

# COMPARISON OF MARINE SEWAGE TREATMENT SYSTEMS

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## ABSTRACT

The impact of sewage on marine environment is a concern. Sea water can be polluted by pathogens, nutrients, detergents, pesticides and heavy metals. These sea water are shared by community for recreation, swimming and food production, the environmental and health risks are high. Improperly treated sewage on-board can harm ecosystem. Most of the vessels has an sewage treatment system, which is designed to remove pollutants from sewage water before releasing it from the vessel to the sea. Primary sewage treatment is a relatively physical process that mainly removes solids. Secondary sewage treatment using bacteria to decomposes organic matters, and final chlorination is used for sterilization of effluent before it is released to environment. The potential pollutants remaining after secondary sewage treatment include heavy metals, nutrients and non-biodegradable organic chemicals. "Advanced sewage treatment" is a generally term covering treatment designed to remove any of these substances. A variety of types of Advanced Wastewater Treatment Systems are available. Some are better proven than others and some are more complex and expensive, depend on their size and design.

**Keywords:** sewage, sewage treatment, advanced sewage treatment system, nutrients

## 1 INTRODUCTION

Marine environment pollution is one of the major ecological problems nowadays.

Pollution of the marine environment causing or liable to cause lethal consequences onto the living conditions of the marine and underwater flora and fauna. A large number of national and international regulations has been set. Besides the international regulations for prevention of marine pollution from vessels, many maritime nations have set forth their own regulations not complying with the international regulations.

Industry which manufactures Sewage Treatment Plants for marine use has been improved in last 10 years, and continue to upgrade existing and producing more complex Sewage Treatment Plants with better quality of effluent.

## 2 LEGAL REGULATIONS AND SHIP'S SEWAGE DISCHARGE

The problem of discharge and storage of sanitary waste waters from vessels, as well as equipment and certificates that the vessels must obtain in order to satisfy the prescribed standards, has been regulated by international rules and regulations as well as national regulations in maritime countries.

The most important international regulation pertaining to the problem of sea pollution from vessels is the *International Convention for the Prevention of Pollution from Ships*,

1973/78 (**MARPOL 73/78**) brought by **IMO**.<sup>1</sup> MARPOL Convention sets standards and rules preventing pollution of the sea by oils, chemicals, harmful matter transported in any form of packages, sewage and garbage, emission of harmful gases and ballast. The Convention comprises of a number of Annexes and Annex IV contains provisions regulating prevention and supervision of marine pollution by sewage waste waters from ships. **Annex IV** to the Convention refers to:

- a) prohibiting or limiting discharge,
- b) issuance of certificates and inspections,
- c) equipment and supervision of discharge,
- d) shore reception facilities. [1]

MARPOL Annex IV, is applicable to ships on international voyages that are 400 gross tonnage and greater; or less than 400 gross tonnage when certified to carry more than 15 persons.<sup>2</sup> [2]

The equipment for supervision of discharge on board must include at least one of the following sewage systems:

- A sewage treatment plant which will be of a type approved by the Administration, taking into account the standards and test methods developed by the IMO.
- A sewage comminuting and disinfecting system approved by the Administration. Such system will be fitted with facilities to the satisfaction of the Administration, for the temporary storage of sewage when the ship is less than 3 nautical miles from the nearest land.
- A holding tank of the capacity to the satisfaction of the Administration for retention of all and which will have means to indicate visually the amount of its contents.
- In case the ship is equipped with sewage treatment plant, then the prescribed quality standards are effluent from sewage plant.<sup>3</sup>

**Table 1: Sewage water effluent standard after treatment plants and prior discharge from the ship into sea, as per MARPOL Annex IV**

	Faecal coliforms / 100 ml	Suspended solids mg/l	Biochemical oxygen demand ( BOD5) mg/l	pH
<b>Treatment plant installed before 1st Jan 2010</b>	<b>250</b>	<b>50 (100)*</b>	<b>50</b>	---
<b>Treatment plant installed after 1st Jan 2010</b>	100	35	25 & Chemical oxygen demand - 125	6,0 - 8,5

Source: (authors)

Remark: \*50 mg/l if plant tested ashore; 100 mg/l if plant tested onboard

<sup>1</sup> MARPOL Convention, (*Official Gazette – International Conventions, No. 1/92, 4/05*). Text of the Convention in Croatian to be found in: *The International Convention on Prevention from Marine Pollution by Ships*, Maritime Journal, Ministry of Sea, Tourism, Traffic and Development.

