FEASIBILITY STUDY:

REDUCING CONCENTRATIONS OF DISSOLVED METALS AND AMMONIA IN LARGE PASSENGER VESSEL WASTEWATER DISCHARGES

FINAL
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Prepared for:

Alaska Department of Environmental Conservation
Cruise Ship Program

Prepared by:

825 W. 8th Ave.
Anchorage, AK 99501

AND SUB-CONTRACTOR TEAM

CONTRIBUTORS:

Max Schwenne	OASIS
Olga Stewart	OASIS
Cody Black, PE (State of Alaska)	OASIS
Joe Mercure	OASIS
Levia Shoutis	OASIS
Anita Erickson, PE (State of California)	OASIS
David Eley	Cape International
Patrick Eberhardt, PE (State of Washington)	Coastwise Corporation
Steve Anzelc, PE (State of Michigan)	Burns & McDonnell
Ira Donovan, MSF	Burns & McDonnell
Reinaldo González, PhD	Burns & McDonnell
Denise Koch	Alaska DEC
Albert Faure	Alaska DEC
Ed White	Alaska DEC

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EXECUTIVE SUMMARY

The Alaska Department of Environmental Conservation (ADEC) issued the Large Commercial Passenger Vessel Wastewater Discharge General Permit in March 2008 (“2008 General Permit”) to meet the requirement of Alaska Statute 46.03.462. ADEC analysis prior to permit issuance had indicated that cruise ships could not immediately comply with the statute’s strict requirement that effluent meet Alaska Water Quality Standards at the “point of discharge” for ammonia, copper, nickel, and zinc. Therefore, the 2008 General permit contained interim effluent limits that were less stringent for the 2008 and 2009 cruise ship seasons. The permit contained a requirement that the long term effluent limits for these parameters, which were equal to the Alaska Water Quality Standards, be met by the 2010 cruise ship season.

Although it was the cruise ships’ responsibility to comply with the terms of the 2008 General Permit, it was important for ADEC to be knowledgeable about the types of technology that may exist to enable cruise ships to meet the long term effluent limits. Therefore, ADEC hired the OASIS team to evaluate successful shore-based technologies as well as existing, new, and emerging technologies that could potentially be adapted for use on cruise ships. A draft of this feasibility study was released on February 16, 2009 in advance of an ADEC Cruise Ship Technology Workshop that was held in Juneau, Alaska on February 18, 2009. The final draft of this feasibility study includes 2009 General Permit sampling data, but does not comprehensively include all new information that may have become available in 2009. In this feasibility study, the OASIS team evaluated nine existing proven technologies that may be able to reduce concentrations of the four pollutants of concern: ammonia, dissolved copper, dissolved nickel and dissolved zinc. Of the nine current technologies, three treat all four pollutants, three only treat ammonia and three only treat dissolved metals. This study also discusses an additional five experimental technologies.

An analysis of 2008 and 2009 cruise ship General Permit sampling data reveals that under current operational practices, most existing wastewater treatment systems installed on large cruise ships cannot consistently treat wastewater to Alaska Water Quality Standards for ammonia, copper, nickel, and zinc. Some ships have consistently met the limits for one contaminant and some ships have met the limits when treating only selected waste streams and limited quantities, but none have consistently met the Alaska Water Quality Standards for all four pollutants.

The information on the technologies contained in this report comes from a variety of research sources as well as from manufacturers, vendors, and researchers. A solicitation to these groups was accomplished by direct e-mailing and through e-mail blasts to the wastewater industry and the maritime industry. Approximately 60 interested parties were contacted. A total of 11 contacts responded and submitted white papers describing potential solutions for meeting the new limits. This document also integrates information gathered from interested stakeholders during the February 2009 ADEC

Cruise Ship Technology Workshop and from comments received - primarily from the cruise ship industry and wastewater treatment system vendors - on the draft report.

In order to make conclusive determinations about whether achieving the Water Quality Standards at the point of discharge for ammonia, copper, nickel, and zinc is possible; more information is needed such as detailed waste stream characterization and analysis, treatability studies, studies including onboard pilot projects, influent and effluent testing, and conceptual designs for ship adaptation. Addressing those items is part of a design and implementation phase that would need to be done by the cruise lines on a case-by-case basis.

However, this study finds that technologies treating similar quality wastewater in land-based applications appear to be able to treat the pollutants (ammonia, nickel, copper or zinc) to the Alaska Water Quality Standards at the point of discharge. The technologies that could be used include chemical precipitation, ion exchange, reverse osmosis, electrodialysis, air/steam stripping, aerobic biological oxidation / nitrification and breakpoint chlorination.

Although land-based technologies exist that can reduce the pollutants to the Alaska Water Quality Standards at the point of discharge, the technology would require modification for adaptation to cruise ships. Further investigation by the cruise lines will be required to determine whether the technologies evaluated in this study will be able to be adapted for use aboard cruise ships. Ship space, inclination, and other constraints must be considered, as well as investigating what technology will provide the most efficient system by evaluating the system source/flow balance, operational costs, long term effluent performance, and other parameters.

This study found that technologies currently used in some ships such as reverse osmosis (RO) and aerobic biological oxidation/nitrification would likely provide the most adaptable systems to achieve the limits for both conventional pollutants (e.g. fecal coliform bacteria, TSS) as well as treating ammonia, copper, nickel, and zinc to the Water Quality Standards at the point of discharge. RO would be able to treat both ammonia and metals. The aerobic biological oxidation/nitrification process would only treat ammonia. It is possible that ion exchange, combinations of ion exchange and RO, and electrodialysis could meet the limits for both ammonia and metals and have good potential for being adapted for on-board use. The vendor-submitted white papers suggest that chemical precipitation, ion exchange, reverse osmosis, and electrodialysis may also be able to treat cruise ship wastewater successfully to the Alaska Water Quality Standards at the point of discharge.

Each of these technologies could be used in conjunction with current systems and would require a significant amount of design and retrofitting for sizing along with marine regulatory approval. It is likely that a full system approach would be needed to coordinate multiple technologies at multiple stages of the water and wastewater flow. The timeline estimates for full implementation of a ship-board system range from six months to two years. This timeline includes many steps from initial waste stream characterization and pilot study to system design, regulatory approval, manufacturing lead time, shipment, installation and operation startup. More sophisticated wastewater treatment systems would also likely require a greater training, maintenance, and operational work load from the cruise ship operator.

There have been several ships that have used reverse osmosis based wastewater treatment systems in Alaska that have been successful in both removing conventional pollutants and reducing the level of ammonia, copper, nickel, and zinc to Water Quality Standards at the point of discharge. These systems have been used to treat both blackwater and graywater. The majority of the effluent data that ADEC has on these systems is from a ship that uses low pressure reverse osmosis to treat selected streams of accommodation graywater. This ship has successfully used this wastewater treatment process for several years. Many of the ships that used reverse osmosis/ultra-filtration to treat blackwater only used those systems in Alaska for a short period of time. Therefore, ADEC does not have a large wastewater effluent data set compared to other wastewater treatment systems for blackwater treated by reverse osmosis.

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1. INTRODUCTION

In August 2006, Alaska voters approved Ballot Measure 2, which applied to large cruise ships Information on this ballot measure is available on the ADEC website at http://www.dec.state.ak.us/water/cruise_ships/Law_and_Regs/Ballot%20Measure%202%20Cruise%20Ship%20Initiative.pdf. The statute required that owners/operators of large cruise ships obtain a wastewater discharge permit from the Alaska Department of Environmental Conservation (ADEC) in order to discharge any treated sewage, graywater, or other wastewater into the marine waters of the state. The law required that vessels meet the Alaska Water Quality Standards for their wastewater effluent at the point of discharge.

ADEC issued the Large Commercial Passenger Vessel Wastewater Discharge General Permit Number 2007DB00002 in March 2008 (2008 General Permit) to meet the requirement of the law. ADEC analysis prior to the issuance of the permit indicated that most cruise ships could not immediately comply with the strict “point of discharge” effluent limits for ammonia, copper, nickel, and zinc. Therefore, the 2008 General Permit contained interim effluent limits for these parameters that were less stringent for the 2008 and 2009 cruise ship seasons. The permit contained long term effluent limits for these parameters that were equal to the Alaska Water Quality Standards that were required to be met by the 2010 cruise ship season.

Over 400 wastewater samples were obtained during the 2008 and 2009 cruise ship seasons. Generally, most ships exceeded the long term Alaska Water Quality Standards but were able to achieve interim effluent limits. Carnival, an exception, was able to meet interim and long term water quality standards for all four effluents but was only discharging graywater. Notably, Silver’s Silver Shadow vessel was able to meet long term water quality standards for ammonia and zinc during both 2008 and 2009 for its mixed wastewater discharge. Sampling data demonstrated a greater ability for all ships to achieve interim and long term water quality standards for zinc rather than for ammonia, copper, and nickel. Therefore under current operational practices the existing wastewater treatment systems installed on most large cruise ships cannot consistently treat wastewater to the long term effluent limits.

Although it was the cruise ships’ responsibility to comply with the terms of the General Permit, it was important for ADEC to be knowledgeable about the types of technology that may exist to enable cruise ships to meet the long term effluent limits. Therefore, ADEC hired the OASIS team to evaluate successful shore-based technologies as well as new and emerging technologies that could potentially be adapted for use on cruise ships.

The scope of this study was to evaluate additional treatment technologies that may be incorporated into the advanced wastewater treatment systems currently in use by large cruise ships as well as replacement technologies. Incorporation may include “add on controls" or "integrated incorporation" of new technologies into the existing wastewater treatment process. The efforts of the OASIS team were primarily focused on finding and understanding wastewater technology treatment options and determining whether the technology would be able to treat cruise ship wastewater to the Alaska Water Quality Standards at the point of discharge.

This effort necessarily included a preliminary look at whether the technology could be adapted for shipboard use. A basic implementation path consisting of analysis, design, approval, and installation is discussed. However, a detailed examination of the shipboard implementation of specific technology is well beyond the scope of this document. The selection and implementation of this technology must be conducted by the cruise lines on a case-by-case basis. However, it may be possible that careful examination of modular unit designs may fit multiple vessels, including vessels of the same class (e.g. identical vessels). The cruise lines should have the appropriate access to influent wastewater characteristics, available shipboard layout and space, current wastewater effluent characterization, safety standards, and available manpower to conduct a valid implementation evaluation and concept design for these technologies. Without this information and analysis, it would be premature and inaccurate for this report to address specific implementation details for vessels.

Treatment technologies that have the potential to meet the Alaska Water Quality Standards at the point of discharge are identified and qualitatively evaluated in this report. The available equipment processes and methods used to reduce the wastewater concentrations of ammonia and the dissolved metals copper, nickel and zinc are evaluated. This feasibility study report presents the regulatory background, discusses the known vessel sources of pollutants, properties of ammonia and dissolved metals in ship wastewater, and assesses current proven technology and emerging treatment technologies.

The draft version of this feasibility study served as a discussion document for an ADEC Cruise Ship Technology Workshop held in Juneau, Alaska on February 18, 2009 for stakeholder input and public comment. Reviewers were invited to make comments, suggest improvements, or nominate promising treatment technologies for evaluation. Information and comments gathered from stakeholders was incorporated into this final version of the feasibility study.

2. BACKGROUND

2.1. Cruise Ship General Permit

In March 2008, ADEC issued the Large Commercial Passenger Vessel Wastewater Discharge General Permit No. 2007DB0002 (http://www.dec.state.ak.us/water/cruise_ships/gp/08gp.html). The 2008 General Permit requires owners/operators of large commercial passenger vessels (any vessel with overnight accommodations for 250 or more passengers) to obtain authorization in order to discharge any treated sewage, treated graywater or other treated wastewater into Alaska marine waters. The 2008 General Permit defines strict conditions to be met including limits on pollutants of concern, restrictions on foam, oily waste, floating solids, garbage, grease, sediment and sludge, and staying within design capacity flow rates of treatment equipment. Proof that all permit conditions are being met is required in the form of an approved wastewater sampling plan and discharge monitoring reports. Any non-compliance must be reported within 24 hours to ADEC. The 2008 General Permit established more lenient interim limits for ammonia, copper, nickel, and zinc during 2008 and 2009. In 2010, cruise ships would have to meet very stringent long term effluent limits that were equal to the Alaska Water Quality Standards.

The wastewater discharge design criteria as determined by ADEC in the 2008 General Permit and previously planned for full implementation in 2010 are presented in Table 2.1.

TABLE 2.1: DESIGN CRITERIA FOR END-OF-PIPE POLLUTANT REDUCTION

Parameter	Typical Effluent Range (Output from AWTS)	Target Effluent [a]
Flow	Max 60 m^3/hour and 1440 m^3/day Highly variable [b]	Not to exceed design capacity
Total Suspended Solids (TSS)	ND – 11 mg/L [c]	150 mg/L max
Biochemical Oxygen Demand (BOD) 5-day	ND – 126 mg/L [c]	60 mg/L max
pH	6.2 – 9.2 [c]	6.5 min / 8.5 max
Total Residual Chlorine	ND – 0.19 mg/L [c]	0.0075 mg/L max
Ammonia (NH_3)	ND – 150.0 mg/L [c]	2.9 mg/L max
Nickel (Ni)	ND – 44.0 µg/L [c]	8.2 µg/L max
Zinc (Zn)	ND – 501.0 µg/L [c]	81.0 µg/L max
Copper (Cu)	ND – 140.0 µg/L [c]	3.1 µg/L max

a. The standards in this column are set by the State of Alaska Large Commercial Passenger Vessel Wastewater Discharge General Permit No. 2007DB00002. See page 7, 2.1
b. Estimated from data collected during the EPA/ADEC dispersion study in Skagway, Alaska, June 2008.
c. From 2008 cruise ship sampling data. Results were highly variable as shown by the broad range and at times the target limits were met.

In 2009, House Bill (HB) 134 was passed by the Alaska Legislature. Without HB 134, the Alaska Water Quality Standards would have applied to large cruise ship wastewater at the point of discharge in 2010. The law now allows ADEC to issue large cruise ships a new wastewater general permit containing effluent limits or standards that are less stringent than the Water Quality Standards at the point of discharge if the permittee is unable to achieve compliance with Water Quality Standards at the point of discharge. This general permit is valid for three years and is only issued if ADEC finds that the permittee is using economically feasible methods of pollution prevention, control, and treatment that ADEC considers to be the most technologically effective in controlling all wastewater and other substances at the point of discharge. ADEC issued a draft of the 2010 Large Commercial Passenger Vessel Wastewater Discharge General Permit on January 31, 2010. The public comment period on the permit ended on March 3, 2010. The final permit was issued April 22, 2010.
(http://www.dec.state.ak.us/water/cruise_ships/gp/10gp.html)

2.2. Current State of Practice

A wastewater treatment process generally consists of four major phases whether performed as a land-based process or as a shipboard process: primary treatment or solids separation, secondary treatment or organic digestion, tertiary treatment or clarification, and disinfection. These processes are not necessarily distinctly separate. For example the primary treatment mechanism may include some forms of filtration, oxidation, and clarification processes.

It is important to note that land-based wastewater treatment plants are generally not limited by space and have the ability to use large reservoirs to complete the various process phases. These large reservoirs allow land-based treatment systems to use gravity separation and long retention times to achieve the treatment objectives. Conversely, shipboard wastewater treatment systems have limited space and time to complete these water treatment phases. Therefore, shipboard systems typically employ alternative compact processes to achieve the objectives of each treatment phase.

Many of the marine sanitation devices (MSDs) on board cruise ships certified[1] for discharge in Alaska are some of the most effective and most expensive available for marine wastewater treatment. [EPA, 2008a] These are advanced wastewater treatment systems (AWTS) that treat both sewage and graywater. The 21 large commercial passenger vessels currently authorized to discharge under the general permit use one of the technologies listed in Table 2.2 to complete treatment.

[1] Certified means approved by the US Coast Guard and Alaska Department of Environmental Conservation for continuous discharge under 33 CFR 159 Subpart E and the 2008 General Permit, respectively.

TABLE 2.2: AWTS TECHNOLOGIES USED ON VESSELS IN 2008 AND 2009 DISCHARGING IN ALASKA FOR SHIPBOARD WASTEWATER TREATMENT PHASES

AWTS	Treatment Phase Methods				Vessels in 2008	Vessels in 2009
	Primary Solids Separation	Secondary Organic Digestion	Tertiary Clarification	Disinfection		
Biopure Marisan	Coarse Screen	Aerobic Biological Oxidation (MBR)	Flotation (DAF) / Microfiltration	UV	1	1
Hamworthy Bioreactor	Screen Press	Aerobic Biological Oxidation (MBR)	Ultrafiltration Membranes	UV	9	9
Hydroxyl Cleansea	Coarse Drum Filter	Aerobic Biological Oxidation (MBBR)	Flotation (DAF) / Polishing Filter	UV	2	0
Scanship	Wedgewire Screen	Aerobic Biological Oxidation (MBBR)	Flotation (DAF) / Polishing Filter	UV	4	4
Rochem Bio-Filt	Vibratory Screens	Aerobic Biological Oxidation (MBR)	Ultrafiltration Membranes	UV	2	0
Rochem	Vibratory Screens	Low Pressure Reverse Osmosis (LPRO)	Reverse Osmosis Membranes	UV	1	1
Zenon	Coarse Screen	Aerobic Biological Oxidation (MBR)	Ultrafiltration Membranes	UV	6	5

AWTSs are successful in meeting treatment objectives for conventional pollutants such as biological oxygen demand, fecal coliform, total suspended solids, and pH. However, most of these systems have had difficulty producing effluent concentrations of ammonia and the dissolved metals copper, nickel, and zinc that are equal to the Alaska Water Quality Standards. Therefore, modification of most AWTS or additional treatment processes would be required to meet these criteria.

From existing data, it appears that there are no currently installed wastewater treatment systems on board cruise vessels that could consistently meet the Alaska Water Quality Standards for ammonia, copper, nickel, and zinc at the point of discharge. There are systems that can consistently meet limits for one or two of the contaminants and there are systems that can consistently meet the limits when treating relatively small volumes of selected influent. The one exception is Carnival Spirit, a large ship that is a graywater discharger, and consistently achieves compliance with both interim and long term Alaska Water Quality Standards.

There does appear to be existing land-based wastewater treatment technologies that are capable of reducing effluent concentrations of dissolved metals and ammonia to the Water Quality Standards. These technologies have effluent performance potential if designed as relatively compact units; therefore they will be discussed in this study even though they have not yet been proven for shipboard use. These technologies could be incorporated into shipboard AWTSs after appropriate design and testing to conform to space verses effluent constraints, which may take between two and three years.

Ammonia has generally been a human and animal waste problem. Most advances in treatment for this contaminant have been attributed to the municipal sewage and animal waste industries. The metal finishing industry has made the most use of technologies for metal removal in wastewater. A survey of 318 metal finishing shops [Cushnie, 1994] found the following metal removal technologies in use with the percentage of shops employing the methods shown in (%):

- Chemical precipitation by pH adjustment (90%)
- Atmospheric evaporation (22%)
- Electrowinning (19%)
- Ion exchange (11%)
- Reverse osmosis (2%)
- Electrodialysis (<1%)

2.3. Sources of Technology Information

Research was performed to identify the various types of treatment methods that are available for reducing concentrations of the four contaminants of interest – ammonia, copper, nickel, and zinc – that would continue to be effective in removing the conventional pollutants (e.g. biological oxygen demand, fecal coliforms, etc.). The search included a wide span of potential methods from those that are still in a research phase to those that are currently being used on ships.

To understand how each technology may be integrated into current systems, approximately 35 vendors, manufacturers, or researchers were directly invited to submit proposals identifying technology that might allow ship wastewater discharge to meet the Water Quality Standards for ammonia, copper, nickel, and zinc at the point of discharge. These invitees are listed in Appendix A. In addition, a general solicitation was sent out by 'e-mail blast' to the marine industry using a contact base maintained by the Maritime Reporter[2] and to land-based wastewater treatment entities using a contact base maintained by WaterWorld[3]. Those that responded with interest in the project were supplied with typical flow rates, influent concentrations and sampling information from the cruise ships as listed in Table 2.1. The specific vessels were not identified with the data to maintain confidentiality for the cruise lines. Appendix B lists the vendors that responded with interest and proposals. Proposals are presented in Appendix C, and general discussions of the vendor supplied information are included in Section 6.

2.4. Feasibility Evaluation Criteria

The evaluation criteria for the technologies in this feasibility study are limited due to the preliminary nature of the current assessment. As a result, the evaluation criteria at this stage are technical feasibility and implementation feasibility. Cost considerations were not addressed because this type of information was not developed and generally not

[2] Maritime Reporter is a trade publication for large ship operators, builders and equipment suppliers.
[3] WaterWorld is a trade publication for operators and researchers in the field of water treatment.

provided by vendors. Cost will be a function of specifics that will need to be determined on a case by case basis for each cruise line AWTS configuration and waste segregation process and can be affected by the amount of source reduction and replacement, recycle and reuse, and other modifications specific to particular situations.

The following list of supplemental criteria should be considered for discussion of each alternative technology as it applies to ships.

1. Environmentally safe and non-hazardous to personnel if reasonable precautions are employed.
2. Add no additional by-products or potential pollutants to the effluent.
3. Ability to consistently meet the Water Quality Standards for ammonia, copper, nickel, and zinc at the point of discharge.
4. Determine a concentration pulse of any of the parameters that would saturate the treatment unit or otherwise render it ineffective.
5. Speed to the market place and proven technology in full scale operations
6. Use in conjunction with other techniques to reduce or recycle source pollutants.
7. Units or components can be installed in the main engine room of existing, currently operating cruise ships.
8. Hazardous by-products or waste can be easily off-loaded from the ship.
9. Simplicity of application or maintenance. Power requirements are economical.
10. Continued ability to treat wastewater for conventional pollutants.

2.5. Systemic Approach to Technology Selection

This technology study is focused on what available and emerging technologies exist for removal of ammonia, copper, nickel and zinc. However, before final selection of a specific technology for a particular cruise ship, it is suggested that the entire cruise ship water and wastewater process be investigated from a systematic process perspective. This would include approaching the metals and ammonia removal equipment as just one component of the overall system so that it can be integrated and be the most efficient and practical system possible.

This will include an approach that should include at a minimum some of the following stages:

- <u>System Balance and Source Evaluation:</u> Create a system balance flow diagram for all of the sources in/out of the ship to include flow and concentration of source pollutants and evaluate for potential modifications.

- Source Reduction: Analyze the flow diagram and reduce pollutants at the source wherever possible to include replacement or substitute chemicals or reductions of chemicals through various process improvements or changes. Replacement chemicals and/or technology changes should be looked at carefully as they may contribute to other environmental or operational concerns.

- Optimize Water Source: Investigate sources of pollutants coming from bunkered water for potable water taken from port. Further investigations may be warranted for at port treatment systems to improve water quality taken on the ships or strategically select the ports where potable water will be bunkered.

- Evaluation of Wastewater Collection and Use: Consider any recycle and reuse of items such as recycling graywater for toilet flushing, cleaning, HVAC, boiler feed, equipment use, etc.

- Ship Constraints: Take into consideration items such as space constraints, mechanical and electrical considerations, motion, temperature, operational ease and maintenance. Consider operational ability to be brought on line and taken off line depending on if the ship will be operating in Alaska waterways.

- Pre and Post Treatment Options:

  - Look at the current wastewater treatment systems and evaluate all technology with how it could be applied as either pre-treatment, as modifications to the existing treatment, or as post treatment to optimize the removal of the targeted contaminants.

  - In many cases, it may be best to add pre-treatment steps to make the downend wastewater treatment equipment operate more efficiently. Be creative in finding ways to modify the current equipment where necessary by adjusting parameters such as resonance time, amount of air used, etc

  - Consider its ability to handle varying flow and intermittent flow conditions with varying influent metal and ammonium concentrations.

Additionally, consider the ship as a system with the wastewater treatment as an integral part of the system and wherever possible employ source reduction, source substitution, optimization of equipment and evaluation of pre and post treatment options. This will result in the most efficient applications of the metals and ammonia removal systems.

3. PROPERTIES AND SOURCES OF METALS AND AMMONIA

Of interest in this study are the elements copper (Cu), nickel (Ni), zinc (Zn) in a dissolved form and the molecule ammonia (NH_3). The electrochemical properties and sources of these constituents are discussed below as they are important in the design and use of the technologies discussed in subsequent sections.

3.1. Dissolved Copper, Nickel, and Zinc

3.1.1. Properties

In water, which is a polarized medium, Cu, Ni and Zn atoms each give up 2 electrons to become electrically charged ions Cu^{+2}, Ni^{+2}, Zn^{+2}. These ions are often referred to as divalent cations. Simplistically, the metal divalent ions (+2 charge) will have a strong affinity or electrical attraction to negative ions.

3.1.2. Sources

Information in this section is partly gathered from Source Reduction Evaluation (SRE) reports, submitted by the cruise lines operating in Alaska under the 2008 General Permit interim discharge limits. At this time, a comprehensive source characterization has not been completed. Additionally, dissolved metal sources are very ship specific and are difficult to characterize as a whole for the cruise industry. However the SRE reports concluded that the on board use of chemicals did not contribute significant sources of metal in the effluent, but that the on board water distribution systems (piping) in combination with on board produced water and bunkered potable water appears to contribute to the metal load in the effluent. Sources that were presented in the SRE reports for at least one ship of the 25 ships that are allowed to discharge in Alaska are presented in the following paragraphs.

One of the main sources, besides the vessel water production and distribution systems appears to be potable water (bunkered water) taken on board from municipalities. The main ports of concern for copper are Vancouver, Victoria, and Juneau. The main ports of concern for zinc are Vancouver and Seattle, and for nickel the main port of concern is Skagway. Sampling results are shown in Table 3.1.
(http://www.dec.state.ak.us/water/cruise_ships/SciencePanel/evaluations.html). Please note that the sample results in Table 3.1 were not verified or endorsed by ADEC because of QA/QC questions.

TABLE 3.1: SAMPLING RESULTS OF BUNKERED POTABLE WATER BY PORTS OF CONCERN FOR COPPER, NICKEL, OR ZINC

(Note: These data were not provided to ADEC directly from the laboratory and did not include QA/QC verification or validation)

Port	Contaminant	Alaska Water Quality Standards (µg/L)	Average (µg/L)	Maximum (µg/L)	Exceedance Rate (% of Samples)
Vancouver	Copper	3.1	20	120	77
	Zinc	81.0	-	280	-
Juneau	Copper	3.1	54	280	83
Victoria	Copper	3.1	4	7	100
Seattle	Zinc	81.0	499	1500	63
Skagway	Nickel	8.2	28	470	29

Another main source for copper and nickel appears to be via on-board evaporators that produce potable water while the vessel is at sea or in open water. This effect is likely magnified by leaching from copper-nickel pipes, fittings, back flow valves and other parts in the distribution systems that contain metals. Leaching from pipes and fittings is increased by "soft water" – water that has little to no dissolved minerals. There is also some evidence that copper may be related to the use of soaps in laundry changing the pH of the water and forcing more leaching (http://www.dec.state.ak.us/water/cruise_ships/SciencePanel/evaluations.html). Further investigation may be warranted to determine the actual corrosion or leaching mechanism as soft water is not a particularly aggressive chemically to cupro-nickel alloys. However, these alloys are prone to erosion and impingement corrosion mechanisms. If impingement is shown to be an issue, piping and elbow change considerations should be assessed as part of the solution to reduce the concentration of metals in the effluent.

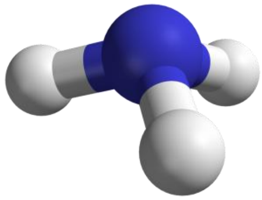
Additional sources of zinc may be the leaching from galvanized pipe and the use of chemicals, including anti-scaling chemicals. However, the effect of chemical use is presumed inconsequential from preliminary testing (http://www.dec.state.ak.us/water/cruise_ships/SciencePanel/evaluations.html).

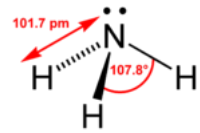
3.2. Ammonia

3.2.1. Properties

Ammonia is a molecule that consists of three hydrogen atoms and one nitrogen atom as seen in Figure 1. With a boiling point of -33.34 °C at a pressure of one atmosphere, NH_3 is a gas at most operating temperatures and pressures.

FIGURE 1: AMMONIA MOLECULE (NH_3) CONFIGURATION [DICKENSON]

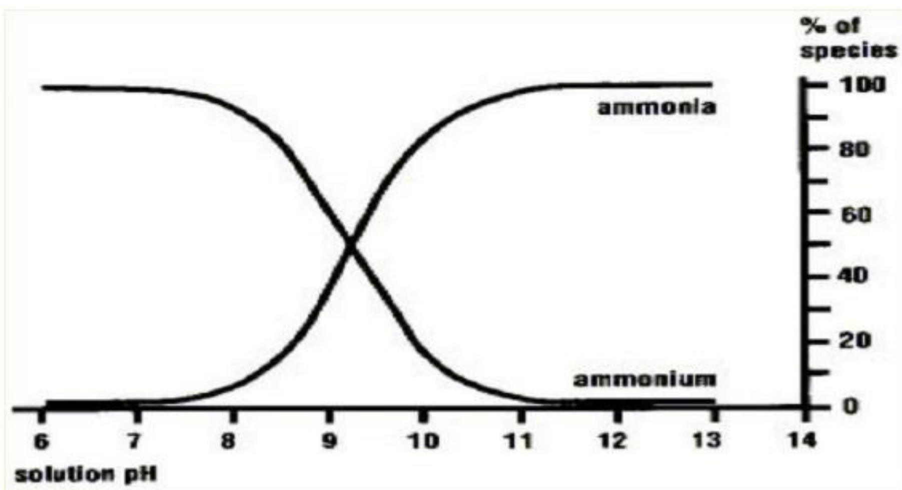




Ammonia gas is highly miscible, or soluble, in water. Nearly 90 grams of the compound can be dissolved in 100 milliliters of water. Depending on the pH (acidity, alkalinity) of the water, ammonia (NH_3) takes on a proton (H+) in water to become the charged ammonium ion NH_4^+. Ammonium may be referred to as a monovalent (single charge) cation. Ammonium with its charge of +1 will be attracted to negatively charged ions, but with less affinity than metals discussed previously due to its monovalence.

Since pH is a scale measure of the H^+ concentration, it follows that pH is the driver for whether ammonia or ammonium exists in higher concentrations. In water and in conditions where the pH is above 8, ammonium readily gives up a hydrogen proton to form ammonia (NH_3). Figure 2 shows the proportion of ammonia to ammonium in water at a given pH [CASTIon, 2008]

Figure 2: Ammonia/Ammonium Proportions (CASTion, 2008)



3.2.2. Sources

The source of ammonia in wastewater comes primarily from human waste during the hydrolysis of urea to the ammonium ion (NH_4^+) [Brooks, 1999]. This understanding of the source of ammonia in shipboard wastewater is reinforced by cruise industry's source reduction evaluation (SRE) reports. It is important to note that ammonia concentrations will likely be higher for systems that combine graywater and blackwater for treatment, thus resulting in a single discharge effluent (i.e. AWTSs) than for systems that treat the two streams separately and discharge only the graywater stream. (http://www.dec.state.ak.us/water/cruise_ships/SciencePanel/evaluations.html).

Ammonia is most highly concentrated in blackwater. The high concentration is likely related to the use of low flush flow toilets that are employed as a water conservation measure but have the added effect of concentrating ammonia in smaller volumes of water.

4. WASTEWATER TREATMENT ALTERNATIVES

ADEC prescribed the feasibility evaluation of the treatment technologies listed in this section for ammonia and dissolved copper, nickel, and zinc. Additional treatment technologies were also considered for evaluation as they were identified during market research and consultation with vendors, researchers, and manufacturers. Complete descriptions of the treatment alternatives evaluated for the constituents of concern are provided below. As stated previously, cost estimation is not possible in this initial overview of treatment possibilities.

It should be noted that many of these potential technologies concentrate contaminates into a sludge or cake for proper disposal off ship. The technologies are discussed in no particular order in the following sections.

4.1. Chemical Precipitation

Process Description (Effect on metal/ammonium)

In chemical precipitation, the pH of the wastewater is adjusted to become more basic with a hydroxide solution (caustic soda, lime, or magnesium hydroxide). Under basic, or alkaline, conditions, soluble metal ions bond to hydroxide ions and precipitate out as insoluble metal hydroxide solids. Due to the solubility product constants listed in Table 4.1, the amount of metal remaining in solution is reduced by significant amounts, in theory, as depicted in Figures 3 through 5.

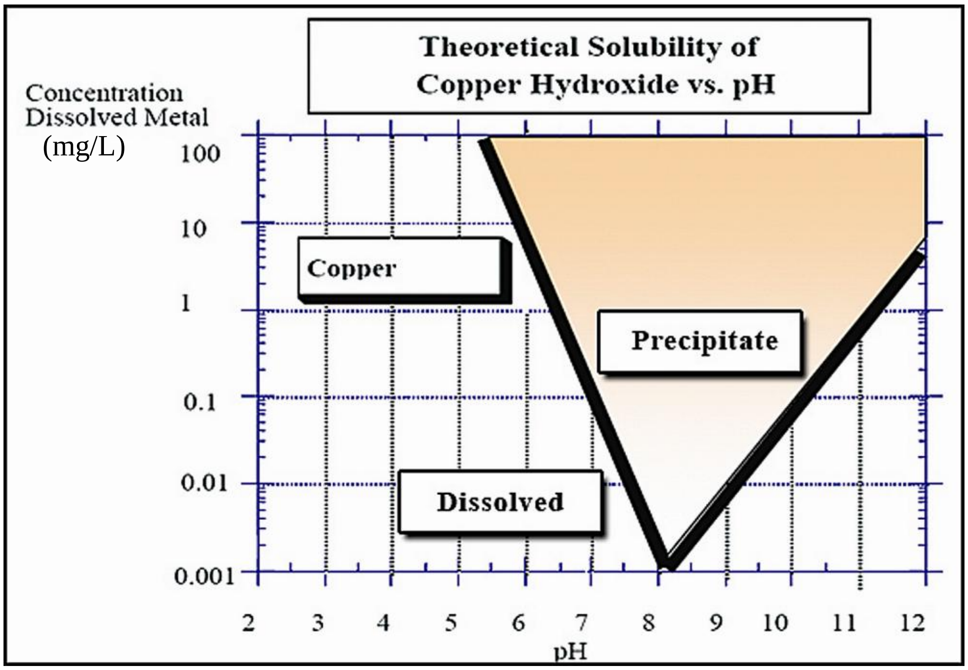
TABLE 4.1: SOLUBILITY CONSTANTS FOR HYDROXIDE PRODUCTS (HANDBOOK OF CHEMISTRY AND PHYSICS, 2000)

Compound	Molecular Structure	K_{sp} (Solubility Product Constant)
Zinc Hydroxide	$Zn(OH)_2$	3×10^{-17}
Copper Hydroxide	$Cu(OH)_2$	2.2×10^{-20}
Nickel Hydroxide	$Ni(OH)_2$	5.48×10^{-16}

Figures 3 and 4 show that in theory, dissolved copper and dissolved nickel in solution can be reduced to a concentration of 1 µg/L. Figure 5 shows that zinc theoretically can be reduced to near 100 µg/L. However, the solubility minimum for different metals occurs at different pH levels. The figures below show that dissolved metals may increase on either side of an optimum pH point, which varies by metal. A compromise must be made when adjusting the pH in the wastewater so that the optimum amount of each metal precipitates out of solution and becomes available for collection. For the three metals in question, the optimum pH would likely be somewhere around 9, however, a single pH may not meet the target metals concentrations for all metals. An alternate methodology that may be employed is a multistage filtration system with interim pH adjustment to remove insoluble metals. This methodology may allow a productive separation of metals within a confined space, which may be foreseen on a sea going vessel.

After precipitation metal hydroxide solids exist as small solid particles and must be removed from the wastewater. Removal could be achieved through sedimentation or filtration. The sludge will then need to be disposed of properly and the water can be discharged.

FIGURE 3: IN THEORY, BY ADJUSTING THE PH OF WASTEWATER TO 8.2, THE DISSOLVED CONCENTRATION OF COPPER IS REDUCED TO 1 MICROGRAM PER LITER. [AYRES, *ET AL.* 1994]



An alternate treatment technology may be sulfide reduction of metals to achieve lower levels of removal from discharged water. As shown below, theoretically, the sulfide reduction process can produce certain results depending on the characteristics of the wastewater to be treated. The solubility constants are presented in Table 4.2.

