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A DECADE OF DELAY IN RATIFICATION OF THE BALLAST WATER MANAGEMENT CONVENTION AND FURTHER UNDERLYING PROBLEMS

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Abstract. Ballast water is a major transport mechanism responsible for the introduction of invasive aquatic species to marine ecosystems around the world. The threat posed by ballast water for future spread of aquatic organisms has been a concern for the international community since the early 1990s.

The International Maritime Organisation introduced the Ballast Water Management Convention in 2004. Global enforcement of this Convention will occur after ratification by at least 30 countries representing not less than 35% of the gross tonnage of the world's merchant shipping. However, after over a decade the tonnage requirement has not been reached and the Convention has not yet entered into force.

The unfamiliarity of stakeholders with multi-dimensional issues of Ballast Water and the lack of technological knowledge has created resistance to ratifying the Convention and hence a delay of over a decade. Collecting representative samples and developing reliable detection tools has been identified as causing delay to the implementation of the BW Convention. However, solutions have been sought for many of the initial Ballast Water issues but not all. This paper discusses three main issues in greater detail: 1. treatment systems, 2. sample size and 3. sample analysis, describing and highlighting the importance of certain underlying problems that still exist and may continue even after implementation of the Convention.

Key words: ballast water Convention, enforcement, delay, compliance

1 INTRODUCTION

The first reported marine introduction was the Asian phytoplankton algae *Odontella sinensis (syn: Biddulphia sinensis)* in the North Sea in 1903 [21]. It was not until the 1970s that the scientific community began reviewing the problem in detail. In the late 1980s, Canada and Australia were among those countries experiencing particular problems with invasive species, and they brought their concerns to the attention of the Marine Environment Protection Committee (MEPC) at the International Maritime Organisation (IMO) [1].

Invasive aquatic species (IAS), such as the zebra mussel, lionfish, comb jellyfish and planktonic forms (bacteria, microbes, small invertebrates, eggs, cysts and larvae of various species), are one of the four greatest threats to the world's oceans [2]. However, climate change, over-fishing and oil pollution represents the biggest threat to the health of our ocean [37].

Shipping is reported to be responsible for the majority of aquatic organism movement as a sole vector (i.e. ballast water, hull fouling, sea chests) and combined with other vectors (including aquaculture, intentional release), e.g. [32]. The expansions of the Suez and Panama Canals will impact invasion rates through altering shipping traffic (e.g. [33]) and enhancing the potential for natural dispersal [34]. While climate change can impact the range of native organisms, it can also aid invasive species by providing a suitable climate for the organisms to spread further [35]. The shipping industry is continually growing and in the future the number of organisms vessels transport may continue to increase. The ballast water capacity of a vessel varies as a function of the cargo carrying capacity and ship type, with an average value of 33 % of the vessel's DWT [22]. At the time this paper is written the world seaborne trade amounted to around 9.5 billion tonnes of cargo per annum [23].

The effects of invasive species in many areas of the world have been devastating and in many cases their damage to the environment and local economies can be irreversible, e.g. [29 – 31]. In one well-known case the comb jelly, *which* was first recorded in the Black Sea in 1982, spread rapidly to the Azov, Marmara and Eastern Mediterranean Seas. Towards the end of 1999 it was recorded in the Caspian Sea where its biomass eventually exceeded levels ever recorded in the Black Sea. It had a devastating impact on commercial fisheries as it competed for food with local species. Landings of anchovy dropped to one-third of their previous levels and caused losses of around $500 million per year. Similar reductions in the biomass of kilka were experienced in the Caspian Sea [2].

The IMO took the lead in addressing the transfer of IAS and developed Guidelines through the MEPC in 1991 [3]. The IMO Assembly supported the move by adopting a resolution [4] in 1993 and invited the member states to adopt a subsequent resolution [5] in 1997. After many years of debate over ballast water's (BW) complex issues, and with hope of a significant step towards protecting the marine environment, the IMO adopted the International convention for the control and management of ships' ballast water and sediments [6] in 2004 (hereafter referred to as the "Convention"). The estimated amount of BW transported at the time was around 3 billion tonnes every year [7].

The defined criteria to bring the Convention into force have still not been achieved after a decade, underpinning the difficulties associated with implementing these regulations.