<sup>2</sup> Under "international navigation" it is to be understood navigation from the country applying this Convention until the port outside that country or viceversa. The term "person" refers to crew members and passengers.

<sup>3</sup> IMO Resolution MEPC.159(55) *Revised Guidelines on Implementation of Effluent Standards and Performance Tests for Sewage Treatment Plants*, adopted on 13th October 2006, is implemented on plants installed as of 1st January 2010. this Resolution replaced the Resolution MEPC.2(6) *Recommendation on International Effluent Standards and Guidelines for Performance Tests for Sewage Treatment Plants*, adopted on 3rd December 1976 and which had set somewhat lower standards.

„**International Sewage Pollution Prevention Certificate**“ will be issued to the ship by the Administration (or persons or organisations authorised by it), and after the general survey of the ship and installations according to the provisions set forth in the Annex IV to the Convention. The certificate comprises general data on the ship, the sewage system and type of sewage plant, as well as the results of tests made in compliance with the stated restrictions. [3]

**Table 2: Vessel Effluent Standard Comparison in US**

Device type	Faecal coliforms	Suspended solids	Biochemical oxygen demand (BOD5)	pH	Chlorine
Type I MSD	1000col/100ml	With no visible floating solids	-----	-----	-----
Type II MSD	200col/100 ml	150mg/100ml	-----	-----	-----
Alaska Standards for Continuous Discharge Blackwater from large commercial vessels <sup>1</sup>	20col/100ml	30mg/l monthly average 45 mg/l weekly average.	30mg/l monthly average 45 mg/l weekly average.	6.0-9.0	<b>10mg/l</b>
Alaska Standards greywater and blackwater from other vessels <sup>1</sup>	<b>200col/100ml</b>	<b>150mg/l</b>	-----	-----	-----

Source: Maine Government (www.maine.gov/dep/blwq/topic/vessels/effluentchart.pdf) (27.02. 2010)

Remarks: <sup>1</sup> Alaska Regulations Section 46.03.463, Subsections b and c

**U.S. Coast Guard** recognizes and approves 3 types of *Marine Sanitation Device (MSD)* which are according to **33 CFR Part 159**<sup>4</sup>:

- Type I MSD – are flow-through treatment devices that commonly use maceration and disinfection for treatment of sewage. Type I devices may be used only on vessels less than 19,7m (65 feet). EPA's performance standard for effluent are max 1000 faecal coliforms per 100 ml of water with no visible floating solids.
- Type II MSD – also are flow-through treatment devices, generally employing biological treatment and disinfection. Some of these devices use maceration and disinfection. Type II MSD may be used on vessels of any size. EPA's performance standard is an effluent with a faecal coliform count not to exceed 200 per 100 ml of water and total suspended solids no greater than 150 mg per litre of water.
- Type III MSD – are holding tanks, where sewage is stored until it can be properly disposed of at a shore-side pump out facility or out at sea (beyond 3 miles from shore). Type III MSD may be used on vessels of any size. However, a Type II MSD may be equipped with installed holding tanks which can be used to store treated sewage until reaching a shore-side pump out facility or discharged overboard when vessel is beyond 3 miles from land. [4]

### 3 SEWAGE TREATMENT TECHNOLOGIES ONBOARD SHIPS

Sewage can be processed with three principal methods: mechanical, chemical and biological. . [5]

The sewage treatment is usually a combination of the three principal methods, such as me-mechanical-chemical, mechanical-biological and chemical-biological. The treatment of sewage includes the following stages:

<sup>4</sup> Code of Federal Regulations, Title 33-Navigation and Navigable Waters, Part 159-Marine Sanitation Devices.