TABLE 4.2: SOLUBILITY CONSTANTS FOR SULFIDE PRODUCTS (HANDBOOK OF CHEMISTRY AND PHYSICS, 2000)

Compound	Molecular Structure	K_{sp} (Solubility Product Constant)
Zinc Sulfide	ZnS	2×10^{-4}
Copper Sulfide	CuS	6×10^{-16}
Nickel Sulfide	NiS	3×10^{-16}

FIGURE 4: IN THEORY, BY ADJUSTING THE PH OF WASTEWATER TO 10, THE DISSOLVED CONCENTRATION OF NICKEL IS REDUCED TO 1 MICROGRAM PER LITER. [AYRES, *ET AL.* 1994]

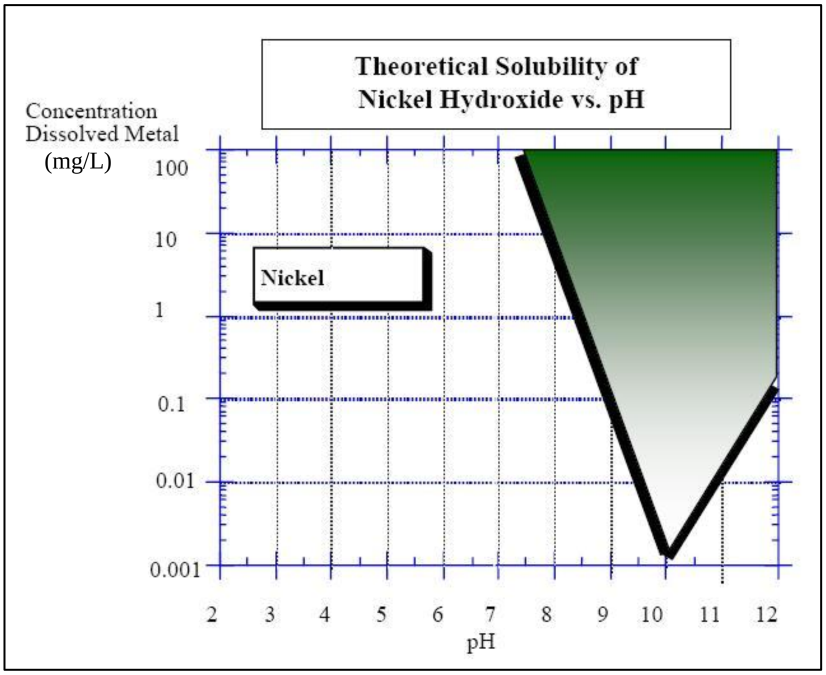
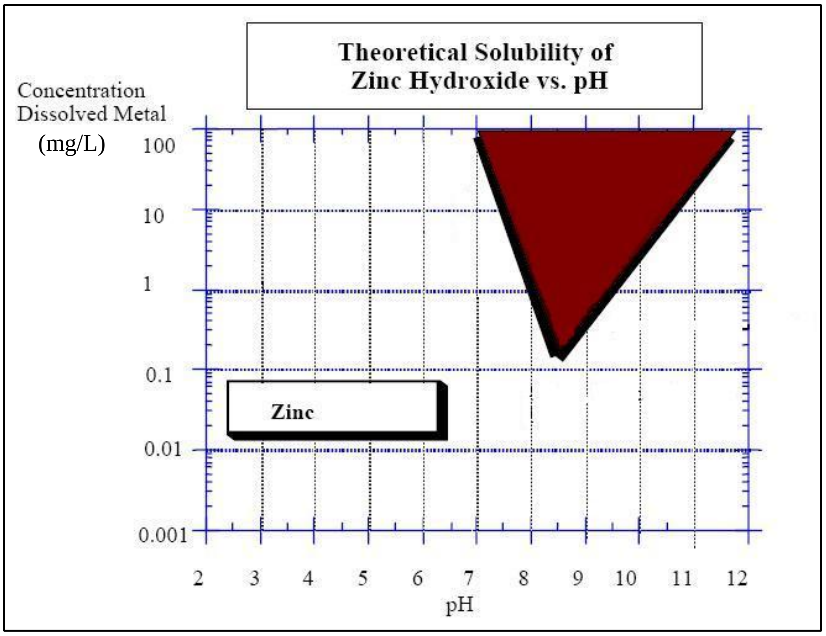


FIGURE 5: IN THEORY, BY ADJUSTING THE PH OF WASTEWATER TO 8.4, THE DISSOLVED CONCENTRATION OF ZINC IS REDUCED TO 100 MICROGRAMS PER LITER. [AYRES, *ET AL.* 1994]



Pending data sharing and a more complete characterization of wastewater from cruise ships, sulfide reduction may be a viable treatment technology, in addition to hydroxide precipitation, to meet the proposed limitations as presented. However, it involves the addition of chemicals and will potentially discharge sulfide ions from the system. Unknown attributes must be investigated to determine actual or installed performance of treatment systems. Inclusion of other source contaminants can affect the overall removal rate of the target constituents. Metal precipitants also can be used to improve metals removal by sedimentation/filtration. This is a method often used in treating municipal wastewater, although in cruise ships it would add more treatment processes and require more space for implementation.

State of Practice (Onshore vs. Shipboard)

In the metal finishing industry, hydroxide precipitation is the standard method of removing heavy metals from wastewater [Cushnie, 1994]. Chemical precipitation is not a process commonly incorporated in current AWTSs. Pre or post treatment options may be available to remove the metals at a given stage of the treatment process. Further data on the water analysis is required to determine the viability of these options. Hydroxide precipitation has been proven on land based systems as an effective technology to meet industrial wastewater limitations for the specified regulated pollutants; however treatability studies and pilot testing would be required to determine the effectiveness of the application in practice to meet the proposed effluent limits. On land, chemical precipitation has been used to treat wastewater to below the limits of the General Permit, but in these cases the starting concentration was much higher and the chemistry was well known. The chemistry of the waste stream dictates the success of this treatment method, as well as additional on-board considerations such as the gravity flow allowed.

Potential Method of Integration in Shipboard AWTS

Chemical precipitation may have an application in post–biological treatment of wastewater. It is not recommended that source water be treated by chemical precipitation as the added salts and subsequent required processes may inhibit the cost benefits and quality of water delivered to the vessel passengers. The sulfide precipitation method may pose issues with the use of the water as potable drinking water.

Post-biological treatment is the suggested placement in the process for this technology as ammonia concentrations negatively affect the ability to precipitate the metal hydroxides [Ayres, 1994] and the process would only reduce them to a fraction of the incoming concentrations, not the required effluent limits. Caustic soda and sulfuric or hydrochloric acid would need to be stored on board and pH would likely need to be adjusted to values within the discharge limits prior to discharge.

Process Byproducts or New Waste Streams

The copper, nickel, and zinc contaminated sludge would be removed for special waste handling which could include metal recovery for recycling or disposal. The substances used to raise and lower the pH of the wastewater would result in a final solution that may not be acceptable for ship offloading. Consideration should be given to the different port offloading wastewater quality requirements as concentrating wastewater may overload the capabilities of systems currently in place. The addition of added concentrated salts, depending on volume, may pose an issue to the dock or Publicly Owned Treatment Works (POTW) treating the off-loaded waters.

Limitations

Efficient chemical precipitation is difficult when applied to treated wastewater with low concentrations of metals such as the 1 to 500 µg/L expected from vessels. Coagulant addition and storage with long retention times would be required. Ammonia concentrations affect the amount of precipitation possible, as it forms metal complexes. These complexes may be treated with sulfide-based compounds to enhance precipitation. If this process is employed on a ship with a membrane bioreactor and denitrification, it would likely be a post treatment process. This method may be able to achieve the limits for nickel and copper, but will likely not meet those for zinc. Use of caustic and acid is a potential safety hazard and proper handling is required to minimize personnel injuries.

4.2. Ion Exchange

Process Description (Effect on metal/ammonium)

Ion exchange is a reversible chemical reaction where an atom or molecule in a solution that has become ionic by losing or gaining electrons (Cu^{+2}, Ni^{+2}, Zn^{+2}, NH_4^+) is exchanged for a like charged ion on a solid particle. Dissolved metal compounds in water exist in a dissociated state. For example, the metal salt copper chloride ($CuCl_2$) is dissolved by the polar nature of water (H_2O):

$$CuCl_2 + H_2O = Cu^{+2} + 2Cl^{-1} + 2H^{+1} + O^{-2}$$

Simplistically, the 'free' copper ion in the aqueous solution (wastewater) can then be attracted to a solid molecule (resin) and exchanged for a more weakly bound positively charged ion (ex. Na^+) on the resin.

The ion exchange separation process consists of two components; the chemistry of the separation and the engineering of the separation. The chemical component is the affinity that the resin has for the target molecule. The engineering component consists of the bed dimensions, flow rates and other engineering parameters of the process. [Dow, 2009]

The ion exchange process will require the accommodation of several factors. A variety of resins may be used independently or in conjunction with each other to achieve the ultimate goals. For the metals to be treated in the cationic state, a strong or weak base resin may be selected for treatment. Moreover, if the contaminant that is out of control is identified; an ion-selective or chelating resin may be employed to single out individually or in conjunction with other preferred ions.

One method for removing dissolved metals from wastewater using ion exchange is to pass the wastewater through a series of solid resin columns. It should be noted that the wastewater should be filtered for particulate and organics prior to introduction to the resin beds as premature fouling or disruption may occur within the treatment process. Such means include particulate filtration and activated carbon filtration to remove unwanted solids and entrained organics followed by an additional particulate filter. Resin beads are shown in Figure 6. As the water flows around the resin beads, the metal ions in solution 'bind' to the solid resin while the more weakly held ion on the 'fresh' resin is simultaneously released into solution.

FIGURE 6 ION EXCHANGE RESIN BEADS [BIOTEC ENGINEERING]

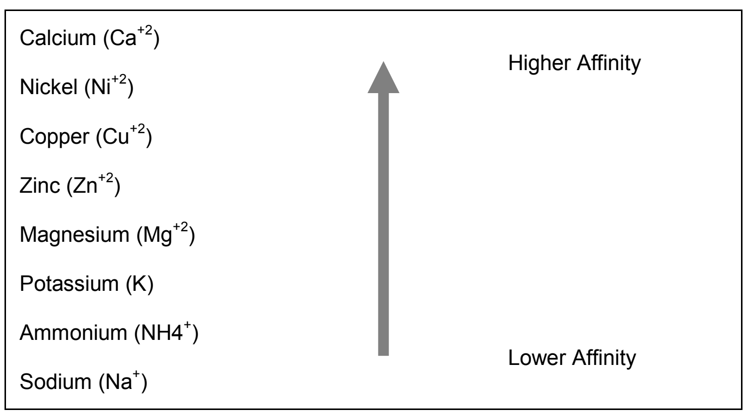
A generic ion exchange chemical separation in a resin column can be described by the following equation where R-COO refers to the resin chemistry, which will vary:

$$(R\text{-}COO)\text{-}Na_2 + Cu^{+2} = (R\text{-}COO)\text{-}Cu + 2\ Na^{+}$$

When the column reaches saturation by having all active resin sites holding a dissolved metal ion, ammonium ion, or other unwanted cation, the resin column must be regenerated. In the case of the ion exchange reaction shown above, the resin would be washed with a brine or heavy salt solution to replace the resin sites with sodium. The unwanted metal and ammonia ions will become concentrated in the wash solution. The ammonia could either be recovered in solution or vented under controlled conditions. It may be required to adjust the pH to effectively vent the ammonia.

Given that metal and ammonium ions are both positively charged cations, both can be exchanged on a cation resin column. However, as noted earlier, the ammonium ion (NH_4^+), being monovalent, has less affinity for the resin than the divalent metal ions (Cu^{+2}, Ni^{+2}, Zn^{+2}). In fact, ammonium has only slightly more affinity for a cationic resin than sodium. Therefore, ammonium can be easily displaced off the resin by a competing ion in the wastewater solution. The hierarchy of resin affinity is shown in Figure 7. In the case of treated cruise ship wastewater, calcium, magnesium, and potassium ions will compete with copper, nickel, zinc, and ammonium ions. Therefore, these ions should be removed before ion exchange or the resin column appropriately sized to accommodate ion competition. Furthermore, there are ion selective resins that may be employed to selectively remove particular ions from the waste stream. It will be necessary to have a full profiled of all ions and compounds within the waste stream to determine the viability and selection of appropriate resins. Ion selective resin performance can be adversely impacted by high concentrations of calcium, especially when trying to achieve low metals in the effluent.

FIGURE 7: SELECTED ION AFFINITY FOR CATIONIC ION EXCHANGE RESIN (REMCO, 2009)



State of Practice (Onshore vs Shipboard)

Ion exchange is not a process commonly incorporated in AWTSs. This technology is used extensively in various industries to remove metal contaminants in a soluble state that need to be removed from discharged waters. Ion selective resins are typically regenerated on site at a land based facility or contracted regeneration at a licensed contractor's site for off-site disposal. Ion exchange is also used in mining to help purify metals and in manufacturing processes to help separate active ingredients. It is most commonly used in homes that have hard water or water with high concentrations of calcium (Ca^{+2}) and magnesium (Mg^{+2}). These ions inhibit soap from lathering and can precipitate out as hard scale on pipes. Water softening consists of the exchange of calcium and magnesium ions for 'soap friendly' sodium (Na^{+1}) or potassium (K^{+1}) ions.

Potential Method of Integration in Shipboard AWTS

Ion exchange would likely be added as a post process, as it is important not to include any ions that may interfere with the exchange. The resin columns could be regenerated on board, which would require additional equipment and regeneration chemicals. Alternately, an ion exchange vendor or technician could periodically come aboard, change out the columns, and take saturated columns ashore for regeneration. These should be able to work continuously for a minimum of 14 days between change outs to accommodate the longest cruise run from a waste reception port.

Ion exchange could potentially be used to treat source water as an additional purification step to reduce the incoming contaminants from either the evaporated water or bunkered water systems. For treating bunkered water, an ion exchange system could be dock-mounted versus ship-mounted. Dock-mounting could be a better option as the column sizes may need to be large to accommodate flow rates during water bunkering. However, the ratio of bunkered water (shore side) and produced water on board is also important. Besides the shore water metal content, the water produced, and distributed on board adds to the metal load. Therefore the level of metals needs to be characterized.

Ion exchange is a very reliable process when properly designed. Equipped with the necessary controls, the unit will operate unattended and regenerate the resins automatically.

Process Byproducts or New Waste Streams

The copper, nickel, zinc, and ammonia contaminated wash water would be removed for special waste handling which could include metal recovery for recycling or disposal. The ammonia could also be vented under controlled conditions rather than being held and disposed in solution; however, venting may not be practical because of the chemical addition required to raise the pH. Furthermore, if on-board regeneration is an applied technology, then the offloading wastewater and receiving entity would have to evaluate the effectiveness of the treatability of each system to prevent overloading of metals.

Limitations

The column size and associated appurtenances may be large and retrofitting of the AWTS would be difficult in a cruise ship main engine room where other wastewater treatment is currently located. Columns are usually sized as a ratio of water volume to resin volume, typically 2 to 4 gal/min per cubic foot of resin (0.26 to 0.52 liter/min per liter of resin). [EPA, 1981] For a maximum flow rate of 60 cubic meters of wastewater per hour the maximum resin column volume would be calculated using the EPA rule:

$$60\ m^3/hour = 1\ m^3/min = 1000\ l/min;$$

$$1000\ l/min/0.26\ l = 3846\ liters\ of\ resin = 3.8\ m^3\ resin$$

This amount of resin could also be expected to recover approximately 100 kg of metal before column exhaustion or breakthrough. Column size could be more precisely calculated as vendors and application engineers investigate design.

Media vessels are bulky and changeout would be difficult. Attaining the discharge concentrations for dissolved metals might be difficult due to the low concentrations in the wastewater. Attaining the discharge concentrations for ammonia would be difficult due to its monovalence and limited affinity for exchange on the column. This could be overcome by the selective sequence of vessel application between strong and weak base resins. Online regeneration of the media would require additional storage of acid, caustic solutions, containment systems, and pumps. Use of caustic and acid is a potential safety hazard and proper handling is required to minimize personnel injuries.

4.3. Reverse Osmosis

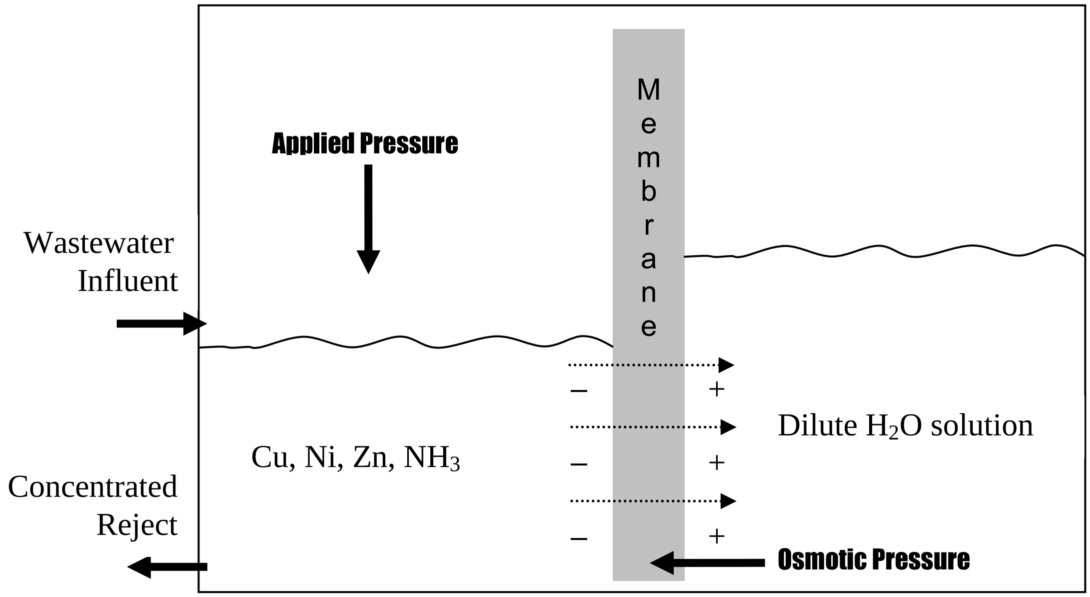
Process Description (Effect on metal/ammonium)

Membrane technology is widely used to filter pollutants from water. Osmotic theory implies pure water will move across semi-permeable membrane into wastewater until the contaminant concentrations of both liquids are equal. However, if external pressure is exerted on the "contaminant" solution, water will flow in the reverse direction from concentrated solution to dilute solution, from wastewater to clean water. This phenomenon, known as reverse osmosis (RO), can separate clean water from contaminated matrices. Contaminants will be excluded by a combination of diffusion characteristics, the electrostatic charge on the membrane, and the physical size of the contaminant. (Figure 8) This process can exclude a variety of contaminants, not only dissolved metals and ammonia but also other metals, organics, and nutrients that are currently regulated or have the potential to be in the future.

The efficiency of the RO membrane filtration of dissolved metals from wastewater depends on several factors:

- The membrane properties, including chemical nature and physical structure. [Bhattacharyya and Williams, 1992]
- The difference in applied pressure, across the membrane, less the difference in osmotic pressure between the concentrated and dilute solutions. [Brandt *et al.,* 1993] Increased pressure will increase the flux or flow rate.
- The solution temperature [Hamdzah, 2007]
- The concentration gradient [Cushnie, 1994]

FIGURE 8: SIMPLE REVERSE OSMOSIS DEPICTION - CONTAMINANTS CONCENTRATE IN WATER BY PORE SIZE FILTRATION AND MEMBRANE ELECTROSTATIC CHARGE.



A variety of semi-permeable membranes can be used in the RO process. Membranes are generally classified based on the pore size, the applied pressure and the molecular weight of the contaminant. Microfiltration and ultrafiltration membranes operate solely with physical size exclusion where nanofiltration (NF) and RO membranes use diffusion and charge along with size exclusion. [WEF, 2005] Manufacturers are not consistent with these terms; an NF membrane to one will be an RO membrane to another.

It is best to separate and filter suspended solids before water is treated by an RO system as they will eventually clog the membrane. Solids that do remain are blocked by mechanical exclusion and dissolved solids are chemically rejected by the membrane surface. Multi-charged ions (dissolved metals) are rejected at rates exceeding 99 percent and single-charged ions (ammonia) have rejection rates in the range of 90 to 96 percent. [Neuman, 2009]

State of Practice (Onshore vs Shipboard)

RO is employed extensively for desalination and also for water purification prior to use as steam in power generation. Many cruise ships use some form of a membrane process in their AWTS, either micro-filtration, ultra-filtration or reverse osmosis. (Eley, Morehouse, 2003). The main advantage of RO is that the technology has been successfully installed and operated on cruise ships that operate in Alaska. The large vessel Carnival Spirit, which utilizes the ROCHEM RO system, consistently achieves interim and long term Alaska Water Quality Standards for ammonia, copper, nickel, and zinc; however, graywater is the only discharge.

Potential Method of Integration in Shipboard AWTS

Current water treatment systems installed on cruise ships could be modified or expanded to incorporate RO membranes. A microfiltration system already in place would reduce the cost of the pre-filtration process. The RO system could be incorporated as one of the final steps of the treatment process. Alternately, when membrane bioreactors (MBRs) are employed shipboard, the integrated microfiltration/ultrafiltration should be sufficient as a pre-filter for the reverse osmosis unit if installed as an end-of-pipe add-on technology. RO may be employed on source water to provide additional purification prior to use to reduce contaminates from evaporated or bunkered water systems.

RO removal of metals is a very reliable process when properly designed, operated, and maintained. Proper treatment of influent water will allow for long term reliability of the membranes. If designed with the necessary controls and staging of membranes, the RO unit would run unattended and the membranes would automatically cycle the clean-in-place system.

Process Byproducts or New Waste Streams

The volume of reject water would vary based upon the efficiency of the membranes and may require additional storage (e.g. tankage). The copper, nickel, and zinc concentrated solution would be removed for special waste handling which could include metal recovery for recycling or disposal.

Limitations

A relatively high pressure is required to create the reverse migration of water, which may have associated high energy and maintenance costs. RO is chlorine intolerant, which is a problem for some ships that use some chlorination for piping disinfection and other incidental disinfection. It can also be a problem for ships that discharge the pool and spa waters through the treatment system. However, careful engineering, back flush, and control of chlorine use for disinfection can minimize these impacts on the RO units. Newly engineered membrane systems are available that are more chlorine tolerant and would need to be selected on a ship-by-ship basis. A MBR treatment prior to RO would consume most chlorine and prevent damage to the membranes. Additionally, chlorine is limited by the Alaska General Permit for discharge. If RO is used as a post-AWTS treatment, e.g. add-on controls, there should be very little chlorine remaining in the waste stream and chlorine flows actively monitored and controlled.

RO membranes are expensive and can be quickly clogged by suspended solids and particles or by cationic polymers. Newly engineered membranes are available that are capable of handling a higher concentration of suspended solids and would need to be chosen on a ship-by-ship basis. For those vessels utilizing MBR units, the suspended solids and particulates are removed within the unit, thus RO could be recommended after the MBR treatment process. For those vessels utilizing MBBR units, an additional filtration step may need to be added before the RO treatment to help prevent fouling. The use of cationic polymers will need to minimized or eliminated to ensure proper operation of an RO treatment system and prevent repeated fouling.

There have been several ships that have used RO based wastewater treatment systems in Alaska. These systems have been used to treat both blackwater and graywater. The majority of the effluent data that ADEC has on these RO systems is from a single ship that uses low pressure RO to treat selected streams of accommodation graywater. This ship has successfully used this wastewater treatment process for several years. Many of the ships that used RO/ultra-filtration to treat blackwater only used those systems in Alaska for a short period of time. Therefore, ADEC does not have a large wastewater effluent data set compared to other wastewater treatment systems for blackwater-treated by RO.

4.4. Surface Clay Filtration

Process Description (Effect on metal/ammonium)

Clay minerals (and other silicate minerals) have been used as inexpensive and available materials for treatment of contaminated water [Aziz, 2008]. Clays accomplish treatment by selectively adsorbing metal cations via ion exchange driven by electrostatic attractive forces between metal cations and anionic clay surfaces. Models used to describe the process suggest that metals are adsorbed in the following order: Cd^{2+}, Cu^{2+}, Zn^{2+}, Ni^{2+}. [Sanchez, 1998] The percent removal of ions from water can be around 95% but is dependent on the pH, ion concentration, hardness, presence of other compounds in the water, surface area of the clay adsorbent, contact time and a variety of other factors that are situation specific. It may not be able to achieve the 95% removal or the target effluent limits because of the low target effluent limits. Precipitation may occur in the form of metal oxides depending on the chemical makeup of the clay.

State of Practice (Onshore vs Shipboard)

This method is used generally in mining and chemical industries, along with drinking water treatment in developing countries. There have been many studies done on variations of clay media and natural soils to determine less expensive methods of reducing concentration of contaminants.

Potential Method of Integration in Shipboard AWTS

Clay surface treatment could treat source water. It would reduce concentrations of metals before use in a fairly inexpensive manner and allow the AWTS to treat the lower concentrations of dissolved metals remaining after use.

Process Byproducts or New Waste Streams

Like conventional ion exchange and RO, using clay or silicate minerals as absorbents only concentrates the metals ions in the clay material solution, creating a waste material requiring disposal. Unlike ion exchange, the adsorbate is relatively inexpensive and would not require regeneration and reuse.

Limitations

Surface clay treatment would not reduce ammonia concentrations in the water. Even in experimental settings, this method has not been found possible to reduce ion concentrations of Cu, Ni and Zn to the levels required for cruise ship effluent. Studies have documented the following levels of performance for contaminants. Treatment rates were very similar for Cu, Ni and Zn and the given removal rates are an average for all three.

- Spain found ~90% removal in a starting concentration of 50mg/L to reach ~5mg/L [Sanchez, 1998],
- Egypt found ~30% removal with natural soils in an initial concentration of 100mg/L to reach ~70 mg/L [Abdullah, 2006],
- Slovak Republic found ~95% removal in a starting concentration of 10mg/L to reach ~0.5 mg/L [Kyncl, 2008],
- Malaysia found ~95% removal with a starting concentration of 2.0 mg/L to reach ~0.1 mg/L [Aziz, 2008].

4.5. Electrowinning

Process Description (Effect on metal/ammonium)

Electrowinning is the process of electrodepositing metals from a solution. The solution in this case is treated wastewater with dissolved metals, which is circulated past an anode (+) and cathode (-). A low voltage direct current is applied through the solution causing metal ions to be reduced at the cathode and water or another ion to be oxidized at the anode. As the metal cation is attracted to the cathode it is deposited on the electrode, coating it.

State of Practice (Onshore vs Shipboard)

Electrowinning is primarily conducted in mining applications in solutions with high dissolved metal concentrations. It is also used in wastewater treatment for industries that create byproduct solutions that contain high metal concentrations, such as plating shops and circuit board manufacturers.

Potential Method of Integration in Shipboard AWTS

Integrating an electrowinning system would require large storage tanks as well as heaters to facilitate the process. It would likely be incorporated as a pre-treatment of source water as it works best at high concentrations and only treats metals. Electrowinning may also be employed on stored waters that have been concentrated by other processes, i.e. ion exchange regenerant or reverse osmosis reject, to recover metal for solids recycling or disposal.

Electrowinning is a simple and reliable process, however it will require periodic attention to monitor metals build-up on the cathods and removal/replacement of cathodes to maintain the process.

Process Byproducts or New Waste Streams

The copper, nickel, and zinc plated on the cathode would be removed as a solid waste for disposal. As it is in a solid form, there are more options for disposal than other methods that create waste in solution.

Limitations

Generally, solutions with a dissolved metal concentration of above 500 mg/L can be effectively electrowinned [Remco, 2009]. Due to the low concentrations of dissolved metals in AWTS effluent, the electrodes would need to have extensive surface area or the effluent would need a long residence time to ensure the ions would come within the attractive field of the cathode. Utilization of fluidized beds in conjunction with electrowinning may assist in depositing more of the metals. The inherent problem with low concentrations of metals is the competing electrolysis reaction which causes hydrogen over potential, thus more of the electrical current applied goes toward electrolysis versus depositing metals on the cathode. As of this writing, the authors have not discovered a situation where electrowinning was used to adequately reduce low concentrations of dissolved metals in the source water. Electrowinning would not be effective at reducing ammonia concentrations in wastewater. However, if used on reject waters, then the effluent can be recycled back to the process that produced the reject.

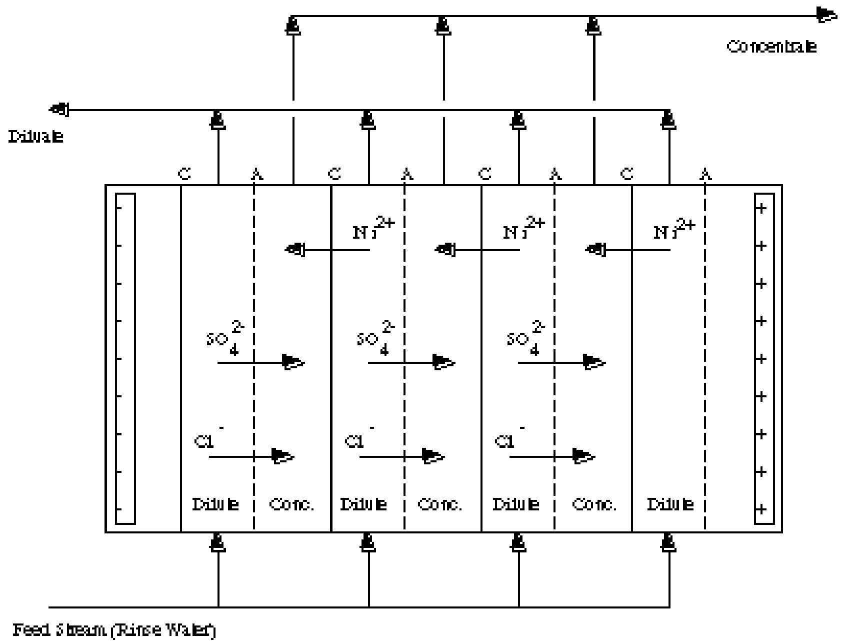
4.6. Electrodialysis

Process Description (Effect on metal/ammonium)

Electrodialysis is an electrical voltage-driven membrane process that treats both ammonia and dissolved metal ions. In electrodialysis (ED) an electric current is passed through an electrolytic solution, which in this case is treated wastewater. A variation of ED is electrodialysis reversal (EDR) where the polarity of the electrodes is reversed on a set frequency to electrically flush the membranes. Ions in the solution subjected to this electric field are attracted to their respective counter-electrodes. When using alternating semi-permeable anion and cation ion-exchange membranes, the spaces between the membranes create compartments of alternating ion concentrate and clean water. Specifically, the compartments bounded by the anion membrane facing the anode and the cation membrane facing the cathode become depleted of ions and are called purifying (or sometimes, diluting) compartments. The compartments bounded by the anion membrane facing the cathode and cation membrane facing the anode will then "trap" ions that have transferred in from the purifying compartments. This compartment configuration is depicted in Figure 9.

FIGURE 9: DIAGRAM OF AN ELECTODIALYSIS PROCESS FOR NICKEL RECOVERY [CUSHNIE, 1994]

(Note the alternating cation (C) and anode (A) semi-permeable membranes)



State of Practice (Onshore vs Shipboard)

ED has limited use in the metal finishing industry for nickel recovery [Cushnie, 1994]. It is used primarily to purify water and is often used in coordination with reverse osmosis (RO). Applications include desalination, drinking water, laundry wastewater, and agricultural water.

Potential Method of Integration in Shipboard AWTS

ED would likely be incorporated into an existing AWTS after the tertiary treatment phase. Many AWTSs use membranes as a portion of the treatment process; consequently it would make sense to use ED in coordination with them. The ED process, unlike RO, is chlorine tolerant and could be used after disinfection even if chlorination is used as part of the AWTS. ED is a very reliable process with minimal maintenance and attended control of the equipment. The unit could have the necessary controls to monitor metals concentration in the discharge effluent.

Process Byproducts or New Waste Streams

The copper, nickel, and zinc concentrated solution would be removed for special waste handling which could include metal recovery for recycling or disposal.

Limitations

ED would require the installation of equipment as an additional treatment phase. At this time there must be further investigation to scale this to treat the volume of water on ships.

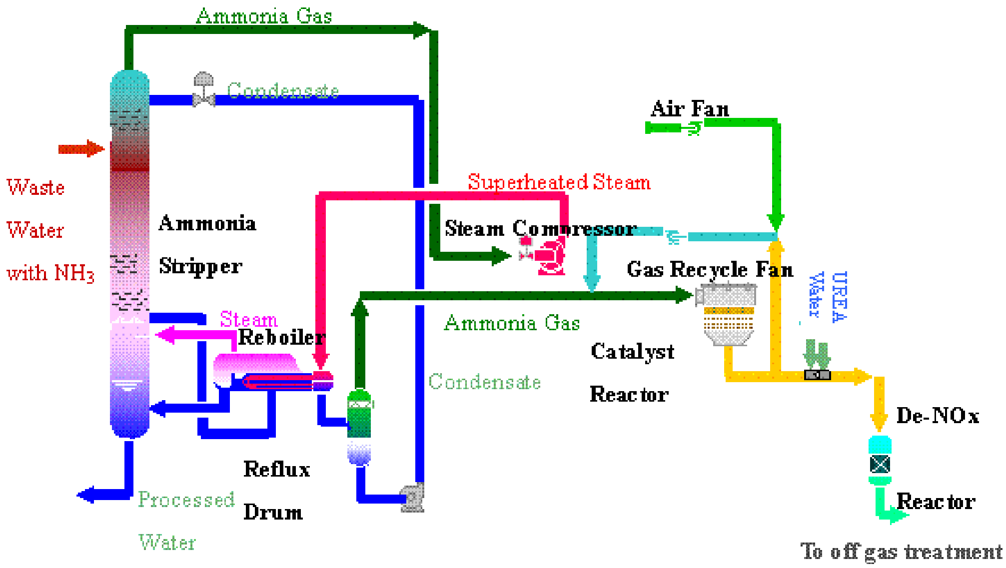
4.7. Air / Steam Stripping

Stripping is not an effective treatment method for dissolved metals at low concentrations in water and hence this section addresses the removal of ammonia only.

Process Description (Effect on metal/ammonium)

Steam or air stripping of ammonia from wastewater capitalizes on the high vapor pressure or low boiling point of ammonia. Steam or air is bubbled through the wastewater to volatize up to 100% of the ammonia present in the wastewater [Elston and Karmarkar, 2003]. Figure 10 depicts a general schematic of the process of ammonia stripping.

FIGURE 10: LAND-BASED STEAM STRIPPING OF AMMONIA [GLOBAL ENVIRONMENT CENTRE FOUNDATION]



The rate of ammonia volatilized in wastewater significantly increases at higher pH and temperature due to an increase in the proportion of ammonia gas versus ammonium ions present (shown previously in Figure 2). A high estimate for the mass of volatized ammonia produced from an air/steam stripping process, based on a concentration of 200 mg/L and a maximum wastewater throughput of 60 m^3/hr, would be approximately 12 kg of ammonia per hour. Researchers and wastewater treatment specialists have found that the optimum pH for ammonia stripping is 10.5-12.0 [Rittstieg et al, 2001, Enviros Consulting, 2008, Organics Group, 2008]. To raise the pH to this level, caustic soda or lime is added to the wastewater. The pH is then reduced to a more neutral pH by adding small amounts of acidifying agents such as hydrochloric, sulfuric or phosphoric acid prior to discharge. Use of caustic and acid is a potential safety hazard and proper handling is required to minimize personnel injuries.

State of Practice (Onshore vs Shipboard)

Stripping of ammonia from wastewater using air or steam is commonly used in industrial settings. Ammonia stripping is currently used to treat industrial wastewater to recover ammonia which is a valuable raw material for the fertilizer industry [Rittstieg et al, 2001, Elston and Karmarkar, 2003, Organics Group, 2008]. Some onshore plants also use stripping to remove ammonia from municipal wastewater and landfill leachate, but it is far less common than the process of aerobic biological oxidation (nitrification) described in the following section. None of the marine vessels sampled in the EPA's December 2008 study [EPA, 2008a] used stripping for ammonia reduction.

Potential Method of Integration in Shipboard AWTS

Ammonia stripping could be integrated into shipboard AWTS, however the number of limitations of this method (see below) would likely make this method very expensive.

Process Byproducts or New Waste Streams

The volatized ammonia must be safely vented, captured, or treated, as shown in Figure 10. Vented ammonia may need to be treated to comply with applicable air emission limits.

The substances used to raise and lower the pH of the wastewater would result in a final solution that may not be acceptable for ship offloading. Consideration should be given to the different port offloading wastewater quality requirements as concentrating wastewater may overload the capabilities of systems that are currently in place. The addition of added concentrated salts, depending on volume, may pose an issue to the dock or POTW treating the waters off loaded.

Limitations

There are substantial limitations to the use of stripping for the removal of ammonia from wastewater. These include: the need to add alkaline substances to raise the pH (e.g. caustic soda/lime), safely venting or capturing the volatilized ammonia, acidifying the wastewater to achieve a more neutral pH prior to discharge (using hydrochloric, sulfuric or phosphoric acid). Use of caustic and acid is a potential safety hazard and proper handling is required to minimize personnel injuries. Most vessels regularly utilize a number of chemicals shipboard; therefore proper training and handling procedures are anticipated to be in place, minimizing potential chemical safety hazards. The efficiency of ammonia stripping is significantly reduced at colder temperatures such as those found even in the summer in coastal Alaska. If the ammonia is not properly captured, or if there are failures in the system, the ammonia may exhibit air quality concerns due to its low odor threshold and warning properties. At low concentrations ammonia gas is highly odorous, and at higher concentrations irritates and causes severe damage to skin, lung and mucous membranes [OSHA, 2008].

