ON THE SURFACE
Environmental Protection

Greenwater

The future of sewage regulations, equipment design, and testing.

by LT Rob Griffiths
U.S. Coast Guard Office of Design and Engineering Standards

Mr. Matthew D. MacGregor
Executive Director
TEi-Testing Services

Commander Stephen P. Markle, USN (Ret.), P.E.
Engineering Director
Navalis Environmental Systems

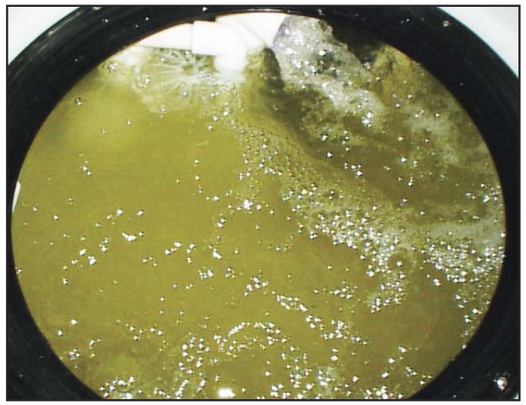
Recent changes to international regulations that govern discharge of ships' sewage into the sea have left many people wondering if the United States will formally adopt the new standards and, if it does, how such action might impact the industry at large. Vessel owners and operators, shipyards, and boat builders; manufacturers of marine sanitation devices and sewage treatment plants; and the independent laboratories that test such equipment are all concerned about the status of MARPOL Annex IV in the United States.

While it may be too soon to predict when or even if the United States will ratify the sewage annex, everyone involved can agree that a clear understanding of both U.S. and international sewage regulations is necessary to avoid running afoul of the enforcement authorities both here and abroad.

Sewage regulations can easily be broken down into three discrete categories covering vessels, equipment, and testing facilities. These regulations can then be placed into one of three different scenarios:

- a U.S.-flagged vessel on an international voyage,
- a U.S.-flagged vessel on a U.S. voyage,
- a non-U.S.-flagged vessel on a U.S. voyage.

These regulations affect nearly all types of vessels, from the larger inspected vessels that carry passengers and cargo, to the smaller uninspected vessels that tow ships and barges, to even private vessels such as yachts and recreational vessels. In essence, any vessel with an installed toilet may be subject to these requirements.



Aerobic digestion of sewage waste by biological device. Courtesy TEi-Testing Services.

U.S. Sewage Regulations and Related Policies

For a U.S.-flagged vessel on a U.S. voyage, existing sewage regulations covering the vessel, its equipment, and related testing requirements can be found in 33 CFR Part 159. These regulations have not changed much since they were first introduced in 1975, with the exception of those for the cruise ship industry operating in certain Alaskan waters.[1]

Inspected vessels with an installed marine sanitation device (MSD) are examined by the U.S. Coast Guard during annual and five-year certificate of inspection renewals. Uninspected vessels (which include recreational vessels) with an installed MSD are checked periodically to ensure the device is in operable condition to the satisfaction of a Coast Guard boarding officer. Equipment is subject to design approval to verify it meets the requirements of 33 CFR Part 159 (or an equivalency) and then undergoes testing, evaluation, and inspection by an independent laboratory under simulated operating conditions. Equipment manufactured in the United States meeting both U.S. and international requirements may be eligible for a certificate of type approval. Finally, testing facilities that meet the requirements of independent laboratory testing standards in 46 CFR 159.010-3 are issued a U.S. Coast Guard letter of acceptance.

Oxidation/Reduction MSD. Courtesy Navalis Environmental Systems.