### **3.1 Waste water accumulation and management**

In this stage of proces waste water (black water, grey water and galley water has been collected in holding tanks before processing planet.

### **3.2 Waste water pre-treatment**

Wastewater pre-treatment protects the other phases of the purification process. Sewage contains a lot of solid waste and grease that may cause problems in the later stages of the process. The pre-treatment process reduces the amount of solids in the waste water. Effective waste-water pre-treatment also reduces the need for oxidation. The pre-treatment is mechanical and consists of sieving and sedimentation units. The large particles pass through a shredding pump before sieving.

### **3.3 Waste water oxidation**

The mechanical filtering results in a maximum of 50% reduction in organic load. The remaining organic compounds have to be oxidized, either chemically or biologically.

Certain chemicals, e.g. ozone, chlorine, hydrogen peroxide, are added to the sewage in the chemical oxidation. The chemicals oxidize the organic impurities in the sewage water. When compared to the ozone and hydrogen peroxide, chlorine is not a very environmental friendly oxidant because of the carcinogenic compounds that develop as a by-product of the reaction. The added chemicals have an impact on the organic matter that has dissolved slightly and the BOD reduction remains small. The estimated treatment results for reduction in BOD and phosphorus are good. “Over-chlorination” results in high levels of residual chlorine in the discharge, which is lethal to marine organisms.

In the biological treatment the micro-organisms use the impurities in the sewage as their nourishment. There are several types of bioprocesses and the most common biological process is the active sludge treatment plant, where the sewage is mixed in a continuous-action aeration tank with active sludge. Biological filters and biorotors are also used as biological treatment plants. In these devices the bacteria that destroy the impurities attach to the filtering material. The biological treatment system is the most efficient way of reducing the BOD load. The estimated reduction in BOD is 80–95% and the reduction in phosphorus is 20–40%. The effectiveness of the bioprocess depends on the amount of active biomass and the bacteria living conditions. [6]

The disadvantages of biological treatment are the long starting period and its sensitivity to external disturbances. The reasons for malfunction of the biological system are the following:

- Strong chemicals that have got into the plant are destroying the bacteria.
- Bacteria die due to the lack of oxygen when the ventilation does not work.
- The return of active sludge does not work.

### **3.4 Waste water clarification and filtration**

After oxidation, the sludge is separated in a sedimentation tank and returned to the aeration tank. Separating the active biomass, sediment particles and bacteria from the water is a critical phase in the wastewater purification process. The clarification and filtration processes used in the ships are membrane filtration, dissolved air flotation (DAF) and settling. The DAF system relies on the injection of microscopic air bubbles into the feed water stream, causing the particles to float on the surface of a basin with inclined settling plates, from which they are continuously skimmed off and removed with a wastewater stream. It is useful when

treating waters that are high in total suspended solids (TSS) or have highly variable suspended solids content.

### 3.5 Waste water disinfection

The last phase in the wastewater purification process is disinfection. Depending on the previous treatment method, the disinfection enhances the quality of the wastewater or is an essential part of the purification process. When the membrane clarification and filtration is used, the disinfection is performed with UV-light. If the water is very turbid, the UV-light is not suitable for disinfection. The other potential disinfectants are, for example, chlorine, radicals and ozone.

### 3.6 Sludge treatment

The sludge production depends on the treatment process. Effective pre-treatment before the bioreactor reduces the sludge production and enhances the sludge drying. The sludge that comes straight from the process is centrifuged. The centrifugal treatment raises the dry-substance concentration to 17–27%, compared to the before treatment dry substance concentration of 2–3%. After the decanter centrifuge, the possible sludge handling techniques are holding, incinerator, steam dryer, filter press or an alternative sludge conditioning process so that combustion is possible.

