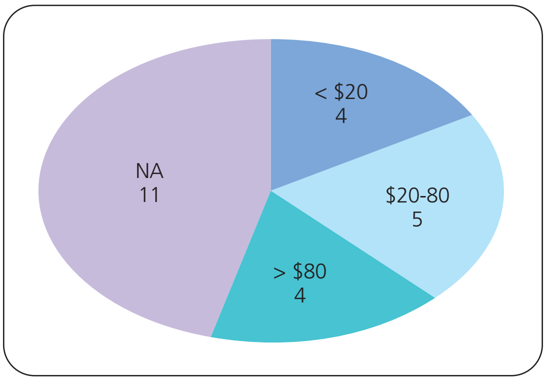

Fig. 8 Estimated plant operating cost per 1000m^3 of treated water: 24 products; information not available or not provided for 11 systems

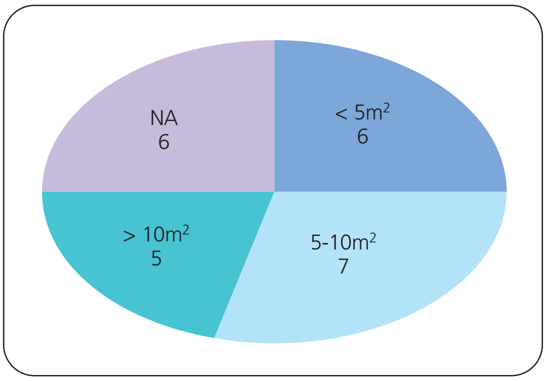

Fig. 9 Estimated footprint of a 200m^3/h plant: 24 products; information not available or not provided for six systems.

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

	Footprint, m^2		Height	Capex \$'000		Opex
	200 m^3/h*	2000 m^3/h*	m	200 m^3/h*	2000 m^3/h*	\$/1000 m^3
Mean	5	25	2.0	337	867	97
Data points	17	13	20	11	8	13
Min	1.6	4	1.0	135	250	5
Max	25	100	3.0	650	2300	320

*System flow rate

Capital cost information is not widely available, and the majority of the suppliers regard this information as confidential. From the 11 sets of data provided, the capital cost of a 200 m^3/h plant ranges from $135k - $650k, with a mean value of around $340k. For a 2000 m^3/h plant, the equivalent values are £250k - £2300k with a mean of £800k. 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 1.6 and 25 m^2 for a 200 m^3/h unit, with a mean value of 5 m^2, according to the data provided by suppliers in relation to 17 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 4, 100 and 25 m^2 respectively. 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 1.0m and 3.0m for the 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 m^2		Estimated Capex $'000 (installed cost)		Estimated Opex
			200 m^3/h	2000 m^3/h	200 m^3/h	2000 m^3/h	$/1000 m^3
Alfa Laval Tumba AB	A + B+ D	5	3	10	NA	NA	80
Ecochlor Inc	A	>10	7.5	9.5	260	400	60
Electrichlor Inc	A + B+ D	>10	3	-	350	NA	NA
Environmental Technologies Inc	B	>10	NA	6	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	2	4.3	36	NA	NA	200
Hitachi	A	>10	20	100	NA	NA	NA
Hyde Marine Inc	A + B + D	>10	7	35	NA	NA	10
JFE Engineering Corporation	A + B + D	1.3	6	12.6	NA	NA	40
Marenco Technology Group Inc	B	1	2	-	135	NA*	100
MH Systems Inc	A + C	>10	3	-	650	950	55
Mitsubishi Heavy Industries	A	NA	NA	NA	NA	NA	NA
Mitsui Engineerg. & Shipbuildg.	A	NA	NA	NA	NA	NA	150
NEI Treatment Systems LLC	A	>10	3	6	150	250	50
Nutech 03	A	>10	NA	NA	350	800	320
Oceansaver AS	A + B + D	>10	NA	NA	NA	NA	NA
Optimarin AS	A + B + D	>10	variable	variable	500	NA	NA
Qwater	A + B + D	NA	15	30	NA	NA	NA
Resource Ballast Technology	A	>10	2	4	150	250	NA
RWO Marine	A + B + D	>10	3	24	NA	NA	NA
Severn Trent De Nora	A+B+C+D	>10	11	11	350	500	20
Techcross	A	>10	1.6	4	150	NA	10
ATG Willand	A + B + D	>10	25	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)