For a U.S.-flagged vessel on an international voyage, sewage regulations covering the vessel, its equipment, and related testing requirements can also be found in 33 CFR Part 159 with a concomitant equivalency made to MARPOL Annex IV by MOC policy letter 03-03. In this case, the U.S. Coast Guard issues a certificate of equivalency to a U.S.-flagged vessel on an international voyage having an installed and operational MSD. Uninspected vessels over 400 gross tons are issued a certificate every five years, endorsed annually during the IOPP (international oil pollution prevention) survey, or can receive a statement of voluntary compliance from their classification society. Inspected vessels over 400 gross tons and those of less than 400 gross tons carrying 15 or more passengers may be issued a certificate every five years, endorsed annually. This is true for all but small passenger vessels (i.e., 46 CFR Subchapter T and K), which receive an endorsement on their certificate of inspection every five years, endorsed annually. Equipment and testing requirements are similar to those detailed above for a U.S. vessel on a U.S. voyage.

For a non-U.S. vessel on a U.S. voyage, sewage regulations can be found in the prior MARPOL Annex IV with an equivalency made to 33 CFR Part 159 by Navigation and Vessel Inspection Circular No. 9-82, Change 1. In this case, the U.S. Coast Guard verifies the vessel's certificate of type test during a port state control examination.

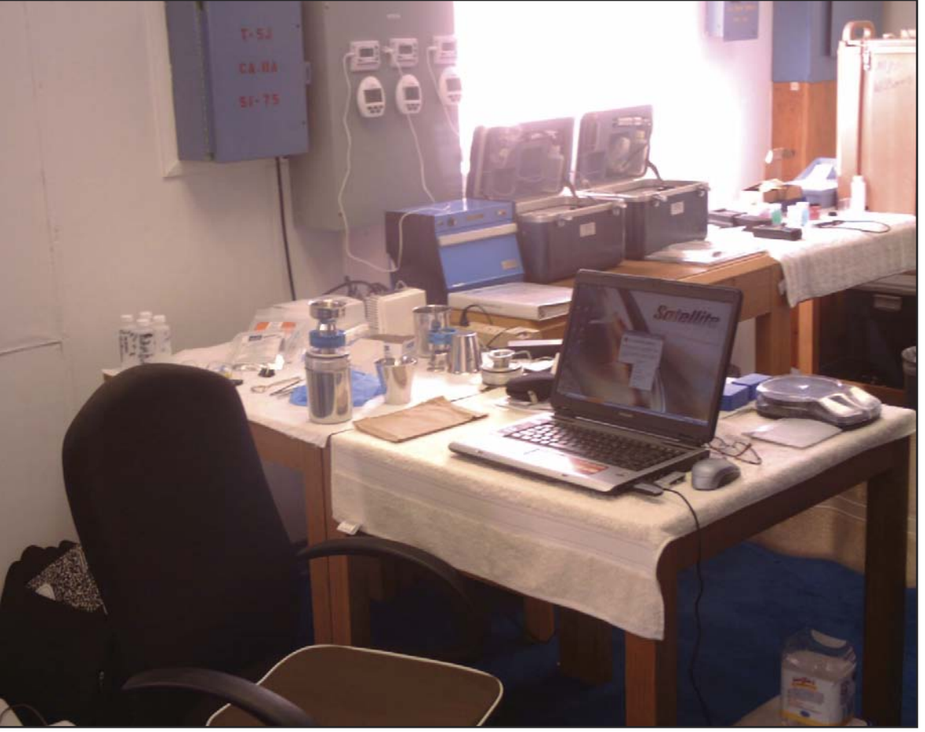
Revised International Sewage Regulations

In 2004, the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO) adopted and reissued the revised MARPOL Annex IV in resolution MEPC.115(51), resulting in several key changes to the international sewage regulations:

- Inspection criteria were enhanced to include onboard surveys of installed sewage systems prior to being placed into service and periodically throughout the life of the vessel.
- Standards for discharging treated sewage (i.e., effluent) into the water were enhanced and made more stringent.
- Equipment testing procedures were standardized.
- Discharge rates for untreated sewage were established.