## 4 SEWAGE TREATMENT UNITS

### 4.1 Traditional Type II Marine Sanitation Devices

Most of a cargo and cruise ships with traditional Type II Marine Sanitation Devices (MSD), sewage is treated using biological treatment and chlorination. Some cruise ships do not treat their sewage biologically, but instead use maceration and chlorination. The treatment system typically includes aerobic biological treatment to remove biochemical oxygen demand and some nutrients, clarification and filtration to remove solids, and final chlorine disinfection to destroy pathogens. The system also may include screening to remove grit and debris. Cruise ships typically install up to four systems, allowing one or two to be placed off-line for maintenance at any one time. Cargo ships uses one unit only.

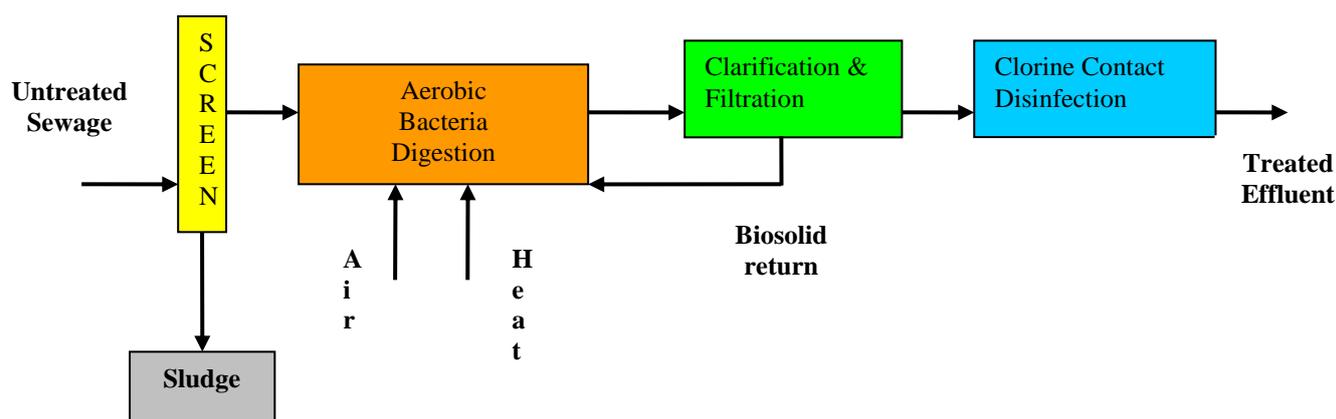


Figure 1: Simplified Schematic of Traditional Type II Marine Sanitation Device Using Biological Treatment and Chlorine Disinfection

### 4.2 Advanced Wastewater Treatment Systems (AWT)

To improve environmental performance, cruise lines are testing and installing wastewater purification systems that utilize advanced technologies. These onboard

wastewater treatment systems are designed to result in effluent discharges that are of a high quality and purity; for example, meeting or surpassing standards for secondary and tertiary effluents and reclaimed water.

Effluents meeting these high standards would not be subjected to the strict discharge limitations. AWT systems are still at the development stage. Generally advanced treatment systems utilize enhanced aerobic digestion with physical filtration to clean shipboard waste water.

On some cruise vessels, sewage and often graywater are treated using AWTs. AWTs generally provide improved screening, biological treatment, solids separation (using filtration or flotation), and disinfection (using ultraviolet light) as compared to traditional Type II MSDs. Some manufacturers of AWT mostly installed on cruise vessels are described below:

**4.2.1 HAMWORTHY'S Membrane Bioreactor (MBR)** system uses aerobic biological treatment followed by ultrafiltration and ultraviolet (UV) disinfection. Hamworthy MBR system treats wastewater from accommodations and sewage. Wastewater is first treated in screen presses to remove paper and other coarse solids. Next, the wastewater enters a two-stage bioreactor, where bacteria digest the organic matter in the waste. Following biological treatment, the wastewater is filtered through tubular ultrafiltration membranes to remove particulate matter and biological mass, which are returned to the bioreactors. In the final stage of treatment, the wastewater undergoes UV disinfection to reduce pathogens.

