WHITE PAPER

Understanding UV performance and measurements in ballast water treatment

Why performance parameters differ and how to benchmark

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Overview

Customers in ballast water treatment may be confused by a perceived difference in performance when ultraviolet (UV) treatment systems operate in United States waters as opposed to IMO-regulated waters. Outside the United States, a UV system may have little or no holding time, which means deballasting can occur soon or directly after treatment. Yet under U.S. Coast Guard (USCG) jurisdiction, the same UV system can have a holding time of up to several days. Likewise, there may be differences as to which UV transmittance (UVT) values the system can handle without reducing flow.

In fact, there is no difference in performance, however it might seem. Both the need for holding time and the difference in UVT values that a given UV system can manage are largely related to the testing method required by the USCG during type approval – not to any difference in biological efficiency. A decision by the USCG to use the same testing methods accepted by IMO would immediately remove many UV system holding times and harmonize UVT boundaries. In the meantime, UV system manufacturers must make compromises in flow, energy consumption or other parameters in order to satisfy a method that is less appropriate for evaluating UV treatment.

In addition, customers may be confused by the two types of UV measurement associated with UV treatment. Some manufacturers promote their systems using the ultraviolet intensity (UVI) value on their type approval certificate, which is a system-specific measurement that cannot be used as a benchmark. Ultraviolet transmittance (UVT) is the only measurement that has value for customers in comparing ballast water treatment systems.

Evaluating the effect of UV treatment

UV ballast water treatment systems neutralize organisms by irradiating the water with UV light. They differ from systems that use heat treatment or chemical substances, which usually disrupt the cell membrane. UV treatment leaves the cell membrane intact but damages the DNA, which either kills the organism outright or prevents it from reproducing. In terms of avoiding biological invasions, both results are equally successful.

For organisms smaller than 50 µm in size, testing method used by manufacturers of UV ballast water treatment systems is the most probable number dilution-culture method, or simply the MPN method. This is a grow-out method combined with statistical analysis. The MPN method is suitable not only for ballast water treatment, but also for many other applications, including drinking water. A variation of it was first described for enumerating phytoplankton in 1978, and it has been accepted by IMO since 2006 as proof of biological efficiency in ballast water treatment.

Unlike IMO, the USCG currently only accepts testing with grow-out methods for the smallest organisms. It does not accept MPN results for larger organisms in the 10–50 µm range. For these organisms, the Environmental Technology Verification (ETV) protocol stipulates the CMFDA/FDA vital stain method, which IMO only requires for organisms larger than 50 µm. This method measures esterase (cellular enzyme) activity. When the vital stain penetrates an organism, the organism's esterase system converts it into a fluorescent product that can no longer pass freely through the cell membrane. Fluorescing organisms are thus classified as "living", while non-fluorescing organisms are classified as "dead".

Why USCG testing leads to different UV performance parameters

The CMFDA/FDA vital stain method is a good method for ballast water treatment systems that use heat treatment or active substances. Because these technologies disrupt the cell membrane, they allow esterase and fluorescent stain products to exit the dead organism. The difficulty for UV systems is that the CMFDA/FDA method is not well suited to UV technology, which leaves the cell membrane largely intact and keeps these substances inside the cell.

Because heat-treated samples were used to verify the CMFDA/FDA method, this discrepancy was not recognized during the design of the ETV protocol. The result is an unfortunate increase in holding time requirements for UV systems when deballasting in United States waters.

An organism that is sufficiently treated with UV light is immediately inactivated and incapable of reproducing. But even if the organism is inactivated instantly, its esterase activity will continue for a significant number of hours or days. To compensate for this, a holding time between ballasting and deballasting is necessary. This is to ensure that UV-damaged cells are fully inactivated before CMFDA/FDA staining occurs.

The only way to reduce the USCG holding time for a UV system is to increase the UV dose, which will shorten the time needed for the UV effect to be recognized by the CMFDA/FDA method. This means exposing the organisms to more or stronger UV light. While this is certainly possible, it cannot be done without affecting the system's balance of parameters. The available methods can be seen in the following table, along with their implications.

Method of increasing UV exposure	Implications for the vessel
Decreasing the flow rate	Slower ballast operations
Increasing the lamp power	Increased power consumption
Increasing the number of UV reactors/chamber	Increased capital expense, space requirements and power consumption
Securing higher water clarity*	Decreased geographical operating range

The last of the options in the table, securing higher water clarity, highlights the other area of confusion when looking at UV systems in United States waters: the UVT values a system can handle. As explained more thoroughly in the next section, UVT is a measure of water clarity. It thus seems odd that the same UV system should have a higher boundary for water clarity in United States waters than in IMO-regulated waters.

As the table clearly shows, however, increasing the UV dose to satisfy the CMFDA/FDA method always involves some form of compromise. Changing one parameter leads to changes in another. Depending on the other choices made by a UV system supplier (reducing flow, increasing power or simply accepting a longer holding time), the lowest possible UVT value may be more or less similar to the UVT limit in IMO-regulated waters.

When looking at any UV solution for use in United States waters, it important for customers to look at the compromises made and determine if the resulting limitations are acceptable. In some cases, suppliers offer systems with different USCG modes, in which case the balance of parameters can be adapted to match the customer's business and operating needs.

Understanding UV dose and UV measurements

In general, whether looking at USCG or IMO parameters, it is important to understand the mechanisms affecting the UV dose. Without at a basic understanding, it can be difficult to accurately compare different UV treatment systems.