4.8. Aerobic Biological Oxidation / Nitrification

Nitrogen is commonly removed from wastewater through the nitrification/denitrification process. Through nitrification, nitrifying bacteria convert ammonia (NH_3) to nitrite (NO_2^-), followed by the conversion of nitrite to nitrate (NO_3^-). This process requires aerobic, or oxygen-rich, conditions. While nitrification results in the conversion of ammonia to nitrate, it is generally not considered a permanent solution, as nitrates are also considered a problem in wastewater effluent. For example, the EPA numeric standard for nitrates in drinking water is 10 mg/L for the protection of human health [EPA 2008b]. Therefore, most wastewater treatment systems couple the use of nitrification with denitrification, which utilizes denitrifying bacteria in anaerobic conditions to convert nitrate to nitrogen gas (N_2), the primary component of our atmosphere. Currently there is no state or federal numeric standard for nitrate in salt water, and nitrates are not regulated under the new ADEC general permit (Table 2.1). In turn shipboard AWTSs would not be required to employ the use of a denitrification system. However, provisions should be taken for nitrate removal for best practices and the potential for future regulations if needed.

The components of efficient nitrification include: a highly aerobic environment provided through aeration within the reactor, sufficient surface area or contact between the bacteria and the compounds to be oxidized, sufficient residence time for microbiological oxidation without compromising needed throughput, optimal conditions for bacteria growth and activity, the right pH and temperature, and sufficient alkalinity for the reactions.

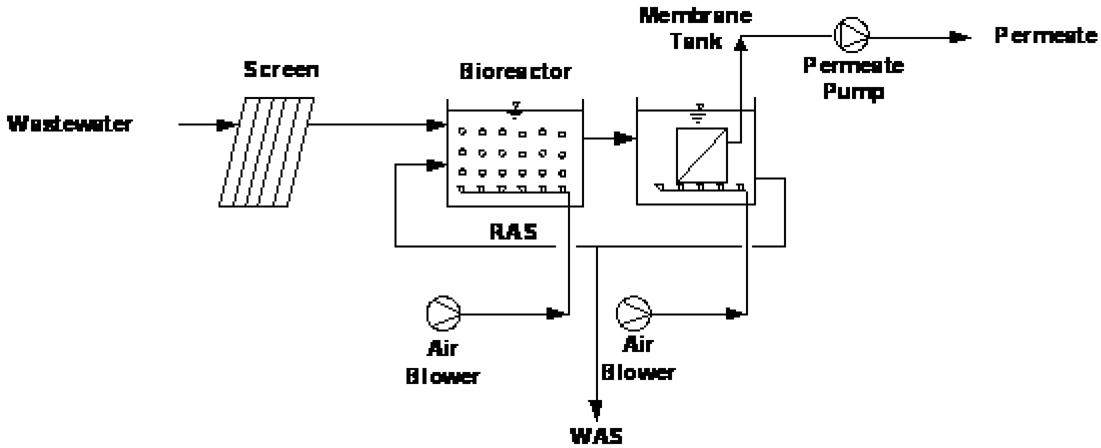
State of Practice (Onshore vs Shipboard)

Nitrification is considered secondary treatment in most onshore municipal wastewater treatment systems. Denitrification is the only method of permanent nitrogen removal from wastewater, and is a common tertiary treatment in onshore wastewater treatment systems. These nitrification/denitrification systems couple aerobic processes via mechanical aeration and microbial processing, with anaerobic processes.

There are two systems commonly used in shipboard AWTSs that employ nitrification: membrane bioreactors (MBR) and moving-bed bioreactors (MBBR). Figure 11 displays a generalized schematic of a membrane bioreactor (MBR). Figure 12 displays a schematic of a moving-bed bioreactor (MBBR). The main differences are that MBR is a suspended growth technology while MBBR is a combination of suspended growth and fixed-film technologies. A membrane is always used for solids separation in MBR while other mechanisms for solids separation may be used in MBBR. The two processes are described further below.

An MBR consists of a suspended growth biological reactor (aeration tank) integrated with a membrane filtration system (typically ultrafiltration). The membrane filtration system replaces the solids separation accomplished with a secondary clarifier in a conventional activated sludge system. The membrane system can be immersed in the aeration tank in direct contact with the mixed liquid, or placed in separate membrane tank. In both cases, vacuum pumps create suction on the membranes to separate treated effluent from the mixed liquid. When the membranes are in a separate tank, like in Figure 11, airflow is introduced to prevent solids from attaching to the membranes. Some biosolids become Returned Activated Sludge (RAS) returned to the bioreactor aeration tank and some become Waste Activated Sludge (WAS) that are thickened, digested and dewatered for disposal.

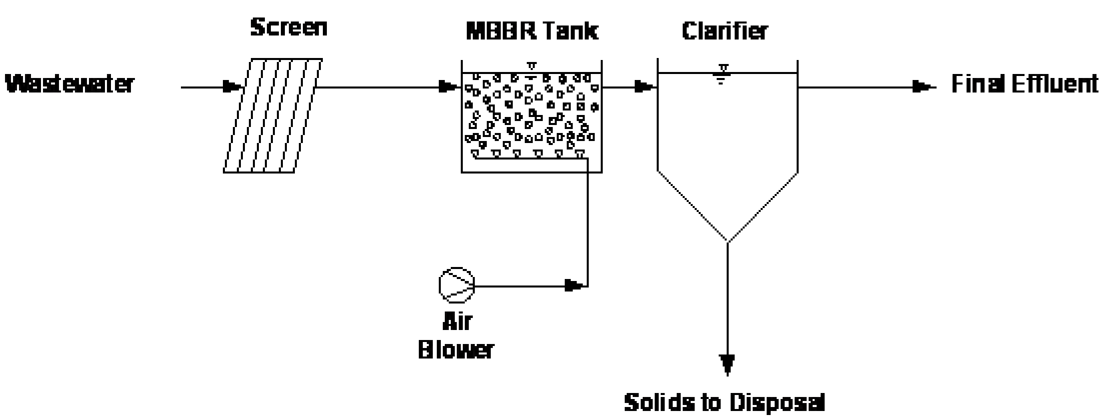
FIGURE 11: MEMBRANE BIOREACTOR (MBR)



An MBBR consists of fixed-film technology and suspended growth technology, both biological treatment processes. A general schematic is shown in Figure 12. The basic principle of the MBBR process is the growth of biomass within engineered plastic media. The media is circulated throughout the MBBR aeration tank/bioreactor by agitation provided either by the aeration system or a mechanical system. This process offers an increased surface area in the bioreactor for the growth of biomass which allows reduction in bioreactor volume. By combining the high biomass concentration in the fixed-film technology with the fluidization of the suspended growth technology, the MBBR can achieve high removal efficiencies in a small footprint.

Soluble organic matter degradation occurs in the MBBR tank and is normally followed by solids separation. Solids separation is typically achieved by conventional clarification processes, however, other techniques such as dissolved air flotation (DAF) or membrane filtration have also been used.

FIGURE 12: MOVING BED BIOREACTOR (MBBR)



Potential Method of Integration in Shipboard AWTS

Although aerobic biological oxidation is already integrated into all AWTSs, concentrations need to be reduced further than they already are with the technology on board. Further reduction of ammonia would require modification or adjustments to the process or reduction of ammonia sources on board the ships.

Given that nitrification is a type of biological oxidation, reductions in ammonia through enhanced nitrification may be attainable by modifying an existing MBR or MBBR within the AWTS. At least one cruise line is pursuing modifications to their AWTS to increase nitrification. This could involve increased residence time, or, if the right conditions for nitrification are given, multiple passes through an MBR to increase conversion of ammonia to nitrate. Other considerations should include aeration, alkalinity, temperature, and any other wastewater characteristics that may be inhibiting nitrification.

Denitrification to permanently remove ammonia could also be one form of existing AWTS enhancement, which would require incorporating an anaerobic step into the treatment process, and the introduction and maintenance of denitrifying bacteria. The EPA 2008a report noted that the AWTSs reduced ammonia but that it was likely through the process of microbial uptake rather than nitrification, as nitrates only increased from 0.325 mg/L to 3.32 mg/L (Table 2-9 in EPA, 2008a). However, given sufficiently long retention time of the wastewater, it is also possible that nitrification is indeed occurring, yet nitrates are being assimilated through microbial processes. As microbes die and decay, other microbes fix their contained nitrogen compounds through the process of ammonification (mineralization) which converts organic nitrogen into ammonia. Therefore, a denitrification step could be helpful as it would permanently remove nitrates (through conversion to nitrogen gas, N_2), thereby avoiding the re-cycling of nitrates back to ammonia through the nitrogen cycle. As described above, this permanent removal of nitrogen from wastewater through denitrification is very common in onshore treatment plants.

The reliability of any biological treatment system depends on several key environmental and operational factors required to maintain a healthy biomass. The main factors affecting the performance of the biological treatment process include the following:

- Consistent wastewater strength or loading
- Consistent wastewater quality
- Nutrients
- Dissolved Oxygen
- pH
- Temperature
- Toxicity
- Mixing
- Hydraulics

These factors need to be analyzed during the conceptual design phase of the wastewater treatment system. Biological nitrification is the most common method of ammonia removal in municipal wastewater treatment because of the low operation and maintenance cost compared to other technologies. While cruise ships may not be able to maintain the same consistency in wastewater quality, strength and loading, the system can be designed in a way to minimize those factors' impacts.

Process Byproducts or New Waste Streams

Nitrate is the only byproduct created through the process of nitrification. While nitrates are not regulated under the new ADEC General Permit, nitrates are regulated as a primary drinking water contaminant due to its chronic effects on human health, and have a numeric standard of 10 mg/L. Precautions would need to be taken to limit human exposure to the treated wastewater which could contain nitrate concentrations greater than the standard. For best practices and safeguarding against potential future regulations, nitrates should be managed to limit exposure.

Limitations

The existing nitrification systems will not reduce dissolved metals concentrations in the effluent. An additional limitation of the described enhancements may include increased space and time required to add a denitrification step to treatment. There are many factors that can inhibit the nitrification process including temperature and water alkalinity that will need to be taken into account when designing a system.

4.9. Breakpoint Chlorination

Process Description (Effect on metal/ammonium)

Insufficient chlorination of waters containing nitrogen compounds, including ammonia, leads to the formation of a mix of chloramines which irritate the skin and eyes and impart an unpleasant odor to the water. At sufficiently high concentrations of active chlorine (hypochlorite, hypochlorous acid, and molecular chlorine), breakpoint chlorination occurs. In breakpoint chlorination, ammonia/ammonium is completely oxidized to dinitrogen and the active chlorine is simultaneously reduced to chloride. [Lenntech, 2009]

The end products of the breakpoint reaction are primarily nitrogen gas (N_2), secondarily nitrate (NO_3^-) and chlorine (Cl^-) [Brooks, 1999], produced by the following reactions:

$$NH_4^+ + 1.5\ HOCl \rightarrow 0.5\ N_2 + 1.5\ H_2O + 2.5\ H+ + 1.5\ Cl^-$$

$$NH_4^+ + 4\ HOCl \rightarrow NO^3 - + H_2O + 6\ H^+ + 4\ Cl^-$$

The weight ratio of chlorine to ammonia required to reach the breakpoint, assuming N_2 is the major end product, is 7.6:1 or, on a molar basis, 1.5:1. Studies have shown that chlorine-to-ammonia dose ratios varied from approximately 8:1 to 10:1 for various wastewaters with the dose ratio required related directly to the extent of pretreatment, with the more highly treated water requiring a lower dose ratio of 8:1. [Pressley, *et al.* 1973].

State of Practice (Onshore vs Shipboard)

Breakpoint chlorination is generally used for treatment of drinking water and swimming pools. It is also used in the pulp and paper industry for bleaching. Its use in wastewater treatment is limited because an activated sludge system (nitrification) system is generally easier and less expensive.

Potential Method of Integration in Shipboard AWTS

Breakpoint chlorination would likely be an added step post-disinfection.

Process Byproducts or New Waste Streams

As can be seen from the chemical reactions, the significant disadvantage of breakpoint chlorination treatment is the release of free chlorine, a marine toxin limited by the General Permit to 7.5 micrograms/liter. See Table 2.1. This by-product limits use of this treatment method.

Limitations

Active chlorine would need to be stored on board and the very high dosing of water creates high levels of free chlorine as a by-product which would likely not meet the ADEC limit as described in Table 2.1.

4.10. Land-Based Facility References

There are facilities currently operating around the United States and the world using technologies examined in this study that treat to the Alaska General Permit 2010 limits. Table 4.3 lists a sample of known systems designed by one consultant that are achieving the limits. The table also lists where the waste stream originates and the location of the installations. Other installations likely exist that are not listed here.

TABLE 4.3: SYSTEMS ACHIEVING LIMITS

Wastewater	Treatment Process	No. of Installations	Location
Ammonia			
Municipal	Nitrification (Activated Sludge)	15	Arkansas (4), Kansas (5), Missouri (2), Monterrey, Mexico (1), Wyoming (3)
Municipal/Commercial (combined)	Nitrification (MBR)	4	New Hampshire (3)**, North Carolina (1)**
Graywater Reuse	Nitrification (MBR)	3	Doha, Qatar**
Refinery	Nitrification	1	Texas

Wastewater	Treatment Process	No. of Installations	Location
	(Kaldness/Activated Sludge)		
Beef Processing	Nitrification (Activated Sludge)	7	Illinois (1), Kansas (2), Nebraska (3), Washington (1)
Pork Processing	Nitrification (Activated Sludge)	6	Illinois (2), Iowa (2), Nebraska (1), Oklahoma (1)
Metals			
Plating and metal finishing containing low concentrations of multiple metals, oils, surfactants, acids, and alkaline cleaning agents	RO and Ion Exchange	1	Pennsylvania
Plating and metals finishing containing low concentrations of multiple metals, oils, surfactants, acids, and alkaline cleaning agents	Chemical Precipitation, Ultrafiltration, RO	1	Florida
Industrial Facility	Carbon Adsorption and Ion Exchange	1	Arizona
Laboratory	RO and Ion Exchange	1	Arizona
Metal Finishing	RO and Ion Exchange	1	Arizona
Aerospace Facility	RO and Ion Exchange	1	Kansas
Aerospace Facility	Electrodialysis	1	Kansas

** Designed for NH_3-N concentration of less than 2.9 mg/L. Not operational yet.

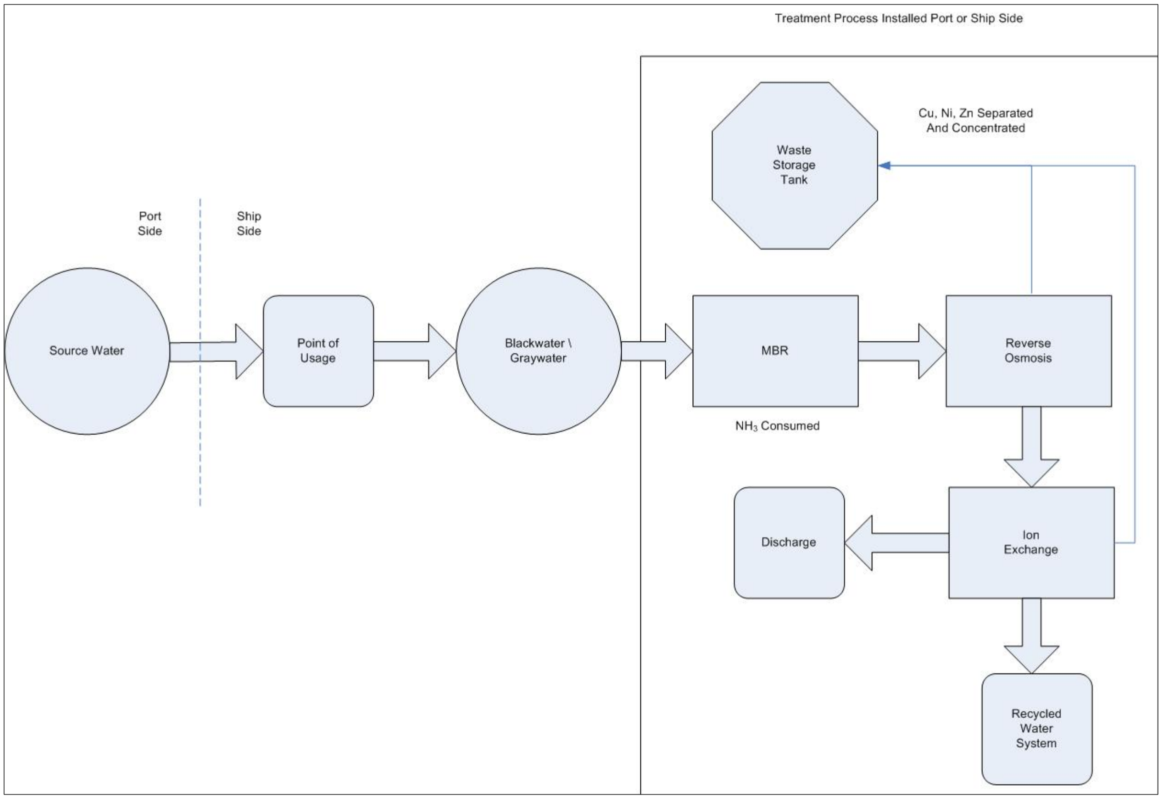
4.11. Treatment Technology Combinations

One of the above-described technologies could be used for treatment of the contaminants of concern and would have the ability to treat to the Alaska General Permit limits. However, a combination of two or more of the technologies would be more effective. Potential combinations of treatment methods are described in the following sections with block flow diagrams showing how the technology will fit into a currently operating system. One consideration that should be noted is biological re-growth. After treatment with one of these systems, disinfection should occur. A treatment system may be added before an already-installed disinfection process or an additional disinfection process may be added after the new treatment system. Actual pilot testing and treatability verification will need to be completed to determine the final applicability to each individual ship. The following combinations are presented in a descending order of preference for treatment application.

4.11.1. Bioreactor / Single Stage Reverse Osmosis and Ion Exchange

This treatment technology uses a bioreactor for biological conversion of ammonia into nitrate. The bioreactor also removes organic matter measured as Biochemical Oxygen Demand (BOD) or Chemical Oxygen Demand (COD). Ship and land based installations should utilize membrane bioreactors (MBR) or similar technology that provides for membrane filtration after biological treatment. This will minimize the need for additional pretreatment for organics prior to metals treatment. One advantage of using biological nutrients removal is that most ships that cruise Alaska already have this type of treatment on board and could potentially be modified to achieve the 2010 limits.

FIGURE 12: BIOREACTOR / SINGLE STAGE REVERSE OSMOSIS AND ION EXCHANGE

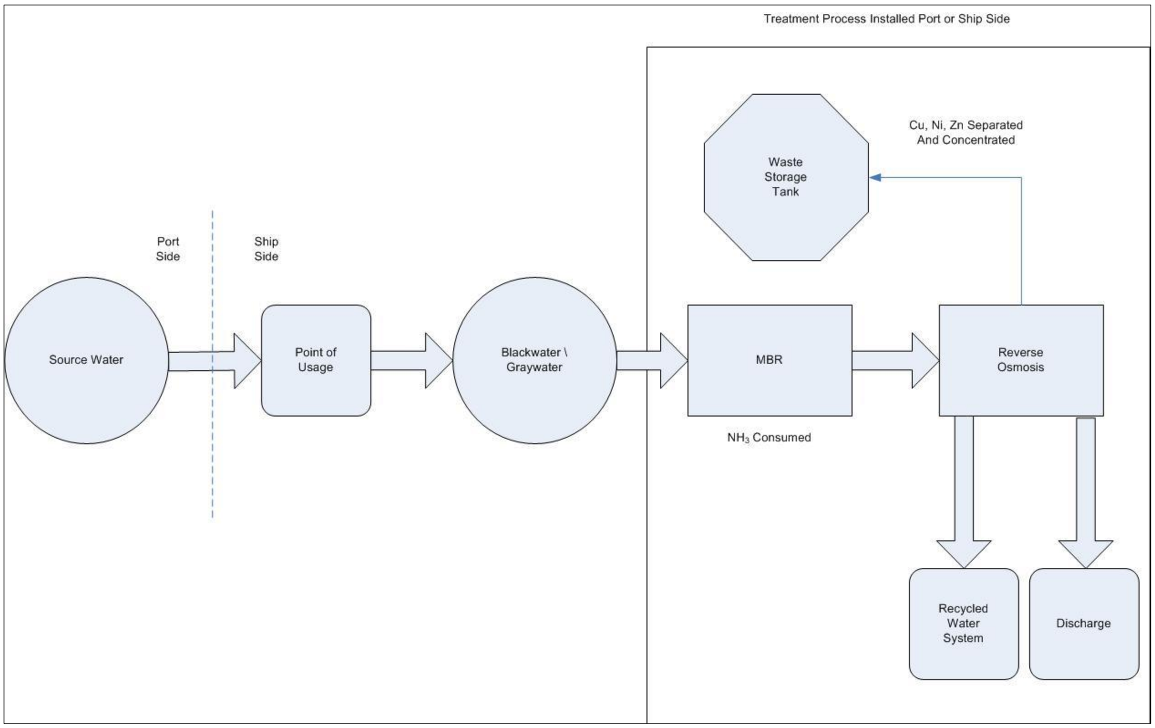


Metals will be removed in a two-step process: reverse osmosis followed by ion exchange. The wastewater will be initially passed across a single-pass membrane system with a removal efficiency of 90-99%. The rejected waste would be stored in a holding tank and discharged to an appropriate waste handler. The permeated wastewater will be passed across a series of ion exchange resins (strong acid cation, weak acid cation, ion selective, chelating or combinations thereof) for final metals removal. The treated water should be monitored for pH and adjusted if necessary prior to discharge from the system. The regeneration waste of the ion exchange resins should be stored in holding tanks and discharged to an appropriate waste handler. A block flow diagram for this option is presented in Figure 12.

4.11.2. Bioreactor / Multi-Stage Reverse Osmosis

The bioreactor is the same as section 4.10.1 and the water will first pass through an RO system. However, then the permeated wastewater will be processed through another single-pass membrane system with a total removal efficiency of 95-99% for metals removal. Reject from the first pass will be stored in holding tanks, and reject from the second-pass is normally mixed with the wastewater that is sent to the first-pass system if the water quality is equal to or better than the wastewater quality. If necessary, the permeated wastewater will continue to be passed across membranes until final metals criteria have been met as determined during treatability studies. The treated water would be monitored for pH and adjusted if necessary prior to discharge from the system. A block flow diagram for this option is presented in Figure 13.

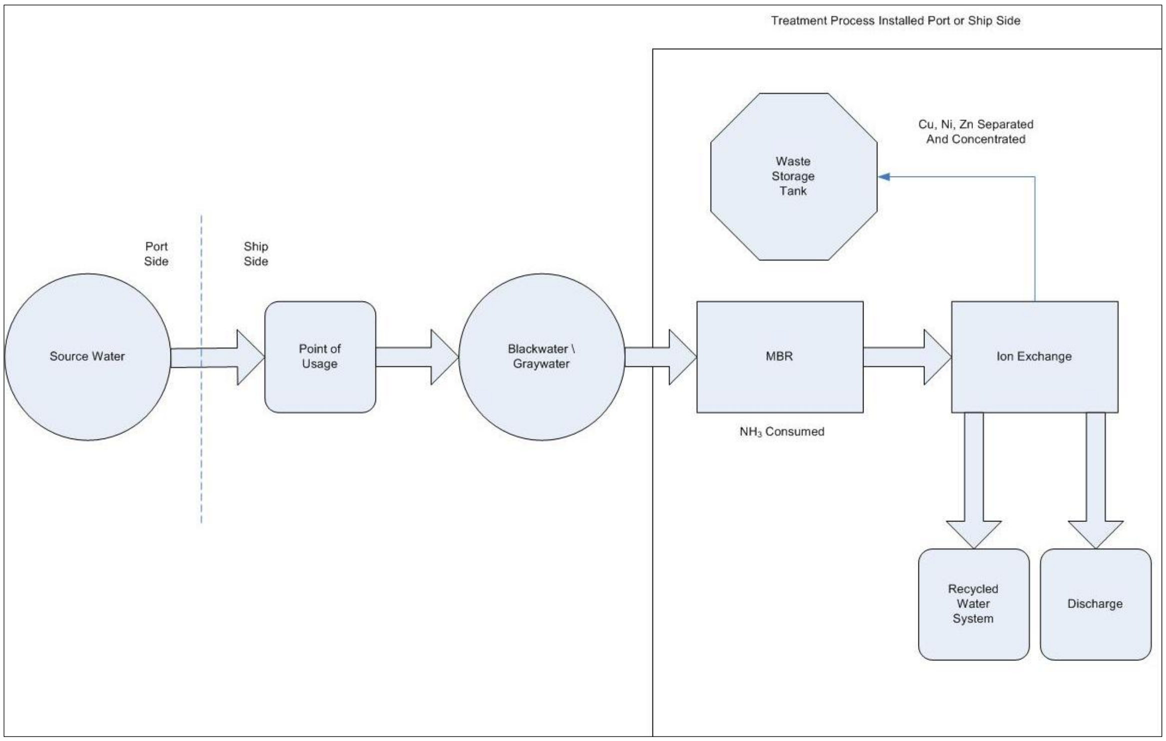
FIGURE 13: BIOREACTOR / MULTI-STAGE REVERSE OSMOSIS



4.11.3. Bioreactor / Ion Exchange

The bioreactor is the same as section 4.10.1 but the metals will be removed in a single treatment by ion exchange. The wastewater will be passed across a series of ion exchange resins such as strong acid cation, weak acid cation, ion selective, chelating or combinations thereof. A block flow diagram for this option is presented in Figure 14.

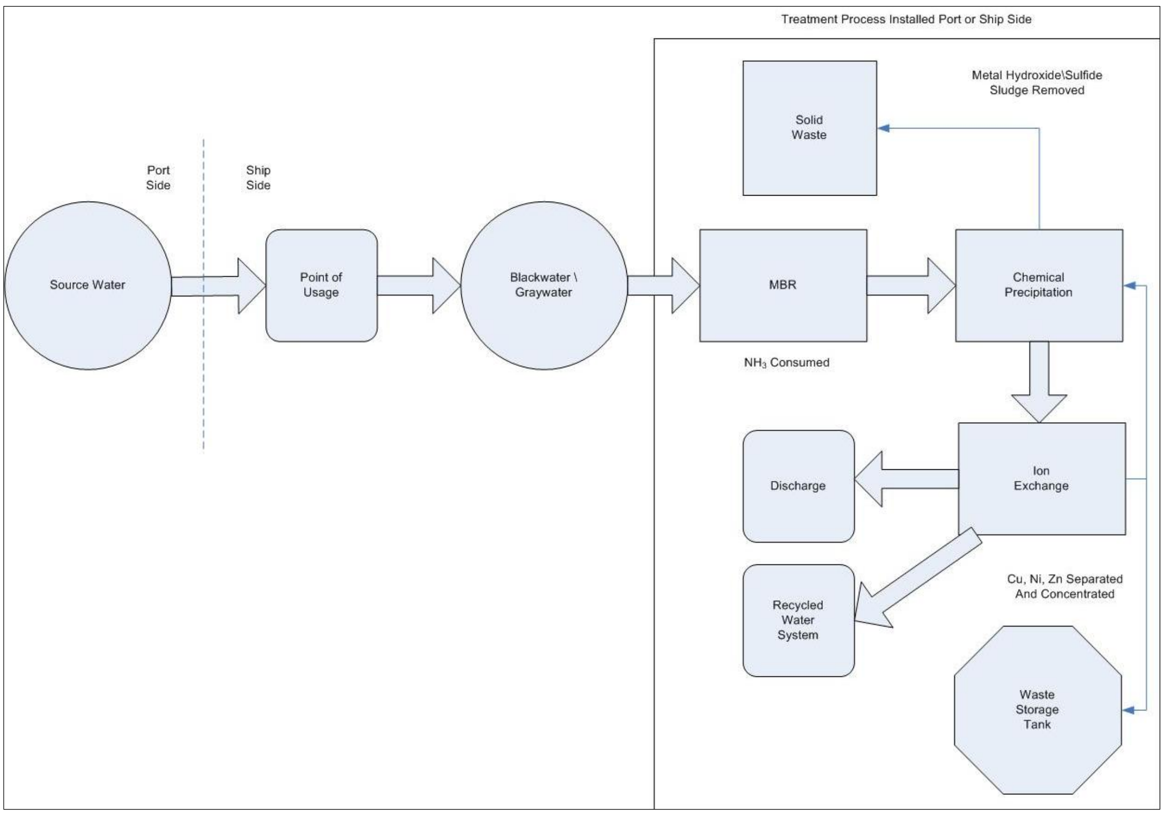
FIGURE 14: BIOREACTOR / ION EXCHANGE



4.11.4. Bioreactor / Chemical Precipitation and Ion Exchange

The bioreactor is the same as section 4.10.1 but the metals will be removed using a two-step process of chemical precipitation followed by ion exchange. The wastewater will be initially treated with sulfur and hydroxide compounds to precipitate metal hydroxides and sulfides. The precipitate would be dewatered as sludge or cake and disposed of as solid waste by an appropriate waste handler. The treated wastewater will then be passed across a series of ion exchange resins. A block flow diagram for this option is presented in Figure 15.

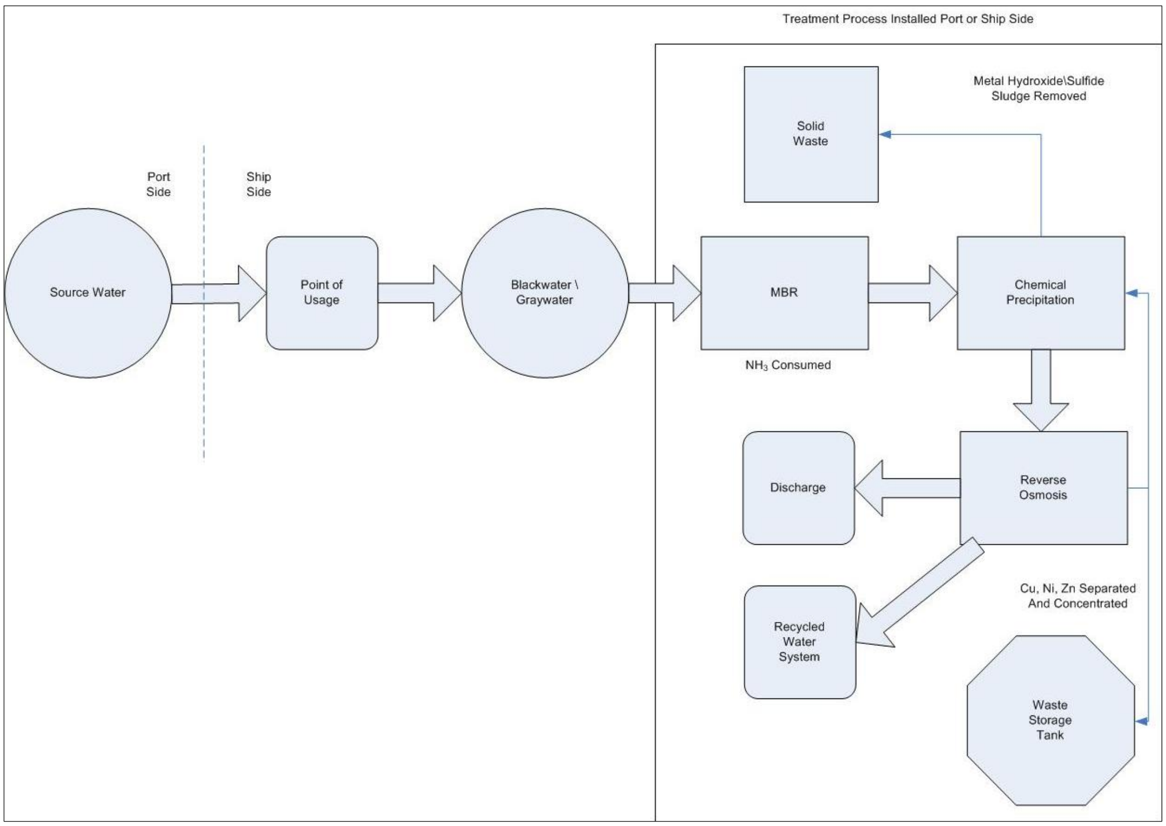
FIGURE 15: BIOREACTOR / CHEMICAL PRECIPITATION AND ION EXCHANGE



4.11.5. Bioreactor / Chemical Precipitation and Reverse Osmosis

The bioreactor and chemical precipitation are the same as section 4.10.4 but the metals will be treated with a single-pass RO after the chemical precipitation. The RO treatment will consist of a single-pass membrane system with a metals removal efficiency of 90-99%. A block flow diagram for this option is presented in Figure 16.

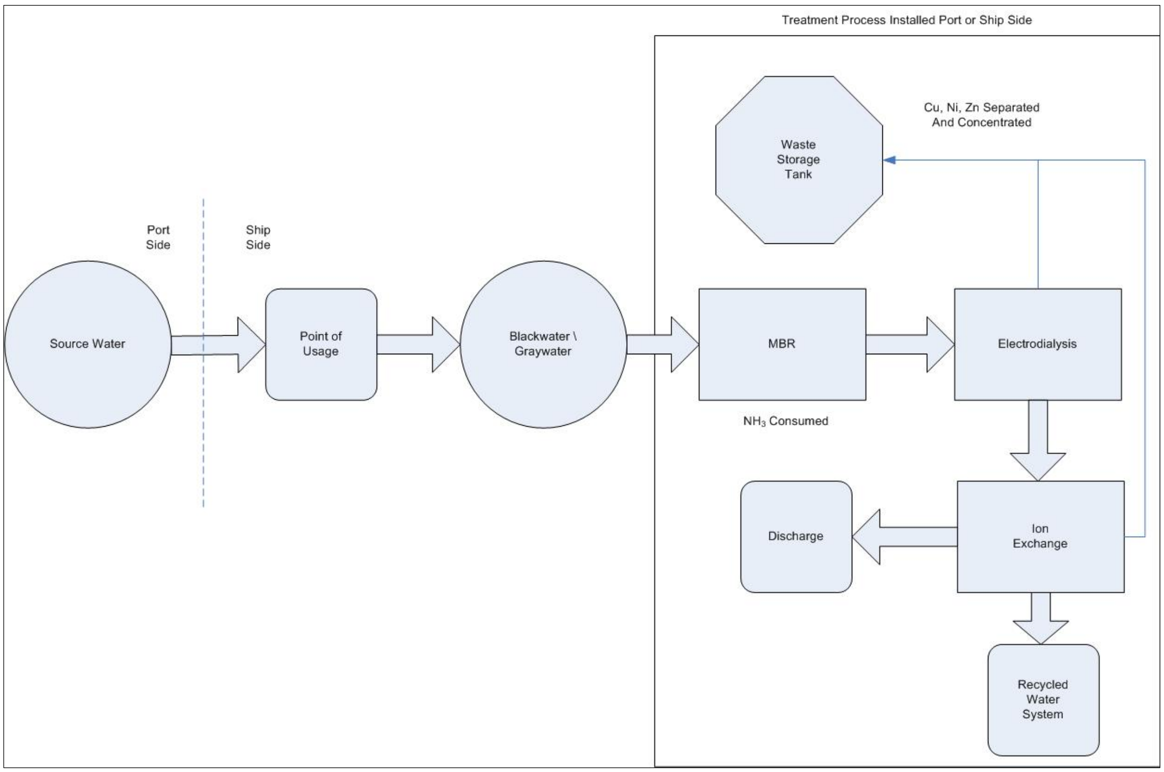
FIGURE 16: BIOREACTOR / CHEMICAL PRECIPITATION AND REVERSE OSMOSIS



4.11.6. Bioreactor / Electrodialysis and Ion Exchange

The bioreactor is the same as section 4.10.1 but the metals will be treated with a two-step process involving electrodialysis followed by ion exchange. The wastewater will be initially passed across a series of semi-permeable membranes and charged with an imposed current to concentrate the metals. The dilute wastewater will be passed across a series of ion exchange resins. A block flow diagram for this option is presented in Figure 17.

FIGURE 17: BIOREACTOR / ELECTROLYSIS AND ION EXCHANGE



5. POTENTIAL EXPERIMENTAL TECHNOLOGIES

Several experimental technologies are described below to give a basic understanding for the purpose of screening or pursuing development for field applications. Further development and research may show that these techniques have marine applications. Reviewers of this study are invited to further develop these technologies or suggest additional experimental technologies for evaluation and inclusion in this paper.

