UV Treatment of Ballast Water: Market, Regulations, Validation Test Methods

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Background
When cargo is unloaded from a ship, ballast water is pumped into onboard ballast tanks in order to keep the ship stable for the journey to another port to take on more cargo. The ballast water that then is discharged as the new cargo is loaded has been implicated in a number of harmful invasions by foreign aquatic species on indigenous ecosystems (aquatic nuisance species).

Two regulations have been promulgated to prevent the transfer of non-indigenous species between marine habitats of the world: the 2004 IMO Ballast Water Management Convention and the 2012 US Coast Guard Standards for Living Organisms in Ships’ Ballast Water Discharged in US Waters. When enforced, these regulations will apply to more than 60,000 vessels that carry ballast water between various worldwide ports.

Regulations
In 2004 the International Maritime Organization (IMO) published the International Convention for the Control and Management of Ships’ Ballast Water and Sediments (BWMC). The convention is awaiting ratification by the required 30 countries representing at least 35% of the world’s shipping gross tonnage in order for it to come into force. Currently there are 51 countries signatory to the convention representing about 34.87% of world tonnage, leaving it 0.13% short of the required tonnage for ratification. The convention will enter into force one year after the tonnage requirement is satisfied.

The United States Coast Guard (USCG) also published its own Final Rule in 2012 for ballast water discharges. The USCG regulations are largely in concert with the IMO BWMC 2004; however, a key difference is the inclusion of specific requirements that any ballast water management system used to treat ballast under the USCG Final Rule is required to be specifically type-approved by the USCG.

The discharge standard
Both the IMO and USCG regulations utilize the same numeric limits for organisms discharged via treated ballast water:

1. Less than 10 organisms per cubic meter greater than 50 microns
2. Less than 10 organisms per mL smaller than 50 microns but greater than 10 microns
3. Sampling of three indicator organisms to prove discharge of no more than:
   • 1 cfu per 100 mL of Vibrio cholera
   • 250 cfu per 100 mL of Escherichia coli
   • 100 cfu per 100 mL of intestinal enterococci

US ballast water treatment regulations are further complicated by the Environmental Protection Agency’s (EPA) Clean Water Act, which is administered via the Vessel General Permit. The USCG and EPA have worked together under a Memorandum of Understanding to develop consistent rules for the discharge of ballast water; however, there are in fact two separate standards to which ship owners must comply.

Disinfection technologies
Ballast Water Management Systems (BWMS) use multiple processes to meet the disinfection standard. Most ballast water treatment technologies utilize a liquid-solid separation technique as a first stage treatment process to remove sediments and larger organisms. Fine mesh screen and disc filters, as well as hydrocyclone separators, typically are employed for this purpose. Coagulation/flocculation also has been used for solids separation.
The second stage of the treatment process can occur by one of several chemical or physical disinfection methods. Chemical disinfection technologies include direct chemical injection, electrochlorination, electrolysis, ozone or any kind of advanced oxidation process. Physical disinfection technologies include UV irradiation, deoxygenation, ultrasonic treatment and cavitation.

**Chemical treatment**

Chemical treatment technologies can be very effective for ballast water treatment. Chlorine is a well-known disinfectant that can be introduced directly in chemical form or generated on board from sea water.

Some advantages of these treatment systems include generally lower power consumption and residual disinfectants being carried in the ballast tank after initial treatment. Disadvantages of chemical treatment include the handling, storage and cost of replacing toxic chemicals on board and the need to maintain neutralization compounds to ensure discharges are not toxic to the receiving water body.

Other systems generate powerful, but short-lived, disinfecting agents to kill organisms in the ballast water. Electrolysis and AOP systems create short-lived hydroxyl radicals, which are a powerful oxidizing agent. However, many of the same concerns apply as with electrochlorination related to safety and the creation of disinfection by-products. Ozone is another powerful oxidizing agent that has been employed for ballast water treatment.

**Physical treatment**

Physical treatment processes like cavitation and ultrasound have been used in combination with other treatment technologies but have not yet been employed as standalone technologies. Deoxygenation is an available technology for large tankers where an existing inert gas generator services the ballast tanks in addition to the cargo tanks. Deoxygenation often requires a constant feed of inert gas to the ballast tanks which has the advantage of providing some corrosion protection, but it is expensive to install the piping and PV valves on each ballast tank for existing vessels.

**Ultraviolet irradiation**

Ultraviolet (UV) irradiation has become the most common treatment technology used for ballast water treatment to date. UV treatment does not create any toxic compounds or change the chemistry of the ballast water, which makes it environmentally neutral and eliminates safety and corrosion risks associated with some chemical treatment technologies.