The IMO adopted MEPC.115(51) on April 1, 2004, and is applicable to new ships on international voyages with a keel laid date on or after September 27, 2003, or delivered on or after September 27, 2006, and existing ships after September 27, 2008, that are 400 gross tons and above or that are certified to carry more than 15 persons. The term "person" is defined here to include both passengers and crew. Annex IV requires ships that engage in international voyages to be equipped with one of the following: a sewage treatment plant; a sewage comminuting and disinfecting system with holding tank, or a sewage holding tank.

Under Annex IV, the discharge of sewage into the sea is prohibited except when:



Mobile testing laboratory for compliance testing. Courtesy TEi-Testing Services.

- The ship has in operation an approved sewage treatment plant.
- The ship is discharging comminuted and disinfected sewage using an approved system at a distance of more than three nautical miles from the nearest land.
- The ship is discharging sewage that is not comminuted or disinfected (untreated) at a distance of more than 12 nautical miles from the nearest land.

The term "sewage" includes drainage and other wastes from toilets and urinals; drainage from medical spaces including wash basins, wash tubs, and scuppers located in such spaces; drainage from spaces containing live animals; and other waste water, when mixed with any of these drainages.

Additionally, on October 13, 2006, resolution MEPC.159(55) adopted the revised effluent standards and performance tests that are applicable to new installations of sewage treatment plants for new ships with a keel laid date on or after January 1, 2010, and for existing ships having plants installed or delivered on or after January 1, 2010. Existing ships having sewage treatment plants installed or delivered prior to that date may continue to use either the 1976 international effluent standards contained in MEPC.2(VI) or other applicable national specifications (e.g., 33 CFR Part 159).

Finally, on October 13, 2006, resolution MEPC.157(55) adopted a standard for the maximum rate of discharge of untreated sewage in holding tanks at a distance equal to or greater than 12 nautical miles from the nearest land.

Prior Equivalency

Considering the recent changes to MARPOL Annex IV, it may well be that the prior equivalency afforded U.S.-flagged vessels on international voyages has been all but eliminated. The effluent standards alone in MPEC.2(VI), when compared to MEPC.159(55), are not only numerically different but also appear to be substantially different. See the comparison between the current sewage regulations and the revised international regulations in Tables 1, 2, and 3.

COMPARISON OF SEWAGE REGULATIONS

Table 1. U.S. Vessel on U.S. Voyage

	U.S. Regulations & Policy	MARPOL Annex IV
Vessel	Inspected vessel MSD examined during annual and 5-year renewals of COI, and checked for compliance with 46 CFR Subchapter F & J. Uninspected vessel MSD must be in operable condition to the satisfaction of the USCG boarding officer.	N/A
Equipment	**MSD Design Approval:** USCG approves MSD design that meets requirements *or equivalency* in 33 CFR Part 159. **MSD Certification:** USCG issues *Certification Number* to manufacturer following evaluation/testing at *Recognized Facility* under simulated operating conditions in 33CFR159 for MSD on either *all vessels* or *uninspected vessels*. Label required.[1] USCG adds MSD to *Approved Equipment List*. **Foreign MSD Manufacturer:** USCG issues *Letter of Certification* to foreign manufacturer that meets above MSD criteria. **Sewage Treatment Plant:** USCG issues *Certificate of Type Approval* to U.S. manufacturers that comply with both MARPOL Annex IV and above MSD criteria.	N/A
Facility	**Recognized Facility:** USCG issues *Letter of Acceptance* to *Recognized Facility* that meets requirements of *Independent Laboratory* testing standards in 46CFR159.010-3. **Classification Society** may apply for and be accepted by USCG as *Recognized Facility* that meets requirements of *Independent Laboratory* testing standards in 46CFR159.010-3.	N/A.

[1] Type III MSD used for storage of sewage/flushwater at ambient air pressure/temperature has no certification number/label under 33CFR159.12a; inspected vessels comply with 46CFR Subchapters F & J.