5.1. Removal of Ammonia as Magnesium Ammonium Phosphate

Ammonia/ammonium in wastewaters having more than 1 g/L of nitrogen is removed by precipitation in the form of a magnesium ammonium phosphate. A single liquid reactant containing sources of magnesium ions, phosphate ions and an acid is added to the wastewater, followed by pH adjustment to between 9 and 11. [Horny, *et al.,* 1994]

5.2. Ammonia Removal by Thermally Activate Charcoal

Research has been conducted in laboratory studies of ammonia removal from wastewater using adsorption by thermally activated charcoal. A number of optimum removal parameters were determined, including temperature, retention time, and adsorbate concentration. [Rashid, S., 2008]

5.3. Anaerobic Ammonium Oxidation

The Agricultural Research Service's Coastal Plains Soil, Water and Plant Research Center has found a way to use anaerobic bacteria to convert nitrite and ammonium to dinitrogen gas. The anaerobic bacteria called anammox are derived from swine sludge. Ammonium (NH_4^+) acts as the electron donor and nitrite (NO_2^-) as the electron acceptor to create dinitrogen gas (N_2). Primary advantages are energy savings and cost savings. [Szogi, 2007]

5.4. Electrolytic Treatment of Aqueous Media

A variety of pollutants and other contaminants may be removed from a variety of aqueous media using electrolytic treatments. The treatment includes inserting an anode and a cathode into the medium undergoing treatment, and applying a high current and voltage to the electrodes. The treatment includes the addition of catalytic enzymes to the medium undergoing treatment. Note: This appears to be very similar to electrodeionization (EDI). [Orlebeke, 2004]

5.5. Biosorption by Immobilized Microorganisms

Microorganisms are known to have the ability to remove metal ions from water through adsorption, metabolism, and/or transport.

The experimental work demonstrates that copper contained in actual waste streams can be removed to sub-parts-per-billion levels using bacterial cells immobilized in a calcium alginate matrix. Once the copper is removed, alumina particles and organics also can be removed from the waste stream using current technologies (filtration and carbon adsorption). Further work is needed for application to continuous-flow wastewater treatment. [Ogden and Muscat, 2007]

6. VENDOR INFORMATION

This information is taken directly from proposals that were submitted to OASIS Environmental, Inc. by vendors, manufacturers and researchers who believe they have a technology that can meet the general permit limits. They were generally directed to solve this problem as a post-treatment, as it was the only situation where sufficient data could be given to determine whether a treatment would work. Any costs given are order of magnitude estimates for a system to the dock to achieve the permit limits at a flow rate given in Table 2.1.

6.1. CASTion

CASTion proposes to use a combination of their RCAST Ammonia Recovery Process (ARP) with an ion exchange system as an add-on to a current AWTS after disinfection. In the ARP segment, ammonia will be separated and converted to sulfate then sent to an ammonium cation exchanger. The water will then flow to a selective metals ion exchanger to remove dissolved metals. The sulfate will be concentrated in a separate unit and sent to storage. The ARP segment will treat to approximately 100 mg/L and the ion exchange segment will further treat to less than 1 mg/L.

The system would include the following components: multi-media filter, cartridge filters, softener unit, RCAST unit, cation exchanger, metals ion exchanger, and sulfate concentration unit. To treat a flow of 440,000 GPD, the estimated cost for equipment to the dock is $3 -5 million.

6.2. Det Norske Veritas AS

Det Norske Veritas (DNV), in coordination with Norwegian University of Science and Technology and KeraNor AS proposes an advanced moving-bed biofilm bioreactor (MBBR) in combination with a ceramic membrane filtration unit. The MBBR removes soluble organic matter and ammonia nitrogen, the filtration unit separates biomass, particulates, and colloidal matters from the effluent.

This company has tested their system to address removal rates of ammonia in the presence of saltwater and oil concentration, believing that this is what is important in a cruise ship wastewater treatment system. They have discovered that longer retention time increases removal of ammonia nitrogen in the presence of oil and that salinity negatively affects the removal of ammonia nitrogen.

Effluent is tested to meet and exceed IMO standards. Treatment capacity of the system is limited due to the limited number of ceramic plates. More research is needed.

6.3. DOW Chemicals

While DOW did not send a formal proposal, they sent a spreadsheet for help on calculating sizing of ion exchange equipment necessary for the ion concentrations and flow rate that are encountered on these large cruise vessels. According to influent concentrations of the components of interest, the bed size would be 0.1 m^3 of resin and 2.9 cf of media. They suggest using multiple containers to hold the media and swapping them out on shore for regeneration off site.

6.4. Evac Oy

This Finland-based company proposes the solution of their EVAC MBR system, which is an AWTS. It mixes all incoming streams, pre-treats using screens then an aerated biotank and a membrane bioreactor (MBR). Solid-liquid separation is performed using a KUBOTA Submerged Membrane Unit. This technology is currently being used on the Celebrity Xpedition cruise liner. It has operated for approximately one year and the proposal states that effluent quality has been “perfect.” Evac Oy believes that with this system, the effluent quality will comply with the ammonia limit of 2.9 mg/L.

To reach the dissolved metal concentrations, Evac Oy proposes using integrated precipitation with an advanced chemical agent that is not hydrogen sulfide as it will react with oxygen forming sulfate. This method appears to be the most cost effective as it requires a limited amount of additional instruments, pumps and tanks to add on to the current system. Evac Oy also suggests that all effluent piping systems be non-metallic and a chemical flocculant should be used in the MBR process. Twenty hydraulic units would be needed and one tank.

Concern is expressed that RO would produce a new waste with high water content needing to be disposed. Similar concerns exist for pH regulation with caustics.

Operational costs of this system would be 10 - 30 cent/m^3 and for a complete turn-key system would be $3.6 – 4.3 million. This total cost is estimated for a daily nominal flow of 1255 m^3 per day. Operating power use would be 162 kWh. Membrane cleaning would be required twice a year and overall maintenance costs are estimated at $30,240 annually for operation 360 days a year. Full analysis of costs is included in Appendix C.

6.5. Ferrate Treatment Technologies, LLC

Ferrate is an oxidized form of iron (Fe^{6+}) that can oxidize ammonia to nitrite and nitrate and also oxidize and remove the metal zinc. No toxic byproducts are formed.

6.6. Filter Flow Technology, Inc.

Filter Flow and a chemical engineer researcher have developed Electro-Chemical Methodology for removing trace metals and the ammonium ion at a pH of 8.5. The system is called Hydratron and was originally designed as a water softening mechanism.

It works by introducing charged electrons, both positive and negative, to force re-association of electrostatic attractions and allow some free electrons to appear in solution and form compounds.

Components needed to fit this in line with AWTS on cruise ships involve a zeolite pre-filter for removal of suspended solids before the OxHydratron (electro-oxidation), then aeration using a venturi. Finally the water would flow to a standard Hydratron. Small doses of sorbent could be used after the standard Hydratron if further precipitation is needed. Filtrate will be recycled for treatment. This system is expected to work on both dissolved metals and ammonia.

The OxHydratron and the Hydratron both are in-line systems that look like piping and can be ½" to 48" in pipe size.

6.7. GE Water and Process Technologies

GE performed a similar feasibility analysis to this study, but used information based on their expertise. GE is now the owner of Zenon systems. They concluded that there are two options that are feasible with some future adjustments as needed. A third suggestion is also included.

The first option is reverse osmosis. GE's thin film composite RO membranes can achieve 99.5 to 99.8% removal for Ni and Zn, 99 to 99.4% removal for Cu and 85 to 99% removal for ammonium. Sizing could designed for the area of intent and the power consumption would be much lower than a comparable desalination system due to lower pressures. A CEIP tank will be required for cleaning and a concentrate recycle will run with the system to enhance crossflow and reduce flux.

The second option is electrodialysis. This unit would be self cleaning via polarity reversal and required no chemicals. EDR has similar removal efficiencies as RO, but is more tolerant to organics and has adjustable driving potential to create flow and modify quality. EDR runs at a lower operating pressure and membranes last longer than in RO.

The third suggestion is to upgrade current MBR systems to include oxygen generation so that nitrification can be enhanced in the same footprint. This would not address the concentration of dissolved metals.

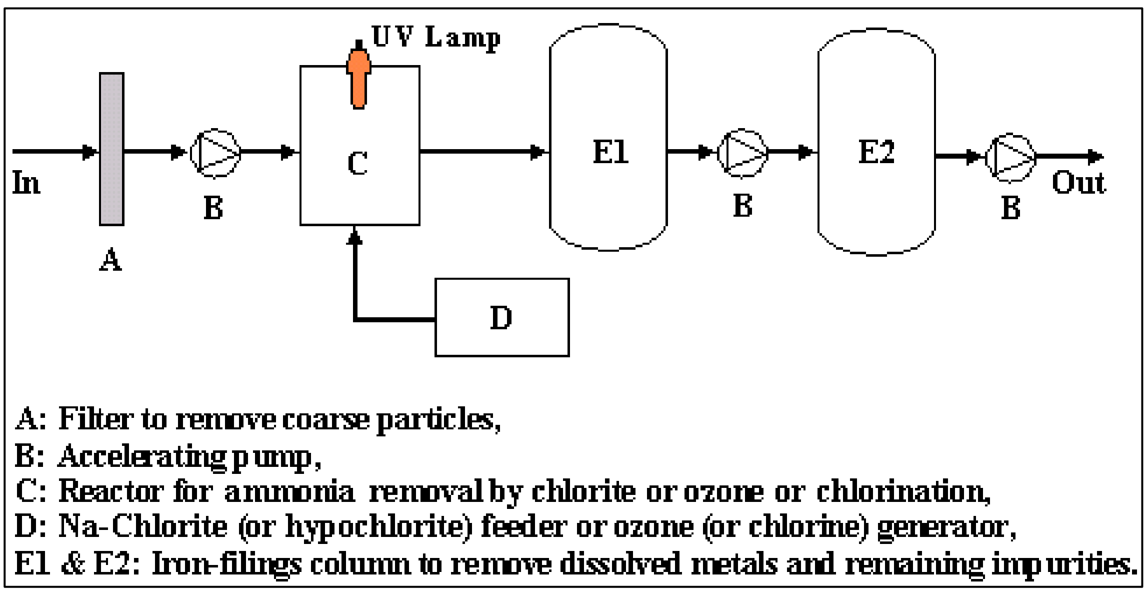
GE submitted a second proposal from another segment of the Water and Process Technologies division. It proposed a specific system design using entrapped air flotation, advanced oxidation, activated carbon and two sets of membranes. This system has been tested and GE claims that it meets all specifications for discharge in Alaska. Full implementation and on-going services are identified along with cost estimations. In addition to meeting the requirements, GE suggests that water reuse will result in energy savings.

[Both of GE's proposals contain proprietary information and are not included in Appendix C.]

6.8. NORAM Engineering

NORAM proposes a 2-stage treatment process to move towards compliance with the long term effluent limits. In Stage 1, ammonia will be oxidized to nitrogen and nitrate by an oxidant such as chlorite under UV radiation. In Stage 2, two columns of iron filings (zero-valent iron) will react with the residual oxidizing agent to create hydrous ferric oxide (HFO) and chlorite. Then HFO/iron will remove metals by HFO adsorption and redox reactions. The process diagram is included below in Figure 10.

FIGURE 12: NORAM ENGINEERING PROPOSED PROCESS DIAGRAM



This treatment option is in research phases and has only tested bench-scale models. NORAM believes that this approach has a much greater metal removal capacity at a significantly lower material cost than ion exchange resins. The iron surface has strong binding strength with cationic metals and ammonia while resin reactivity depends on the structure of the reactive functional groups and their distribution density. The HFO/iron columns can also remove oxidizing agents such as chlorine and ozone, which will be important for some ships that have trouble meeting the chlorine limits for discharge.

No wastes are generated by this process. The columns could last for 1 to 2 years before regeneration is required. Iron filings are readily regenerated and the ammonia removal is very rapid at 5 minutes.

[NORAM's proposal contains proprietary information and is not included in Appendix C.]

6.9. Ohio University Chemical and Biomolecular Engineering

Dr. Gerardine Botte and members of her research team have developed a system of ammonia removal involving electrolysis that converts the ammonia to pure nitrogen and hydrogen. The reaction that takes place in alkaline material is:

$$2NH_3 + 6OH^- \Leftrightarrow N_2 + 6H_2O + 6e^-$$

This is followed by the reaction that reduces water at the cathode of the electrolytic cell:

$$2\ H_2O + 2e^- \Leftrightarrow H_2 + 2OH^-$$

These reactions both take place but in different compartments, so the overall cell reaction is:

$$2NH_3 \Leftrightarrow N_2 + 3H_2$$

The energy consumption for this process at 25°C is 1.55 W-h per gram of H_2 produced. This process is demonstrated in the Ammonia Electrolytic Cell (AEC) technology for wastewater treatment and can reduce a concentration of ammonia at 340 mg/L to 30 mg/L. Additional laboratory research has demonstrated that this process can achieve results lower than 1 mg/L, but this is not yet producible in the AEC.

The wastewater flows through the anode of the AEC creating pure nitrogen at the anode that can be released into the atmosphere and pure hydrogen at the cathode that should be used to power a fuel cell or combustion engine. At a flow rate of 60 m^3/hr and inlet ammonia concentration of 150 mg/L, 1.59 kg/h of hydrogen will be produced while consuming 52 kW of power and producing 26.2 kW of power in conjunction with a fuel cell. Basic dimensions of this system are 9.8’ x 1.64’ x 1.3’ and 68 kg.

The concept of this technology may provide opportunities to modify the electrolyzer for treatment of zinc, copper or nickel. Further research must be done to try this.

6.10. ROCHEM

ROCHEM already provides systems to Alaska cruise ships, as shown in Table 2.2. Currently, there are six cruise ships that have low pressure RO systems installed on board that have cruised in Alaska. Only one of those was permitted to discharge in Alaska during 2009. Rochem also uses RO to treat landfill leachate to surface water discharge criteria at installations around the world. Data from 2008 cruise ship sampling shows that the Carnival Spirit met the long term discharge limits using an RO system to treat graywater. ROCHEM believes that their systems can treat wastewater to the new permit limits using LPRO membranes, or if necessary, tighter RO membranes.

The FM Module should be used as it involves a membrane stack with open feed channels with which ultrafiltration, microfiltration, nanofiltration and reverse osmosis membranes can all be used. These can also be combined with an MBR to ensure removal of suspended solids. ROCHEM has other membrane module designs that are used in wastewater treatment with long membrane life and are not as susceptible to clogging with suspended solids or particles.

Installation of this system is possible and has been done while the vessel is under a commercial itinerary.

7. IMPLEMENTATION CONSIDERATIONS

The implementation of AWTSs aboard a large cruise ship will involve a series of planning steps, beginning with a thorough evaluation of the vessel and progressing through a selection process to narrow and identify optimum treatment alternatives. After the selection of a preferred treatment alternative, the implementation effort will focus on detailed design including sizing considerations, the regulatory approval process, and the actual vessel modification. This section describes a potential plan, rules, and other considerations associated with the implementation process.

Although ADEC is interested in the potential of vessels being able to meet the General Permit requirements, it is the cruise line's responsibility to comply with the permit and take the necessary steps to achieve implementation of a suitable technology.

7.1. Selection of Treatment System

The first step in an implementation plan is the completion of the systemic vessel wastewater evaluation. This evaluation is discussed in detail in Section 2.5, so is only shown here in outline form:

1. System Balance and Source Evaluation
2. Source Substitution
3. Optimize Water Source
4. Evaluate Wastewater Collection and Use
5. Ship constraints (such as sizing)
6. Pre and post treatment options

Given that available technologies have been identified and the wastewater evaluation plan has been conducted, the next step is to narrow down the choices of treatment options and pick the optimum alternative. Each treatment alternative will likely contain a combination of water source, waste influent, and waste effluent treatment in combination with one or more selected treatment devices. This alternative selection process can occur in many different forms, but its basic steps are the following:

1. Create multiple treatment alternatives. Examine each for:
    a. Treatment Effectiveness
    b. Installation Feasibility
        i. Available space in vessel
        ii. Impact to vessel's existing systems

   iii. Electrical/mechanical requirements

  c. Cost Optimization

   i. Installation design costs

   ii. Operational and Maintenance costs

   iii. Capital cost

2. Prioritize alternatives and select optimum alternative

Prior to discussing installation requirements, an important issue must be considered regarding any selected machinery. This issue is the approval process that is required for any machinery or systems that will installed aboard a large cruise ship.

7.2. Regulatory Approval of Device

Very large cruise ships are highly regulated environments. These vessels are subject to the rules of the country in which they are registered, the rules of the classification agency through which the vessel is inspected and certified, any applicable international agreements such as MARPOL and SOLAS, and any rules enforced by a port of call as a portion of a vessel's permission to enter port.

Installation of any mechanical device or system aboard a very large, foreign flagged cruise ship is governed primarily by the rules of the classification agency hired by the owner to inspect and certify the vessel. These agencies, such as Lloyd's, Det Norske Veritas, etc. all publish a comprehensive set of rules that apply to ship construction, modification, and inspection. International rules will also apply, but most classification agencies incorporate international rules into their own rule set. At this time it is not known if the devices need typical Class Approvals or Class Certification. In the case of a US flagged vessel, the device will also need to meet the requirements of the US Coast Guard. The rules of the US Coast Guard may, or may not, be aligned to the international rules, although the trend is towards alignment.

Classification agencies make a distinction between the certification or approval of a device and the installation of a device. All classification agencies require approval of a mechanical device or system before it can be installed on a classified vessel. Agencies can grant "type approval" for devices that are mass produced or "individual approval" for one-of-a-kind devices. Both processes require plan approval, inspection, and operational testing. However, in some cases the Classification Societies may accept on board testing and approval.

There is a further clarification required for the definition of approval by classification agency. For most mechanical systems, such as generators or marine sewage treatment plants, approval requires a combination of performance standards and equipment capability or safety. In rare cases, usually for systems not normally installed in vessels, classification approval governs only the safety of a mechanical component or system, not its performance. This means that even if the device is approved, its performance is not guaranteed and any testing must be accomplished by entities other than the classification agency.

Approval of any wastewater treatment device can be broken down into two primary categories:

- Those devices defined as a sewage treatment plant
- All other water treatment devices

If the device to be installed is defined as a sewage treatment plant, good international rules exist for its approval. The International Maritime Organization (IMO) Annex 26 MEPC.159(55), commonly called MEPC 55/23, defines certain rules for the treatment standards. It also addresses environmental testing of the sewage treatment plant and contains a "Form Certificate of Type Approval". See Appendix D. MEPC 55/23 is normally incorporated into all classification agency rules by reference.

US Coast Guard regulations also exist for approval of the design and construction of marine sewage treatment devices. These are defined in 33 CFR 159.51. Although these rules do not contain testing standards applicable to advanced wastewater treatment devices, they do provide a thorough list of construction requirements.

For equipment not classified as sewage treatment devices, classification approval or certification will be specially granted. This allows each classification agency a fair bit of discretion concerning the approval process, which results in some uncertainty regarding the definition of required approval parameters. However, most agencies each have a reasonably standardized set of rules regarding the approval of equipment. These rules can be generally described as follows:

For the purpose of this description, we have selected the rules of the American Bureau of Shipping (ABS) as an example reference rule set. ABS is not the classification agency of choice for many cruise ship owners, but ABS rules are well written and, most importantly, they are available for free electronic download on the internet at www.eagle.org/absdownloads/index.cfm. (Set up free account, select "Steel Vessel Rules 2009", select "part 4, Vessel Systems and Machinery".) This will allow interested parties to have a full copy of representative rules and easily view referenced citations.

1. General: For definitions of rules applicable to machines, rules applicable to systems, general intent, type approval programs, trials, and other general information see ABS Part 4 Chapter 1.
2. Inclinations: Angles of inclination: athwartship static 15 degree, dynamic 22.5; Fore-and-aft static 5 degree, dynamic 7.5 degree. Athwartship and fore-and-aft

inclination occur simultaneously. The Fore-and-aft static inclination is usually reduced for vessels over 328 feet in length. See also ABS Part 4, Ch. 1, Sect. 1, 7.9.

3. Ambient Temperatures: Air: enclosed spaces 0 to +45 degrees C, open deck -25 to +45 degrees C, electrical equipment in machinery space +45 degrees C. Water: +32 degrees C. See also ABS Part 4, Ch. 1, Sect. 1, 7.11.
4. Electrical Systems: In accordance with ABS Part 4, Chapter 8.
5. ACM/Hazardous materials: No asbestos containing material, with rare exceptions. See ABS Part 4, Ch. 1, Sect. 1, 7.15.
6. Fire Safety: Depends on location on vessel. In general machinery and system components must be non-flammable. The use of flammable liquids or dangerous substances anywhere on the vessel needs to be specially considered.
7. Pressure Vessels: In accordance with ABS Part 4, Chapter 4.
8. Piping System Components: In accordance with ABS Part 4, Chapter 6.

Alternate standards for approval of equipment, components, and systems are available from classification societies. However, these standards cannot be any less restrictive than the existing classification rules, as determined by the classification society. In all cases, the equipment, components, and systems are subject to design review, survey during construction, and tests and trials.

Experience has proven that classification approval of non-standard vessel machinery is a highly variable process, and should be considered early in the selection and design process.

7.3. Installation of Device

Once the preferred treatment alternatives are known, and treatment device is (or will be) approved by a classification agency, planning can begin for the actual installation of the device. Ship board modifications and machinery installation are processes that are well understood by cruise ship owners and managers. Discussions of these issues are briefly presented in this paper for the benefit of non-marine readers.

- Concept Design: The first step in the installation process is a concept design, which is the first comprehensive review of all major design parameters. A good concept design should quantify all of the major vessel modifications, system impacts, costs, and construction issues including the space and weight requirements. In this stage an equipment space optimization would be done. This would include items such as a ship process system balance and analysis, waste characterization and a treatability study. At the conclusion of the concept design, all system performance parameters, costs, and installation impacts should be established and known with good engineering certainty.

- Pilot Project: In the case of technology that is very new, or where a concept design cannot adequately quantify all risks, a pilot project may need to be considered. This will probably be necessary for every treatment technology evaluated in this study as the limits are strict and the technology has not been proven shipboard. The purpose of the pilot project will be to test, on a smaller scale, the areas of uncertainty. The results of a pilot project would be incorporated into a revision of the concept design.

- Final Selection: Based on the results of the concept design and pilot project, sufficient data should be available for cruise ship managers to make an informed design regarding the installation of treatment systems.

- Installation: Once a final decision has been made to install a treatment system, the installation process follows a well-defined path for vessel modification as follows:
  - Installation Design
  - Plan Submittal to Classification Agency for review / approval
  - Construction
  - Testing

7.4. Conceptual Timeline

The time frame necessary to successfully implement a chosen technology is difficult to quantify because it depends on: system analysis, development, testing, approval, fabrication, design, and installation of new equipment. Most of the steps in this process are sequential, meaning a delay in one step will delay the entire process. During the workshop in Juneau, much discussion was given to the details and challenges of the implementation process. Some of the participants in this discussion were experienced manufacturers of advanced wastewater treatment systems on cruise ships. They offer the following "best case" time line for implementation of reasonably well known technology units.

Implementation Step	Length of Time
Characterize Influent	3 months
Initial Selection of Treatment Technology	2 months
Initial Design for Pilot System	2 months
Pilot Project	2 months
Final Selection of Treatment Technology	4 months
Final Design of System	6 months
Regulatory Approval	2 months
Order Technology	4 months
Shipping	2 months
Construction	2 months
Testing	3 months
Time to Full Operation	**32 months**

8. CONCLUSIONS

Nine treatment methods were examined in this study to determine whether any could be used to reach the proposed 2010 end-of-pipe effluent limits for cruise ships discharging into waters of Alaska. These methods are the following:

- Chemical Precipitation
- Ion Exchange
- Reverse Osmosis
- Surface Clay Filtration
- Electrowinning
- Electrodialysis
- Air / Steam Stripping
- Aerobic Biological Oxidation / Nitrification
- Breakpoint Chlorination

Additionally, five experimental technologies were listed and discussed briefly. Due to insufficient information, they will not be discussed further in conclusions.

8.1. Technical Feasibility

Of the nine treatment methods, three selectively treat only ammonia (air/steam stripping, aerobic biological oxidation/nitrification, and breakpoint chlorination), three selectively treat only the dissolved metals (chemical precipitation, surface clay filtration, and electrowinning) and three are able to treat both ammonia and dissolved metals (ion exchange, reverse osmosis, and electrodialysis).

It is theoretically possible for most of these treatment methods to treat the water to the necessary concentration for discharge. Without having complete data on the influent and sources of contaminants, a full discussion of feasibility is premature. Based on current data, biological nitrification, ion exchange, reverse osmosis, and electrodialysis appear to be the best suited for achieving the limits. Combinations of these methods treat all four contaminants, seem to be able to reduce contaminant concentrations by the necessary amount, and are currently in use in land-based industries.

Surface clay filtration and electrowinning technologies will likely have inherent trouble meeting the limits. Chemical precipitation may have trouble meeting the limits for zinc due to zinc's solubility parameters and precipitation is usually performed on higher concentration metals. Breakpoint chlorination will likely increase the chlorine levels in the effluent above the discharge limits. Air / steam stripping will likely volatilize ammonia to above the air emission limit. The other methods technically could be used as a step in the process to treat one of the contaminants.

8.2. Implementation Feasibility

There are many considerations that need to be addressed as a part of implementation. These include system size, new waste streams, approval of devices, coordination with the current treatment systems, costs, safety, manpower, reliability and many more. Most of these considerations require a more detailed analysis of the design and installation than is possible in this study. The cruise ships will need to address implementation issues when a system design begins. For the purpose of this study, a preliminary assessment of implementation considerations was completed.

All nine of the assessed technologies will produce new waste streams. Substances will be needed to adjust pH, enhance precipitation, recharge resin, and act as absorbents. Nearly all of the treatment methods will need support systems beyond the actual treatment step such as pre-filters, activated carbon to control organics, storage tanks, heaters, and vent systems.

In all treatments except breakpoint chlorination, air/steam stripping, and aerobic biological oxidation/nitrification, the dissolved metals or ammonia will be concentrated in a sludge that will need to be handled and disposed as waste. Some of this concentrate cake may have very high metals concentrations which makes it more appropriate for metals recovery.

Many AWTSs already use some form of membrane filtration and also aerobic biological oxidation/nitrification. These may be able to be modified or added-on to meet the new discharge limits. The other technologies are not currently in use on board ships and will require additional testing and approval for incorporation.

8.3. Summary

Table 8.1 offers a summary of the findings of this study. The categories high, moderate and low are used to characterize ability both technologically and implementation-wise. In order to make conclusive determinations about whether achieving the proposed limits by 2010 is possible, more information is needed such as detailed waste stream characterization and analysis, treatability studies, pilot plant studies including onboard pilot testing, and conceptual designs for ship adaptation. That information will be gathered and assessed by the cruise lines required to meet the 2010 General Permit limits.

For technology, “high” refers to a system that treats all contaminants and appears to be able to meet the new limits. “Moderate” refers to a treatment that could meet the limits for at least one contaminant, depending on further testing. “Low” refers to a treatment that it appears will not be able to meet the new limits.

For implementation, “high” refers to a system that is already in use on ships and could be incorporated with relative ease. “Moderate” refers to a system that would require some additional study for incorporation on board ship and involve a reasonable amount of added waste streams. “Low” refers to a system that would compromise the ability to meet other regulations.

Table 8.1 also includes information on vendors that believe they could use the technology to achieve the new limits.

It is apparent from this summary table of findings that the most promising technologies at this point in time appear to be reverse osmosis, electrodialysis, ion exchange, and aerobic biological oxidation/nitrification. Biological nitrification could be used to treat ammonia, and ion exchange or a combination of ion exchange and reverse osmosis or electrodialysis could be used to treat metals.

TABLE 8.1: SUMMARY OF FINDINGS FOR TREATMENT METHODS

Treatment Method	Effective for		Technical Feasibility	Implementation Feasibility	Vendor Interest	Other Considerations
	Ammonia	Dissolved Metals				
Chemical Precipitation		✓	Moderate	Moderate	Evac Oy, Filter Flow	Retention time
Ion Exchange	✓	✓	High	Moderate	GE, DOW, CASTIon	Resin recharge
Reverse Osmosis	✓	✓	High	High	GE, ROCHEM	Low chlorine tolerance
Surface Clay Filtration		✓	Low	Moderate	-	
Electrowinning		✓	Low	Moderate	-	
Electrodialysis	✓	✓	High	Moderate	GE	
Air / Steam Stripping	✓		Moderate	Low	-	Potential Air emission regulations on ammonia /odors
Aerobic Biological Oxidation / Nitrification	✓		Moderate	High	-	Retention time
Breakpoint Chlorination	✓		Moderate	Low		Discharge limit on chlorine
Oxidation using Hydrous Ferric Oxide/Iron	✓	✓	-	-	NORAM	Research Only
Magnesium Ammonium Phosphate	✓		-	-	-	Research Only
Thermally Activated Charcoal	✓		-	-	-	Research Only
Anaerobic Ammonium Oxidation	✓		-	-	-	Research Only
Electrolytic Treatment	✓		-	-	Ohio University	Research Only
Biosorption by Immobilized Microorganisms		✓	-	-	-	Research Only

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APPENDIX A

Vendors Directly Solicited for Technology

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No.	Company	Inquiry Sent	Website	Contact Information
1	A3 Water Solutions	3 Jan e-mail: We are interested in compact polishing units for tertiary-treated cruise ship wastewater to further remove small concentrations of ammonia and dissolved metals. Might your water treatment technologies be applicable?	http://www.a3-gmbh.com	A3 Water Solutions GmbH, Phone: +49 (0) 209 98099-809, Fax: +49 (0) 209 98099-801
2	ACM	26 Dec e-mail		Mike Warner, 344 Granary Road, Forest Hill, MD 21050,Tel: 410/420-8001, E-mail: sales@acmix.com
3	Alken-Marray	29 Dec e-mail	http://www.alken-murray.com/indusmuni.html	
4	Arcadis Anchorage	19 Dec e-mail 22 Jan called and spoke with Glen 22 Jan sent email to Enric Fernandez	http://www.arcadis-us.com/	Enric Fernandez, 907-277-3770, ernic.fernandez@arcadis-us.com, 420 L Street, Anchorage, AK 99501
5	BioProcessH2O	29 Dec spoke to company receptionist	http://bioprocessh2o.com/site/aboutus/	
6	Bord Na Mona	Evaluated – housing developments. But not app to ships.	http://www.bordnamona.com	
7	CastIon	29 Dec e-mail	http://www.castion.com/	Mark Simon (VP-Process Chemistry), 10 New Bond Street, Worcester, MA 01606, 508-854-1628 ext 302 George Chapas, VP Sales, T 904-522-1531, C 907-607-2084, Gchapas@castion.com Tom Bisson, T 800-628-7528 x321 or 508-854-1628 x321
8	Celgard / Membrana-Charlotte	29 Dec e-mail	http://www.liqui-cel.com/	Andy Hooper, Sales/Tech Support, 13800 South Lakes Drive, Charlotte, NC 28273, Ph: 704-587-8619, Fax: 704-587-8768, andyhooper@celgard.com
9	Electrometals Technologies Limited	6 January e-mail		Kevin Powell, General Manager - Sales & Marketing, kevin@electrometals.com.au, Phone: +61-7- 5526 4663, Fax: +61-7- 5527 0299, A.B.N. 25 000 751 093, Head Office: 28 Commercial Drive, Ashmore Queensland, 4214, Australia
10	Enviroquip	3 Jan e-mail: Good day: We are interested in nitrification enhancement of cruise ship wastewater beyond what is accomplished in traditional MBR. Can your technologies be applied to marine systems?	http://www.Enviroquip.com	Phone 512.834.6000, Fax 512.834.6039, info@enviroquip.com
11	FWC	3 Jan e-mail 22 Jan called and was transferred to a phone that never went to voicemail, just rang forever	http://www.netl.doe.gov/publications/proceedings/03/scr-sncr/Final_Elston.pdf	John Elston and Dileep Karmarkar, Foster Wheeler Power Group, Perryville Corporate Park, Clinton, NJ 08809-4000, (908) 730-4000 - Phone, (908) 713-3210 – Fax, john_elston@fwc.com, dileep_karmarkar@fwc.com
12	GE Infrastructure, Water & Process Technologies	26 Dec e-mail	http://www.zenon.com	Geert-Henk Koops, PhD, Director R&D Membrane Products, T: 905-332-6694 x 213, geet.koops@ge.com, 5316 John Lucas Drive, Burlington, ON L7L 6A6 Canada Bill Roth, GE Water, 480-273-5953, Phoenix, AZ Donna Hartman, M.Eng,P.Eng, Regional Manager & Green Leader, GE Water & Process Technologies, 905-465-3030 x3216, F: 905-465-3050, C: 416-2588210. donna.hartman@ge.com
13	Graver Water	26 Dec e-mail 22 Jan spoke with Bob Applegate	http://www.graver.com/	Robert Appelgate, 750 Walnut Ave, Cranford, NJ 07016, 908-653-4200, rapplegate@graver.com
14	Health Chem/W2 Systems	26 Dec e-mail	www.w2systems.com	Bob O'Dell, 290 Industrial Way, Brisbane, CA 95005, Tel: 800/676-3689, Fax: 415/468-9854, E-mail: bob@w2systems.com Basil Mackrodt, Operations Manager, 46722 Fremont Blvd., Fremont, CA 94538, 408-649-5639, F 408-649-5639, C 408-660-7605, bmackrodt@ionexchangeglobal.com
15	Kinetico Engineered Systems	26 Dec e-mail	www.kinetico.com	10975 Kinsman Rd., P.O. Box 193, Newbury, OH 44065, Tel: 440/564-5397, 800/633-5530, Fax: 440/338-8694, E-mail: esd@kinetico.com
16	Microdyn-Nadir GmbH	3 Jan e-mail	http://www.nadir-filtration.de	
17	Naston	19 Dec e-mail	http://www.naston.co.uk/	
18	Ohio University	19 Dec e-mail, Follow-up e-mail sent 6 Jan 2009		Gerri Botte, botte@ohio.edu, 740-593-9670, Chemical and Biomolecular Engineering, Ohio University Stocker Engineering Center Room 183
19	Parkson	18 Dec E-mail	http://www.parkson.com/	1-800-553-5419
20	Radbout University Nijmegen	Unable to locate e-mail contact	http://www.ru.nl/english/research/research_institutes/vm/institute_for_1/	
21	Remco	19 Dec talked to Bob, e-mail inquiry sent	http://www.remco.com/ix-procs.htm	Bob Musik(?), 4835 Colt Street, Ventura, CA 93003, Ph. 805-658-0600, Fax: 805-658-0667, remcobob@remco.com
22	Royal Haskoning	19 Dec e-mail	http://www.maritime.ws/	Jan Appelman, Project Manager Industrial Water, PO Box 151, 6500 AD NIJMEGEN, The Netherlands, Tel: (011) +31-243-284-881, Fax: (011) +31-243-232-918, j.appelman@royalhaskoning.com Ben Bisseling Tel: +31 243-284-290 Alexander Hendriks, Tel: +31-243-284-978, Mob: +31-61-51-19-257, a.hendriks@royalhaskoning.com
23	Severn Trent Services	18 Dec e-mail	http://www.severntrentservices.com/index.aspx	Brian Riedel, Commercial Manager, Severn Trent De Nora, Phone: 1-281-274-8448, Mobile: 1-832-298-9369, Fax: 1-281-240-6762, E-Mail: briedel@severntrentdenora.com
24	Siemens	18 Dec Talked to David Whelan 3 Jan 2009 talked to Adam Szczesniak	www.water.siemens.com	Adam.Szczesniak@siemens.com, 1-800-593-2063 Nathan Antonneau, PE, Sales Process Engineer, Envirex Products, 1901 South Prairie Avenue, Waukesha, WI 53189, nathan.antonneau@siemens.com, 262-521-8401
25	SnowPure	7 Jan 2009 e-mail	http://www.snowpure.com/edi-products.html	Ron O'Hare, Manager Engineering and Tech Service, Ph 949-240-2188 x111, fax 949-240-2184
26	Solucorp and WITS	19 Dec e-mail 19 Jan called and left voice message 22 Jan spoke with receptionist, left message for engineer	http://www.solucorpltd.com/ , http://www.witsec.net/index.html	250 West Nyack Road, Suite 200, West Byack, NY 10994, T: 845-623-2333
27	THE BERGHOF GROUP	Evaluated 3 Jan	http://www.berghof-gruppe.de	
28	Wastech Controls and Engineering	18 Dec e-mail	http://www.wastechengineering.com/heavy_metal_removal.html	
29	Worldwide Technology, Inc.	Via Norwegian Cruise Lines Randall Fiebrandt		Ed Contreras, 141 Stevens Ave., Unit 10, Oldsmar, FL 34677, T: 813-855-2443, F 813-855-2655