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

Ten of the 24 companies participating in this review have already installed units on board ship (Table 6). As of May 2007, a total of 28 ballast water treatment units have been installed. Of these, over half have been installed by two companies (Optimarin and Hyde Marine) and are UV based systems. It is very likely that the underlying reasons for UV based technology being adopted lie with the ready availability of commercial UV units in the water disinfection area, relatively low capital cost, very small footprint and ease of installation. However, the fact that companies have units installed and have commercially available units does not mean that the systems have the necessary approvals in accordance with the IMO guidelines. Approval status which is fundamental to commercial acceptance in the future is discussed below.

Table 6 System status: commercial development and approval

	Active substance approval (if applicable)		System approval		Test site	Commercially available[1]	Units installed[2]	Projected production[3]
Manufacturer	Basic	Projected final	Shipboard	Landbased				Units/y
Alfa Laval Tumba AB	Apr-06	Dec-07	Dec-07	Apr-07	NIVA	2006	3	NA
Ecochlor Inc	Aug-07	2008	Jun-08	Jun-08	ND	2006	2	NA
Electrichlor Inc	NA	NA	NA	NA	ND	2006	0	240
Environmental Technologies Inc	-	2008	2007	2008	ND	2008	0	24-48
Gauss	NA	NA	NA	NA	ND	NA	0	NA
Greenship	Jul-07	Oct-07	Jul-07	Jul-07	NIOZ	2006	2	NA
Hamann AG	Dec-05		Jun-07	Jun-07	NIOZ	2006	1	NA
Hitachi	Mar-08	Mar-09	Mar-09	Jul-08	ND	2009	0	50
Hyde Marine Inc	-	-	NA	NA	ND	2000	7	70
JFE Engineering Corporation	Mar-08	Jul-09	NA	NA	ND	2009	0	NA
Marenco Technology Group Inc	NA	NA	NA	NA	MLML	NA	0	240-360
MH Systems Inc[4]	-	Aug-08	Jul-08	Dec-07	SIO	2006	0	240
Mitsubishi Heavy Industries	Dec-06	2009	2008	2008	ND	NA	0	10
Mitsui Engineerg. & Shipbuildg.	May-06	Mar-08	Dec-07	Dec-07	JAMS	2009	1	40-100
NEI Treatment Systems LLC[4]	[5]	[5]	[5]	[5]	NOAA	2006	2	200
Nutech 03	Feb-07	2008	2008	2008	KORDI	2007	2	50
Oceansaver AS[4]	-	-	Dec-07	Oct-07	NA	2007	0	NA
Optimarin AS	-	Jun-08	Dec-07	NA	NIVA	2006	7	NA
Qwater	-	-	NA	NA	ND	2008	0	NA
Resource Ballast Technology	NA	NA	2007	2007	SAMSA/AISA	2008	0	NA
RWO Marine	Oct-06	Apr-08	Dec-07	Jul-07	MWB	2007	1	NA
Severn Trent De Nora	Dec-07	Dec-08	Dec-08	Jan-07	USNRL	2007	0	50
Techcross	NA	NA	Aug-07	Aug-07	KORDI	2007	0	100
ATG Willand	-	NA	NA	NA	ND	NA	0	NA

[1]Year commercialised or anticipated for commercialisation for ballast water treatment; [2]refers to existing installations; [3]Figures for 2009, production capacity projected to increase in following years; [4]IMO 'G8' ballast water management systems approval protocol does not lend itself to testing of this type of technology; [5]tests comparable to IMO 'G8' ballast water management systems testing protocol stated to have been completed prior to introduction of 'G8' protocol.