Figure 1 highlights the challenges that have been encountered in implementing the convention since 2004. In efforts to minimise future invasions due to BW two important regulations were formed: Regulation D-1 (BW Exchange Standard) and Regulation D-2 (BW Performance Standard). Regulation D-1 requires vessels to exchange their ballast water while in the open ocean during transit. This process replaces coastal water picked up in the port of origin with oceanic water containing organisms that should be less well adapted to survive in the port conditions at the destination. BW exchange has been in mandatory use for many years now, and thus associated problems have been identified and solutions developed. The shipping industry and in particular, seafarers were familiar with the operations expected from D-1. The second regulation, D-2 is based on a defined concentration of live organisms that can be present in BW at the point of discharge. In order to obtain this concentration of live organisms, vessels must employ treatment systems to kill individuals present in ballast water. The unfamiliarity of stakeholders with multi-dimensional issues of Ballast Water and the lack of technological knowledge created a resistance to ratifying the Convention and hence a delay of over a decade. This paper describes several issues that have delayed ratification of the Convention and highlights the importance of certain underlying problems that still exist and may continue even after implementation of the Convention.

The Convention will enter into force 12 months after ratification by 30 States, representing 35 percent of world merchant shipping tonnage. The current status by August 2015 indicates ratification of 44 states having 32.86 percent of tonnage. However, a number of additional countries with an aggregate of more than 2% of the tonnage have indicated their intention for ratification, which may accede to this Convention in the near future.

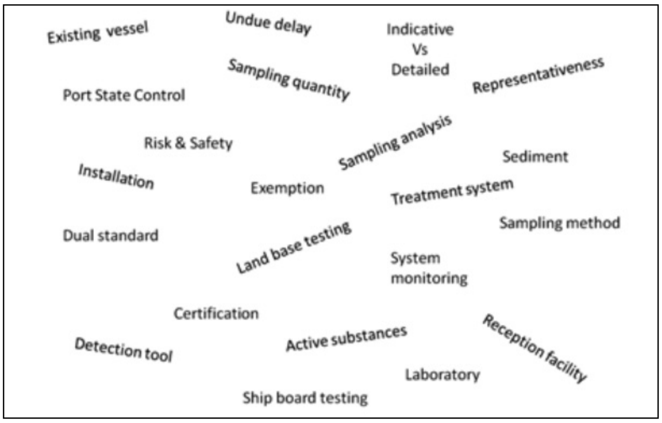

Figure 1 Challenges at the time of introduction of Convention in 2004

The Convention was drafted with an implementation schedule and since it is clear that Entry Into Force (EIF) will not occur before 2016, therefore, the latest position on compliance as per the IMO-Resolution A.1088(28) is:

All ships over 400 GT	To comply with the D-2 standard
With keel laying dates before EIF	On her first IOPP renewal survey after EIF
With keel laying dates after EIF	On delivery

2 OVERVIEW OF THE LAST DECADE

There will be several complications in compliance monitoring at the time of introducing BW Convention. Evaluating ballast water treatment technologies installed on vessel, including issues with sample size and sample analyses [24] are three main concerns, which have been very difficult to resolve. Scientific and technical research would play an important role in addressing these issues. The Convention also required a review to be undertaken to determine whether appropriate technologies are available to achieve the discharge standard.

2.1 Treatment systems

In order to standardise the approval of ballast water management systems the IMO introduced the G8 guidelines: "Guidelines for approval of ballast water management systems". Many of the developed systems were expected to use Active Substances (e.g. biocides, chlorination) and therefore the IMO introduced a two-tier approval process including separate evaluations of the treatment system and the active substance. The G9 Guidelines ("Procedure for approval of ballast water management systems that make use of active substances") were developed to ensure that active substances utilised by certain ballast water management systems do not pose an unreasonable risk to the environment, human health or resources.

Initially industry used existing water treatment technologies e.g. UV light and chlorination, on ballast water to determine their efficiency in treating marine organisms. This was considered to be a shorter route to finding a solution as the technologies had already been used successfully in a range of applications, e.g. purification of swimming pool water, drinking water, irrigation water and aquaria.

Currently, there are reviews that have used vendor supplied survey information or data to evaluate the availability and potential efficiency of these systems [25]. Due to the inherent complexities in determining the efficacy of ballast water treatment systems, an overview of their capabilities is given in the next section. Some of these systems were less successful in the initial stages of defined projects [26], and some could not pass the rigorous land-based testing. However, a few technologies were more promising and current systems in the market are mostly designed and manufactured based on those technologies.

BWTS are broadly based on three main processes: physical separation, biocidal treatment, and physical-chemical processes. This section discusses two biocidal treatment systems (Hydrogen peroxide & Ozone) and three systems using physical-chemical processes (Heat treatment, Biological de-oxygenation and Ultraviolet irradiation). Some BWT systems incorporate a combination of these processes.