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APPENDIX B

Vendors Responding to Solicitation

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No.	Company	Inquiry Sent	Website	Contact Information
PROPOSALS				
1	CastIon	29 Dec e-mail	http://www.castion.com/	Mark Simon (VP-Process Chemistry), 10 New Bond Street, Worcester, MA 01606, 508-854-1628 ext 302 George Chapas, VP Sales, T 904-522-1531, C 907-607-2084, Gchapas@castion.com Tom Bisson, T 800-628-7528 x321 or 508-854-1628 x321
2	DNV Research & Innovation Materials	Unknown	www.dnv.com/moreondnv/research_innovation/	Dr. Qinglan Wu, Principle Researcher, Det Norske Veritas AS, Veritasveien 1, N-1322 HÅ, vik, Norway, T +47 6757 9510, C +47 97 01 76 80
3	Dow Chemical	3 Jan e-mail: We are interested in compact polishing units for tertiary-treated cruise ship wastewater to further removal small concentrations of ammonia and dissolved metals. Have you supplied your products to manufacturers or end-users for marine applications? It looks like a combination of RO and ion exchange might work.	http://www.dow.com/liquidseps	H. Robert Goltz, Ph.D., Dow Water Solutions, 989-636-2023, hrgoltz@Dow.com
4	Evac Oy	Unknown	www.evac.com	Jari Jokela, Senior Process Specialist, Sinimäentie 14, 02630 Espoo, Finland, T +358 20 763 0239, C +358 50 430 471, F+358 20 763 0222. jari.jokela@evac.zodiac.com
5	Ferrate Treatment Technologies, LLC	13 Jan e-mail blast	www.ferrate.biz	Craig S. Alig, COO, 6432 PineCastle Blvd. Suite C, Orlando, FL 32809, T 407-857-5721, F 407-826-0166, C 321-695-8033, calig@ferrate.biz
6	FilterFlow Technology, Inc.	Unknown		Tod S. Johnson, PO Box 645, Montgomery, TX 77356, C: 832-385-8296, F:936-570-1184
7	GE Infrastructure, Water & Process Technologies	26 Dec e-mail	http://www.zenon.com	Geert-Henk Koops, PhD, Director R&D Membrane Products, T: 905-332-6694 x 213, geet.koops@ge.com, 5316 John Lucas Drive, Burlington, ON L7L 6A6 Canada Bill Roth, GE Water, 480-273-5953, Phoenix, AZ Donna Hartman, M.Eng,P.Eng, Regional Manager & Green Leader, GE Water & Process Technologies, 905-465-3030 x3216, F: 905-465-3050, C: 416-2588210. donna.hartman@ge.com
8	NORAM Engineering	13 Jan e-mail blast	www.noram-eng.com	mzhuang@noram-eng.com
9	Ohio University	19 Dec e-mail, Follow-up e-mail sent 6 Jan 2009		Gerri Botte, botte@ohio.edu, 740-593-9670, Chemical and Biomolecular Engineering, Ohio University Stocker Engineering Center Room 183
10	ROCHEM	Unknown	www.rochem.com	Erick Neuman, Director US Operations, 922 NE 13th Street, Fort Lauderdale, FL 33304, T 305-577-9991, F 305-675-2395
INTERESTED, NO PROPOSAL				
11	Alliance Air US, LLC	13 Jan e-mail blast	www.allianceair.us	Tony Cokola, 269-978-0574, F 269-978-6528, airguy@allianceair.us, Kalamazoo, MI
12	Celgard / Membrana-Charlotte	29 Dec e-mail	http://www.liqui-cel.com/	Andy Hooper, Sales/Tech Support, 13800 South Lakes Drive, Charlotte, NC 28273, Ph: 704-587-8619, Fax: 704-587-8768, andyhooper@celgard.com
13	ENRJ International Group, Ltd.	13 Jan e-mail blast	http://enrjint.com	Dannie B Hudson, Director of Engineering, ENRJ International, 2015 Azalee Lane, Summerville, SC 29483, Phone: 843-873-8332, Fax: 843-873-0036, dhudson@enrjint1.com
14	Enviroquip	3 Jan e-mail: Good day: We are interested in nitrification enhancement of cruise ship wastewater beyond what is accomplished in traditional MBR. Can your technologies be applied to marine systems?	http://www.Enviroquip.com	Phone 512.834.6000, Fax 512.834.6039, info@enviroquip.com
15	Genoil	13 Jan e-mail blast	www.genoil.net	David Lifschultz, Chairman and CEO, T 914-834-7794 dklifschultz@linvestment.com, Paul Costinel, Manager, Oil Water Separation Division, T 403-750-3450, pcostinel@genoil.net, Maria Eugenia Gisondo, PR Mgr, T 403-750-3450, maria@genoil.net
16	Graver Water	26 Dec e-mail 22 Jan spoke with Bob Applegate	http://www.graver.com/	Robert Appelgate, 750 Walnut Ave, Cranford, NJ 07016, 908-653-4200, rapplegate@graver.com
17	Health Chem/W2 Systems	26 Dec e-mail	www.w2systems.com	Bob O'Dell, 290 Industrial Way, Brisbane, CA 95005, Tel: 800/676-3689, Fax: 415/468-9854, E-mail: bob@w2systems.com Basil Mackrodt, Operations Manager, 46722 Fremont Blvd., Fremont, CA 94538, 408-649-5639, F 408-649-5639, C 408-660-7605, bmackrodt@ionexchangeglobal.com
18	Ion Exchange, LLC	Unknown		
19	Remco	19 Dec talked to Bob, e-mail inquiry sent	http://www.remco.com/ix-procs.htm	Bob Musik(?), 4835 Colt Street, Ventura, CA 93003, Ph. 805-658-0600, Fax: 805-658-0667, remcobob@remco.com
20	Royal Haskoning	19 Dec e-mail	http://www.maritime.ws/	Jan Appelman, Project Manager Industrial Water, PO Box 151, 6500 AD NIJMEGEN, The Netherlands, Tel: (011) +31-243-284-881, Fax: (011) +31-243-232-918, j.appelman@royalhaskoning.com Ben Bisseling Tel: +31 243-284-290 Alexander Hendriks, Tel: +31-243-284-978, Mob: +31-61-51-19-257, a.hendriks@royalhaskoning.com

No.	Company	Inquiry Sent	Website	Contact Information
21	SELG & Associates	13 Jan e-mail blast	www.selg.us	Jon Anderson, 22224 Third Ave SE, Bothell, WA 98021, T: 425-487-6059, C: 206-818-8133, F: 425-487-4086
22	Shelton Associates	13 Jan e-mail blast		Mark Shelton, 717-687-0737, marks@sheltonassoc.com, near West Chester, PA
23	Siemens	18 Dec Talked to David Whelan 3 Jan 2009 talked to Adam Szczesniak	www.water.siemens.com	Adam.Szczesniak@siemens.com, 1-800-593-2063 Nathan Antonneau, PE, Sales Process Engineer, Envirex Products, 1901 South Prairie Avenue, Waukesha, WI 53189, nathan.antonneau@siemens.com, 262-521-8401
24	SnowPure	7 Jan 2009 e-mail	http://www.snowpure.com/edi-products.html	Ron O'Hare, Manager Engineering and Tech Service, Ph 949-240-2188 x111, fax 949-240-2184
25	Ulstein Marine Services	via GE	www.ulsteingroup.com	Geir Erik Samnoy, Technical Director, geir.erik.samnoy@ulsteingroup.com, C +47 99 00 28 13
26	URS Corp - Juneau Office / Tryck Nyman Hayes	13 Jan e-mail blast		Christina Anderson, Senior Environmental Planner Mr. Kris Turschmid, 206-438-2343 Carl Ferlauto, PE, 907-463-4916 207 Second Street, Suite 207, Juneau, AK 99801
27	Water Tectonics	13 Jan e-mail blast	www.watertectonics.com	Lisa Dottie, 206-371-1693
28	Worldwide Technology, Inc.	Via Norwegian Cruise Lines Randall Fiebrandt		Ed Contreras, 141 Stevens Ave., Unit 10, Oldsmar, FL 34677, T: 813-855-2443, F 813-855-2655

APPENDIX C

Vendors Supplied Treatment Information

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Wastewater & Chemistry
Recovery Systems for Industry

CASTion Corporation
10 New Bond Street
Worcester, MA 01606
Phone 508-854-1628
800-628-7528
Fax 508-854-1753
www.castion.com

February 6, 2009

Ms. Olga Stewart
OASIS Environmental, Inc.
825 W. 8th Avenue
Anchorage, AK 99501

Tel: (907) 258-4880
Direct: (907) 264-4467
Fax: (907) 258-4033
E-mail: o.stewarrt@oasisenviro.com

Re: Ammonia and Metals Reduction from Treated Waste Water Effluent of Large Cruise Ships for the Alaska DEC Cruise Ship Program

Dear Ms. Stewart:

Per your inquiry, CASTion is pleased to offer this waste water treatment solution proposal for reducing ammonia and heavy metals from treated waste water effluent of large cruise ships for the Alaska DEC Cruise Ship Program. Based upon the requirements provided, approximately 440,000 GPD of treated ship effluent will be further treated shipboard to reduce ammonia and heavy metals from the existing effluent discharge limits to meet the following new limits to be enforced beginning in 2010:

- 2.9 mg/liter Ammonia
- 8.2 μg/liter Nickel
- 3.1 μg/liter Copper
- 81.0 μg/liter Zinc

The recommended treatment method to meet these stringent requirements involves the utilization of CASTion's core, proprietary Reverse Controlled Atmosphere Separation Technology (RCAST®) in conjunction with ion exchange technology. CASTion's unique, proprietary Ammonia Recovery Process (ARP®) uses Reverse Controlled Atmosphere Separation Technology (RCAST®) as the primary treatment method to separate ammonia from the wastewater and chemically convert it to ammonium sulfate. The RCAST® system is combined with ion exchange (IX) as a final polishing step to remove most of the remaining ammonia. The ARP® technology is an effective and inexpensive alternative to more expensive enhanced biological nitrogen removal processes and it has significant benefits as a treatment technology including lower greenhouse gases, lower energy consumption and better wastewater treatment plant operating efficiencies. Selective ion exchange is employed to reduce the metals to the trace levels in the effluent as required.

The attached Figure 1 depicts the basic block flow diagram providing an overview of the proposed wastewater treatment process system and is described in the following:

- Effluent from the existing wastewater treatment system is pre-filtered through a multi-media filter to remove the bulk of particulate matter, periodically returning backwash water to the existing treatment system. This step may not be required for higher quality effluents as from MBR based treatment systems.

- The multi-media filtrate is pre-filtered further through cartridge filters as to remove any remaining suspended particulates.

- The cartridge filters effluent is passed through a softener unit to remove hardness, regenerating the resin with a sodium chloride solution as necessary.

- The softened effluent is processed by the RCAST® unit where ammonia is separated from the wastewater under vacuum as an overheads vapor and then recovered as an ammonium sulfate solution by a sulfuric acid injector that also generates the vacuum required for ammonia separation.

- The recovered ammonium sulfate solution is concentrated approaching the solubility limit by the CAST® flash vacuum distillation unit, periodically returning distillate to the existing treatment system.

- The concentrated ammonium sulfate solution is pumped to storage until it can be hauled off dockside.

- The ammonia reduced wastewater bottoms from the RCAST® unit is pH adjusted to an acidic level to convert ammonia to ionic ammonium and processed through cation exchange columns to remove ammonium to meet the effluent discharge limit.

- The cation exchange columns are periodically regenerated with sodium hydroxide, feeding the spent, ammonia-enriched regenerant along with the softener effluent to the RCAST® unit for ammonia recovery.

- The ammonium cation exchanger effluent is processed by a selective metals ion exchange unit to meet the effluent discharge limits, replacing and/or regenerating the spent resin dockside.

- The ammonium cation exchanger effluent is ph adjusted and discharged accordingly.

Some distinct advantages of the CASTion approach include the following:

- Ammonia reduction is a completely non-biological process
- Haul-off solution volumes are highly concentrated and minimized
- Haul-off ammonium sulfate solution has value and can be sold

Attached for your review and consideration is the following literature:

- CASTion Capabilities Brochure
- Ammonia Recovery Process (ARP) Fly Sheet

The projected price for this wastewater treatment system is estimated to be in the range of $3 M to $5 M for equipment only, excluding installation and startup, and depends upon the specific requirements of the client. An engineering pilot test study would be required to complete the final design.

We look forward to working with OASIS Environmental, Inc. on this project and are available for technical or financial questions.

Sincerely,

Thomas Bisson
Sr. Applications Engineer
CASTion Corporation
10 New Bond Street
Worcester, MA
01606 USA

Tel: (508) 854-1628 x321
Tel: (800) 628-7528
Fax: (508) 854-1753
E-mail: tbisson@castion.com

George Chapas
Vice President, Sales
CASTion Corporation
10 New Bond Street
Worcester, MA
01606 USA

Tel: 904-522-1531
Tel: 800-628-7528 x330
Fax: (508) 854-1753
e-mail: gchapas@castion.com

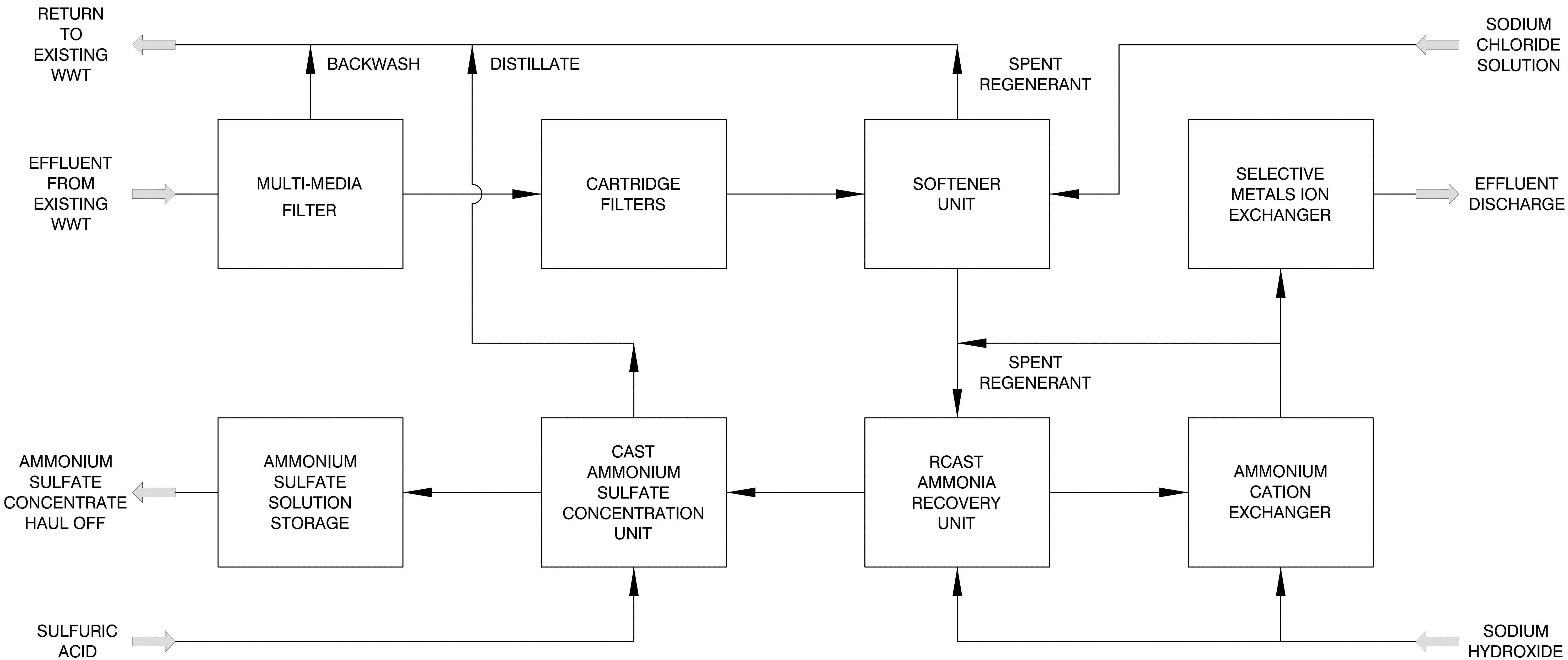


FIGURE 1 - CRUISE SHIP WASTEWATER TREATMENT BLOCK FLOW DIAGRAM
AMMONIA & HEAVY METALS REDUCTION

ThermoEnergy Corporation

Ammonia Recovery Process (ARP)

Cleaner, Safer Water, this is the goal of every community. ThermoEnergy Corporation has risen to meet this need with its Ammonia Recovery Technology. This patented process has received several awards for innovation. Its unique approach establishes a new standard for cost-effective, energy efficient, compact treatment. Utilizing a unique design it captures the ammonia, which is then converted into a commercial grade, ammonium sulfate fertilizer.

The compact size of the ARP process allows it to be retrofit into existing wastewater treatment plants, making it the perfect solution for plants seeking treatment in already limited spaces. A 0.5 mgd facility can be placed in a 6000 sq ft area. The removal of ammonia can decrease the aeration load on an existing plant and not require use of existing capacity for anaerobic nitrogen removal steps. ARP produces neither biological nor chemical sludge and is designed to produce no odor, therefore eliminating the need for additional treatment.

HOW IT WORKS

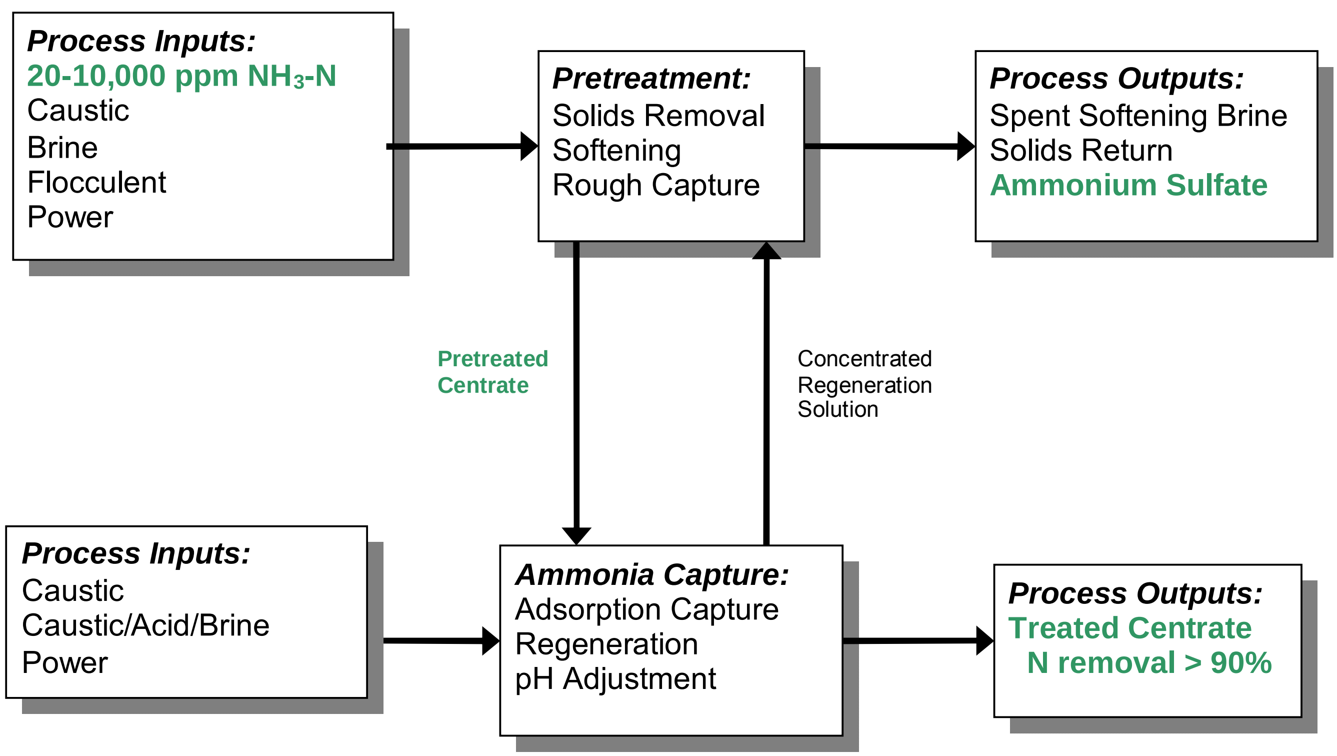
To begin the ARP Process, the waste water is conditioned so that neither suspended solids nor precipitates can reach the ammonia removal operations. If the ammonia concentration is high, vacuum stripping is used to capture the ammonia that would readily volatilize. If effluent concentrations of below 100 ppm are required, the wastewater with 200 ppm ammonia-nitrogen or less is then input to an industrial grade ion exchange resin which selectively adsorbs the ammonia. The adsorption columns are regenerated using either a brine or caustic. The regeneration solution is used repeatedly, where the ammonia concentration builds up to several thousand ppm. The spent ammonia-laden regeneration solution is stripped of ammonia with vacuum distillation to produce a commercial-grade (about 40%) solution of ammonium sulfate.

Benefits:

- ***Cost effective***
- ***Small footprint***
- ***Uses less energy than biological systems***
- ***Modular construction***
- ***Recoverable and recyclable bi-products***
- ***No Sludge generation***

The ARP Process is extremely effective in removing ammonia from aqueous streams. Traditional gas-liquid stripping technologies have intrinsic mass transfer limitations that cause operating costs to increase dramatically as the ammonia concentration decreases. The ARP Process has demonstrated reduction of centrate ammonia concentrations to undetectable levels. Consequently, unlike steam and water stripping, the ARP Process removes ammonia at both dilute and concentrated levels at lower energy requirements. Typically, no chemical addition to the discharge stream is required. However, depending on the plant, it may be desirable to increase the pH of the low ammonia centrate return stream by a small caustic addition.

ARP Technology can selectively remove ammonia based on specific waste characteristics, tailoring the physical aspects of the process to individual operations and facilities. This makes the process a good fit for most systems. The ARP Process is the perfect, cost effective choice for ammonia removal.



Nitrification in Biofilm-MBR Process for Shipboard Wastewater Treatment

Cheng Sun
**NTNU - Norwegian University of Science and Technology, Department of Hydraulic and Environmental Engineering, S.P. Andersensvei 5, N-7491 Trondheim, Norway*
(E-mail: cheng.sun@ntnu.no Tlf: +47 7355 0375, Fax: +47 7459 1298)

Introduction

Det Norske Veritas AS, together with the Norwegian University of Science and Technology (NTNU) and KeraNor As, have been developing a concept for an integrated shipboard wastewater treatment system. The work was carried out within the MEMSHIP project with financial support from the Norwegian Research Council.

An advanced moving-bed biofilm bioreactor unit in combination with ceramic membrane has been developed and tested at Norwegian University of Science and Technology. The system is capable of handling a range of wastewater streams (black water, grey water and bilge water) in one treatment unit. As part of our MEMSHIP project we have tested the effect of inlet oil concentration and salinity on ammonia removal. This paper summarises our experimental results and shows the capability of the system in removal of ammonia in shipboard wastewater.

1. Background

Ammonia exists in two forms in the water: NH_3 and NH_4^+. Together, these two forms of ammonia are called total ammonia nitrogen. NH_3 is the principal form of toxic ammonia. It has been reported toxic to fresh water organisms at concentrations ranging from 0.53 to 22.8 mg/L. Therefore, the removal of total ammonia nitrogen by nitrification is important and necessary for shipboard wastewater treatment system.

Nitrification is the biological oxidation of ammonia to nitrate via nitrite (Equation 1, 2) by two groups of chemolithotrophic bacteria, ammonia oxidizers and nitrite oxidizers; both groups have low specific growth rates and are very sensitive to environmental change [1]. In this short report, the nitrification characteristic of biofilm-MBR process for shipboard wastewater treatment is presented.

$$NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^- \qquad \text{Equation 1}$$

$$NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e^- \qquad \text{Equation 2}$$

2. Methods

The biofilm–MBR system is a combination of the moving-bed-biofilm reactor (MBBR) with membrane technology as illustrated in Figure 1. The treatment train consists of two stages/reactors, the biofilm reactor (MBBR) followed by a membrane filtration unit. The biofilm reactor removes the soluble organic matter and ammonia nitrogen from the wastewater, while a membrane unit separates the biomass, particulates and colloidal matters from the biofilm effluent. By dividing these two reactors into separate entities each process step can be designed and operated at optimal conditions.

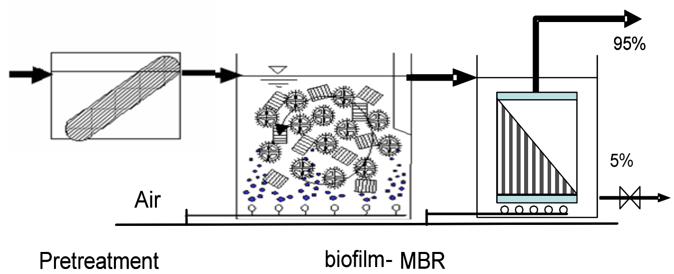


Figure 1. Concept of the biofilm-MBR process

3. Results and discusses

As for all biofilm reactor, nitrification rates are influenced by the organic load, the dissolved oxygen (DO) concentration in the reactor, the total ammonium nitrogen concentration, the temperature, the pH and alkalinity, and the previous history of the biofilm [2]. High oil concentration and salinity fluctuation are the nature of shipboard wastewater, which may impact the nitrification in biofilm-MBR process.

3.1 The effect of inlet oil concentration on ammonia removal

Figure 1 presents the nitrification rate showed by ammonium nitrogen removal. It is shown that the nitrification rate was close to a first-order function of the oxygen concentration in the reactor. Due to diffusion effects in biofilm, nitrification rates are very dependent on ammonium nitrogen concentration and DO concentrations. Normally, oxygen will be the rate limiting substrate at high ammonium nitrogen concentrations, and ammonium nitrogen will be the rate limiting substrate at low ammonium nitrogen concentrations. In shipboard wastewater investigated in this study, the average concentration of ammonium nitrogen is 31 mg/L, so the DO will be the limiting substrate. The increase of inlet organic load, by increasing oil concentration in the feed, increased the consuming of dissolved oxygen (DO). Therefore, Do has the opposite relation with the inlet oil concentration. Increasing inlet oil concentration has a decreasing on nitrification rate, observed on Figure 2.

Figure 3 shows the effect of Hydraulic Retention Time (HRT) on nitrification. Longer HRT (8 hours) results lower organic load and higher Do concentration in biofilm reactor, therefore a higher NH_4-N removal rate is observed on Figure 3.

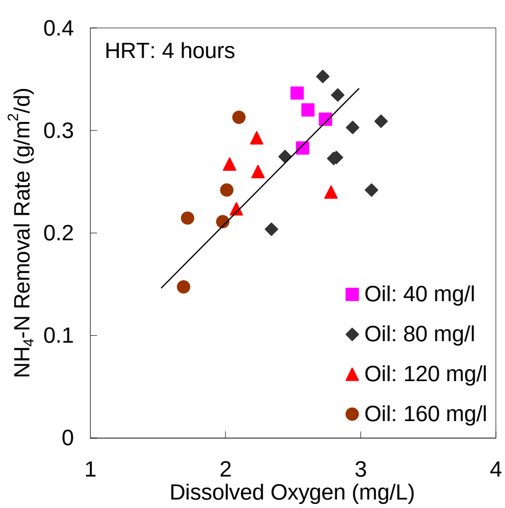


Figure 2. Inlet oil load effect on ammonia nitrogen removal

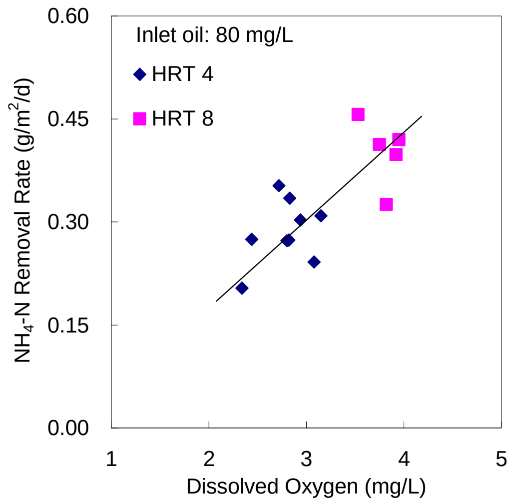


Figure 3. HRT effect on ammonia nitrogen removal

3.2 The effect of salinity on ammonia removal

Salinity is one of the major characters of shipboard wastewater. High or fluctuations in salt concentration may present a challenge to the biological treatment stage, especially nitrification process. Figure 3 shows that the average ammonia nitrogen removal rate is 0.40 $g/m^2/d$ for fresh water (0 g/L NaCl) while less ammonia removal rates (0.32-0.33 $g/m^2/d$) were observed under high salinity conditions (5 g/L, 10 g/L and 15 g/L). The nitrification rate of saline wastewater tested was around 81 % of fresh wastewater in experiments. It is well known that high and greatly fluctuating saline concentrations could inhibit nitrification process [3-6]. On the other hand, nitrifiers has low growth rate and the nitrification capacity of biofilm was hard to resume completely in 8 days testing duration of each salinity concentration. The longer experiment duration is necessary for microorganism acclimation in future work.

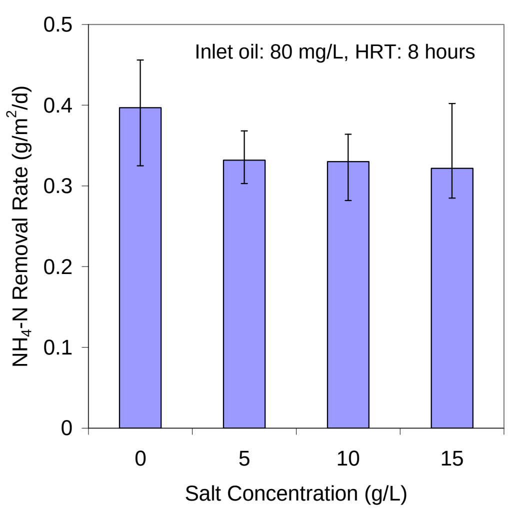


Figure 3. Salinity effect on NH_4-N removal

4. Conclusion

- The biofilm-MBR process can be applied for ammonia nitrogen removal for shipboard wastewater treatment;
- Increasing inlet oil concentration has a decreasing on nitrification rate;
- Nitrification can be improved by increasing HRT;
- In 8 days testing duration, high salinities have negative effect on ammonia nitrogen removal.

Reference

1. Prosser, J.I., *Nitrification, Special Publication of the Society for General Microbiology*. Vol. 20. 1986: Oxford IRL Press, Oxford.
2. Hem, L.J., B. Rusten, and H. Ødegaard, *Nitrification in a moving bed biofilm reactor*. Water Research, 1994. **28**(6): p. 1425-1433.
3. Moussa, M.S., et al., *Long term effects of salt on activity, population structure and floc characteristics in enriched bacterial cultures of nitrifiers.* Water Research, 2006. **40**(7): p. 1377-1388.
4. Campos, J.L., et al., *Nitrification in saline wastewater with high ammonia concentration in an activated sludge unit.* Water Research, 2002. **36**(10): p. 2555-2560.
5. Catalan-Sakairi, M.A.B., P.C. Wang, and M. Matsumura, *Nitrification performance of marine nitrifiers immobilized in polyester- and macro-porous cellulose carriers.* Journal of Fermentation and Bioengineering, 1997. **84**(6): p. 563-571.
6. Uygur, A. and F. KargI, *Salt inhibition on biological nutrient removal from saline wastewater in a sequencing batch reactor.* Enzyme and Microbial Technology, 2004. **34**(3-4): p. 313-318.

SYSTEM SPECIFICATION

EVAC OY

ADVANCED WASTEWATER TREATMENT PLANT

Dated 01st February 2009

The Alaska Department of Environmental Conservation
Request for Effluent Ammonia and Metal Removal Technology

INTRODUCTION

Evac is an international company that forms part of the French Zodiac Marine & Pool Group. Evac designs, manufactures and markets environmentally friendly wet and dry waste collection and treatment systems for the shipbuilding industry.

Skilled personnel, professional design and high-quality technical solutions have facilitated continuous growth, both in turnover and market share. In the 2006/2007 fiscal year, Evac Marine had a turnover of EUR 42 million.

Evac Ltd. is responsible for the worldwide Marine operations supported by other Evac companies and representatives in more than 40 countries. Evac Ltd. has ISO 9001:2000 quality certification and an ISO 14001:2004 environmental system certificate.

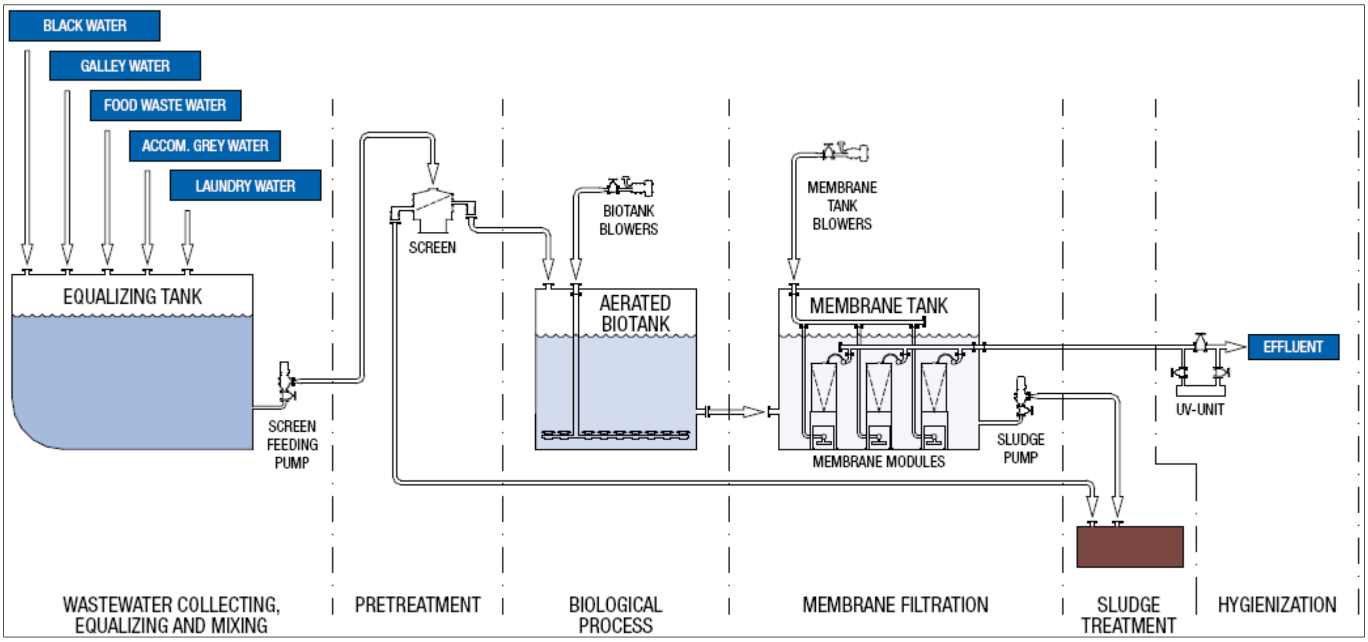
Evac Marine is the market leader in the marine field, with more than 30 years of experience in the business. We have over 9,500 references from sailing boats to large luxury cruise liners. Our premises are located in Espoo/Finland, Rockford/USA, Paris/France, Shanghai/China and Notodden/Norway.

Further information about our company is available on our website at www.evac.com.

EVAC OY - Sinimäentie 14 - FIN-02630 Espoo - Finland
Tel.: +358 20 7630 200 Fax : +358 20 7630 222 and +358 20 7630 233
flastname@evac.zodiac.com
www.evac.com www.zodiac-marine-pool.com

1. GENERAL PRESENTATION OF THE EVAC MBR PROCESS

The Evac MBR is a single stream Advanced Wastewater 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.



Basic principle of the Evac MBR single stream 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. Kubota is the pioneer of membrane treatment developed directly for waste water purposes. Evac process knowledge is supported by companies Kubota and COPA (ex. MBR technology) having the longest knowhow in the world on MBR municipal wastewater treatment. There exist also a lot of published information on tests done by company Qinetic on a UK frigate on the Kubota process supported by COPA on one of the oldest MBR installations onboard a ship. Evac has three installed marine AWT references as an evidence of proven technology. The best reference is Celebrity Xpedition cruise liner. Evac MBR system has been in operation over one year onboard Xpedition with perfect effluent quality and with very high operational reliability.

Evac MBR – Principles of operation:
The Evac MBR is an advanced wastewater treatment process where all the wastewater streams are treated to meet all the current and future standards. The MBR tank layout is presented in Appendix 1.

Wastewater Collecting, Equalizing and Mixing:
Knowledge on the ships operational profile, source and amount of wastewater and the collection methods of the waste water streams, among others, is the key to the most optimum process. Wastewater is produced unequally during the day. The best results can be achieved by securing a constant feed to the treatment plant. The Evac MBR is a modular design and the mixing/equalizing can be done either in ships holding tanks or in a specialized collecting/ equalizing/mixing tank supplied by Evac.

Pretreatment by screens:
Foreign objects (towels, rubber gloves, rings etc.) not belonging in wastewater have to be removed in the front end of the process. Efficient pre-treatment by screens also reduces organic loading, increasing the treatment efficiency. The Evac MBR screens are supplied with mesh sizes between 100-3000µm depending on the vessel type.