COMPARISON OF SEWAGE REGULATIONS

Table 2. U.S. Vessel on International Voyage

	U.S. Regulations & Policy	MARPOL Annex IV
Vessel	USCG issues *Certificate of Equivalency* to U.S. vessel with installed/operational MSD on international voyage: • **Uninspected Vessel** >400GT every 5 years, endorsed annually at IOPP survey; or *Statement of Voluntary Compliance* issued by class; ≤400GT no program in place. • **Inspected Vessel** >400GT and <400GT carrying 15 or more *passengers*, every 5 years, endorsed annually, *except* **Small Passenger Vessel** (Subchapters T & K) receive endorsement on COI, every 5 years, endorsed annually as per MOC Policy Ltr 03-03.	*International Sewage Pollution Prevention Certificate* issued/renewed by Administration (or authorized entity) after onboard *Survey* described in MEPC.115(51) at: • Initial installation; • Renewal every 5 years; • Repair to all vessels on international voyages: • ≥400GT • <400GT w/ >15 *persons* (i.e., passengers & crew) that are applicable to: • **New Vessels:** Keel laid on/after 27Sept2003 or Delivered on/after 27Sept2006; • **Existing Vessels:** on/after 27Sept2008. Vessels <400GT w/ ≤15 persons shall establish *appropriate measures* per Administration.
Equipment	**MSD Design Approval:** USCG approves MSD design that meets requirements *or equivalency* in 33 CFR Part 159. **MSD Certification:** USCG issues *Certification Number* to manufacturer following evaluation/testing at *Recognized Facility* under simulated operating conditions in 33CFR159 for MSD on either *all vessels* or *uninspected vessels*. Label required.[1] USCG adds MSD to *Approved Equipment List*. **Foreign MSD Manufacturer:** USCG issues *Letter of Certification* to foreign manufacturer that meets above MSD criteria. **Sewage Treatment Plant:** USCG issues *Certificate of Type Approval* to U.S. manufacturers that comply with both MARPOL Annex IV and above MSD criteria.	**9.1.1 Sewage Treatment Plant:** *Certificate of Type Approval* issued by Administration to manufacturer following full-scale testing using actual operating conditions of effluent & performance standards in MEPC.159(55) and environmental standards in MEPC.107(49); applicable to equipment installed or delivered on or after 01Jan2010. **Existing Vessels:** *Acceptable* to use *national specifications* in lieu of effluent/performance standards in MEPC.159(55). **9.1.2 Comminuting & Disinfecting System** and **9.1.3 Holding Tank** are not issued *Certificate of Type Approval* but may be issued *International Sewage Pollution Prevention Certificate* if they meet MARPOL Annex IV.
Facility	**Recognized Facility:** USCG issues *Letter of Acceptance* to *Recognized Facility* that meets requirements of *Independent Laboratory* testing standards in 46CFR159.010-3. **Classification Society** may apply for and be accepted by USCG as *Recognized Facility* that meets requirements of *Independent Laboratory* testing standards in 46CFR159.010-3.	**Qualified Testing Facility:** Testing facility is *Qualified* by Administration to assure uniformity among various testing facilities; effective for all vessels 01Jan2010. **Sewage Reception Facility:** Government provides adequate facilities at port and terminals for reception of sewage from holding tank used by Comminuting & Disinfection System 9.1.2 or holding tank 9.1.3.

[1] Type III MSD used for storage of sewage/flushwater at ambient air pressure/temperature has no certification number/label under 33CFR159.12a; inspected vessels comply with 46CFR Subchapters F & J.