The UV exposure an organism receives can be broken down into two factors:

- The amount of time the organism is exposed to UV light
- The amount of UV light the organism is exposed to during that time

When it comes to the second factor, it is necessary to understand the different measurements associated with UV light. Two measurements are commonly used in relation to ballast water treatment systems:

- *Ultraviolet transmittance (UVT) – Expresses the relationship between light and water clarity*
  UVT is a standardized measurement, usually performed in a lab, that uses a specific wavelength of UV light (254 nanometres). Expressed as a percentage, it states how much UV light remains after travelling a distance of one centimetre through a water sample. It is not a measurement of how much UV light is produced, but rather an indication of water clarity.
- *Ultraviolet intensity (UVI) – Expresses the total amount of light reaching a sensor*
  UVI is a measurement of how much light reaches a UVI sensor within a given system, such as a ballast water treatment system. Expressed in watts per unit of area, it accounts for the total number of photons reaching the sensor in a specified range of UV wavelengths. However, it is a system-specific measurement that will vary depending on the lamp and sensor setup.

Both of these measurements may be used by manufacturers of ballast water treatment systems to describe the performance of their systems on type approval certificates and in marketing materials. For customers, however, UVI values are a misleading and irrelevant benchmark.

Why UVI values should not be compared

Some manufacturers of ballast water treatment systems use a UVI value to promote the amount of UV light their systems produce. However, as explained previously, UVI measurements are relative. They are specific to a given UV system and cannot be compared between systems.

The amount of light reaching the UVI sensor will depend on these factors within a UV system:

- *Lamp intensity*
  The higher the lamp pressure, the more light is produced. Low-pressure UV lamps produce around 1 W/cm over the lamp length, whereas medium-pressure UV lamps produce around 100 W/cm.
- *Sensor placement*
  The position of the UVI sensor within a system impacts the measured intensity. Moving the sensor closer to the lamp will produce a higher UVI value, while moving it farther away will produce a lower UVI value. In either case, the amount of UV light produced by the lamp is the same.
- *Reactor geometry*
  The size and configuration of the reactor (UV chamber) affect the way UV light is able to travel within it. In addition, different reactors create different levels of water turbulence, which affects the mixing of organisms and their level of UV exposure. Different reactors will achieve type-approved performance at different UVI values.

In other words, there are many variables affecting a ballast water treatment system's UVI value. The UVI value stated on a type approval certificate is only a system specification, i.e. a way of defining the equipment. It has no value when compared to any other ballast water treatment system.

The table below, taken from the USCG type approval certificate for Alfa Laval PureBallast 3 and presenting its UVI values in USCG mode, shows how UVI values vary even between reactors from the same manufacturer. Due to the difference in their lamp parameters, the 300 m^3/h and 1000 m^3/h reactors, for example, achieve type-approved treatment at different UVI levels.

UVI differences in reactors from the same manufacturer

UV reactor size	Minimum UVI at 50 % TRC (Treatment Rated Capacity)	Minimum UVI at 100 % TRC (Treatment Rated Capacity)
300 m^3/h	530 W/m^2	820 W/m^2
1000 m^3/h	772 W/m^2	1383 W/m^2

Effectively benchmarking UV treatment systems

When it comes to comparing different ballast water treatment systems, the only relevant UV measurement is UVT. The UVT value indicated for a system is not tied to the system's individual design, but rather to its performance. The UVT value plainly states the clarity of the water the system can process.

Water clarity can vary greatly from port to port, as shown in the following table, as well as with prevailing tidal and seasonal conditions within the same port.

Water quality by port

Port	UVT(%)	Temp(°C)	Salinity (PSU)
Istanbul, Turkey	95	6	24
San Pedro, CA, USA	95	2	32
Halifax, NS, Canada	94	–0.8	20
Veracruz, Mexico	94	26	36
Rotterdam, Netherlands	93	5	0.3
Port of Singapore, Singapore	93	27	31.5
Houghton, MI, USA	91	–0.1	0.1
Erie, PA, USA	87	–0.1	0.3
Zeebrugge, Belgium	76	5	26
Gothenburg, Sweden	85	0	20
Charleston, SC, USA	84	10	24
Baltimore, MD, USA	83	11	12
Hong Kong, China	80	17	33
Houston, TX, USA	74	11	20
Hamburg, Germany	69	2	0.1
Antwerp, Belgium	66	5	6.5
Bremerhaven, Germany	60	2	4
Lisbon, Portugal	53	14	35
Southampton, England	51	5	32
Shanghai, China	49	4	1.2

The lower the UVT value a system can handle, the more challenging water the system can treat. Though their UVI values differ, the 300 m^3/h and 1000 m^3/h Alfa Laval PureBallast 3 reactors discussed previously both provide type-approved ballast water treatment down to 42 % UVT in IMO-regulated waters.

The relative UVI value for a ballast water treatment system is always in relation to a standardized UVT value – even if the manufacturer chooses not to promote it. If no UVT value is stated, customers should ask the manufacturer about the system's UVT performance. Likewise, if their vessel will traffic a certain route, they should check the UVT values for relevant ports and ensure that the system can meet them.

Only UVT values can accurately benchmark ballast water treatment systems from different manufacturers.

Explore UVT data in your ports of call

For UVT data from additional ports and a clearer understanding of how UVT impacts UV ballast water treatment systems, try the free Compliance Navigator tool at www.pureballast-compliancenavigator.com

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