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**The market**

In all, approximately 60,000 vessels will need to be fitted with BWMS over the next 10 years. UV treatment systems make up about 46% of the global sales of ballast water treatment systems to date (roughly 3,000 systems) while electrochlorination and electrolysis systems make up the bulk of the remaining 54%. For retrofit installations, UV treatment systems make up an even larger percentage of global sales to date due to their modular nature and relatively small footprint.

**Testing of ballast water treatment systems**

Ballast water treatment systems (BWTS) are required to be tested to show they perform to the regulatory requirements. Testing of any equipment for suitability on a ship is called “type approval.”

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**Type approval**

In type approval, representative equipment is tested against a set of standards to demonstrate that it is compliant by design. Typically, the type approval process involves rigorous testing of an example piece of equipment against a set approval standard. In the case of BWTS, this involves the shore-based and shipboard testing of equipment to demonstrate seaworthiness.
and its capability to achieve the discharge standard. In principle, the IMO, USCG and the United States Environmental Protection Agency (EPA) regulations stipulate the same type approval approach to the certification of BWTS.

The main difference between the USCG and IMO regulations is that the USCG requirements for testing are more clearly defined than for the IMO. All testing of BWTS for USCG must be done in accordance with a strict EPA test protocol. Under this protocol the allowed methods for all aspects of the testing are defined – unlike the IMO regulations, where the testing laboratory has some discretion in the test methods used.

The testing of equipment to satisfy the requirements of the US regulations must be conducted by an independent laboratory (IL) that has been approved by the USCG. The IL’s responsibility differs significantly from that of a class society in a “traditional” type approval arrangement.

Typically, type approval testing can be combined to conform to both IMO and USCG regulations and consists of:

1. land-based testing
   - five tests at each of three salinities
2. shipboard testing
   - five consecutive successful shipboard runs
3. seaworthiness testing
   - so-called “shake and bake” or environmental testing
   - pressure vessel compliance
   - explosion-proof where necessary (tankers)

**Land-based testing**

For land-based testing, the natural water is often augmented to ensure it has sufficient organisms of each size class.

<table>
<thead>
<tr>
<th>Size class</th>
<th>Required inlet</th>
<th>Disch. standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 50 µm (zooplankton)</td>
<td>&gt; 100,000 org/m³</td>
<td>&lt; 10 org/m³</td>
</tr>
<tr>
<td>10 to 50 µm (phytoplankton)</td>
<td>&gt; 10,000 org/mL</td>
<td>&lt; 10 org/mL</td>
</tr>
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In addition, suspended solids, dissolved organics and a UV absorber may be added.

The testing consists of five consecutive successful tests at each of three salinities (fresh, brackish and salt) for a total of 15 tests with the treatment requirements shown in Table 1. For a typical test, water is first pumped into an influent tank where it is augmented as required to meet requirements (the larger tank in Image 4 below). From there it is pumped through the treatment system to a smaller (250 m³) holding tank, where it is held for up to five days to simulate the hold in the ballast tank during a voyage. For UV systems, it then is pumped back through the treatment system bypassing the filter for a second dose of UV before discharge. Samples are taken before treatment.

**Test methods**

The test methods vary by size class.

> 50 µm (zooplankton) test method

The larger (> 50 µm zooplankton) do not reproduce fast enough to be able to practically use a reproductive test. A poke and prod method that tests for mobility is commonly used. Since UV-inactivated heterotrophs are generally motile for up to 72 hours but ultimately die off due to the inability to reproduce, this method is very conservative for UV treatment systems. Large sample incubation where the sample is held for up to five days under ideal growth conditions and the sample monitored over time have been proposed, but this technique would need further research and validation to be accepted by the USCG and most international authorities.

10 to 50 µm (phytoplankton) test method

The US Coast Guard Rule and associated ETV protocol incorporates a vital stain method that tests for the presence of enzymatic activity for phytoplankton. Since UV does not directly impact such cellular activity, this method is not effective in determining inactivation by UV.

A grow-out method employing Most Probable Number (MPN) is being used internationally and has been proposed for use to the USCG.
Most probable number test method
The Most Probable Number Dilution-Culture Method (MPN method) measures the number of viable phytoplankton cells in a sample via their ability to reproduce.

- A ballast water sample is serially diluted.
- The dilutions are incubated at favorable light and temperature levels together with nutrients and purified water constituents from the ambient (source) water.
- After 14 days, dilutions are monitored for chlorophyll fluorescence with a standard laboratory fluorometer. If one or more viable cells are present in any dilution, they will reproduce and increase the chlorophyll fluorescence.
- Dilutions are simply scored for growth or no growth, based on changes in chlorophyll fluorescence over the incubation period.
- Scores at each dilution are used in an MPN calculator to determine the probable number of viable cells that were present in the original sample.