Heat treatment

Heat basically appeared to be an effective solution in treating IAS and there are good records of the projects that have researched thermal treatment. One of the advantages of using this treatment is the availability of a large quantity of wasted heat on board every ship. That could be an attractive option for many owners as installing such a system would be more economical to run.

In one of the European projects MARTOB [8], the effects of temperature on phytoplankton and zooplankton were tested under laboratory and ship board conditions. The results indicated that high temperature was effective, however, experiments carried out at lower temperatures (40° and 45°C) resulted in a significantly lower reduction of chlorophyll *a*. Temperatures of 50°C and above were more efficacious at reducing phytoplankton biomass [9]. In theory, exposure to high-temperature treatment for a few seconds could be sufficient to cause the denaturation of organisms in ballast water, but a necessity for any high-temperature treatment option is steam. Given the amount of BW to be treated, this option was not economically feasible and hence was not welcomed by the industry.

Biological de-oxygenation

The aim of this approach was to develop a de-oxygenation process that could be applied in large-scale and used efficiently on selected organisms. Biological de-oxygenation is based on the fact that the addition of nutrients to ballast water will stimulate the growth of the bacteria in the ballast water. The growth of the bacteria will consume the available oxygen in the water, and when the ballast water becomes anoxic, organisms that require a steady supply of oxygen will die.

In a series of laboratory studies, biological de-oxygenation of the seawater killed all added zooplankton species [27]. The killing rate increased with increasing time under anoxic conditions while available oxygen in the seawater decreases. Temperature variation plays an important role in mortality rate and treatment could be as long as 3-4 days at 4°C.

In another approach, the uploading BW is mixed with the low-oxygen gas (inert gas) to strip out the dissolved oxygen. Therefore, the system establishes low oxygen equilibrium in the ballast tanks. This system was suitable for tanker ships that have an inert gas generator and could avoid the high costs of installing a complete BWTS.

Published research suggests the killing effect on phytoplankton in both systems was limited and the change in the concentration of chlorophyll *a* was not significant. The addition of inorganic substances with possible consequences on metal corrosion and coatings was another source of uncertainty and a considerable increase in the concentration of bacteria made biological treatment methods less attractive to industry.

Oxicide treatment

Hydrogen peroxide (H_2O_2) is an oxidising compound and can be produced by an electrochemical conversion of dissolved oxygen in an electrochemical reactor. Hydrogen peroxide is known to be of limited risk to humans, but at low concentrations it can prove toxic to plankton and microorganisms [10]. It has been used in to treat swimming pool water as an alternative to chlorine based disinfectants. It decays within a period of days to a few weeks [11], and breakdown results in the formation of water and oxygen. Therefore, it was considered to be a good solution for the BW treatment.

Application of Oxicide on BW was promising and the result of tests on zooplankton indicated a high kill rate [12]. A higher concentration of H_2O_2 was required for some species. Unfortunately, exposure of phytoplankton to Oxicide did not provide an intense kill rate and therefore, this technique was not recommended for BW treatment. In addition, the production of H_2O_2 significantly increases the Redox potential of the water, which has a negative effect on the metal in terms of corrosion and coatings.

Ultraviolet irradiation

Ultraviolet (UV) light uses short wavelength to kill or inactivate microorganisms [13]. It is effective in destroying the nucleic acids in these organisms so that their DNA is disrupted by the UV radiation, rendering them unable to perform vital cellular functions. Since UV had been employed to sterilize drinking-water and waste-water, it was a good solution to destroy or render the BW microorganisms inactive.

At the time of introduction of the Convention, it was known that UV disinfection was more effective on bacteria and viruses, yet the effectiveness had to be tested for zooplankton and phytoplankton. Stehouwera have showed by experiment [36] that organisms can regrow after treatment by the BWTS using UV radiation when provided with optimal growth conditions. This means that the risk of invasive species is not eliminated by ballast water treatment.

Ozone

An ozone generator uses ambient air and concentrates oxygen content through a nitrogen stripping process, producing Ozone (O_3) by a high frequency electrical field. The Ozone is then injected into the incoming ballast water to oxidize and destroy the aquatic organisms. Ozone is a powerful oxidizing agent that reacts with other chemicals in seawater to form Total Residual Oxidants (TRO). TRO is composed of hypobromous acid and a hypobromide ion and can effectively neutralise viruses, bacteria, algae and organic material.

One major drawback of using ozone for BW treatment is that it impacts corrosion rates. There are certain materials that are not recommended for use with ozone, e.g. ozone can break down carbon steel within days or even hours of use and therefore is unsuitable for BWTS. However, in cases where ships take on fresh water as ballast brominated compounds are not formed, and the Ozone alone acts as the Active Substance.