KORDI Korean Ocean Research and Development Institute; JAMS Japan Association of Marine Safety; NIVA Norwegian Institute for Water Research; USNRL US Naval Research Laboratory; NOAA US National Oceanic and Atmospheric Administration; SAMSA South African Department of Transport; AISA Agricultural Institute of South Africa; SIO Scripps Institution of Oceanography; MLML Moss Landing Marine Laboratories; MWB Motorenwerke Bremerhaven.

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 (of which there are approximately 9-12 out of the 27 reviewed) may reach the marketplace earlier because submission to the GESAMP BWWG for approval is not required. This perceived reduced environmental impact and lack of requirement for GESAMP approval may favour non-AS systems. However, systems using active substances may be expected to perform more reliably. Notwithstanding this observation, preliminary tests conducted by all the suppliers appear to be positive with respect to disinfection capability.

According to information provided by the suppliers, all 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 only four of the active substance systems have received basic approval from GESAMP. It is not clear, however, how many other systems are undergoing ‘G8’ ballast water management systems approval without having received basic approval from GESAMP. Approximately eight companies have undertaken or are scheduled to undertake ballast water management systems testing at test facilities in 2007. Several US companies who have been operating in this field for over 5 years have carried out extensive testing to satisfy local state legislation.

It remains unclear as to whether data from some of the above tests, performed before the IMO regulation was put in place, will be approved - but it appears unlikely. One of the reasons behind the very specific nature of the ‘G8’ ballast water management systems testing protocol is to overcome some of the variability of these early tests and put systems testing on a level playing field. However, the gas injection/deoxygenation technologies do not lend themselves to testing under the strict protocol given in ’G8’, since these rely on sealed tanks and operation over a number of days. They are none-the-less effective for journeys in excess of two days.

5. Summary

Most of the products included in this publication are either currently commercially available or are to be commercialised in 2007. Almost all should be commercially available by 2009, according to approval schedules provided and manufacturing capability detailed by the technology suppliers. However, these estimates may be optimistic and will be reviewed in the future in an update of this publication.

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. Having said this, and despite the encouraging data from pilot-scale tests systems provided by the suppliers for these technologies, the efficacy of technologies not employing active substances is likely to be more variable than many of those which do, and are also more likely to be impacted by ballast water quality (such as turbidity in the case of UV treatment). Commercial technologies employing generically the same unit process can be expected to give a similar performance and be subject to similar constraints.

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. Half of the ballast water treatment technology processes reviewed are based on a combination of either filtration or hydrocyclone separation followed by either electrolytic treatment or ultraviolet irradiation.

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 in 2007 or 2008, though only seven to nine companies have scheduled or completed the tests required for IMO approval. Only one or two of the 24 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

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 200 m^3/h	Footprint, m^2 for unit capacity of: 2000 m^3/h	Maximum height m	Capex, $k 200 m^3/h	Capex, $k 2000 m^3/h	Opex $per 1000 m^3/h	Company formed	No. employees
5	3	10	1-1.2	NA	NA	NA	1883	9500
Active substance approval (if applicable) Basic	**Active substance approval (if applicable) Final**	**System approval Shipboard**	**System approval Landbased**	**Test site**		**Commercially available**	**Units installed**	**Projected production Units/y**
04/2006	12/2007	12/2007	04/2007	NIVA		2006	3	NA*

Comments *According to an evaluation of potential growth to 2016, manufacturing not seen as a limiting factor

Supplier **Ecochlor Inc.**
Process ClO_2
System used Ballasting

Country US
Web site www.ecochlor.com

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 200 m^3/h	Footprint, m^2 for unit capacity of: 2000 m^3/h	Maximum height m	Capex, $k 200 m^3/h	Capex, $k 2000 m^3/h	Opex $per 1000 m^3/h	Company formed	No. employees
>10	7.5	9.5	2.5	260	400	9500	2001	6
Active substance approval (if applicable) Basic	**Active substance approval (if applicable) Final**	**System approval Shipboard**	**System approval Landbased**	**Test site**	**Other regs.**	**Commercially available**	**Units installed**	**Projected production Units/y**
08/2006	06/2008	06/2008	06/2008	ND	STEP	2006	2	NA*