MPN method and the US Coast Guard
The US Coast Guard Rule and associated ETV protocol incorporates a vital stain method that tests for the presence of enzymatic activity for phytoplankton that is incompatible with UV since after exposure to UV the enzymatic activity can continue but, due to DNA damage, the organism cannot reproduce and hence populate a foreign environment. However, the rule does allow for alternate methods to be approved.

Meetings with the USCG indicated that any alternate method needed to be fully “validated” (backed up with testing and data). For example, the percent of organisms that do not grow out in an MPN needed to be quantified. The Coast Guard asked EPA ETV to convene a UV technical panel to investigate alternatives that suit UV.

This ETV UV tech panel met in 2013 and decided that the MPN grow-out method was the most suitable approach. An MPN Subgroup was formed with representatives from the Coast Guard, EPA, marine biology experts, testing laboratories and UV manufacturers. The UV manufacturers banded together to fund research by three testing laboratories that practiced MPN (DHI and NIVA in Europe and Moss Landing in the US) to obtain data needed to prove the validity of the method – under guidance of MPN Subgroup.

Taxonomic studies showed that a majority of the organisms in an MPN do grow-out. The small proportion of organisms that may not grow-out is analogous to the fact that not all organisms stain sufficiently to be counted in a vital dye test. Testing was done to standardize the incubation conditions, such as temperature, time and nutrient media.

It was postulated that grazers (zooplankton) may impact the result by consuming all the phytoplankton in a given test cell. It was determined that the ratio of phytoplankton to zooplankton at >1,000:1 makes this statistically insignificant. This work resulted in harmonized protocol of the methods employed by the three laboratories that was finalized early in 2015 as an MPN Method Document suitable for approval by the EPA for incorporation into the ETV protocol as an alternate test method and was submitted to the US Coast Guard by four UV manufacturers for approval.

US Coast Guard Decision
On Dec. 14, 2015, the USCG announced a preliminary decision not to approve MPN. Specifically, the decision found that the MPN method is not equivalent to the vital stain method in measuring the efficacy of ballast water management systems. This preliminary decision essentially prohibits the practical and efficient use of ultraviolet (UV) light-based systems in spite of the fact that the MPN method is a well-established,
sound, scientific measurement method that is being employed internationally to test UV systems for type approval. This decision is being appealed by the four UV manufacturers directly impacted. For information, visit http://mpnballastwaterfacts.com.

The recent decision by the US Coast Guard to consider the MPN method as not being an equivalent method to measure the effectiveness of BWMS in treating the 10-50 µm organism class is unfortunate and wrong since:

• Ultraviolet (UV) technologies render organisms non-productive and therefore harmless in the context of preventing invasions.
• The MPN method is a well-established and sound scientific measurement method.
• The MPN method consistently induces organisms to grow. There is no evidence to support the rhetoric that most phytoplankton species are unculturable.
• The MPN method is more accurate, more conservative and more protective of the environment than the ETV stain method.

The UV dosage required to damage esterase systems as measured by the ETV stain method is approximately 10 times greater than the dose used to prevent the infestation of aquatic nuisance species by rendering organisms incapable of reproduction as determined by MPN. Therefore, holding UV-based systems to this method puts them at a decided disadvantage and is a disservice to the maritime industry in general, limiting its choice of BWM systems and increasing the cost and size of the resulting treatment system whether it be a larger UV system or forcing the use of an alternate technology.

Conclusion
New regulations from the IMO and USCG soon will govern ballast water discharges throughout the world and require the installation of BWMS on most vessels. Treatment by filtration followed by UV is very effective in preventing the transfer aquatic nuisance species via ballast water. Methods that are used to test the efficacy of all BWTS should be tailored to their effect on the organism in preventing reproduction and therefore the possibility of a harmful invasion.

For UV-based systems, the only effective means for measuring the inactivation of phytoplankton is via grow-out to show their incapability of reproduction. A proven and reliable method for this exists and is being used internationally in determining the efficacy of UV systems. It is important that the US Coast Guard rescind its decision and approve this method and other reproductive measures that may be developed in the future for the benefit of the environment and the maritime industry in general. ■

References


3. EPA/600/R-10/146, Generic Protocol for the Verification of Ballast Water Treatment Technologies, version 5.1, (dated September 2010), IBR approved for §162.060-26 and 162.060-28