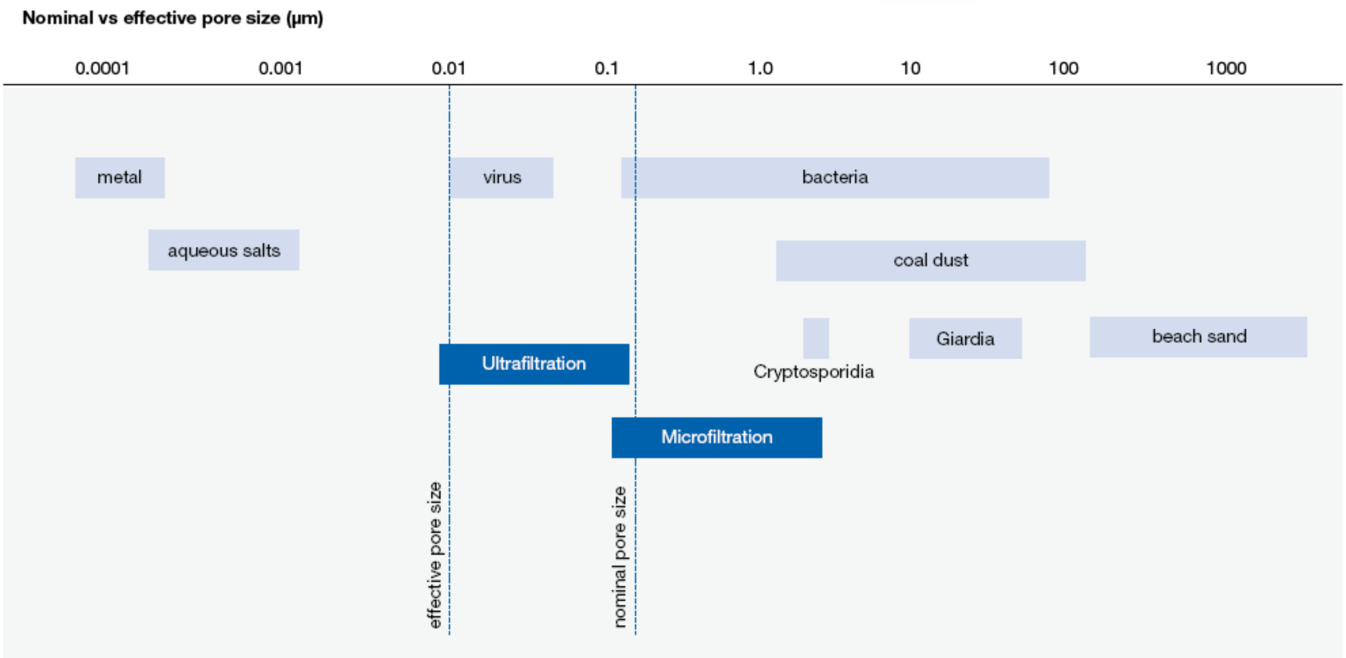
Biological process:
Soluble organic waste cannot be removed from the wastewater purely by mechanical filtration. In a biological wastewater treatment process, organics are turned into carbon dioxide, water and biomass (MLSS). The Evac MBR is designed to operate on elevated concentrations of biomass. Oxygen supply for the biomass is secured through air diffusers and the oxygen and MLSS concentrations are constantly monitored through automation.

Membrane filtration:
Clean water is separated from the biomass by membrane filtration. A membrane filter is a physical barrier, securing treated water without solids. The lifetime of the Kubota submerged membranes is between 7 to 10 years, or even longer. The Evac MBR does not require any back-flushing or constant chemical cleaning, making it the most economic and maintenance-friendly membrane solution. Pressure difference for the membrane filtration is created either by a slight vacuum or by a gravity head. Treated water does not need any further disinfection and can be discharged directly into the sea.

EVAC OY - Sinimäentie 14 - FIN-02630 Espoo - Finland
Tel.: +358 20 7630 200 Fax : +358 20 7630 222 and +358 20 7630 233
flastname@evac.zodiac.com
www.evac.com www.zodiac-marine-pool.com

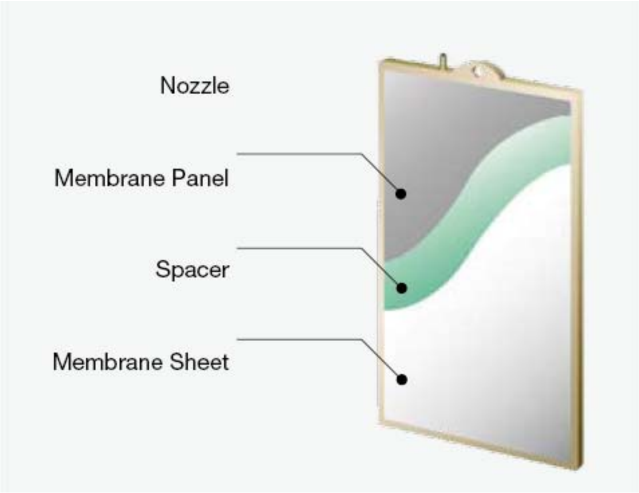
Sludge:
All bioprocesses produce surplus sludge as part of the biomass is removed from the process. The biomass concentration in the Evac MBR is constantly monitored and sludge removal is automated. Sludge removal rates are between 1-3% from the wastewater flow. Evac can offer several options for sludge treatment. Please contact Evac for further details!

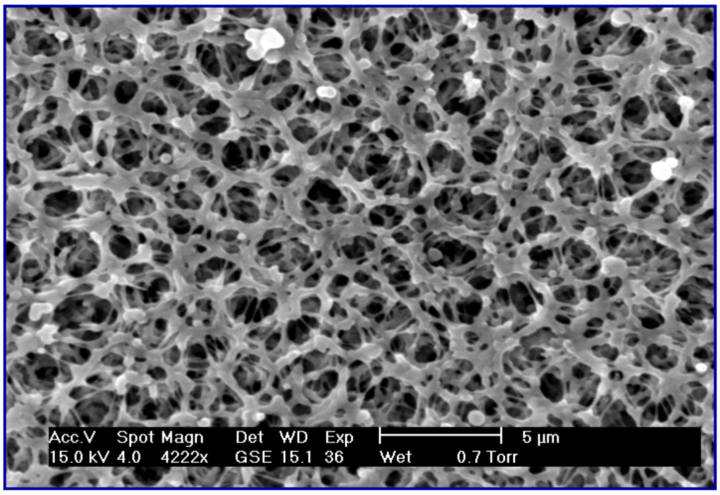
High quality principle by Kubota
The KUBOTA Submerged Membrane Unit® has been developed to treat wastewater to a very high quality with low environmental impact. Operating as a solid-liquid separation device using microfiltration membranes, it is very compact and yet enables you to get high quality effluent. There are various applications such as sewage treatment, industrial wastewater treatment and small household package plants



Nominal and effective pore size of Kubota technology

Structure of the KUBOTA Submerged Membrane Unit®
The Membrane Unit consists of a Membrane Case and a Diffuser Case. The Membrane Case accommodates multiple Membrane Cartridges, which are connected to a manifold with transparent Tubes. The Diffuser Case has a Diffuser Pipe inside. You can pull out each Membrane Cartridge for maintenance. Structure of the Membrane Cartridge The membrane sheets are ultrasonic-welded on both surfaces of the membrane panel. They are made from chlorinated polyethylene with nominal pore size of 0.4μm. Treated water permeates through the membrane sheets and internal spacers to come out via the Nozzle.





A picture of one membrane sheet and typical membrane surface

Features of the KUBOTA Submerged Membrane Unit®
Permeate without solids The membrane separation system removes not only solids but also substances difficult to biodegrade such as detergent, by taking advantage of its longer Sludge Retention Time (SRT). Moreover, nutrients such as nitrogen and phosphorus can be treated, which enables the treated water to be reused.

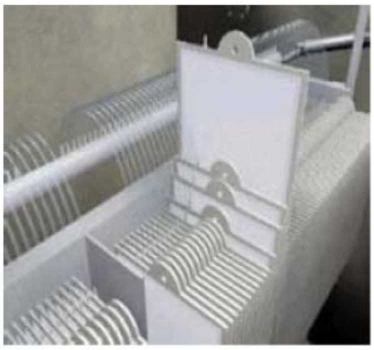
Simple Maintenance
Volume control of return sludge or microscopic observation of the micro-organism is not necessary. All that is required is control of trans-membrane pressure and basic water quality analysis, both of which you can easily learn. Telemetry can be used to remotely control and check the operational conditions.

Energy Conservative Operation
The KUBOTA Submerged Membrane Unit® System is designed for energy conservation. Aeration plays two roles in order to save energy; oxygen supply for biological treatment and cleaning of membrane surface with turbulent flow.

Remarkably Small Footprint
The KUBOTA Submerged Membrane Unit® is installed in an aeration tank. Since it performs high-concentration activated sludge treatment, no settling tank or sludge thickening tank is required. The size of the aeration tank is also minimized. Consequently, the whole treatment system becomes simple and compact.

Copa MBR Technology

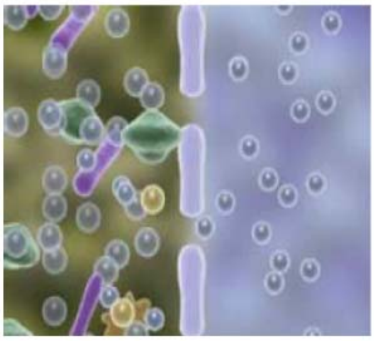
A typical Evac MBR Sewage Treatment Plant will include a series of Kubota Flat Sheet Membranes which are housed in a purpose made stainless steel (AISI 316) rack fitted to the floor of MBR Tank.



Kubota Flat Sheet Membranes

The permeate from the Copa MBR Technology® process is typically:

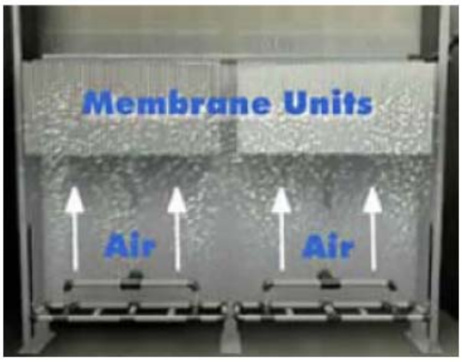
- TSS: 5 to 2mg/litre on 95 percentile basis.
- Turbidity – 0.4 NTU
- BOD: 7 – 10mgl
- Coliform: 5 Log Removal of Faecal Coliform
- Free of pathogens, viruses and bacteria;
- Compliant with IMO, EU MED & Alaskan standards



The membrane operates in the ultrafiltration range

A series of membranes are submerged within an activated sludge treatment tank. The aeration necessary for treatment of the liquors also generates an upward cross-flow over the membranes; essential to keep fouling of the filtration surface to a minimum. An advantage of this design is that the membrane panels are securely retained and do not touch or abrade each other whilst the units also act as a flume to ensure effective tank mixing and even distribution of the biomass.

This tank has four membrane units



Membrane units are aerated by a coarse bubble system

EVAC OY - Sinimäentie 14 - FIN-02630 Espoo - Finland
Tel.: +358 20 7630 200 Fax : +358 20 7630 222 and +358 20 7630 233
flastname@evac.zodiac.com
www.evac.com www.zodiac-marine-pool.com

2. DESCRIPTION OF DESIGN DATA AND PERFORMANCE

The Evac Advanced wastewater treatment process is designed for 5020 people fulfilling the performance criteria required by IMO and Alaska permit limits. The system is designed for a total flow of 250 liters/person/day onboard with a design margin of 1.30 for organic load. In terms of hydraulic loading, the membranes are designed for flux of 0.52 m^3/m^2/day, but membranes can filtrate peak flow of 1.1 m^3/m^2/day for several days. Thereby, half of the membrane capacity can be maintained whilst the other half can take the full flow to treatment without decreasing the membrane life time.

The Evac process is calculated for following flow rates:

Black:	5020 people * 17 liters/day = 85 m^3/day
Galley:	5020 people * 50 liters/day = 251 m^3/day
Food waste:	5020 people * 3 liters/day = 15 m^3/day
Accommodation grey water:	5020 people * 155 liters = 778 m^3/day
Laundry water:	5020 people * 25 liters = 125 m^3/day

⇨ TOTAL daily nominal flow = 1255 m^3/day

	Evac MBR AWP for ADEC study												
	5020	passanger cruise ship											
	design values:								Kubota EK400 men		320	m^2/module	
	l/pax/d								Kubota ES200 men		160	m^2/module	
Black wat	17								**Kubota ES150 mei**		**120**	**m^2/modu**	**20**
Galley wa	50								Kubota FS75 memb		60	m^2/module	
Food wat	3								Kubota FS50 memb		40	m^2/module	
Laundry v	25							**After pretreatment**					
Grey wate	155							**with 0.29+0.1 mm sieves**		Design flux	0.55	m^3/m^2/day	
Total:	250				**30**		**%**	**BOD_5 reduction**					
								Reduced			**Gravity Flow**		
	Flow	**BOD_5**	**BOD_5**	**TSS**	**TSS**	**N**	**NH3-N**	**BOD_5**	**Membran**	**ES150**	**=>Flux**	**Max. flux**	
	m^3/day	gO_2/l	kgO_2/day	g/l	kg/day	gN/l	kg/day	kgO_2/day	m^2	modules	(m/d)	(m/d)	
Black wat	85.3	2.5	213.35	1.5	128.01	0.2	17.07	213.35					
Galley wa	251.0	2.5	627.50	2.5	627.5	0.125	31.38	627.50					
Food wat	15.1	30.0	451.80	20	301.2	0.15	2.26	451.80					
Laundry v	125.5	0.30	37.65	0.30	37.65	0.01	1.26	37.65					
Grey wate	778.1	0.20	155.62	0.10	77.81	0.013	10.12	155.62					
Sum:	**1255.0**		**1485.9**		**586.1**		**31.0**	**1040.1**	**2281.8**	**19.02**	**0.523**	**1.10**	

Daily sludge production:

- Bioprocess 27 m^3 (1.6 %-TS)

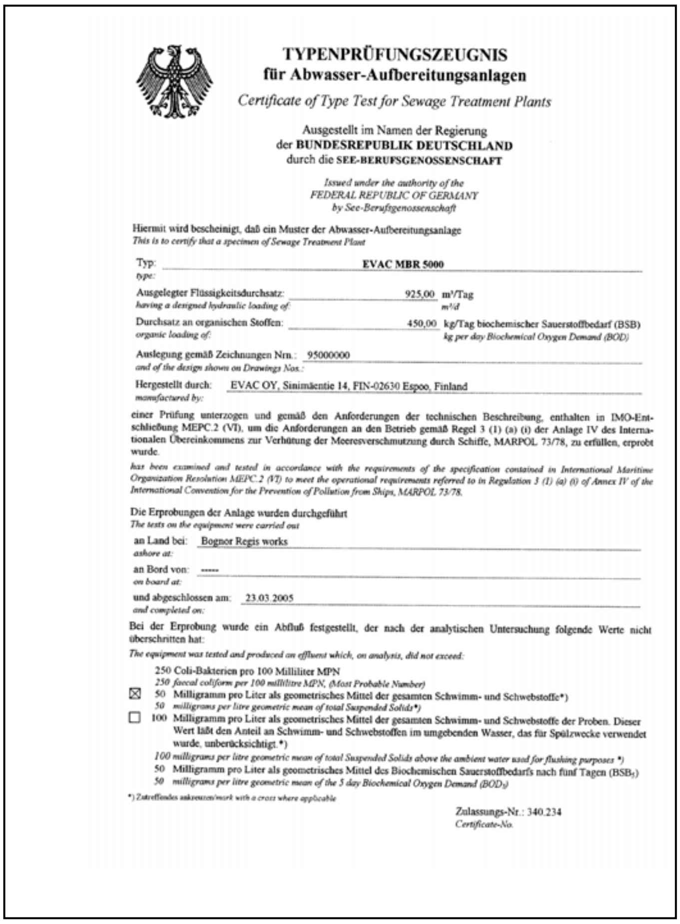
- Pretreatment 12.5 m^3 (4.0 %-TS)

Total 39.5 m^3 (2.4 %-TS)

The system meets all requirements of MARPOL Annex IV, V and it has also passed successfully IMO MEPC Resolution 159(55) 10 days test. In addition, the effluent as discharged initially from the system or overboard from the holding tanks shall not exceed the below figures:

BOD5	< 15 mg/l
TSS	< 15 mg/l
Fecal Coliforms	< 10 CFU/100ml
Residual Chlorine	< 0.01mg/l
pH	6 – 8.5

Additionally, Evac MBR AWP process is also readily nitrifying process owing to the long sludge age (>12 days). Thereby, the effluent quality will also comply the ammonia limit of 2.9 mg/l set by the new requirement by State of Alaska. For details, see in App. 2 process calculations.



TYPENPRÜFUNGSZEUGNIS
für Abwasser-Aufbereitungsanlagen
Certificate of Type Test for Sewage Treatment Plants

Ausgestellt im Namen der Regierung
der **BUNDESREPUBLIK DEUTSCHLAND**
durch die **SEE-BERUFSGENOSSENSCHAFT**

Issued under the authority of the
FEDERAL REPUBLIC OF GERMANY
by See-Berufsgenossenschaft

Hiermit wird bescheinigt, daß ein Muster der Abwasser-Aufbereitungsanlage
This is to certify that a specimen of Sewage Treatment Plant

Typ: **EVAC MBR 5000**
type:

Ausgelegter Flüssigkeitsdurchsatz: 925,00 m^3/Tag
having a designed hydraulic loading of: m^3/d

Durchsatz an organischen Stoffen: 450,00 kg/Tag biochemischer Sauerstoffbedarf (BSB)
organic loading of: *kg per day Biochemical Oxygen Demand (BOD)*

Auslegung gemäß Zeichnungen Nrn.: 95000000
and of the design shown on Drawings Nos.:

Hergestellt durch: EVAC OY, Sinimäentie 14, FIN-02630 Espoo, Finland
manufactured by:

einer Prüfung unterzogen und gemäß den Anforderungen der technischen Beschreibung, enthalten in IMO-Entschließung MEPC.2 (VI), um die Anforderungen an den Betrieb gemäß Regel 3 (1) (a) (i) der Anlage IV des Internationalen Übereinkommens zur Verhütung der Meeresverschmutzung durch Schiffe, MARPOL 73/78, zu erfüllen, erprobt wurde.

has been examined and tested in accordance with the requirements of the specification contained in International Maritime Organization Resolution MEPC.2 (VI) to meet the operational requirements referred to in Regulation 3 (1) (a) (i) of Annex IV of the International Convention for the Prevention of Pollution from Ships, MARPOL 73/78.

Die Erprobungen der Anlage wurden durchgeführt
The tests on the equipment were carried out

an Land bei: Bognor Regis works
ashore at:

an Bord von: -----
on board at:

und abgeschlossen am: 23.03.2005
and completed on:

Bei der Erprobung wurde ein Abfluß festgestellt, der nach der analytischen Untersuchung folgende Werte nicht überschritten hat:
The equipment was tested and produced an effluent which, on analysis, did not exceed:

250 Coli-Bakterien pro 100 Milliliter MPN
250 faecal coliform per 100 millilitre MPN, (Most Probable Number)

☒ 50 Milligramm pro Liter als geometrisches Mittel der gesamten Schwimm- und Schwebstoffe*)
50 milligrams per litre geometric mean of total Suspended Solids)*

☐ 100 Milligramm pro Liter als geometrisches Mittel der gesamten Schwimm- und Schwebstoffe der Proben. Dieser Wert läßt den Anteil an Schwimm- und Schwebstoffen im umgebenden Wasser, das für Spülzwecke verwendet wurde, unberücksichtigt.*)
*100 milligrams per litre geometric mean of total Suspended Solids above the ambient water used for flushing purposes *)*

50 Milligramm pro Liter als geometrisches Mittel des Biochemischen Sauerstoffbedarfs nach fünf Tagen (BSB_5)
50 milligrams per litre geometric mean of the 5 day Biochemical Oxygen Demand (BOD_5)

*) Zutreffendes ankreuzen/*mark with a cross where applicable*

Zulassungs-Nr.: 340.234
Certificate-No.

Evac MBR certification: IMO Marpol EC certificate

3. The metal (zinc, copper, nickel) removal alternatives from Evac-Zodiac MBR effluent

The concentrations that are used to design the metal removal in MBR effluent are shown in Table 1. The initial values originate from latest EPA Cruise Ship Discharge Assessment Report (Dec. 28, 2008). Table shows also the target concentrations and corresponding removal rates.

TABLE 1. Metal (zinc, copper, nickel) concentrations in water, target concentrations and corresponding removal rates

Metal	Initial concentration mg/l	Target concentration mg/l	Removal rate %
Zinc	1.610	0.081	95 %
Copper	0.195	0.0031	98 %
Nickel	0.0182	0.0082	55 %

(please note that initial concentrations may be significantly lower in some locations, e.g. values for zinc, copper, and nickel of <0.1, <0.1, and <0.06, respectively are measure also)

The estimated maximum flow through the is taken to be 1580 m3/d, which corresponds to the metal loading rates of 2.55 kg/d zinc, 0.31 kg/d copper, and 0.03 kg/d nickel.

i) Integrated precipitation of metals in MBR

Different chemicals are used to remove metals from wastewaters. For example, hydrogen sulfide reacts with metals forming metal sulfides that are not soluble and subsequently removable in the MBR process. Other commercial chemicals for heavy metal removal exist today also. Advanced commercial chemical agents are more preferred to use in integrated solution than hydrogen sulfide as it will react with oxygen forming sulfate.

Integrated precipitation is apparently the most cost-efficient method to produce required efficiency in the MBR systems as it demands only limited amount of additional instruments, pumps and storage tanks to operate. Incineration of excess sludge from the MBR integrated with chemical precipitation needs to be verified that no harmful compounds or technical issues rise during the further sludge destruction. However, as there is without any doubt high variations of metal concentrations in the wastewater streams in different locations, no conclusions of possible unwanted effects of precipitated metals in sludge can be withdrawn.

The effluent piping systems should be non-metallic in order to prevent the metal desorption and increased effluent values in the discharge.

The integrated precipitation of metals into the sludge in MBR systems is considered the most sustainable and cost-efficient method. Even though reverse osmosis would be most secure method to remove metals, but could probably produce retentate with high water content, which would not be sent to incineration but would probably be overboarded. Use of separate chemical precipitation, e.g. with hydrogen sulfide, caustic pH regulation or such a system, would probably also lead to this consequence as well.

Chemicals such as MetClear or PolyFloc, would be used in the MBR process so that they bind the chemicals into larger compounds that are possible to retain inside the bioreactor and subsequently are discharged from the process together with biosludge. To avoid sea contamination, the sludge should be dewatered and incinerated. Evac Oy has not yet any commercial references in precipitation of these metals and thereby, onboard testing needs to be carried out to verify the needed capacity in precipation

Operational costs would probably be in order of 10-30 cent/m^3, depending on the cost and usage of the chemical.

4. PRICE

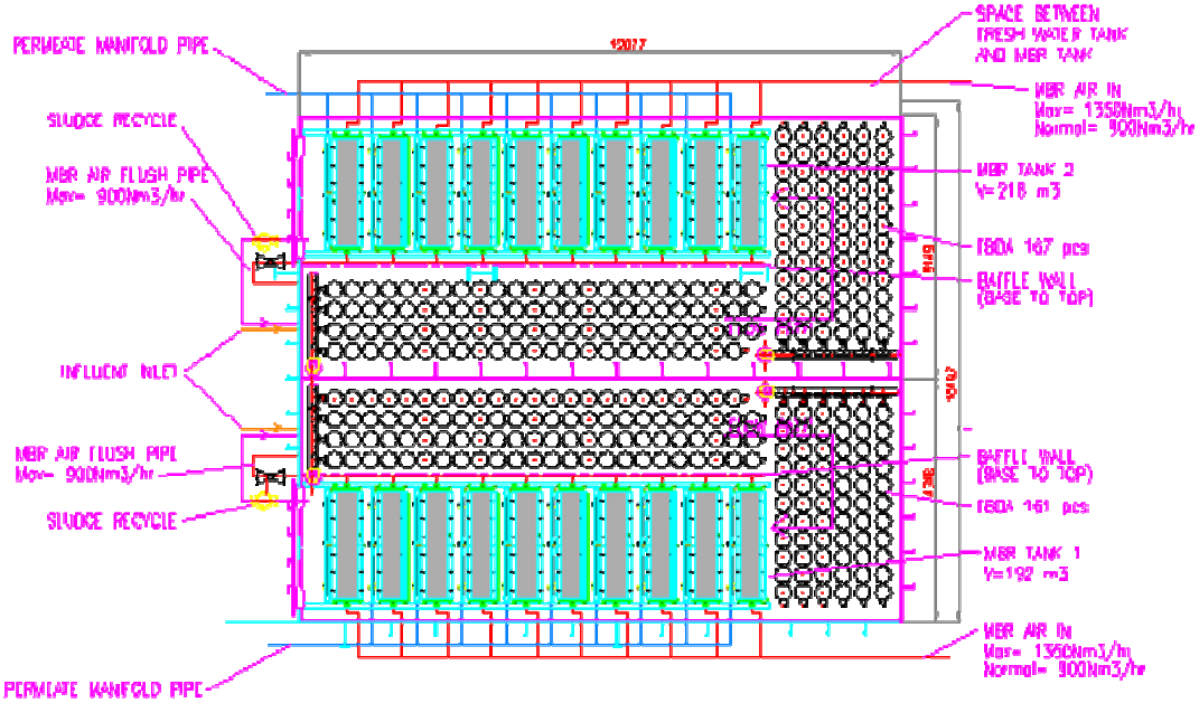
The price for one complete turn key Evac AWT system according the technical specification:

Price per ship (range depending on the extent of work) from 3 600 000 to 4 300 000,- USD

5. APPENDICES

APPENDIX 1	Evac MBR lay-out
APPENDIX 2	Evac MBR process design
APPENDIX 3	Life cycle cost analysis

APPENDIX 1


PERMEATE MANIFOLD PIPE
SLUDGE RECYCLE
MBR AIR FLUSH PIPE
Max= 900Nm3/hr
INFLUENT INLET
MBR AIR FLUSH PIPE
Max= 900Nm3/hr
SLUDGE RECYCLE
PERMEATE MANIFOLD PIPE
SPACE BETWEEN
FRESH WATER TANK
AND MBR TANK
MBR AIR IN
Max= 1350Nm3/hr
Normal= 900Nm3/hr
MBR TANK 2
V=218 m3
FBDA 167 pcs
BAFFLE WALL
(BASE TO TOP)
BAFFLE WALL
(BASE TO TOP)
FBDA 161 pcs
MBR TANK 1
V=192 m3
MBR AIR IN
Max= 1350Nm3/hr
Normal= 900Nm3/hr

CLIENT: The Alaska Department of Environmental Conservation
PROJECT: Metals Removal Technology Inventory
5020 pax Cruise Ship MBR Process Design
Project No.:
Compiled by: Date:
Checked by: Dr. Jari Jokela Date: 1.2.2009

Sinimäentie 14
02630 Espoo, Finland
Tel: +358 50 4300471 (mobile)
e-mail: jari.jokela@evac.zodiac.com

MEMBRANE BIOREACTORS DESIGN

Evac MBR AWP for ADEC study

5020 passanger cruise ship

design values:

	l/pax/d
Black wate	17
Galley wa	50
Food wate	3
Laundry w	25
Grey wate	155
Total:	250

Kubota EK400 memb	320	m^2/module
Kubota ES200 memb	160	m^2/module
Kubota ES150 mem	**120**	**m^2/modul**
Kubota FS75 membr	60	m^2/module
Kubota FS50 membr	40	m^2/module

20

After pretreatment with 0.29+0.1 mm sieves

Design flux 0.55 m^3/m^2/day

30 % BOD_5 reduction

	Flow	BOD_5	BOD_5	TSS	TSS	N	NH3-N	Reduced BOD_5	Membrane	ES150	Gravity Flow =>Flux	Max. flux
	m^3/day	gO_2/l	kgO_2/day	g/l	kg/day	gN/l	kg/day	kgO_2/day	m^2	modules	(m/d)	(m/d)
Black wate	85.3	2.5	213.35	1.5	128.01	0.2	17.07	213.35				
Galley wa	251.0	2.5	627.50	2.5	627.5	0.125	31.38	627.50				
Food wate	15.1	30.0	451.80	20	301.2	0.15	2.26	451.80				
Laundry w	125.5	0.30	37.65	0.30	37.65	0.01	1.26	37.65				
Grey wate	778.1	0.20	155.62	0.10	77.81	0.013	10.12	155.62				
Sum:	**1255.0**		**1485.9**		**586.1**		**31.0**	**1040.1**	**2281.8**	**19.02**	**0.523**	**1.10**

1.0 WASTEWATER CHARACTERISTICS

1.1 Influent Flows and Loads

Blue values = Given

Black values = Calculated

Qdwf	Qav.	Qpk.	COD		BOD		SS		TKN		NH3-N	
(m^3/d)	(m^3/d)	(m^3/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)
1 255	1 255	1 255	1 244	1 561	829	1 040.40	467	586.09	56	70.28	28	35.14

TP		pH	ALK
(mg/l)	(kg/d)		(mg/l)*
16.00	20.08	7.00	300.00

1.2 Effluent Loads

COD		BOD		SS		TN		NH_3-N		TP		pH
(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	
n/a	#VALUE!	15.00	18.83	15.00	18.83	n/a	#VALUE!	1.50	1.88	n/a	#VALUE!	6.0 - 9.0

T-Coli	E-Coli	Parasites	Turbidity	Chlorine	Conductivity
(/100ml)	(/100ml)	(/l)	(NTU)	(mg/l)	(mS/cm)
n/a	20.00	-	n/a	n/a	n/a

1.3 Environmental Data

Elevation	Ambient Temp.		Sewage Temp.		Relative Humidity	
(m)	min (oC)	max (oC)	min (oC)	max (oC)	min (%)	max (%)
-	5.00	40.00	10.00	20.00	60.00	80.00

* as calcium carbonate (CaCO3)

2.0 MEMBRANE DESIGN

2.1 Hydraulic

Design for Max Flux at FFT	=	0.60	m/d
Unit Used	=	150	ES
No Units Required	=	17.43	
No Units Provided	=	20.00	
Actual Peak Flux	=	0.52	m/d
Actual Average Flux	=	0.52	m/d

2.2 Tank Sizing

Number of Membrane Tanks	=	1.00	
Number of Units per Tank	=	20.00	
Tank Length	=		m
Adjusted Tank Length	=	11.55	m
Tank Width	=	3.07	m
Adjusted Tank Width	=	5.44	m
Tank Water Depth	=	3.50	m
Total Volume (Net)	=	203.86	m^3

4.2 **Design Sludge Age**

		12 000	15 000	18 000	mg/l
		Overall MLSS (mg/l)			
Rs Tmin	=	10.50	14.00	18.00	days
Rs Tmax	=	11.50	15.50	19.00	days

4.3 **Mass of Volatile Solids**

M(Xv) Tmir	=	2 166	2 371	2 531	kg/d
M(Xv) Tma	=	2 233	2 438	2 547	kg/d

4.4 **Cell Nitrogen Uptake**

NSc Tmin	=	32.00	26.00	22.00	mg/l
NSc Tmax	=	33.00	27.00	22.00	mg/l

5.0 **OXYGEN REQUIREMENTS**

Actual Oxygen Demand	=	1 094.10	1 165.01	1 215.26	kg/d
	=	45.59	48.54	50.64	kg/h
Peak Actual Oxygen Demand	=	68.38	72.81	75.95	kg/h

6.0 MEMBRANE TANKS COARSE BUBBLE DIFFUSION

6.1 Oxygen Provided

Membranes Normal Air Flow Rate	=	=	1 800	kg/h
	=	=	2 700	kg/h

7.0 FINE BUBBLE DIFFUSSED AERATION

7.1 Oxygen Required

MLSS	=	20.00 °C					
Peak	=		=	38.69	46.07	52.63	kg/h
Average	=		=	25.79	30.71	35.08	kg/h
MLSS	=	10.00 °C					
Peak	=		=	38.69	46.07	52.63	kg/h
Average	=		=	25.79	30.71	35.08	kg/h

7.3 Standard Air Requirements

Maximum Air Throughput per Diffuser	=	=	8.00	8.00	8.00	m^3/h
Number of Diffusers Required	=	=	162	232	331	
Average Air Throughput per Diffuser	=	=	5.33	5.33	5.33	m^3/h

8.0 SURPLUS ACTIVATED SLUDGE (SAS) PRODUCTION

Rs	=	10.50	14.00	18.00	days		SAS	=	487.34	450.40	421.63	kg/d
					@	1.20	%DS	=	40.61	37.53	35.14	m^3/d
					@	1.50	%DS	=	32.49	30.03	28.11	m^3/d
					@	1.80	%DS	=	27.07	25.02	23.42	m^3/d
					@	6.00	%DS	=	8.12	7.51	7.03	m^3/d
					@	8.00	%DS	=	6.09	5.63	5.27	m^3/d
					@	16.00	%DS	=	3.05	2.82	2.64	m^3/d
					@	18.00	%DS	=	2.71	2.50	2.34	m^3/d

AWP ELEC POWER COSTS

kWh

	Installed kWh	Operating kWh	Annual Power, kWh	Annual Cost, $
Evac	260	162	817 000	$ 81 700

<u>Assumptions</u>:
Cost/kWH = $0,10
Operating 360 days/yr, 24 hrs/day or 8,640 hrs/yr (Please note: All pumps not on 24/7

Evac AWP CHEMICAL, MEMBRANE & FILTER CONSUMPTION

Function	Qty	Units	Chemical Name	Cost/Unit	Cost/Mo $ or €	Annual Cost $ or €	Comments
Defoamer	32	liters/day	Nalco MPE-50	1USD/liter	960	11520	Worst case !!
Membrane Cleaning	9800	l/cleaning	NaOCl	0,5USD/liter		490	twice / year
Membrane Cleaning							
Filters							
Other Chemical 1			oils etc.			1000	
Other Chemical 2							
Caustic (pH Balance)	5	kg/day	NaOH (100%)	0,3USD/kg		1095	Worst case !!
Acid, pH Balance							
Total-Estimated							$13 615

AWP LABOR COSTS

Daily Labor Costs (Assumes 30 days/month)

	Hrs/Day	Cost/Hr $ or €	Cost/Mo	Annual Cost	Comments
Evac					
Officer, Operation	1.00	$ 40	$ 1 200	$ 14 400	
Officer, Testing	0.00	$ 40	$ -	$ -	
Officer, Maintenance	1.00	$ 40	$ 1 200	$ 14 400	
Mechanic Cleaning	0.20	$ 20	$ 120	$ 1 440	
Mechanic Maintenance	0.20	$ 20	$ 120	$ 1 440	
Total Labor Costs	2.40		$ 2 520	$ 30 240	

AWP MAJOR OVERHAUL COSTS

(Assumes 30 Year Life of the Vessel)

Evac

	Description	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30	Total
Overhaul Activity 1	Membrane replacement										528000										528000											$ 1 056 000.00
Overhaul Activity 2																																$ -
	TOTAL	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 528 000.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 528 000.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1 056 000.00

Filter Flow Technology, Inc.

PO. Box 645, Montgomery, TX 77356

Tel: 832-385-8296 Fax:-936-570-1184 e-Mail filterflowtech@verizon.net

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I. Statement of Problem.

The State of Alaska, Department of Environmental Conservation (DOEC) has established a "Source Reduction Program" for water, wastewater, grey water and bilge water from Large Commercial Passenger Vessels (LCPV). The goal of this program is to identify technology and methodology and to develop guidance criteria that potentially, could be used by LCPV to reduce the Daily Avg and Monthly Avg, Discharge Limits for trace metals (Cu, Ni and Zn) and Kjeldahl Nitrogen.

Table I. Effluent Limits and Discharge Reporting of the State of Alaska Discharge General Permit No. 2007DB0002 (May 1, 2008) LCPV require Daily Maximum and Monthly Avg. limits for Cu, Ni, Zn trace metals. These priority, trace metals for water, waste water, grey water and bilge water, source reduction from LCPV discharges. For the LCPV aqueous, discharge streams (pH ~neutral to 8.5), essentially four different, treatment groups exist, which are outlined below.

Type A: Water or wastewater having trace metals (with or without trace Kjeldahl Nitrogen) not within Daily Avg or Monthly Avg Discharge Limits.

Type B: Water or wastewater with elevated, Kjeldahl Nitrogen (with or without trace metals, within Daily and Monthly Avg Discharge Limits.

Type C: Grey water with Kjeldahl Nitrogen, with or without trace metals within Daily or Monthly Avg Discharge Limits.

Type D: Bilge water (high TDS) with elevated TPH, organics, BOD's, trace metal, TSS, microbes, with or without Kjeldahl Nitrogen.

a) Requires pre-treatment (biological or other) to reduce TPH to <100 mg/l.
b) Total Suspended Solids (TSS) and micro-contamination.

Importantly, the priority trace metals (Cu, Ni, Zn) in these LCPV discharge streams exist not simply as pure ionic species, rather multiple chemical/physical forms (e.g., ionic, organo-metallic forms, Cu and Zn and/or NH_4-ion associated forms, chemically complexed forms, colloidal and micro-particle forms that alter the chemical reactivity properties. Hence, cost-effective, source reduction for the LCPV discharge streams for the trace metals particularly is not "straight forward", rather complex.

Filter Flow Technology, Inc. has more than 25 years experience and extensive expertise treating a wide range of water, waste water, grey water and bilge water for removal of trace metals, TPH, hydrocarbons, organics, NH_4-ion) and TSS. Innovative and proprietary methodology developed by FFT and consulting engineer (F. Rodriquez, Ch.E. have direct application to meet the Alaska DOEC, LCPV "Source Reduction Program" for Kjeldahl Nitrogen.

outlined in Table 1 "Effluent Limits and Discharge Reporting shown in the General Permit No. 2007DB0002 publication dated May 1, 2008. Regarding Kjeldahl Nitrogen treatment strategies, FFT has developed two practical, economical, methods that have application for the Alaska LCPV "Source Reduction Program", which are outlined below. [Refer to Part I of this proposal for a description of trace metal removal methodology applicable to the LCPV discharge problems.