**4.2.2 ROCHEM's ROCHEM LPRO and ROCHEM Bio-Filt** system treats high concentration and low concentration waste streams with different processes. ROCHEM LPRO part of the system treats wastewater from laundry and accommodations (low concentration waste streams) while the ROCHEM Bio-Filt treats wastewater from galley and sewage, as well as the membrane concentrate from the ROCHEM LPRO system (high concentration waste streams). The ROCHEM LPRO system uses screens to remove fibers and hair, reverse osmosis membranes to remove particulates and dissolved solids, and UV disinfection to reduce pathogens. The ROCHEM Bio-Filt system uses vibratory screens to remove coarse solids, bioreactors to biologically oxidize the waste, ultrafiltration membranes to remove particulate matter and biological mass (which are returned to the bioreactors), and UV disinfection to reduce pathogens.

**4.2.3 The Zenon ZeeWeed MBR** system uses aerobic biological oxidation followed by ultrafiltration and UV disinfection. Graywater from the laundry, galley, accommodations, and food pulper combines with sewage and flows through two coarse screens into a collection tank. From the collection tank, the wastewater is pumped to an aerated bioreactor. After the bioreactor, the wastewater flows through the proprietary ZeeWeed hollow-fiber ultrafiltration membrane system under a vacuum. In the final stage of treatment, the combined wastewater from the membranes undergoes UV disinfection to reduce pathogens. The Zenon system is the only system that EPA sampled that treats all graywater and sewage sources

**4.2.4 SCANSHIP AWP (Advanced Wastewater Purification)** system uses aerobic biological oxidation followed by dissolved air flotation and UV disinfection. Sewage and graywater from the galley, accommodations, and laundry combine in one graywater and sewage holding tank. The combined wastewater is pumped through a coarse drum filter and then through two separate aerated bioreactors. Each bioreactor contains free-floating plastic beads to support biological growth, eliminating the need for recycled biological mass. After aeration, the wastewater is pumped to two dissolved air flotation (DAF) units to separate

solids. From the DAF units, the wastewater is pumped to polishing screen filters. In the final stage of treatment, the wastewater undergoes UV disinfection to reduce pathogens.

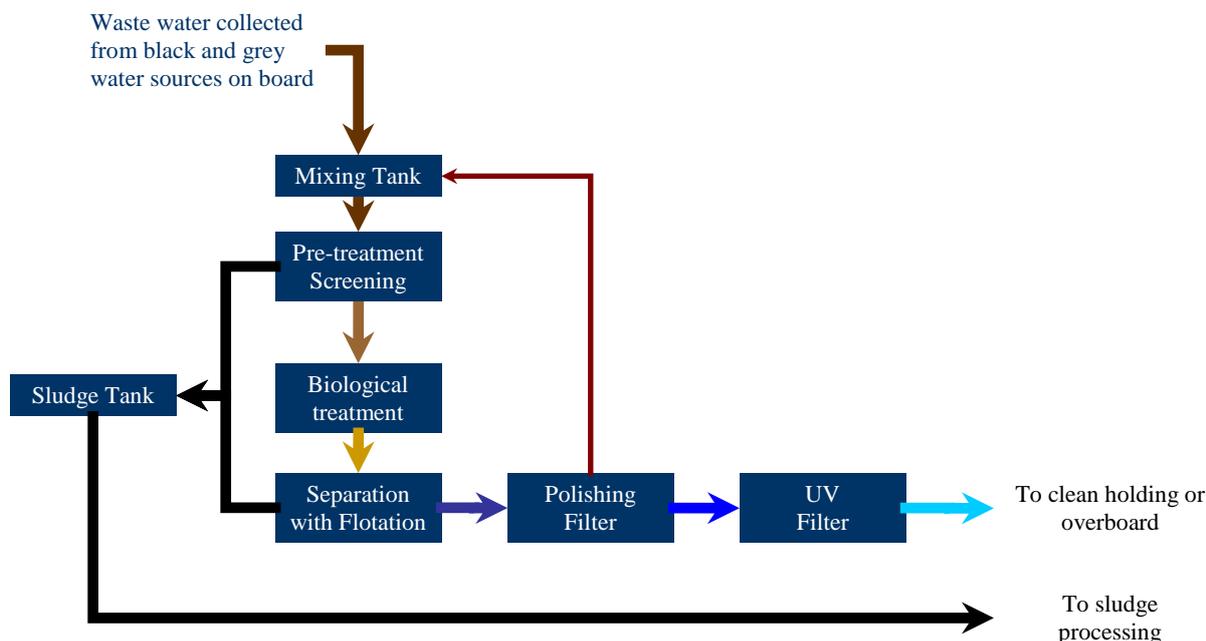


Figure 2: Simplified Schematic of Scanship Advanced Wastewater Purification System