2.2 Current technology for BWTS

To date a number of techniques have been proved to treat ballast water effectively. It seems that the technological barrier for treating ballast water has been removed and systems are progressing through the approval processes for global use. MEPC has conducted a number of such reviews and agreed that appropriate technologies are available to achieve the standard contained in regulation D-2 of the BWM Convention.

In addition to the plankton suspended in the water column ballast tanks contain sediment deposits home to benthic organisms and the resting stages of plankton (e.g. diatoms and dinoflagellates). A further challenge to BWTSs is to effectively kill the viable organisms present in this sediment. Little research has been published on the efficacy of different technologies to treat resting stages, e.g. [36] and [37]. As treatment systems are approved and put into use vessels must address the presence of these ballast tank sediments as a habitat for viable organisms.

Filtration effectively removes sediments and larger aquatic species from the ballast water, and can enhance the effectiveness of a secondary treatment step, e.g. UV light.

Thus, filtration has become routinely implemented in BWTSs. Many of these filtration technologies are geared with an automatic self-cleaning mechanism to improve efficiency without interrupting ballasting operations. Hence, the majority of BWTSs available on the market consist of two main configurations:

– Filtration and UV
– Filtration and biocide.

Filtration + UV

This combination provides a better robust and reliable system. The current filters are capable of removing organisms above 25 microns and can handle high sediment loadings. Automatic back-flushing keeps the ballast flow rate high in a low differential pressure, allowing the use of standard ballast pumps. Subsequently, UV disinfects the BW effectively by killing the organisms without any chemical additives.

Nevertheless, there are still challenges in optimising the UV system design. Several approved systems may not be able to cope with the low UVT in turbid water, where the difference in performance can be significant. Turbidity is a condition that ships meet in real operation. Power requirements are high and even systems capable of treating BW with lower UVT consume a lot of energy.

Filtration+ Biocide

These types of systems have grown faster in the market due to some advantages: require lower initial investment, energy consumption, maintenance and operation. Systems that employ electro-chlorination have resolved the disadvantage of storing chemicals on board by producing the biocide using seawater.

In one of the two-stage treatment system shown in figure 2, particles, organisms and sediments are separated during BW upload with the means of mechanical filtration. In the second step, the hydroxyl radicals produced by the electrolysis cell disinfect the BW, killing bacteria and organisms, prior to transferring it to the BW tanks.

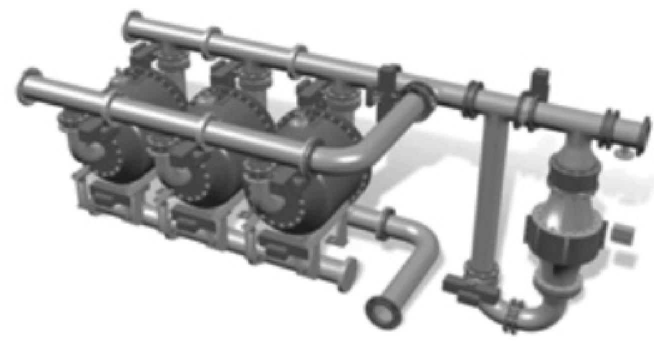

Figure 2 Two stage BW treatment system: filtration and electrolysis. Courtesy of RWO, http://www.veoliawaterst-sea.com/industries/others/marine/

An alternative method uses sodium hypochlorite for the BW treatment. After filtration, the system electrolyses seawater to produce high concentration of sodium hypochlorite solution for disinfection. Sodium hypochlorite is widely used as a general-purpose disinfectant with proven safety and global availability. However, if active oxidants are detected to be higher than a set level during de-ballasting the BW must be neutralised prior to discharge. This therefore requires additional chemicals to complete the treatment process.

3 SAMPLING: A REQUIREMENT OF CONVENTION

At the time the Ballast Water Management Convention was introduced there was no standard protocol for on-board testing. Thus, sampling methods and detection technologies were the primary concern for verifying compliance. Ships are subject to inspection in ports as per the Convention's requirements and a port state control officer may collect samples of the ballast water. A standard sampling method to detect whether or not a ship's ballast water meets the Discharge Standard must be developed.

A suitable method should be rapid to allow multiple replicate samples to be collected and analysed for statistical accuracy. It is always difficult to draw conclusions from an individual sample because the outcome is influenced by the natural variation of species in BW. It is even more uncertain when the sample is turbid as this can make detection extremely demanding and time-consuming.