II. Removal of Trace Metals from LCPV Water Streams.

Filter Flow Technology, Inc. (FFT) has developed extensive expertise and experience for water and waste water treatment of a broad spectrum of heavy metals over the past 25 years including special projects with the USDOE, USEPA, General Electric and numerous engineering groups and customers in the USA, Canada, Mexico, South America, South Korea, Middle East, Russia and other countries. [Refer to Table 1]. FFT has developed innovative technology recognized by the USDOE, USEPA for removing trace metals and radionuclildes from ground water and waste water and more recently worked with F. Rodriquez, Ch.E. in Houston to develop electro-chemical methodology (Hydrotron) to enhance trace metals removal from aquesous streams. The FFT methodology has application to cost-effectively remove Cu, Ni and Zn from LCPV waste streams (water, waste water, grey water or bilge water).

A new, innovative, electro-chemical process has been developed that can be used with existing and upgraded water and wastewater, Grey Water or Bilge Water treatment systems to enhance trace metals and or Kjeldahl Nitrogen removal. This innovative, electro-chemical, water treatment method was developed in Houston, TX in 2004 initially to provide more economical and environmentally, friendly water softening, anti-scaling to replace resin based, water softeners. The innovative, Hydrotron device is a stainless steel tube used as an alternating (+/-, electric field device) installed "in-line" that eliminates ion exchange beds and brine regeneration; oxidation agents; and costly membranes. The proprietary, Hydrotron represented a reliable and cost-effective alternative for water softening to remove Iron, $CaCO_{3,}$ $MgCO_{3,}$ $CaSO_{4.}$ M $SO_{4,}$ Alkalinity and Sulfur odor & taste. [Refer to figures 1 and 2].

How does it work? Soluble, inorganic ions, molecules and colloids in water exist in dynamic, whirling, chaotic (i.e., random) movement. Clusters of the soluble ions and molecules interact, then breaking their electrostatic attractions (or bonds) and then re-associate, with different chemical groups. Hydrotron treatment *enhances* formation of the inorganic, water contaminants for ion pair formation, electrostatic associations, molecular reactions and inter-species reactions. Operationally, feed water flows through the Hydrotron (electric field), where additional +/- electrons are introduced into the water to enhance the ionic, electrostatic and molecular dissociations, re-associations and interactions of the inorganic contaminants. The additional electrons displace some already captured by molecules and ions such as CO_3^{2-}, HCO^{3-}, SO_4^{2-} and OCI^- during the turbulent orbiting of the various electrons. This allows the "displaced" electrons to become "free electrons" in the solution. Ions and colloids (e.g., Ca^{2+} and Mg^{2+}) capture "free electrons" and undergo change in the inorganic form, (e.g., to CO_3^{2-}, SO_4^{2-} and HCO_3^-). The elevated, electron concentration in the water also slows the breakdown of bicarbonate ion into H^+ and CO_3^2-.

Subsequently, in early 2008 R&D development with FFT in Houston indicated that the by modifying the Hydrotron, stainless steel chamber; electronics; and electrode, it was feasible to use the equipment to achieve effective oxidation of a wide spectrum of TOC's, organics, hydrocarbons, etc. Importantly, the oxidation yields from the modified Hydrotron are more efficient and more economical than ozone generators or using chemical oxidation methods and has potential application for oxidation of Kjeldahl Nitrogen for the Alaska DOEC, LCPV "Source Reduction Program". This innovative, electro-chemical, oxidation methodology could be easily installed in a LCPV engine room or other water utility space using minimal tank storage capacity and footprint. Operationally, "in-line" MNPT, pipe connections, would be used for small, (½", ¾". 1") installations and flanged connections for larger installations as illustrated in Table II. Pre-filter specifications are also listed if needed. To date numerous Hydrotron have been installed and are operating effectively fro ½" to 48" pipe size. Low to moderate TDS, grey water or pre-treated, waste water, would be positive pressure pumped to a zeolite, pre-filter (nominal rating <5μ), then flow to the OxHydrotron.. Aeration, would be achieved immediately down steam employing an "in-line", venturi (eductor loop) then flow to a standard Hydrotron for electric field effect. Efficient, zeolite filtration would be used to remove the suspended solids formed by the process. If necessary, small doses of sorbant could be used downstream of the standard Hysrotron to enhance metals precipitation. Treated and filtered water, would be discharged and the filter back wash secondary filtered to trap TSS for disposal and the filtrate recycled for treatment.

FFT developed an innovative, economical, treatment strategy to remove trace metals from water and waste water in 2006 and 2007 using the Hydrotron, electro-chemical device originally designed by a FFT consultant (F. Rodriquez) in Houston, TX. The proprietary, Hydrotron was originally designed to replace resin/salt brine, water softeners. Figures 1 shows an engineering drawing for a by-pass vs straight-through configuration. Figure 2 shows a photograph of a small, 1"Hydrotron ready for installation. Table Iists the available Hydrotron sizes, weights and service ratings (gpm flow) for the standard Hydrotron equipment.

Treatment Train for Type A and Type B Water & Wastewater.

The proposed treatment train process for Type A and Type B LCPV water and wastewater streams is shown in Figure 3 The bases of this innovative methodology is to: *first*, as outlined above, exist in complex, chemical/physical forms not just pure ionic forms, hence OxHydrotron, electrochemical oxidation, will "free" the metals from NH_4-ion association for subsequent precipitation. S*econd*, that Hydrotron, electric-field treatment, with aeration (+/- some chemical addition) will results in solubility shift towards insolubility. And, *third*, that the particles can be effectively removed via physical filtration using high purity, zeolite media (nominal rating <5μ). The suspended solids from the filter, would be removed (i.e., trapped) during back wash cycles using an "in-line", filter bag (~25 micron) filled with 4 x 8 mesh, zeolite meda and the filtrate recycled for treatment. The bag filter solids, would be combined, with other wastewater solids for disposal.

Importantly, the electro-chemical process (i.e., electro-oxidation followed by electric field, solubility shift treatment) will enhance the removal of cu, Ni and Zn via the oxidation treatment plus enhancing precipitation reactions. Some treatment train assumptions for the trace metal chemistry are provided below.

<u>Chemical Associations & Reactions</u>: Inorganic metalics (e.g., Cu, Ni, Zn) existing in ionic, Colloidal, organo-metallic, NH_4-ion associated, complexed, or other chemical/physical forms in the Hydrotron feed water, undergo enhanced, particle formation (via ionic, chemical reactions/associations, charge layering) for feed water with low TSS, pH neutral to 8.5.

Aeration: Venturi (eductor loop) aeraton down stream of the Hydrotron insures that the oxygen tension in the water is non-limiting for chemical reactions.

Metals Associate NH_4-ion*:* Significant % of Cu or Zn NH_4-ion associated will exist in the LCPV waste streams. OxHydroton, electro-chemical oxidation, will be employed to "break" the metals-NH_4-ion association for subsequent precipitation.

Organo-Metallic Forms*:* When TOC's, organics or trace hydrocarbons are present then some of the Cu, Ni, Zn will exist as organo-metallics or organic complexed forms. These will be resistant to precipitation, hence Ox-Hydrotron "oxidation: will be used to "free" the trace metals for subsequent precipitation.

Solbility Shift: Cu, Ni, Zn contaminants in the Type A and B water and wastewater can be electro-chemically treated to induce precipitation reactions. Some waste water may require additional chemical addition using the proprietary ChemSorb-500Z sorbant upstream to the Age Zone. Generally, ~5 min Age Zone time will be adequate to form particles for zeolite filtration removal.

Zeolite Filter: Zeolite media, pressure vessel filters would have a service flow rate in the range of 15 gpm/ft^2 bed area designed with automatic back wash cycles. The back wash TSS, would be collected via bag filter (with added 4 x 8 mesh zeolite granules) and the filtrate recycled for treatment.

III. **Type C (Grey Water) and Type D (Bilge Water) with Kjeldahl Nitrogen, Trace Metals and Other Contaminants (BOD, TOC, TSS, TPH) to Meet Daily and Monthly Avg Discharge Limits.**

Kjeladhl Nitrogen in the LCPV water, waste water, grey water and bilge represent to a large extent: a) decomposition and microbial metabolism; of organic nitrogen compounds (e.g., proteins, peptides, amino acids, etc.); b) indirect, microbial nitrogen fixation and algae photochemical fixation; or c) contaminants from surfactants, detergents or cleaning agents used "on board". Historically, four basic, treatment strategies have been used to remove Kjeldahl Nitrogen from aqueous streams, which are listed below.

> **Air Stripping***:* Based on caustic (or other strong base) titration to pH>11 to convert >98% of the Kjeldahl Nitrogen in the aqueous stream to NH_3 (Ammonia gas) followed by air stripping techniques to collect the NH_3 gas.
>
> **Cation Exchange***:* Resin or zeolite (Clinoptilolite, molecular sieve), cation exchange bed(s) configured with pre-filtration, back wash and media regeneration cycles.
>
> **Chemical Treatment (Non-Oxidation):** pH titration to <9.0 plus chemical reactions to convert Kjeldahl Nitrogen to NH_4-ion then usable reactant species (e.g., liquid fertilizer or precipitating salts).
>
> **Oxidation Reactions***:* The basic nitrogen cycle entities (including Kjeldahl Nitrognen species) are essentially, electron exchange, electron transport reactions representing different oxidation or reduction, energy states. To convert a lower energy form to a higher energy form (e.g., to oxidize species A to B) requires energy input. Oxidation reactions using, hydrogen peroxide, ozone or highly reactive, free radicals has proved effective to oxidize NH_4-ion.

For large ships and vessels a widely used treatment strategy for Grey Water has been to use electro-chemically, generated, Hyperchlorite employing an electrolytic cell. FFT has worked with this type of equipment in the USA and is familiar with this technology. The new, electro-chemical, OxHysrotron and standard Hydrotron, could be used downstream (or in place of) the above, conventional, Ammonium ion (or Kjeladhl Nitrogen) treatment methodology to enhance source reduction of LCPV discharges. Similary, downsteam from the oil water sep equipment and pre-filtration, the Bilge Water (Type D) can be treated using essentially the same equipment and process (with small modifications) as Grey Water.

Treatment Train to Remove Kjeldahl Nitrogen from LCPV Water Streams.

FFT would be interested in working with the State of Alaska DOEC and LCPV to pilot test this innovative, electro-chemical oxidation method for reduction of Kjeldahl Nitrogen to the stricter discharge limits. The Type D (Bilge Water) will contain high TDS, sea water, with high TSS, TPH (oil), microbe growth, algae contaminants, as well as chemical and detergent additives. Additives. FFT proposes to use an innovative electro-chemical oxidation (OxHydrotron), and standard Hydrotron treatment. Additional ChemSorb-500Z sorbant (chemical treatment) will also be used down stream from the standard Hydrotron to enhance the trace oils and trace metals removal. Importantly, the Ox-Hydrotron equipment represents a new, cost-effective methodology to: a) oxidize the NH_4-ion (oxidation); and b) to oxidize organics representing orgao-metallic complexed, trace metals. The feed water to the OxHydrotron will require the TPH to <100 mg/l and TSS <20 mg/l.

Figure 4 and 5 show the preliminary, treatment train, process flow diagram for LCPV Type C (Grey Water) and Type D (Bilge Water) respectively. The process is similar to the treatment train for Type A, Type B water and wastewater and to the treatment train for Type C (Grey Water), except the feed stream to the OxHydrotron requires the bilge water to have pre-oil water separation and pre-filtration. The basis for the new methodology resides in the innovative, economical, small foot-print, electro-chemical oxidation technology, The OxHydrotron and other proposed, treatment train for the Type C and Type D water and waste water, etc. will effectively kill microbes, viral agents and oxidize organics.

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Table II. Hydrotron Models and equipment prices. Filter Vessel spec's are provided for Hydrotron installations requiring a pre-filter or post-filter.

PUMPING RATE	Connections	Electro-Chemical Module	WT (lbs)List Price USA Dollar]	FILTER VESSEL (*Specification*)
3-17	¾" MNPT	H-075	18 [$800.^{00}]	12" vessel *
18-27	1" MNPT	H-100	90 [$1,710.^{00}]	18" vessel
28-47	11/4"MNPT	H-125	93 [$1,920.^{00}]	24" vessel
48-65	11/2" MNPT	H-150	97 [$2,136.^{00}]	30" vessel
66-105	2" MNPT	H-200	103 [$2,872.^{00}]	30"or 36 vessel
106-233	3" Flange	H-300	165 [$.3,488.^{00}]	36"or 48"vessel
234-402	4" Flange	H-400	180 [$4,020.^{00}]	2 x 48"vessels(1 x 72")
403-805	6" Flange	H-600	200 [$4,479.^{00}]	4 x 48" vessels
806-1,610	8" Flange	H-800	300 [$5,710.^{00}]	2 x 72" vessels (1 x 96")
1,611-2,550	10" Flange	H-1000	345 [$7,620.^{00}]	Special Design**
2,551-3,750	12" Flange	H-1200	400 [$9,881.^{00}]	Special Design
3,751-4,830	14" Flange	H-1400	460 [$12,026.^{00}]	Special Design
4,831-6,440	16" Flange	H-1600	620 [$14,194.^{00}]	Special Design
6,441-8,260	18" Flange	H-1800	650 [$16,325.^{00}]	Special Design
8,261-0,310	20" Flange	H-2000	710 [$22,412.^{00}]	Special Design
10,311-15,000	24" Flange	H-2400	800 [$32,779.^{00}]	Special Design
15,001-23,558	30" Flange	H-3000	1,300 [$47,454.^{00}]	Special Design

**FRP Vessel dia. shown with 3 ft. bed Ht. using zeolite media. Refer to Table III.*
***PLC controlled, vertical, pressure vessels 10 to 15 gpm/ft^2; or gravity flow (2-3 gpm/ft^2). .*

Figure 1. Installation systems diagram for a basic (1") Model H-100 Hydrotron illustrating code vs standard installation configurations. (Left Panel) shows a by-pass installation. (Right Panel) shows a "straight through" configuration.

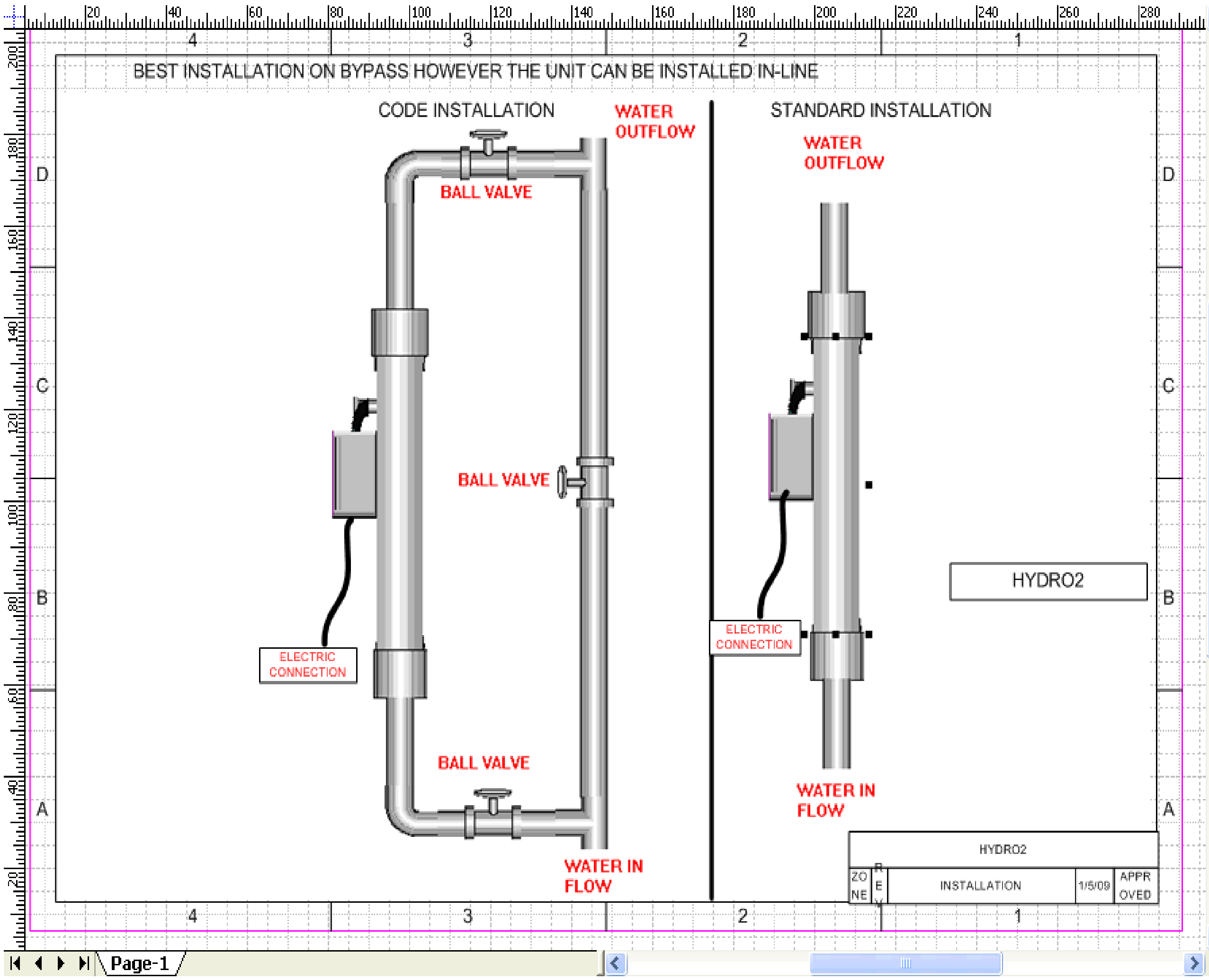


Figure 2. Photograph of a Model H-100 (1") Hydrotron ready for installation Note: the Power Switch is on the front panel; Voltage Test Point located on the side of the box; and the stainless steel "Flow Chamber" is shown, behind the Power Box.

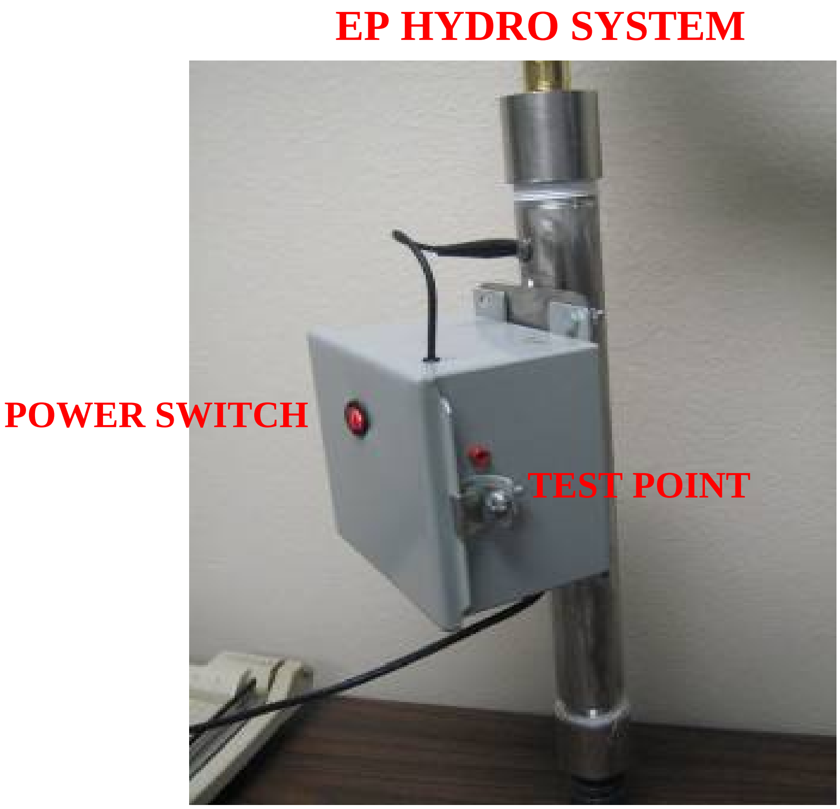


Figure 3 Type A and Type B Water and Wastewater process flow (

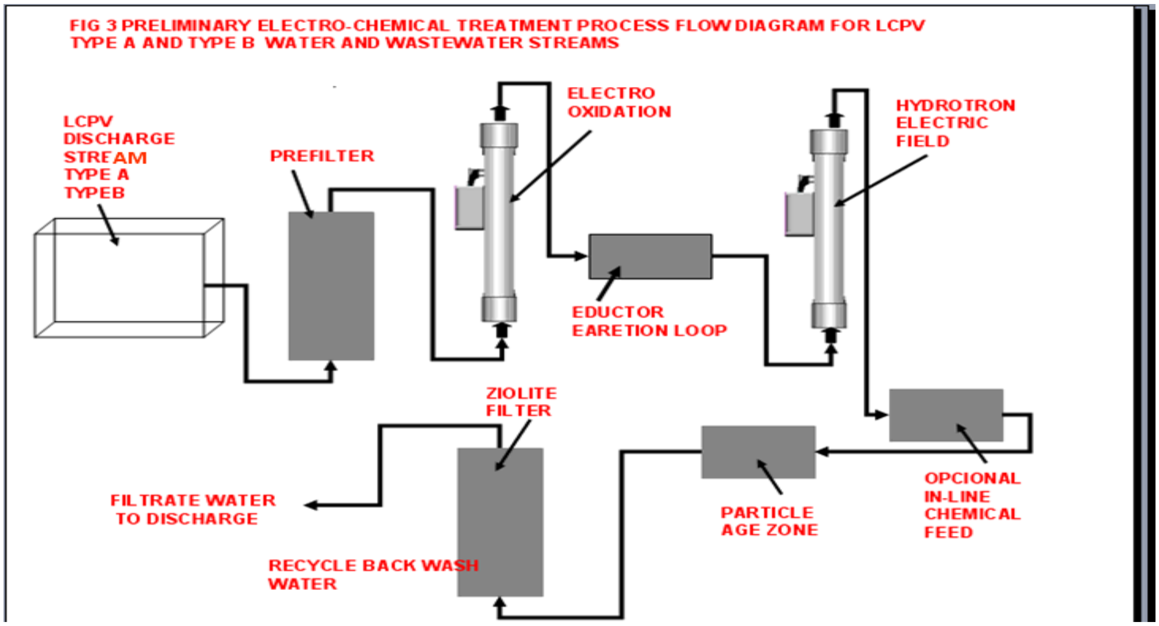


Figure 4. Type C (Grey Water) Process Flow for Electro-Chemical Treatment Process.

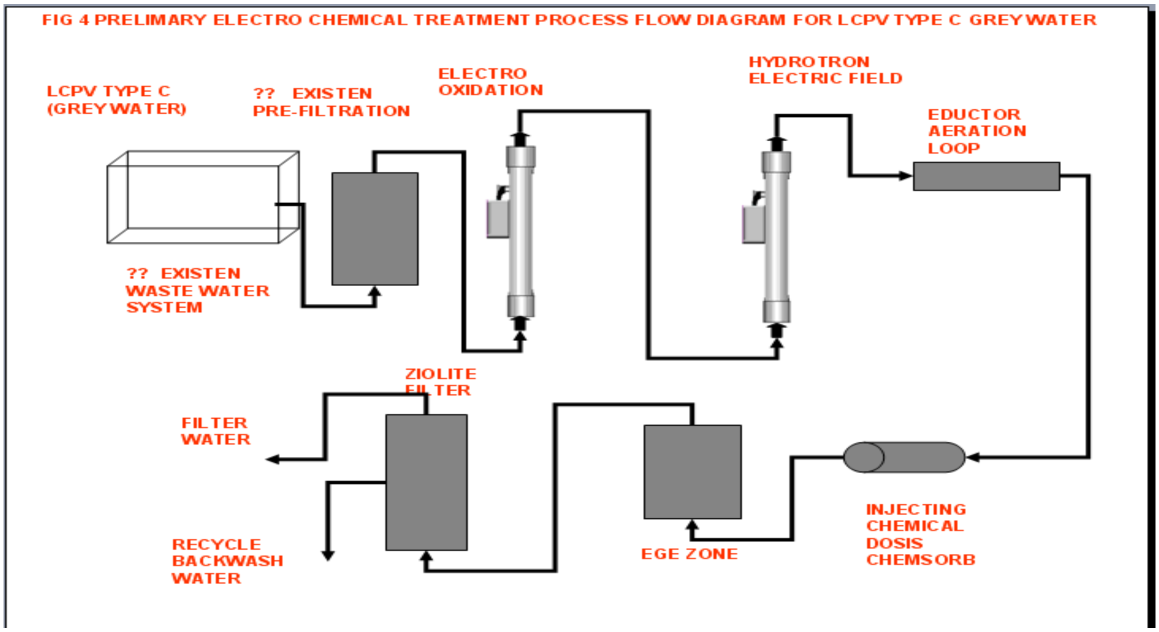
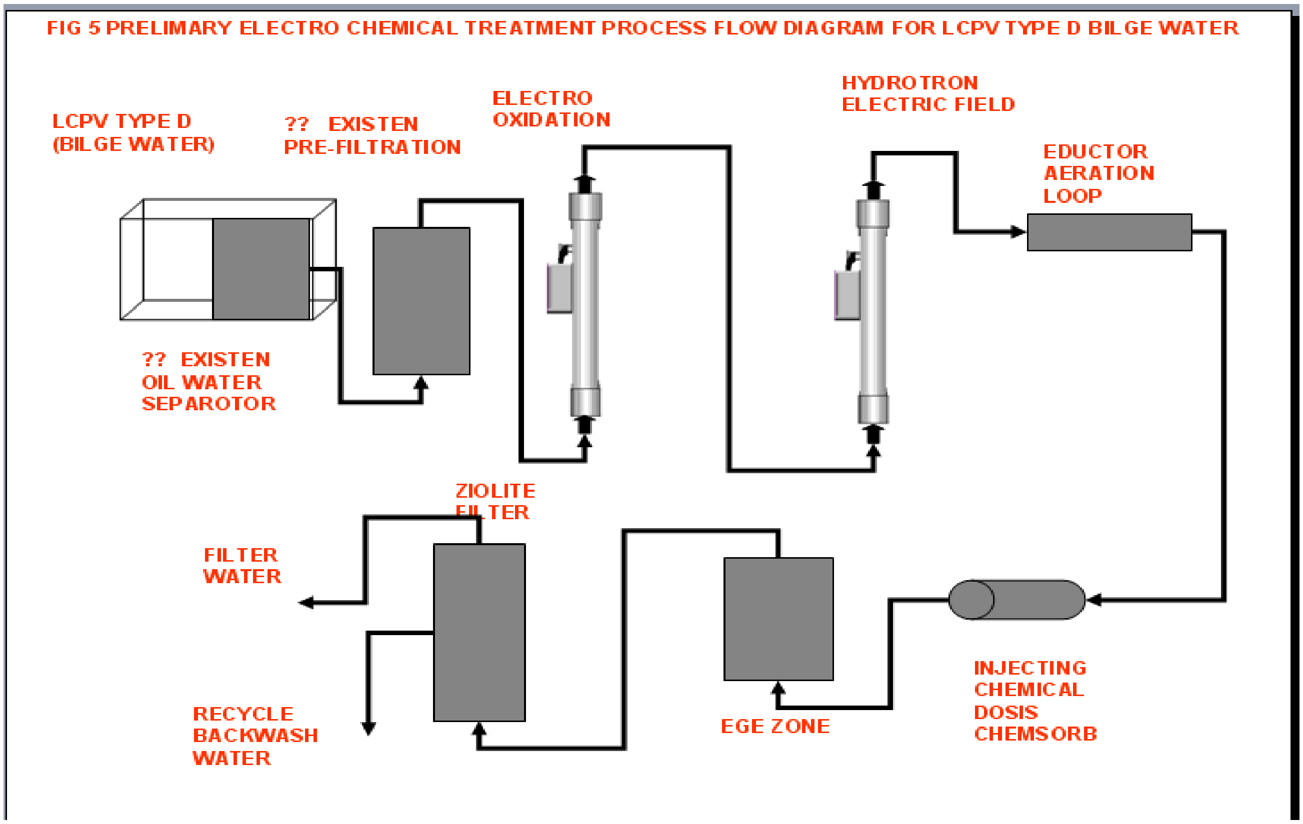


Fig.5 Type D (Bilge Water) Process Flow for Electro-Chemical Treament Train.



Electrolysis of Ammonia as a Wastewater Remediation Process

Gerardine G. Botte, PhD
Associate Professor, Chemical and Biomolecular Engineering Department
Director of the Electrochemical Engineering Research Laboratory
Ohio University
183 Stocker Center
Athens, OH 45701
botte@ohio.edu
Phone: 740-593-9670
web: http://webche.ent.ohiou.edu/eerl/

SUMMARY

This report describes how the "Ammonia Electrolysis" technology can be implemented for the removal of ammonia from wastewater at the conditions required for the discharge originated from cruise ships in the State of Alaska. The technology represents an alternative method that has the potential to minimize the concentration of ammonia in the effluent to values lower than the current permissibility limit for ammonia. A conceptual design of the cell is described.

TECHNOLOGY DESCRIPTION

The Environmental Protection Agency (EPA) considers ammonia a threat to environmental quality because of its contribution to impaired air quality, surface water eutrophication, and nitrate contamination of ground water. Ammonia emissions to the atmosphere play a significant role in the formation of fine particulate matter ($PM_{2.5}$). These fine particulates have been shown to cause respiratory problems in humans and contribute to haze and poor visibility. Furthermore, the deposition of atmospheric ammonia and chemical compounds resulting from atmospheric chemical reactions with ammonia contributes to acidification and eutrophication of water and soil.

Dr. Botte and members of her research laboratory at Ohio University had developed a new technology that consists of the electrolysis of ammonia to pure nitrogen with simultaneous hydrogen cogeneration [1-8]

The electro-oxidation of ammonia takes place in alkaline media according to the following reaction [2]

$$2NH_3 + 6OH^- \Leftrightarrow N_2 + 6H_2O + 6e^- \quad (1)$$

with a theoretical potential of -0.77 V vs. standard hydrogen electrode (SHE) at 25^o C. At the cathode of the electrolytic cell, the reduction of water takes place to produce hydrogen according to [2]

$$2H_2O + 2e^- \Leftrightarrow H_2 + 2OH^- \quad (2)$$

with a theoretical potential of -0.82 V vs. SHE (at 25^o C). Both reactions take place in different compartments; therefore, pure nitrogen and pure hydrogen are obtained in the process. The overall cell reaction is

$$2NH_3 \Leftrightarrow N_2 + 3H_2 \quad (3)$$

The theoretical voltage for reaction **Error! Reference source not found.** at 25^o C is 0.058 V which represents an energy consumption of *1.55 W-h* per gram of H_2 produced (95% energy reduction compared to water electrolysis).

Ohio University has demonstrated the use of the Ammonia Electrolytic Cell (AEC) technology for the removal of ammonia at the concentrations of ammonia found in waste sewage water. Bonnin and Botte demonstrated that ammonia can be removed from concentrations as low as 20 mM ammonia (340 mg/l) to 1.8 mM (30 mg/l) with 91.5% conversion and 92% Faradaic efficiency [8]. Further research performed in the lab had demonstrated that ammonia can be reduced to concentrations lower than 1 mg/l.

PRELIMINARY DESIGN OF THE PROCESS

This section describes scenarios in which the ammonia electrolyzer (AEC) could be used as a remediation process for the removal of ammonia from cruise ships effluents. The design described is based on 100 mW and 10 W prototypes designed, built, and tested at the Electrochemical Engineering Research Laboratory at Ohio University (EERL). The parameters were estimated to address the design criteria provided for the system by OASIS Environmental Inc, and summarized in Table 1.

Table 1: Design Criteria for End-of-Pipe Pollutant Reduction

Parameter	Typical Influent Range (Output from AWTS)	Desired Effluent [10] (Removal rate)
Flow	Max 60 m^3/hour (1440 m^3/day) but highly variable [9]	
TSS	11 – 1 mg/l	150 mg/l max
BOD	126 – 3.1 mg/l	60 mg/l max (50%)
pH	9.5 – 6.2	8.5 – 6.5
Total residual chlorine	0.20 – ND mg/l	0.0075 mg/l max (96%)
NH_3	150.0 – 4.6 mg/l	2.9 mg/l max (98%)
Nickel	44.0 – 7.0 micrograms/l	8.2 micrograms/l max (82%)
Zinc	501.0 – 7.0 micrograms/l	81.0 micrograms/l max (84%)
Copper	140.0 – 1.0 micrograms/l	3.1 micrograms/l max (98%)

Figure 1 presents a schematic diagram of the AEC. Wastewater containing ammonia flows through the anode of the AEC; at the outlet the concentration of ammonia is reduced to less than 1 mg/l (99.33 % conversion). Simultaneously, pure nitrogen gas is produced at the anode. The nitrogen could be released directly to the environment without any environmental damage. At the cathode of the cell pure hydrogen is produced. The hydrogen co-generated during the process could be used to power a fuel cell and/or a hydrogen combustion engine.

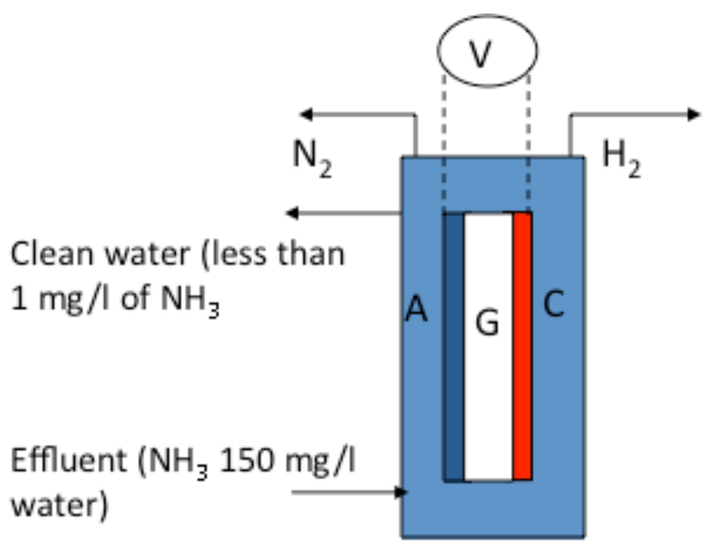


Figure 1. Schematic Diagram of the AEC

A summary of the design and operating parameters for the use of the AEC on board is given in Table 2. Sufficient hydrogen is co-generated that can be used to generated power (26.2 kW with a 50% efficient fuel cell). The design presented in Table 2 could be modified to evaluate other options. The configuration and weight of the cell could be optimized to minimize the dimensions and other requirements if required. In addition it will be worth to evaluate other alternatives, such as stationary units available at the port to be used by the ships. The advantage of this approach is that it will allow the use of other sources of electricity for the AEC instead of the diesel generators used in the boats.

Table 2. Summary of the Design and Operating Conditions

Parameter	**Specification**
Flow rate	60 m^3/hr
Inlet ammonia concentration	150 mg/l
Outlet ammonia concentration (based on bench-scale lab data)	less than 1 mg/l (99.34 % removal)
Hydrogen co-generated	1.59 kg/h
Nitrogen co-generated	7.40 kg/h
Power consumed	52 kW (without reusing H_2 generated)
Power produced if Couple with Fuel Cell technology (assuming 50% electric efficiency)	26.2 kW
Net Power consumed by the process	25.8 kW (after reusing H_2 generated in a fuel cell)
Approximate dimensions* • Length • Height • Width	 • 9.80 ft • 1.64 ft • 1.31 ft
Approximate weight	68 kg

*Dimensions are based on 10W prototype. The system could be optimized to minimize dimensions if required.

CONCLUSIONS AND RECOMMENDATIONS

A conceptual design on the use of the ammonia electrolysis technology as an ammonia remediation process for wastewater from cruise ships was performed. The results indicate that the technology is suitable for use in the cruise ships.

The conceptual design presented is based on the in-situ remediation of waste on board (in the ship). However, it is recommended that other options such as stationary units located at the ports could be evaluated. The advantage of such approach is that renewable energy sources such as photovoltaic panels could be used to power the ammonia electrolyzer.

It is also recommended to re-use the energy provided in the hydrogen generated during the electrolysis. Alternatives included fuel cells (20 to 30 kW PEM fuel cells have already been produced by some vendors) and hydrogen combustion engines.

It is recommended that a significant large prototype (500 W) of the electrolyzer is built and tested with the effluent coming from the ships. This prototype could be built and tested in an 8 to 11 months program. Ohio University has the facilities and the personal to execute such a project.

The concept of the technology provides opportunities to modify the electrolyzer to introduce additional cells to remove other contaminants such as Zinc, Copper, and Nickel [11].

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9. The standards in this column are set by the State of Alaska Large Commercial Passenger Vessel Wastewater Discharge General Permit No. 2007DB00002.
10. Estimated from data collected during the EPA/ADEC dispersion study in Skagway, Alaska, June 2008.
11. G. G. Botte and X. Jin*, "Electrochemical Technique to Measure Concentration of Multivalent Cations Simultaneously*," May 2006 (Pending Patent US).