**4.2.5 The Hydroxyl CleanSea** system uses aerobic biological oxidation followed by dissolved air flotation and UV disinfection. Sewage and graywater are combined and pumped to a fine wedgewire screen for coarse solids removal. Next, the wastewater enters the ACTIVECELL biological reactors where free-floating plastic beads support biological growth without the need for recycled biological mass. The wastewater then enters the ACTIVEFLOAT dissolved air flotation units for solids separation. Final treatment steps include polishing filters and UV disinfection to reduce pathogens.

**4.2.6 EVAC** is a company that designs, manufactures and markets environmentally friendly waste and wastewater collection and treatment solutions for the marine industry worldwide. The Evac MBR is a single stream Advanced Waste Water Treatment system where all the waste streams are treated in one process. The Evac MBR is based on effective equalizing and mixing of the incoming waste streams, pre-treatment by screens, an aerated biotank and a membrane bioreactor. In this proposal, a nutrient removal step is added to the basic process. The Evac MBR process is fully automated and controlled through a PLC by vacuum/pressure switches, level switches, DO, TSS and pH sensors, flow meters and foam detectors. Membranes are of submerged type, supplied by Japanese company Kubota.

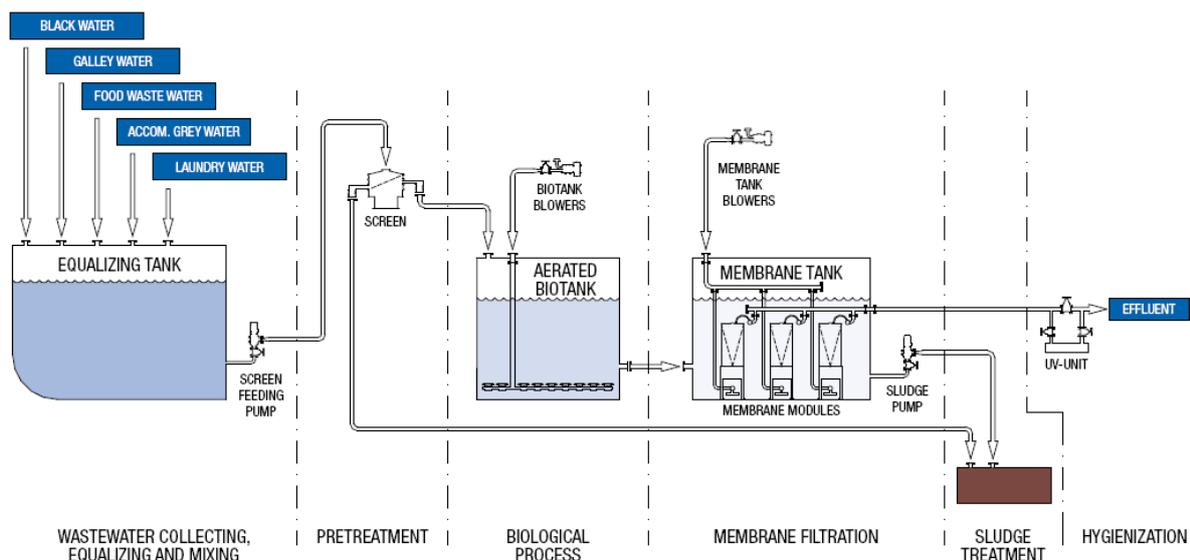


Figure 3: Basic principle of the Evac MBR single stream process (Evac, 2008)

## 5 COMPARISON TO WASTEWATER EFFLUENT DISCHARGE

Table 3. shows the comparison of average effluent analyte concentrations from traditional

Type II Marine Sanitation Devices and from Advanced Wastewater Treatments.