Some of the initial challenges were to identify appropriate sampling techniques, equipment and standardised protocols that are universally acceptable and scientifically verifiable. It was also necessary to identify sampling points on-board ships, sampling equipment and ballast tank locations, in order to assess and provide a frame-of-reference with which the on-board sampling regimes can be benchmarked [14]. Several criteria had to be defined such as: accessibility, safety, cost, simplicity, support, training, time, representativeness and interferences.

Approaches by individual parties to find solutions carry with them various limitations of different measures, since the “Guidelines for ballast water sampling (G2)” provided only general recommendations. Nine years after the introduction of the Convention a technical discussion [15] was issued to be employed for enforcement. This discussion provided background information on the development and use of methodologies for both indicative and detailed analysis. It also includes appropriate sampling method as well as analysis of the sample at an accredited laboratory.

3.1 BW sampling and analysis

Since sampling and associated analysis is a complex issue the guidelines highlight two performance steps to simplify the process: 1. detailed analysis and 2. indicative analysis.

3.2 Detailed analysis

The Convention states that representative samples must be collected to determine whether a vessel’s ballast water meets the D-2 standard. To be considered representative the samples collected should be of sufficient quality and quantity to provide a precise measurement of organisms’ concentration in the entire ballast water discharge [16]. However, developing a protocol to achieve this has been a challenge since the Convention was introduced. In order to simplify the process and avoid performing detailed analysis on every vessel, indicative analysis was introduced.

The MEPC guidelines [15] have defined 10 detailed analysis methods for use when testing for compliance with D-2 standard; yet level of confidence or detection limit and citation for validation studies of each method needs to be determined. It indicates that not only the complication in analysis has caused over a decade of delay but also there is still a long way to go in order to convince the stakeholders on a unified approach.

3.3 Indicative analysis

Indicative analysis was introduced as a first step to establish whether a ship is potentially compliant with the D-2 Regulation [16]. This analysis is used as a means of screening and does not supersede detailed analysis for the final judgment. A dispute could arise if indicative analysis is positive and a ship detained, but detailed analysis shows the ship is fully compliant with the D-2 standard. In such cases, there is a possibility that the port State and/or port authority would be challenged or sued by the shipping company as a result of the indicative analysis being incorrect [17].

The MEPC guidelines have defined eight indicative analysis methods for use when testing for potential compliance with D-2 standard [15], yet the level of confidence or detection limit and citations for validation studies are still to be determined. It is a similar case as for the detailed analysis, where no international protocols for analysis thus far have been introduced.

Many options are now available for indicative analysis after a decade of research considering all the potential methods, but each of them suffers from one or more issues in terms of practicalities, applicability or limitations [15]. Some of these methods are: Adenosine triphosphate (ATP), chlorophyll *a*, dissolved oxygen levels, residual chlorine levels and nucleic acid [15]. Detection tools are still under development and some of the advanced technologies that have great potential are:

- FlowCam (Fluid Imaging Technologies)
- MALDI-TOF (Matrix Assisted Laser Desorption/Ionization-Time Of Fly)
- Ovizio microscopes, based on ‘Differential Digital Holography’

Sampling is required for compliance inspection should there be any doubt about the quality of BW treatment throughout the ship’s passage. There are many ways to prove whether the discharge of a ship is meeting the D-2 standard, but they are limited to the requirements of the methodologies available for sampling the BW discharge. The MEPC guidelines [15] have defined five general approaches for sampling but the sample error and detection limits are still to be determined.

The organisms present in ballast water tanks are known to be heterogeneously distributed throughout the tanks [28], and therefore, ballast drawn from a discharge with a population varies significantly. So after a decade of discussion the challenge remains to determine the volume of water that must be sampled to accurately assess compliance and identify methods to collect and analyse these samples.

4 CONCLUSIONS

The applicability of each ballast water treatment is limited by factors such as cost, biological effectiveness and possible residual environmental toxicity. It has been a long process to develop a mature system and thus build the confidence in the stakeholders. The lengthy process has been a major drawback and delayed the enforcement of the Convention. However, some technologies proved to be efficient and a number of systems are now on the market.

Sampling analysis was the focus of the BW Convection since the beginning, and many guidelines have been established by the IMO to address this issue. However, the proposed methods are not comprehensive enough to be acceptable worldwide. There is a definite need for a standard sampling protocol, which would be applicable to every port and received by each party.

Further study should be undertaken to establish sampling size, since this issue has not been resolved yet. The large sample size is always in contrast with avoiding undue delay to the vessels activities, which has been well emphasised in the Convention. Research is still needed to develop an innovative assessment method, which automatically takes and analyses samples. Ideally, technologies will be developed that can analyse the sample during discharge events and enable crew to stop discharge if the system shows an exceedance of the D-2 Discharge Standard.

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