INVENTOR'S PROFILE

Dr. Botte is an Associate Professor at Ohio University in the Chemical and Biomolecular Engineering Department. She is the director of the Electrochemical Engineering Research laboratory and the Editor in Chief of the Journal of Applied Electrochemistry.

Dr. Botte and members of her research group are working on projects in the areas of electrochemical engineering, power sources and fuel cells, numerical methods, mathematical modeling, material science, and electro-catalysis. Their research consists in the application of chemical engineering principles to study fundamental problems associated with electrochemical technologies. Current research focuses on the understanding, development and design of fuel cells, hydrogen generators (from the electrolysis of unconventional domestic fuels), and advance battery systems.

Dr. Botte holds a Ph.D. in Chemical Engineering from the University of South Carolina. Before going to graduate school she worked as a process engineer for three years at a Petrochemical Company.

Dr. Botte has been working on the analysis of electrochemical systems for ten years and has over 20 per review publications, one allowed US patent, eight patent applications, three book chapter contributions in the field, and over seventy presentations in international meetings (including invited speaker to the 2008 Gordon Research Conference in Electrochemistry).

STAGE OF DEVELOPMENT AND LICENSING OPPORTUNITIES

The performance of the cells has been tested with different levels of contamination. Efficiencies of up 92% have been observed during the removal of ammonia. Prototypes for wastewater remediation at the bench-scale (up to 100 mW) have been built and tested.

Several patents for this technology have been filed. Licensing opportunities are available. For more information contact:

Ohio University
Technology Transfer Office
340 West State Street, Unit 11
Athens, OH 45701
T: 740.593.0462
F: 740.593.0186
tto@ohio.edu

Effluent Ammonia and Metal Removal Technology

REF: Large Commercial Passenger Vessel Wastewater Discharge General Permit

ROCHEM Experience & Input
Reverse Osmosis

Water Reduce, Reuse & Recycle

for

OASIS Environmental, Inc.

2 February 2009

Prepared by
ROCHEM Worldwide Group of Companies
US Representative:
ROCHEM
922 N.E. 13th Street
Fort Lauderdale, FL 33304

Tel (305) 577-9991
Fax (305) 675-2395

What is the value of water?

Water makes up 75% of the earth surface and seems to be without end. Why then has the quality and availability of water become one of the greatest concerns of the 21st century? Water plays a greater role in everyone's (and every organism's) life than oil supplies, nutrition sources or other basic need.

As times seem to be changing fast, it is difficult to understand the current value of water much less its future value. What is demonstrated worldwide is:

- Investors are buying water assets around the world for billions of dollars. Large conglomerates are amassing substantial portfolios based on water assets and clean water producing technologies.
- Large geographical areas are suffering major losses without the benefit of water: Both human and political.
- We are now facing the impact of micropolluntants, made up of pharmaceutical and biologically-active compounds, which will have widespread effects that will show up as these compounds build up in concentration.

There is nothing more important than water to our future.

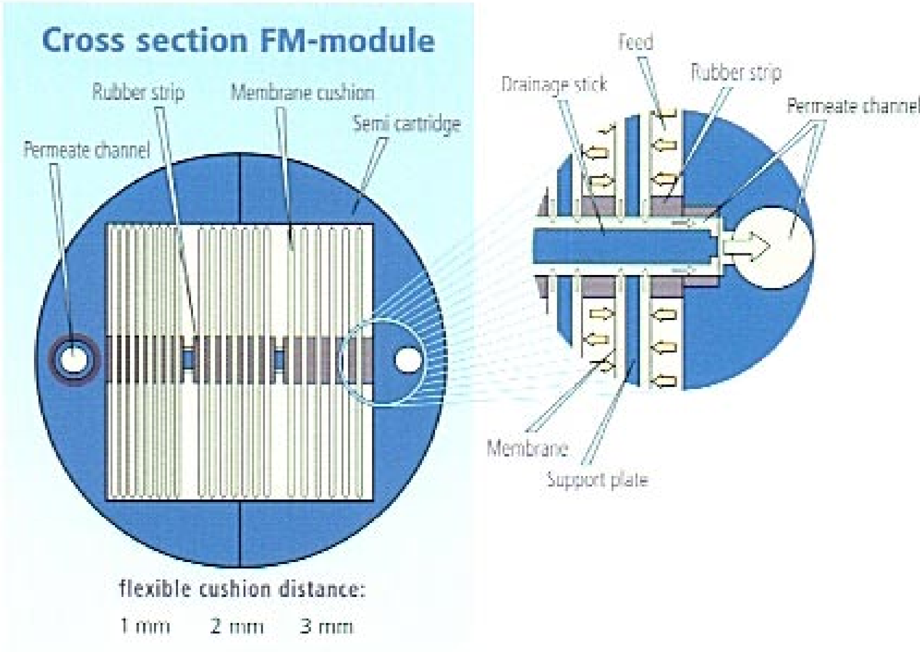
Effluent Ammonia and Metal Removal Technology

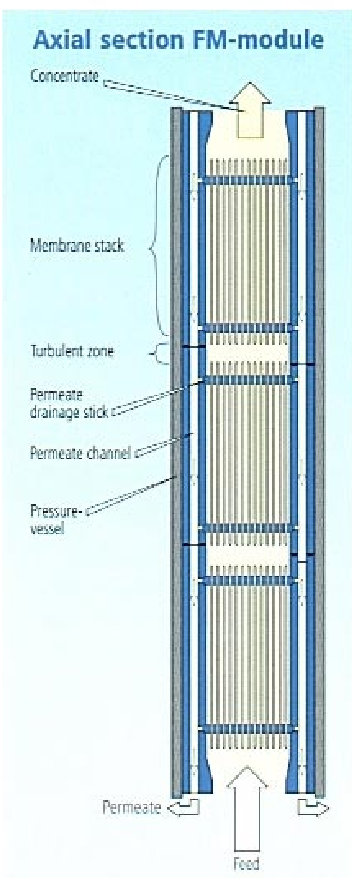
Rochem has a 25 year history of providing equipment and services to the cruise lines, navies, other marine industries as well as land-based applications. Rochem has supplied its equipment for the treatment of both gray water and gray & black water mixtures. This includes operation on cruise line vessels, navy vessels and research vessels in operation world-wide.

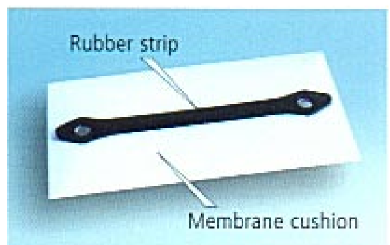
It is understood that your request is for effluent ammonia and metal removal technology. ROCHEM has supplied systems that can meet the Alaskan discharge permit requirements as a primary treatment unit treating raw wastewater influents. This ROCHEM technology can be used as an effluent treatment process if the primary process cannot maintain the permit discharge criteria.

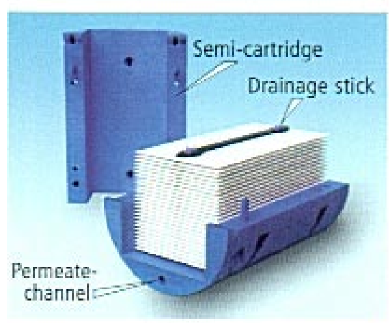
ROCHEM wastewater solutions are based on the use of membranes. Rochem has supplied advanced wastewater treatment plants (AWWPs) that utilize membrane separation with Rochem's FM membrane module. These systems treat a combination of black, galley, accommodation grey and laundry water. It has been shown to be reliable and can meet high quality discharge requirements.

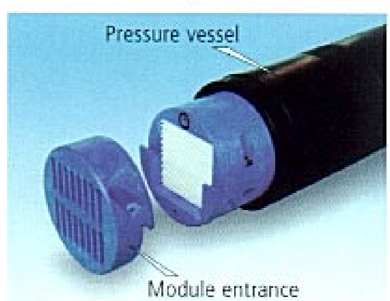
The design is based on the Rochem FM module, which is unique and avoids the problems that are associated with other membrane configurations. The membrane design utilizes the patented concept of a membrane stack with completely open feed channels (no spacer plates) in combination with the straight-through feed flow combining the advantages of the common tube and plate/frame technologies. In addition, the wide spectrum of commercially available flat sheet membranes for ultrafiltration (UF), microfiltration (MF), nanofiltration (NF) and reverse osmosis (RO) allows the optimal selection of a membrane for each application.









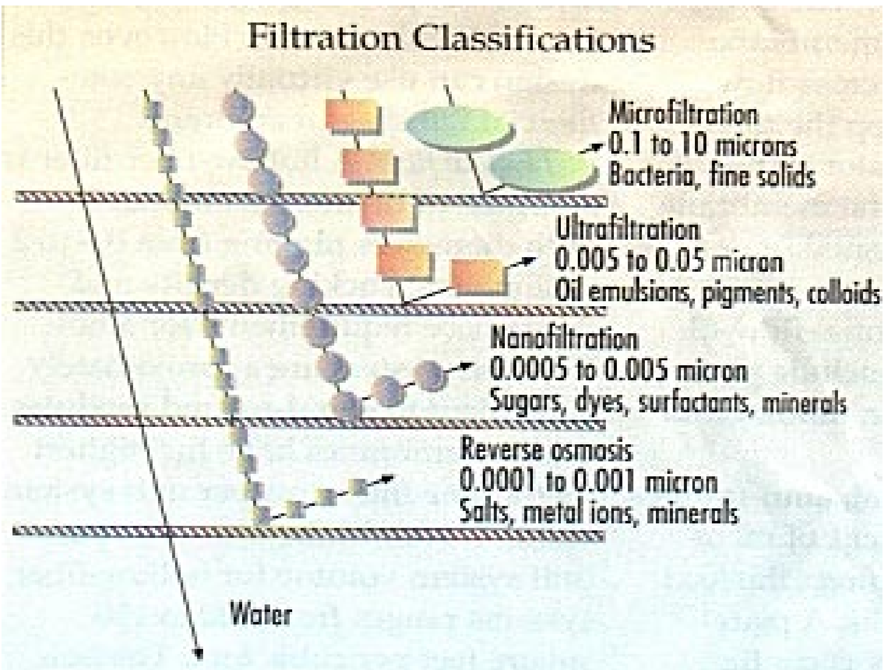


ROCHEM'S FM MODULE

This module design avoids the typical problems associated with fouling and plugging due to biological activity and suspended solids.

Currently, four membrane processes are being used:

- Microfiltration (MF) is effective for separation of particulate matter greater than 0.2 microns in size, including bacteria and protozoan cysts. Membrane can be combined with biological reactor to augment membrane separation, e.g. hollow fine fiber integrated into biological reactor.
- Ultrafiltration (UF) removes essentially all particulate matter, and is an effective barrier to viruses. Membrane can be combined with biological reactor to augment membrane separation, e.g. Rochem BioFilt®.
- Nanofiltration (NF) is effective at removing dissolved organic compounds having molecular weight greater than 200 to 400 daltons (a unit describing molecular weight cut-off [MWCO] and most divalent salts, including sulfate and hardness ions.
- Reverse Osmosis (RO) removes most dissolved organics, metals and nearly all salts (98% or greater).



In the membrane process, the treated water is forced through a membrane barrier to become product water by applied pressure; contaminants are retained on the feed side of the membrane in the form of a concentrate. The two streams, clean product water and the concentrated are collected separately and are directed to storage or discharge.

Applicability of Membrane Processes to Constituents of Marine Concern				
Constituent of Concern for Discharge	**Microfiltration (MF)**	**Ultrafiltration (UF)**	**Nanofiltration (NF)**	**Reverse Osmosis (RO)**
Total Suspended Solids (TSS)	Excellent	Excellent	Excellent[1]	Excellent[1]
Pathogenic Organisms	Excellent	Excellent	Excellent	Excellent
Viruses	Good	Excellent	Excellent	Excellent
Biochemical Oxygen Demand (BOD)	Poor	Poor	Good	Excellent
Salts, Minerals, Total Dissolved Solids (TDS)	Poor	Poor	Good	Excellent
Toxic metals	Poor	Poor	Good	Excellent
Ammonia	Poor	Poor	Poor	Good to Excellent[2]
Micropollutants	Poor	Poor to Good	Good	Excellent

[1]Pretreatment is required for spiral wound and hollow fine fiber membrane module designs. Rochem FM module does not require pretreatment due to the open flow channel design.
[2]Pretreatment is required to maintain ammonia in ionic form of ammonium.

In addition, Rochem also offers membrane systems, marketed as Bio-Filt®, that are combined with a biological reactor (MBR) to treat gray water as well as black water. The benefits of the MBR are the reduction in footprint compared to conventional biological reactors and the low concentrate or sludge volume. The MBR's function is to treat the gray/black water by removing the organic components by biological degradation. The membrane provides a barrier to keep the purified water free of total suspended solids, pathogenic organisms and, depending on the pore size of the membrane, viruses as well.

Applicability of Membrane Bioreactor (MBR) and Reverse Osmosis		
Constituent of Concern	**Membrane Bioreactor (MBR)**	**Reverse Osmosis (RO) Rochem FM**
Total Suspended Solids (TSS)	Excellent	Excellent
Pathogenic Organisms	Excellent	Excellent
Viruses	Excellent	Excellent
Biochemical Oxygen Demand (BOD)	Excellent	Excellent
Salts, Minerals, Total Dissolved Solids (TDS)	Poor	Excellent
Toxic metals	Poor	Excellent
Ammonia	Excellent	Excellent
Micropollutants	Good	Excellent

Proven ROCHEM Effluent Quality Meeting AK General Permit Limits

ROCHEM has been supplying AWWPs to cruise lines with Alaskan iteneraries since 2000. A substantial amount of sampling and analysis has been completed. **Data clearly indicates that the effluent values of Table 1 Effluent Limits and Discharge Reporting of the General Permit No. 2007DB0002 can be maintained utilizing ROCHEM reverse osmosis systems. This is supported by EPA testing as well.**

In addition, the systems supplied so far to the cruise lines and have proven to meet the discharge requirements utilize low pressure RO membranes. Higher removal performances can be achieved utilizing tighter reverse osmosis membranes.

Reuse Opportunities

Using membrane equipment, the quality of the treated water is determined by the openness of the membrane. The water quality improves as the membrane pore size is reduced with reverse osmosis providing the best water for reuse. The ultimate quality of the reused water is determined by the manufacturers' technical specifications designed to provide optimum chemical and operating performance and to protect the equipment from corrosion and surface fouling.

Below is a list of water components that are a concern in reusing water at the laundry facilities. The analysis indicates that key components for reuse can only be controlled through the use of nanofiltration or reverse osmosis membranes.

Applicability of Membrane Processes to Constituents of Concern				
Constituent of Concern For laundry reuse[1]	**Membrane Bioreactor (MBR)**	**Ultrafiltration (UF)**	**Nanofiltration (NF)**	**Reverse Osmosis (RO)**
Water Hardness	Poor	Poor	Good	Excellent
Alkalinity	Poor	Poor	Good	Excellent
Total Dissolved Solids (TDS)	Poor	Poor	Good	Excellent
Toxic metals	Poor	Poor	Good	Excellent
pH[2]	Poor	Poor	Poor	Poor

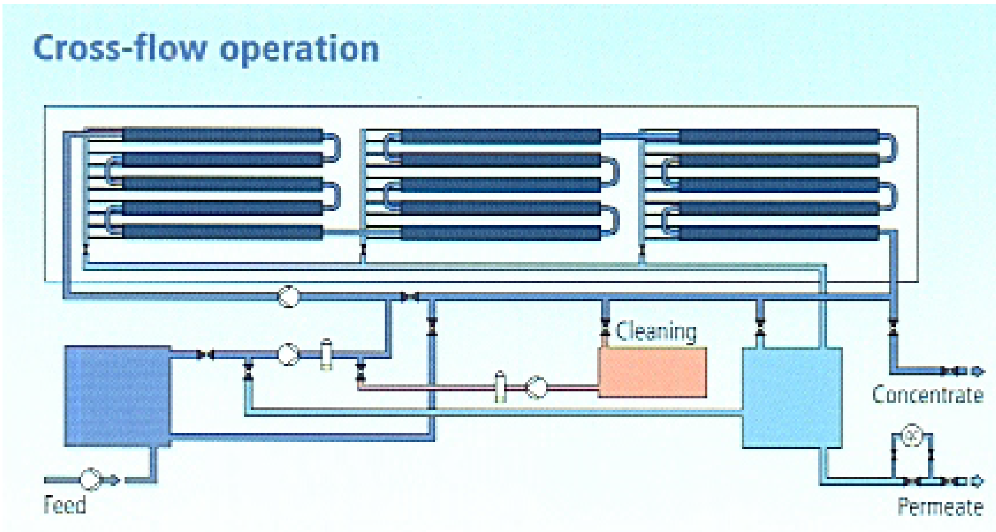
[1]Source: Diversey Lever Overseas
[2]These processes cannot substantially change the pH of the water. Simple provisions can be incorporated to control the pH to the desired value.

EFFLUENT Treatment Units

The Rochem FM units are built in standardized, compact modular stainless steel skid frames for long life and clean looking surfaces. The modular and compact construction allows modification for the installation according to the space requirements. We can dismantle the supply frame to a transport size that can fit through existing passage ways so that the system can be installed while the vessel is under a commercial itinerary.

The control and regulation system is handled by a high quality programmable microprocessor, which allows full automatic operation of the system in an unmanned engine-room. The control includes a complete Fail-Safe System with fault indication and the automatic cleaning sequences for the FM membrane modules. Remote control and the alarm monitoring can be offered for use by ship’s monitoring system at the ECR (Engine Control Room) through an interface connection.

The Rochem FM units are designed for simple handling and access to all components for ease of maintenance and to enable the operation of the unit by non-skilled personnel/operators as well.



The influent is to be supplied through an external feed pump from the holding tank system to the buffer tank of the Rochem FM system to provide convenient system integration. The Rochem FM system is a fully independent stand-alone operating system. The booster pump is continuously feeding the influent to the internal circulation system of FM module system. The circulating pump will increase the velocity of grey water feed upon passing through the feed channels and crossing membrane surfaces. This method avoids an accumulation of finely suspended solids and organic matters on the membrane surfaces.

The clean effluent achieved will be a percentage of the influent after passing the separating treatment process. The remaining concentrate is directed to the concentrate holding tank.

Summary

ROCHEM has been supplying AWWPs to the marine market for 10 years. Reverse osmosis (RO) has been proven to achieve the effluent values of Table 1 Effluent Limits and Discharge Reporting of the General Permit No. 2007DB0002. This is supported by EPA testing as well. Therefore, reverse osmosis is a viable treatment technology for cruise ships trading in Alaskan waters.

ROCHEM has proven that these discharge limits can be met utilizing RO as primary treatment unit. Costs of treatment as well as space requirements are reduced if RO is utilized solely as an effluent treatment technology.

ROCHEM would be a willing participant in further discussions to answer detailed questions on the use of these technologies for effluent ammonia and metal removal.

ROCHEM Low Pressure Reverse Osmosis (LPRO) Systems Supplied to Celebrity Cruise Line, Holland America Line and P&O Cruise Line vessels

ROCHEM LPRO Systems Installed on Holland America Line Vista Class Vessels

ROCHEM High Pressure Reverse Osmosis Modules Installed on Carnival Vessel

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APPENDIX D

MEPC 159(55) Device Approval

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ANNEX 26

RESOLUTION MEPC.159(55)
Adopted on 13 October 2006

REVISED GUIDELINES ON IMPLEMENTATION OF EFFLUENT STANDARDS AND PERFORMANCE TESTS FOR SEWAGE TREATMENT PLANTS

THE MARINE ENVIRONMENT PROTECTION COMMITTEE,

RECALLING Article 38(a) of the Convention on the International Maritime Organization concerning the functions of the Marine Environment Protection Committee (the Committee) conferred upon it by international conventions for the prevention and control of marine pollution,

NOTING resolution MEPC.2(VI) adopted on 3 December 1976 by which the Marine Environment Protection Committee adopted, at its sixth session, the Recommendation on International Effluent Standards and Guidelines for Performance Tests for Sewage Treatment Plants and invited Governments to apply the Effluent Standards and Guidelines for approving sewage treatment plants; to take steps to establish testing programmes in accordance with the Guidelines for Performance Tests; and provide the Organization with a list of sewage treatment plants meeting the standards,

NOTING ALSO resolution MEPC.115(51) adopted on 1 April 2004 by which the Marine Environment Protection Committee adopted, at its fifty-first session, the revised MARPOL Annex IV and which entered into force on 1 August 2005,

NOTING FURTHER the provisions of regulation 9.1.1 of MARPOL Annex IV, in which reference is made to the above-mentioned guidelines,

RECOGNIZING that resolution MEPC.2(VI) should be amended in order that current trends for the protection of the marine environment and developments in the design and effectiveness of commercially available sewage treatment plants be reflected; and the proliferation of differing unilateral more stringent standards that might be imposed worldwide be avoided,

HAVING CONSIDERED the recommendation made by the Sub-Committee on Bulk Liquids and Gases, at its tenth session,

1. ADOPTS the Revised Guidelines on Implementation of Effluent Standards and Performance Tests for Sewage Treatment Plants, the text of which is set out in the Annex to this resolution;

2. INVITES Governments to:

(a) implement the Revised Guidelines on Implementation of Effluent Standards and Performance Tests for Sewage Treatment Plants and apply them so that all equipment installed on board on or after 1 January 2010 meets the Revised Guidelines in so far as is reasonable and practicable; and

(b) provide the Organization with information on experiences gained from their application and, in particular, on successful testing of equipment against the Standards;

3. FURTHER INVITES Governments to issue an appropriate "Certificate of type approval for Sewage Treatment Plants" as referred to in paragraph 5.4.2 and the annex of the Revised Guidelines and to recognize such certificates issued under the authority of other Governments as having the same validity as certificates issued by them; and

4. SUPERSEDES the Recommendation on International Effluent Standards and Guidelines for Performance Tests for Sewage Treatment Plants contained in resolution MEPC.2(VI).

ANNEX

REVISED GUIDELINES ON IMPLEMENTATION OF EFFLUENT STANDARDS AND PERFORMANCE TESTS FOR SEWAGE TREATMENT PLANTS

TABLE OF CONTENTS

REVISED GUIDELINES ON IMPLEMENTATION OF EFFLUENT STANDARDS AND PERFORMANCE TESTS FOR SEWAGE TREATMENT PLANTS

1 INTRODUCTION

1.1 The Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO) adopted resolution MEPC.2(VI) Recommendation on International Effluent Standards and Guidelines for Performance Tests for Sewage Treatment Plants in 1976.

1.2 This document contains the Revised Guidelines on Implementation of Effluent Standards and Performance Tests for Sewage Treatment Plants (Guidelines). These Guidelines are intended to assist Administrations in establishing operational performance testing programmes for sewage treatment plants for the purpose of type approval under regulation 9.1.1 of Annex IV of the Convention.

1.3 These Guidelines apply to sewage treatment plants installed on board on or after 1 January 2010.

2 DEFINITIONS

Annex IV – the revised Annex IV of the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) as amended by resolution MEPC.115(51).

Convention – the International Convention for the Prevention of Pollution from Ships 1973/1978 (MARPOL 73/78).

Geometric mean – the *n*th root of the product of *n* numbers.

Greywater – is drainage from dishwater, shower, laundry, bath and washbasin drains.

Testing onboard – testing carried out on a sewage treatment plant that has been installed upon a ship.

Testing ashore – testing carried out on a sewage treatment plant prior to installation e.g. in the factory.

Thermotolerant coliforms – the group of coliform bacteria which produce gas from lactose in 48 hours at 44.5ºC. These organisms are sometimes referred to as “faecal coliforms”; however, the term “thermotolerant coliforms” is now accepted as more appropriate, since not all of these organisms are of faecal origin.

3 GENERAL

3.1 An approved sewage treatment plant must meet the standards in section 4 and the tests outlined in these Guidelines. It should also be noted that, when ships are operating approved sewage treatment plants, Annex IV also provides that the effluent shall not produce visible floating solids or cause discolouration of the surrounding water.

3.2 It is acknowledged that the performance of sewage treatment plants may vary considerably when the system is tested ashore under simulated shipboard conditions or onboard a ship under actual operating conditions. Where testing ashore demonstrates that a system complies with the standards, but subsequent onboard testing does not meet the standards, the Administration should determine the reason and take it into account when deciding whether to type approve the plant.

3.3 It is recognized that Administrations may wish to modify the specific details outlined in these Guidelines to take account of very large, very small or unique sewage treatment plants.

4 STANDARDS

4.1 For the purpose of regulation 4.1 of Annex IV, a sewage treatment plant should satisfy the following effluent standards when tested for its Certificate of Type Approval by the Administration:

.1 Thermotolerant Coliform Standard

The geometric mean of the thermotolerant coliform count of the samples of effluent taken during the test period should not exceed 100 thermotolerant coliforms/100 ml as determined by membrane filter, multiple tube fermentation or an equivalent analytical procedure.

.2 Total Suspended Solids (TSS) Standard

(a) The geometric mean of the total suspended solids content of the samples of effluent taken during the test period shall not exceed 35 mg/l.

(b) Where the sewage treatment plant is tested onboard ship, the maximum total suspended solids content of the samples of effluent taken during the test period may be adjusted to take account of the total suspended solid content of the flushing water. In allowing this adjustment in maximum TSS, Administrations shall ensure sufficient tests of TSS are taken of the flushing water throughout the testing period to establish an accurate geometric mean to be used as the adjustment figure (defined as *x*). In no cases shall the maximum allowed TSS be greater than 35 plus *x* mg/l.

Method of testing should be by:

.1 filtration of representative sample through a 0.45 μm filter membrane, drying at 105°C and weighing; or

.2 centrifuging of a representative sample (for at least five minutes with mean acceleration of 2,800-3,200 g), drying at least 105°C and weighing; or

.3 other internationally accepted equivalent test standard.

.3 Biochemical Oxygen Demand and Chemical Oxygen Demand

Administrations should satisfy themselves that the sewage treatment plant is designed to reduce both soluble and insoluble organic substances to meet the requirement that, the geometric mean of 5-day Biochemical Oxygen Demand (BOD_5) of the samples of effluent taken during the test period does not exceed 25 mg/l and the Chemical Oxygen Demand (COD) does not exceed 125 mg/l. The test method standard should be ISO 15705:2002 for COD and ISO 5815-1:2003 for BOD_5, or other internationally accepted equivalent test standards.

.4 pH

The pH of the samples of effluent taken during the test period shall be between 6 and 8.5.

.5 Zero or non-detected values

For thermolerant coliforms, zero values should be replaced with a value of 1 thermotolerant coliform/100 ml to allow the calculation of the geometric mean. For total suspended solids, biochemical oxygen demand and chemical oxygen demand, values below the limit of detection should be replaced with one half the limit of detection to allow the calculation of the geometric mean.

4.2 Where the sewage treatment plant has been tested ashore, the initial survey should include installation and commissioning of the sewage treatment plant.

5 TESTING CONSIDERATIONS

5.1 Testing of the operational performance of a sewage treatment plant should be conducted in accordance with the following subparagraphs. Unless otherwise noted, the subparagraphs apply to testing both onboard and ashore.

5.2 Raw sewage quality

5.2.1 Sewage treatment plants tested ashore - the influent should be fresh sewage consisting of faecal matter, urine, toilet paper and flush water to which, for testing purposes primary sewage sludge has been added as necessary to attain a minimum total suspended solids concentration appropriate for the number of persons and hydraulic loading for which the sewage treatment plant will be certified. The testing should take into account the type of system (for example vacuum or gravity toilets) and any water or greywater that may be added for flushing to the sewage before treatment. In any case the influent concentration of total suspended solids should be no less than 500 mg/l.

5.2.2 Sewage treatment plants tested onboard - the influent may consist of the sewage generated under normal operational conditions. In any case the average influent concentration of total suspended solids should be no less than 500 mg/l.

5.3 Duration and timing of test

5.3.1 The duration of the test period should be a minimum of 10 days and should be timed to capture normal operational conditions, taking into account the type of system and the number of persons and hydraulic loading for which the sewage treatment plant will be type approved. The test should commence after steady-state conditions have been reached by the sewage treatment plant under test.

5.4 Loading factors

5.4.1 During the test period the sewage treatment plant should be tested under conditions of minimum, average and maximum volumetric loadings.

.1 For testing ashore, these loadings will be as laid down in the manufacturer's specifications. Figure 1 shows suggested timings for sampling each loading factor.

.2 For testing onboard, minimum loading will represent that generated by the number of persons on the ship when it is alongside in port, and average and maximum loadings will represent those generated by the number of persons on the ship at sea and will take account of meal times and watch rotations.

5.4.2 The Administration should undertake to assess the capability of the sewage treatment plant to produce an effluent in accordance with the standards prescribed by section 4 following minimum, average and maximum volumetric loadings. The range of conditions under which the effluent standards were met should be recorded on the Certificate of Type Approval. The form of the Certificate of Type Approval and appendix is set out in the annex to these Guidelines.

5.5 Sampling methods and frequency

5.5.1 Administrations should ensure that the sewage treatment plant is installed in a manner which facilitates the collection of samples. Sampling should be carried out in a manner and at a frequency which is representative of the effluent quality. Figure 1 provides a suggested frequency for sampling, however, the frequency should take account of the residence time of the influent in the sewage treatment plant. A minimum of 40 effluent samples should be collected to allow a statistical analysis of the testing data (e.g. geometric mean, maximum, minimum, variance).

5.5.2 An influent sample should be taken and analyzed for every effluent sample taken and the results recorded to ensure compliance with section 4. If possible, additional influent and effluent samples should be taken to allow for a margin of error. Samples should be appropriately preserved prior to analysis particularly if there is to be a significant delay between collection and analysis or during times of high ambient temperature.

5.5.3 Any disinfectant residual in samples should be neutralized when the sample is collected to prevent unrealistic bacteria kill or chemical oxidation of organic matter by the disinfectant brought about by artificially extended contact times. Chlorine (if used) concentration and pH should be measured prior to neutralization.

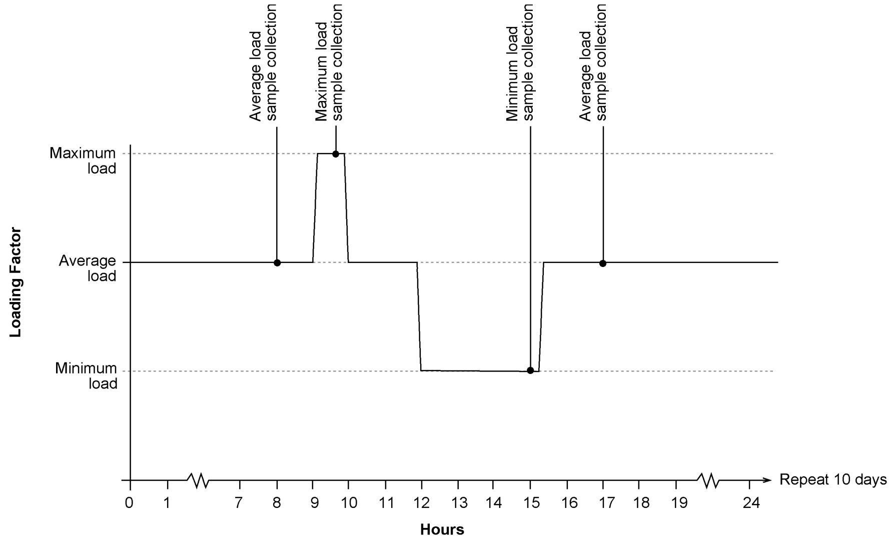

Figure 1: Suggested hydraulic loading factors and sampling frequency for testing sewage treatment plants. May be modified as necessary to take account of characteristics of individual sewage treatment plants

5.6 Analytical testing of effluent

5.6.1 The Administration should give consideration to the recording of other parameters in addition to those required (thermotolerant coliforms, total suspended solids, BOD_5, COD, pH and residual chlorine) with a view to future technological development. Parameters which might be considered include total solids, volatile solids, settlable solids, volatile suspended solids, turbidity, total phosphorus, total organic carbon, total coliforms and faecal streptococci.

5.7 Disinfectant residual

5.7.1 The potential adverse environmental effects of many disinfectant residuals and by-products, such as those associated with the use of chlorine or its compounds, are well recognized. It is, therefore, recommended that Administrations encourage the use of ozone, ultra-violet irradiation or any other disinfectants which minimize adverse environmental effects, whilst pursuing the thermotolerant coliform standard. When chlorine is used as a disinfectant, the Administration should be satisfied that the best technical practice is used to keep the disinfectant residual in the effluent below 0.5 mg/l.

5.8 Scaling considerations

5.8.1 Only full-scale marine sewage treatment plants should be accepted for testing purposes. The Administration may certify a range of the manufacturer's equipment sizes employing the same principles and technology, but due consideration must be given to limitations on performance which might arise from scaling up or scaling down. In the case of very large, very small or unique sewage treatment plants, certification may be based on results of prototype tests. Where possible, confirmatory tests should be performed on the final installation of such sewage treatment plants.

5.9 Environmental testing of the sewage treatment plant

5.9.1 The Administration should be satisfied that the sewage treatment plant can operate under conditions of tilt consistent with internationally acceptable shipboard practice.

5.9.2 Tests for certification should be carried out over the range of temperature and salinity specified by the manufacturer, and the Administration should be satisfied that such specifications are adequate for the conditions under which the equipment must operate.

5.9.3 Control and sensor components should be subjected to environmental testing to verify their suitability for marine use. The Test Specifications section in part 3 of the annex to resolution MEPC.107(49) provides guidance in this respect.

5.9.4 Any limitation on the conditions of operation should be recorded on the Certificate.

5.9.5 The Administration should also consider requiring the manufacturer to include in the operating and maintenance manuals, a list of chemicals and materials suitable for use in the operation of the sewage treatment plant.

5.10 Other considerations

5.10.1 The type and model of the sewage treatment plant and the name of the manufacturer should be noted by means of a durable label firmly affixed directly to the sewage treatment plant. This label should include the date of manufacture and any operational or installation limits considered necessary by the manufacturer or the Administration.

5.10.2 Administrations should examine the manufacturer’s installation, operating and maintenance manuals for adequacy and completeness. The ship should have on board at all times a manual detailing the operational and maintenance procedures for the sewage treatment plant.

5.10.3 Qualifications of testing facilities should be carefully examined by the Administration as a prerequisite to their participation in the testing programme. Every attempt should be made to assure uniformity among the various facilities.

6 RENEWAL AND ADDITIONAL SURVEYS

6.1 Administrations should endeavour to ensure, when conducting renewal or additional surveys in accordance with regulations 4.1.2 and 4.1.3 of Annex IV, that the sewage treatment plant continues to perform in accordance with the conditions outlined in regulation 4.1.1 of Annex IV.

7 FAMILIARIZATION OF SHIP PERSONNEL IN THE USE OF THE SEWAGE TREATMENT PLANT

7.1 Recognizing that the appropriate regulations relating to familiarization are contained within the Ships Safety Management Systems under the International Safety Management Code, Administrations are reminded that ship staff training should include familiarization in the operation and maintenance of the sewage treatment plant.

ANNEX

FORM OF CERTIFICATE OF TYPE APPROVAL
FOR SEWAGE TREATMENT PLANTS AND APPENDIX

BADGE
OR
CIPHER

NAME OF ADMINISTRATION

CERTIFICATE OF TYPE APPROVAL
FOR SEWAGE TREATMENT PLANTS

This is to certify that the Sewage Treatment Plant, Type ...., having a designed hydraulic loading of .... cubic metres per day, (m^3/day), an organic loading of .... kg per day Biochemical Oxygen Demand (BOD) and of the design shown on Drawings Nos. .. manufactured by ....

has been examined and satisfactorily tested in accordance with the International Maritime Organization resolution MEPC.159(55) to meet the operational requirements referred to in regulation 9.1.1 of Annex IV of the International Convention for the Prevention of Pollution from Ships, 1973/78 as modified by resolution MEPC.115(51).

The tests on the sewage treatment plant were carried out
ashore at* ....
onboard at* ....
and completed on ....

The sewage treatment plant was tested and produced an effluent which, on analysis, produces:

(i) a geometric mean of no more than 100 thermotolerant coliforms/100 ml;
(ii) a geometric mean of total suspended solids of 35 mg/l if tested ashore or the maximum total suspended solids not exceeding 35 plus *x* mg/l for the ambient water used for flushing purposes if tested on board;
(iii) a geometric mean of 5-day Biochemical Oxygen Demand (BOD_5) of no more than 25 mg/l;
(iv) a geometric mean of Chemical Oxygen Demand of no more than 125 mg/l;
(v) pH of the effluent is between 6 and 8.5.

The Administration is satisfied that the sewage treatment plant can operate at angles of inclination of 22.5° in any plane from the normal operating position.

Details of the tests and the results obtained are shown on the Appendix to this Certificate.

A plate or durable label containing data of the manufacturer's name, type and serial numbers, hydraulic loading and date of manufacture is to be fitted on each sewage treatment plant.

A copy of this Certificate shall be carried on board any ship equipped with the above described sewage treatment plant.

Official stamp Signed ....…………………………………………….…

Administration of ………………………………………

Dated this………..……day………..of……..…20.…

* Delete as appropriate.