Comments *Manufacturing capability in US and China

Supplier **Electrichlor Hypochlorite Generators Inc.**
Process Filtration + electrolysis/electrochlorination
System used Ballasting + discharging

Country US
Web site www.electrichlor.com

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 200 m^3/h	Footprint, m^2 for unit capacity of: 2000 m^3/h	Maximum height m	Capex, $k 200 m^3/h	Capex, $k 2000 m^3/h	Opex $per 1000 m^3/h	Company formed	No. employees
>10	3	-	2	350	NA	19	2000	19
Active substance approval (if applicable) Basic	**Active substance approval (if applicable) Final**	**System approval Shipboard**	**System approval Landbased**	**Test site**		**Commercially available**	**Units installed**	**Projected production Units/y**
NA	NA	NA	NA	ND		2006	0	240

Supplier **Environmental Technologies Inc**
Process Filtration + ultrasound
System used Discharging

Country US
Web site www.zebra-mussels.com

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 200 m^3/h	Footprint, m^2 for unit capacity of: 2000 m^3/h	Maximum height m	Capex, $k 200 m^3/h	Capex, $k 2000 m^3/h	Opex $per 1000 m^3/h	Company formed	No. employees
>10	NA	6	2.4	NA	500	5	1994	3
Active substance approval (if applicable) Basic	**Active substance approval (if applicable) Final**	**System approval Shipboard**	**System approval Landbased**	**Test site**		**Commercially available**	**Units installed**	**Projected production Units/y**
-	2008	2007	2008	ND		2008	0	24-48

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

Capacity	Footprint, m^2 for unit capacity of:		Maximum height	Capex, $k		Opex $per	Company formed	No. employees
1000 m^3/h	200 m^3/h	2000 m^3/h	m	200 m^3/h	2000 m^3/h	1000 m^3/h		
NA	NA	NA	NA	NA	NA	NA	1996	10
Active substance approval (if applicable)		System approval		Test site		Commer-cially available	Units installed	Projected production
Basic	Final	Shipboard	Landbased					Units/y
NA	NA	NA	NA	ND		NA	0	NA

Comments Research organization. Progress in product development dependent on securing funding.

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

Capacity	Footprint, m^2 for unit capacity of:		Maximum height	Capex, $k		Opex $per	Company formed	No. employees
1000 m^3/h	200 m^3/h	2000 m^3/h	m	200 m^3/h	2000 m^3/h	1000 m^3/h		
>10	1.6	15	1.8	147	1175	NA	1994	5
Active substance approval (if applicable)		System approval		Test site		Commer-cially available	Units installed	Projected production
Basic	Final	Shipboard	Landbased					Units/y
07/2007	10/2007	7/2007	7/2007	NIOZ		2006	2	NA

Supplier **Hamann AG**
Process *SEDNA*® system: Filtration + Peracetic acid (as *Peraclean*)
System used Ballasting
Partner(s) Degussa
Country Germany
Web site www.hamannag.com/ballast

Capacity	Footprint, m^2 for unit capacity of:		Maximum height	Capex, $k		Opex $per	Company formed	No. employees
1000 m^3/h	200 m^3/h	2000 m^3/h	m	200 m^3/h	2000 m^3/h	1000 m^3/h		
2	4.3	9.0	2.2-2.9	NA	NA	200	1970	70
Active substance approval (if applicable)		System approval		Test site		Commer-cially available	Units installed	Projected production
Basic	Final	Shipboard	Landbased					Units/y
12/2005	-	06/2007	06/2007	NIOZ		2006	2	NA

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

Capacity	Footprint, m^2 for unit capacity of:		Maximum height	Capex, $k		Opex $per	Company formed	No. employees
1000 m^3/h	200 m^3/h	2000 m^3/h	m	200 m^3/h	2000 m^3/h	1000 m^3/h		
>10	20	100	NA	NA	NA	NA	1929*	356,000
Active substance approval (if applicable)		System approval		Test site		Commer-cially available	Units installed	Projected production
Basic	Final	Shipboard	Landbased					Units/y
03/2008	03/2009	07/2008	06/2008	ND		2009	0	50