COMPARISON OF SEWAGE REGULATIONS

Table 3. Non-U.S. Vessel on U.S. Voyage

	U.S. Regulations & Policy	MARPOL Annex IV
Vessel	USCG verifies *Certificate of Type Test* issued to foreign flagged vessels by their Administration during Port State Control boardings, accepted by policy in NVIC 9-82 Ch-1.	*International Sewage Pollution Prevention Certificate* issued/renewed by Administration (or authorized entity) after onboard *Survey* described in MEPC.115(51) at: • Initial installation; • Renewal every 5 years; • Repair to all vessels on international voyages: • ≥400GT • <400GT w/ >15 *persons* (i.e., passengers & crew) that are applicable to: • **New Vessels:** Keel laid on/after 27Sept2003 or Delivered on/after 27Sept2006; • **Existing Vessels:** on/after 27Sept2008. Vessels <400GT w/ ≤15 persons shall establish *appropriate measures* per Administration.
Equipment	N/A	**9.1.1 Sewage Treatment Plant:** *Certificate of Type Approval* issued by Administration to manufacturer following full-scale testing using actual operating conditions of effluent & performance standards in MEPC.159(55) and environmental standards in MEPC.107(49); applicable to equipment installed or delivered on or after 01Jan2010. **Existing Vessels:** *Acceptable* to use *national specifications* in lieu of effluent/performance standards in MEPC.159(55). **9.1.2 Comminuting & Disinfecting System** and **9.1.3 Holding Tank** are not issued *Certificate of Type Approval* but may be issued *International Sewage Pollution Prevention Certificate* if they meet MARPOL Annex IV.
Facility	N/A	**Qualified Testing Facility:** Testing facility is *Qualified* by Administration to assure uniformity among various testing facilities; effective for all vessels 01Jan2010. **Sewage Reception Facility:** Government provides adequate facilities at port and terminals for reception of sewage from holding tank used by Comminuting & Disinfection System 9.1.2 and holding tank 9.1.3.

Equipment Design and Manufacturing

The design of a wastewater treatment system is fundamentally the same for both land- and marine-based systems. Most successful designs follow a rule of thumb by first removing that which settles and that which floats, and then treat the remaining 95 percent of liquid, referred to as "mixed liquor." At this point, roughly 90 percent of the treatment challenge has already been accomplished, leaving the dissolved and suspended material for subsequent processing. It is therefore useful to break down the regulatory requirements into functional system requirements in order to meet the discharge standards. These requirements exist as six discrete functions, as depicted in Figure 1.

While land-based sewage treatment systems have incorporated these steps in a variety of ways, only recently has regulatory action required the manufacturers of marine systems to consider such functional requirements. For example, sludge or bioresidue is the byproduct of those systems that produce the highest-quality effluent. Management has typically been to dump it at sea where permitted, bring it ashore, or with limited success, incinerate it onboard. However, for those systems that treat to a less stringent standard, the effluent is typically discharged overboard either as part of the process or where legally permitted to do so.

Making the transition from functional requirements to engineering specifications requires a firm understanding of process chemistry as well as material standards. U.S. regulations offer several sections with robust design guidance. Similarly, ASTM standard F 2363-06, specification for United States Coast Guard type II, or IMO MARPOL 73/78 Annex IV marine sanitation devices (flow-through treatment) offers specific materials and testing requirements for these types of systems.

Today, most marine systems employ biologic activities that remove dissolved organic material. These systems employ bio-reactors that are exceptionally sensitive to influent loading from hydraulics and pollutants. Hydraulic loading is handled through equalization tanks and onboard flow management to ensure the system receives a fairly constant rate of influent. The more successful biological systems are coupled with chemical equalization to maintain constant nutrient loading. What is difficult to plan for are upsets caused by the introduction of cleaning and disinfecting products commonly used throughout the ship that harm the bacteria in the bio-reactor.

Modern biological systems can be grouped into one of three categories:

- systems that remove solids using dissolved air flotation and remove suspended solids by flocculation and mechanical means;
- systems having high concentrations of solids as measured by mixed liquor suspended solids using membrane technology to filter the water;
- systems that operate primarily on the principle of gravity-driven clarification, where gravity causes suspended matter to fall out, resulting in clarified material passing over a wall or weir and onto the next step, which is typically disinfection.