Traditional Type II MSD effluent concentrations exceeded the MARPOL Annex IV standards and EPA (US Environmental Protection Agency) standards for discharges from Type II MSDs. Also, even that all Type II MSD are certificated before installation onboard, and produced that can meet MARPOL and US EPA standards, in regular operation those units often running with errors, so that quality of effluent doesn't meet standards.

In contrast to traditional Type II MSD effluent, the average effluent concentrations from AWTs are lower than all of the discharge standards, with the exception of total residual chlorine. Chlorination is used to disinfect potable water produced underway or bunkered in port.

Table 3: Comparison of AWT and Traditional Type II MSD Effluent to Wastewater Discharge Standards

Analyte	Average Concentration in AWT Effluent 1	Average Concentration in Traditional Type II MSD Effluent 2	Effluent Standard as per MARPOL Annex IV.	USA Performance Standards for Type II MSDs (33 CFR Part 159 Subpart C)	USA Standard for Continuous Discharge in Alaskan waters (33 CFR Part 159 Subpart E)
Fecal coliform (fecal coliform/100 ml)	14.5	2,040,000 MPN* / 100 ml	<250 installed before 1.1.2010. <100 installed after 1.1.2010	<200	<20
Total residual chlorine (µg/l)	338	1,070			<10
Biochemical oxygen demand (5-day) (mg/l)	7.99	133	<50 <25		<45 <30
Total suspended solids (mg/l)	4.49	627	<50 if plant tested ashore <100 if plant tested onboard	<150	<45 <30
pH	99.5% of pH samples between 6.0 and 9.0	90.5% of pH samples between 6.0 and 9.0	between 6.0 and 8.5		between 6.0 and 9.0

Source: (authors)

Remarks:

1 Based on data collected by ADEC/Coast Guard from 2003 to 2005; data collected by EPA in 2004; and data collected through EPA's 2004 cruise ship survey. Source: *Cruise Ship Discharge Assessment Report, Section 2: Sewage*, United States Environmental Protection Agency, 29th December 2008.

2 Based on data collected by the Alaska Cruise Ship Initiative (ACSI) in 2000; the average fecal coliform concentration in traditional Type II MSD effluent was 2,040,000 MPN/100 ml (total of 92 samples, calculation used detection limits for nondetected results). The range was from nondetect (detection limit of 2) to 24,000,000 MPN/100 ml. Of the 92 samples, 51 were greater than 200 MPN/100 ml, 35 were greater than 100,000, and 22 were greater than 1,000,000. Source: *Cruise Ship Discharge Assessment Report, Section 2: Sewage*, United States Environmental Protection Agency, 29th December 2008.

\* MPN (Most Probable Number)

## 6 CONCLUSION

The international community has set forth legal regulations covering this issue in order to properly protect not only the marine environment but also the human health, which is also often exposed to hazards due to pollution from sewage waste waters. Nevertheless, the sea has still remained a fragile area exposed to various pollutants and risks. Consequently, besides the international regulations, some states have set forth their own regulations which are more strict, aiming to better protection of their particularly sensitive areas, since the internationally recognised regulations have their disadvantages and there is still room for improvement.

According to international regulations, sewage treatment plant has to satisfy the effluent standards for its certificate of type test.

Most of traditional (Type II MSD) in practise operate on the vessels with certain errors due to late start of the system before arrival in the port, reduced bio sludge, overchlorination, or disrupted by intermittent flow common to shipboard life.

Advanced Wastewater Treatment Systems of many different brands are more complex, installed mostly on cruise vessels, and it has better results in effluent quality.

Most of the manufacturers of the AWT systems are still upgrading existing AWT systems and developing new systems that can reduce components (heavy metals, nutrients, phosphorus and nitrogen ) from effluent that is polluting marine environment, and still is not subject of any regulations.

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