Comments *As Hitachi Plant Technologies; original company formed in 1910

Supplier **Hyde Marine**
Process Filtration + ultraviolet; *Seakleen*
System used Ballasting + discharging (filter bypassed on discharging)
Partner(s) *Arkal* filter
Country US
Web site www.hydemarine.com

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 200 m^3/h	Footprint, m^2 for unit capacity of: 2000 m^3/h	Maximum height m	Capex, \$k 200 m^3/h	Capex, \$k 2000 m^3/h	Opex \$per 1000 m^3/h	Company formed	No. employees
>10	7	35	2	NA	NA	10	1969	NA
Active substance approval (if applicable) Basic	**Active substance approval (if applicable) Final**	**System approval Shipboard**	**System approval Landbased**	**Test site**	**Other regs.**	**Commercially available**	**Units installed**	**Projected production Units/y**
2007	-	NA	NA	ND	STEP, WA, CA	2000	7	70

Comments Filtration + ultraviolet system will be first technology accepted into STEP.
Seakleen system currently awaiting USEPA registration

Supplier **JFE Engineering Corporation**
Process Filtration + chlorination + chemical reduction + cavitation
System used Ballasting + discharging
Country Japan
Web site www.jfe-rd.co.jp

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 200 m^3/h	Footprint, m^2 for unit capacity of: 2000 m^3/h	Maximum height m	Capex, \$k 200 m^3/h	Capex, \$k 2000 m^3/h	Opex \$per 1000 m^3/h	Company formed	No. employees
1.3	-	12.6	2.3	NA	NA	40	1975	NA
Active substance approval (if applicable) Basic	**Active substance approval (if applicable) Final**	**System approval Shipboard**	**System approval Landbased**	**Test site**		**Commercially available**	**Units installed**	**Projected production Units/y**
03/2008	07/2009	NA	NA	ND		2009	1	NA

Supplier **Marenco**
Process Filtration + ultraviolet
System used Discharging
Country US
Web site www.marencogroup.com

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 200 m^3/h	Footprint, m^2 for unit capacity of: 2000 m^3/h	Maximum height m	Capex, \$k 200 m^3/h	Capex, \$k 2000 m^3/h	Opex \$per 1000 m^3/h	Company formed	No. employees
1	165	-	1.4	135	165	100	1999	NA
Active substance approval (if applicable) Basic	**Active substance approval (if applicable) Final**	**System approval Shipboard**	**System approval Landbased**	**Test site**		**Commercially available**	**Units installed**	**Projected production Units/y**
-	NA	NA	NA	MLML*		NA	3	240-360

Comments *May not be strictly to IMO 'G8' standards

Supplier **M H Systems**
Process Deoxygenation
System used During voyage
Country Norway
Web site www.mhsystemscorp.com

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 200 m^3/h	Footprint, m^2 for unit capacity of: 2000 m^3/h	Maximum height m	Capex, \$k 200 m^3/h	Capex, \$k 2000 m^3/h	Opex \$per 1000 m^3/h	Company formed	No. employees
>10	7	-	1.8	650	950	60	1989	12
Active substance approval (if applicable) Basic	**Active substance approval (if applicable) Final**	**System approval Shipboard**	**System approval Landbased**	**Test site**	**Other regs.**	**Commercially available**	**Units installed**	**Projected production Units/y**
-	08/2007	07/2007	12/2007	SIO	WS, MS, S-363	2006	0	240

Supplier **Mitsubishi Heavy Industries**
Process Filtration + electrolysis/electrochlorination
System used Ballasting
Country Japan
Web site www.mhi.co.jp

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	NA	NA	NA	NA	NA	NA	1950	32,000
Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site		Commer-cially available	Units installed	Projected production Units/y
12/2006	2009	2008	2008	ND		NA	0	10

Supplier **Mitsui Engineering and Shipbuilding Co. Ltd.**
Process Cavitation (by high shear) + Ozonation
System used Ballasting
Partner(s) Japanese Association of Marine Safety
Country Japan
Web site www.mes.co.jp