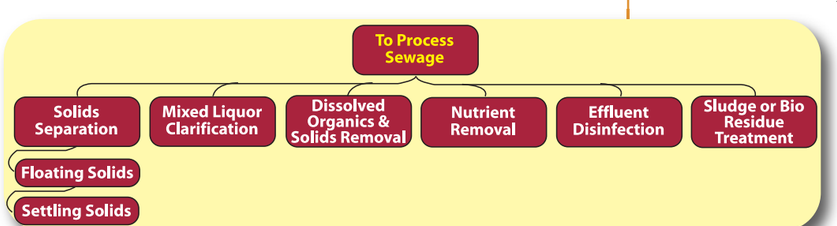


Figure 1.

When operated within strict guidelines, these systems generally produce excellent effluent, but are susceptible to periodic upset and require not only large quantities of air to maintain the bio-reactor but also large tanks. While most systems still employ chlorination disinfection, some have recently switched to ultraviolet (UV) light-based systems for this function. Although UV systems are very effective at disinfecting highly clarified water, biological treatment systems often produce effluent with color or turbidity that diminish the effectiveness of this technology.

Another marine system commonly used today is the physical/chemical type. These systems macerate incoming wastewater, then mix it with high concentrations of chlorine-containing compounds that are typically generated from seawater. These systems rely on chlorine to oxidize a fraction of the organic material and to disinfect. Many of these systems also introduce, as process water, the seawater that was used to generate the chlorine compounds. Some systems use 10 times the amount of process water compared to the amount of wastewater being treated and are typically found on smaller vessels where available space is at a premium. Increased effluent quality standards coming into force over the next several years will create serious challenges for smaller systems of this type, especially for residual chlorine content and removal of solids and nutrient material.

A third type of system has recently entered both the large and small ship markets, receiving USCG certification as a Type II MSD in January of 2008. This system is based on advanced oxidation to remove dissolved pollutants in wastewater. The trick here is to remove the particulate organic and inorganic material to offer the oxidizer an easier target. Solids are first screened, flocculated, filtered, and then ultra-filtered to produce a permeate with turbidity approaching one NTU (nephelometric turbidity unit). The permeate is then brought into contact with dissolved ozone gas in a stirring device where oxidation of dissolved material occurs. The ozonated water is then introduced into a high-power UV system that converts the residual ozone gas to a highly reactive oxygen species that further polishes the effluent. This process not only removes residual organic material, but is also highly effective at disinfecting the effluent. Typical effluent values are below detection for suspended solids and fecal coliform, and average five-day biochemical oxygen demand is below five milligrams per liter.[2]

Subsequent system development has led to an ozone-based sludge management system that reduces the volume of organic solids through oxidation but increases the settleability of solids, thus allowing a higher-content sludge that is partially disinfected and mineralized. These systems are now being adapted to marine use, having already proven themselves in land-based sewage treatment systems as well as graywater reuse applications.

The future of reusing water aboard ships looks promising. In the previously mentioned system, blackwater consisting of sewage and galley water can be treated in a system separate from graywater. By separating out the water in laundry and hotel accommodations, treatment becomes greatly simplified and produces an effluent that is suitable for reuse aboard the ship as technical water. Treated water[3] can be readily used in a ship's laundry, for engineroom technical water, as a source for fuel oil emulsification for engine oxides of nitrogen reduction, or for deck washdown and the like. With the ability to treat upwards of 80 percent of shipboard domestic wastewater, future systems may eventually lead to reduced fuel consumption from water generation, storage, and transport. Perhaps we can have smaller ship sizes, given reduced requirements for tankage, and even reduced operational costs through lower maintenance of water management technology.

Compliance Testing

Initial qualification testing evaluates mechanical and electrical performance as well as effluent processing. The mechanical and electrical performance requirements are based on a device's ability to withstand the rigors of the marine environment such as corrosion, vibration, and incidental impacts. The new international requirements for such testing are not much different from current requirements and therefore will not be presented here.

There is, however, a substantial difference in effluent processing performance during the initial qualification testing. First, the device manufacturer should consider where the device will be placed into service (coastal, intercoastal, etc.). Second, consideration should be given to the type of device. For example, if you have a comminuting/disinfecting system that simply transforms the sewage into an effluent reduced in size, which then disinfects to prevent the spread of harmful pathogens but keeps its original nutrient value, this produces an effluent that must be discharged beyond three nautical miles from shore. That is different from a treatment device that first reduces the sewage bio-limiting nutrients through biological digestion or oxidation and then disinfects the effluent to prevent propagation of harmful pathogens, which would produce an effluent that can be discharged within three nautical miles from shore. Another type of device might be a totally "green" device with an environmentally compatible effluent that not only addresses bio-limiting nutrients using an alternate disinfection method, but also is capable of reducing both graywater and blackwater effluents to a zero ecological effect on the aquatic system, thus producing an effluent that can be discharged virtually anywhere, including in designated no discharge zones. To decide which system is best for a given application, a background in processing testing may be helpful.

Processing testing is based on the ability of a given device to affect the basic composition of sewage that has physical, chemical, and biological elements. Testing for these elements is done using three types of analysis—physical, chemical, and biological challenges.

Physical testing determines the amount of matter discharged in the effluent which is made up of the solid residues found in sewage such as fibrous, cellular, and foreign material. Testing looks for the amount of total solids untreated by the MSD that are subsequently passed into the environment.

Chemical testing determines the amount of natural and introduced chemicals found in the influent. These chemicals constitute what is known as bio-limiting nutrients and hazardous materials. Bio-limiting nutrients are naturally occurring in human waste and, if untreated, promote unwanted growth in an aquatic system. These bio-limiting nutrients are determined by testing for chemical oxygen demand, nitrogen, phosphorus, and total organic carbons.

Hazardous chemicals include those used to treat waste such as disinfectants or chemicals found in graywater that are introduced into the MSD. Testing for residues indicates the presence of hazardous chemicals, which drastically affects the acidity, alkalinity, chlorides, pH, semi-volatiles, volatiles, and other analytical methodology. The type and amount of analysis done is based

on the extent of purity desired for the effluent. For example, you would not test for chemicals not listed in the regulation unless you wanted to demonstrate the purity of the effluent for possible use of a MSD in a "no discharge" zone.

Biological testing determines the amount of natural pathogens found in human waste. These pathogens constitute harmful microorganisms that promote illness and use available oxygen, thus limiting or destroying the growth within the natural aquatic system. These microorganisms are determined by testing for biological oxygen demand and thermotolerant coliforms.

Another factor in MSD design involves dilution. The U.S. Environmental Protection Agency strictly prohibits the use of dilution to reduce effluent to meet discharge requirements. Although dilution is not applicable to comminuting/disinfecting devices, the amount of processing water used by an MSD indicates whether it is a dilution device. If the ratio of process water to influent water is greater than 5:1 when cycled, an investigation should be made as to whether the MSD is using dilution to meet the discharge requirements.

It is important to realize that design approval and certification indicates a device is capable of meeting discharge regulations, but does not necessarily guarantee that a given device will always meet the discharge requirements. The condition, maintenance, and operation of the MSD all affect the quality of the effluent. When properly maintained and operated, most MSDs will remain compliant with the discharge criteria, but should be tested periodically to verify compliance.

The future of testing will be based on using analytical methods that will evaluate the MSD effluent to ensure minimum effect on the aquatic system to the extent that all physical, chemical, and biological elements of shipboard graywater and blackwater have been removed or otherwise neutralized. Only then will the most sensitive of aquatic systems be unaffected by the passage of a ship, thus creating a more earth-friendly environment.