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 300 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	13	NA	2.8	NA	NA	150	1917	11,500
Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site		Commer-cially available	Units installed	Projected production Units/y
05/2006	03/2008	12/2007	12/2007	JAMS		2009	1	40-100

Supplier **NEI Treatment Systems LLC**
Process Deoxygenation + cavitation
System used Ballasting
Country US
Web site www.nei-marine.com

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	6	2.5-3	150	400	50	1997	5
Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Other regs.	Commer-cially available	Units installed	Projected production Units/y
*	*	*	*	NOAA	Michigan	2006	2	200

Comments *Tests comparable to IMO 'G8' ballast water management systems protocol stated to have been completed prior to introduction of 'G8' protocol

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

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*	NA	NA	NA	NA	4
Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site		Commer-cially available	Units installed	Projected production Units/y
NA	NA	NA	NA	-		2007	0	50

Comments *Also provided as modular plant

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

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	NA[1]	NA[1]	NA	NA	NA	60	2003	7
Active substance approval (if applicable) Basic	**Final**	**System approval Shipboard**	**Landbased**	**Test site**		**Commercially available**	**Units installed**	**Projected production Units/y**
-[2]	NA	2007	2007	NIVA		2007	2	NA

Comments [1]System footprint difficult to estimate, since there a number of sub-components and the largest of these can be located anywhere
[2]applicability not confirmed

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

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	variable	variable	2.4	400	NA	NA	1995	3
Active substance approval (if applicable) Basic	**Final**	**System approval Shipboard**	**Landbased**	**Test site**		**Commercially available**	**Units installed**	**Projected production Units/y**
-	06/2008	12/2007	2008	NIVA		2009	7	NA

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

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
Active substance approval (if applicable) Basic	**Final**	**System approval Shipboard**	**Landbased**	**Test site**		**Commercially available**	**Units installed**	**Projected production Units/y**
-	-	NA	NA	-		2008	0	NA

Supplier **Resource Ballast Technology**
Process Filtration + electrolysis/electrochlorination + cavitation **Country** South Africa
System used Ballasting **Web site** www.resource-technology.com

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	2	4	1*	150	250	NA	NA	3
Active substance approval (if applicable) Basic	**Final**	**System approval Shipboard**	**Landbased**	**Test site**		**Commercially available**	**Units installed**	**Projected production Units/y**
NA	NA	2007	2007	AISA		2008	0	NA

Comments *Derived from values of ~2m^3 and ~4m^3 respectively for unit capacity of 200m^3/h and 2000m^3/h

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

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	24	2.5	NA	NA	NA	1975	45
Active substance approval (if applicable) Basic	**Final**	**System approval Shipboard**	**Landbased**	**Test site**		**Commercially available**	**Units installed**	**Projected production Units/y**
10/2006	04/2008	End 2007	07/2007	MWB		2007	1	no limit

Comments System specifically designed for heavy duty operation at high sediment load: continuous full-scale operation on the container pier in Bremerhaven (Germany) where the sediment load greatly exceeds IMO test water standards.

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

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	11	11	2.5	350	500	20	1923	125
Active substance approval (if applicable) Basic	**Final**	**System approval Shipboard**	**Landbased**	**Test site**	**Other regs.**	**Commercially available**	**Units installed**	**Projected production Units/y**
12/2007	12/2008	12/2008	01/2007*	UNSRL	WS, MS	2007	0	50

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

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	1.6	4	1.8	150	NA	NA	2005	NA
Active substance approval (if applicable) Basic	**Final**	**System approval Shipboard**	**Landbased**	**Test site**		**Commercially available**	**Units installed**	**Projected production Units/y**
2007	NA	08/2007	08/2007	KORDI		2007	0	100

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

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	1985	NA
Active substance approval (if applicable) Basic	**Final**	**System approval Shipboard**	**Landbased**	**Test site**		**Commercially available**	**Units installed**	**Projected production Units/y**
NA	NA	NA	NA	-		NA	0	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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