About the authors:
LT Rob Griffiths is a mechanical engineer in the U.S. Coast Guard's Office of Design and Engineering Standards, where he oversees the independent testing labs and related equipment approvals for shipboard sewage treatment systems and pollution prevention equipment. He has served 21 years in the Coast Guard, including assignments as a marine inspector and chief of waterways management in Los Angeles/Long Beach, migrant interdiction officer in Miami, search and rescue controller in San Diego, operations officer and law enforcement boarding officer on a patrol boat in Miami, and as a quartermaster on a medium endurance cutter in St. Petersburg, Fla. He is a 2007 graduate of the Naval Postgraduate School in Monterey, Calif., where he received his master of science degree in mechanical engineering, and a 1999 graduate of San Diego State University, where he received his bachelor of science degree in criminal justice.

Commander Stephen P. Markle, P.E., is a retired U.S. Navy engineering duty officer and is the engineering director for Navalis Environmental Systems. He is a 1993 graduate of the Naval Construction and Engineering program at the Massachusetts Institute of Technology, where he received a naval engineer's degree and master of science degree in mechanical engineering. He is a professional engineer registered in the state of New York and commonwealth of Virginia. He serves as the chair of the joint ASNE/SNAME committee on environmental engineering and also as chair of ASTM ships and marine technology—marine environmental protection subcommittee.

Mr. Matthew D. MacGregor is the executive director of TEi-Testing Services, LLC. Mr. MacGregor has over 25 years experience in testing and is a technical expert for marine sanitation devices, bilge separators, and oil content monitors and has served as a professional services advisor for the U.S. State Department and the U.S. Coast Guard at United Nations IMO proceedings. Mr. MacGregor holds both a bachelor's and master's degree. Mr. MacGregor is also a LTC in the U.S. Army Reserves and has completed the U.S. Army command and general staff college. LTC MacGregor is a master aviator and has over 2,500 hours flying military aircraft. His current qualification is in the AH-64A "Apache" helicopter.

Bibliography

Regulations for Prevention of Pollution by Sewage from Ships, Revised Annex IV MARPOL 73/78, adopted by MEPC.115(51) on April 1, 2004.

Effluent Standards and Performance Tests for Sewage Treatment Plants, adopted by MEPC.159(55) on October 13, 2006.

Specifications for Environmental Testing for Type Approval of Pollution Prevention Equipment, Annex: Part 3, adopted by MEPC.107(49) on July 18, 2003.

Standards for the Rate of Discharge of Untreated Sewage from Ships, adopted by MEPC.157(55) on October 13, 2006.

33 Code of Federal Regulations Part 159

American Public Health Association, American Water Works Association, & Water Environment Federation, "Standard methods for the examination of water and wastewater (21st ed.)," 2005.

Metcalf & Eddy; G. Tchobanoglous, F.L. Burton; & H.D. Stensel, "Wastewater engineering: Treatment and reuse (4th ed.)," Boston: McGraw-Hill, 2003.

Endnotes:

1. In 2001, a new Subpart E was added to 33 CFR Part 159 to implement "Title XIV—Certain Alaskan Cruise Ship Operations" governing the discharges of sewage and graywater from cruise vessels, requiring sampling and testing of sewage and graywater discharges, and establishing reporting and record-keeping requirements. This subpart applies to each cruise vessel authorized to carry 500 or more passengers operating in the waters of the Alexander Archipelago and the navigable waters of the United States within the State of Alaska and within the Kachemak Bay National Estuarine Research Reserve.
2. Development of this system is further described in *"Design and Prototype Development of Advanced Oxidation Black and Gray Water Treatment Systems,"* presented at the American Society of Naval Engineers (ASNE) Marine Environmental Engineering Symposium in January 2006 and published in Naval Engineers Journal, Volume 118, Number 3, 2006, pp. 51-64(14).
3. E.g., "California Code of Regulations Title 22" water reuse criteria.