FINAL REPORT

Novel Membrane Separation System for Shipboard Oily Wastewater Treatment

ESTCP Project WP-200215

DECEMER 2010

David Maribo
Naval Surface Warfare Center
Researchers Organization

This document has been cleared for public release

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
10 September 2010

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*
June 2002-September 2010

4. TITLE AND SUBTITLE
Novel Membrane Separation System for Shipboard Oily Wastewater Treatment

5a. CONTRACT NUMBER
N00167-03-C-0021

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
0603851DBZ

6. AUTHOR(S)
Maribo, David W.

5d. PROJECT NUMBER
WP-0215

5e. TASK NUMBER

5f. WORK UNIT NUMBER
09-1-6330-180

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Surface Warfare Center
Carderock Division Code 633
9500 MacArthur Blvd
W. Bethesda MD 20817-5700

Membrane Technology and Research, Inc
1360 Willow Rd.
Menlo Park, CA 94025

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
ESTCP Program Office
901 N Stuart St. Suite 303
Arlington, VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)
ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The objective of the demonstration is to improve fouling resistance and process reliability of ceramic membrane modules used in the secondary treatment of oily wastewater using a nonporous polymer coating, thereby reducing life-cycle costs. A secondary objective was to improve acquisition cost of membranes through the use of polymeric spiral-wound membranes in lieu of ceramic. This study has so far shown that ceramic membranes coated with one layer of 0.1% Pebax® 1074 have at least doubled the life of uncoated membranes in the laboratory. Oil separation performance is equal. Spiral-wound polymeric membranes could not pass the required amount of flux after the coating was applied, and so were deemed unsuitable for this application. Full-scale coated membranes were then installed on USS JAMES E. WILLIAMS (DDG 95). Unfortunately, the membrane system suffered an electrical failure during the deployment, so the membrane lifetime at sea could not be determined. It is recommended that the membranes continue to be monitored until sufficient data is obtained.

15. SUBJECT TERMS
ceramic membranes, non-porous coating, Pebax®, oily wastewater, bilge water

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			David Maribo
unclassified	unclassified	unclassified	UU	64	**19b. TELEPHONE NUMBER** *(include area code)* 301-227-5220

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

List of Tables

Abbreviations

AAE	Aircraft Appliances and Equipment
AFFF	Aqueous Film Forming Foam
APPS	Act to Prevent Pollution from Ships
CTC	Concurrent Technologies Corporation
CWA	Clean Water Act
CWF	Clean Water Flux
DoD	Department of Defense
ECAM	Environmental Cost Analysis Methodology
EMI	Electromagnetic Interference
EOSS	Engineering Operating and Sequencing System
EPA	United States Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
ft	Feet
FTIR	Fourier Transform Infrared Reflectance
gfd	Gallons per square foot per day
gpm	Gallons per minute
hr	Hour
IPR	In-Progress Review
L	Liter
MARPOL 73/78	Annex I of the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978
m	Meter
MPCD	Marine Pollution Control Device
MRC	Maintenance Requirement Card
MTR	Membrane Technology and Research, Inc.
NSWCCD	Naval Surface Warfare Center, Carderock Division
OPNAVIST	Chief of Naval Operations Instructions
OSA	Open Systems Architecture
OWHT	Oily Waste Holding Tank
OWMS	Oily Waste Membrane System
OWS	Oil/Water Separator
PEI	Polyetherimide
PLC	Program Logic Control
ppm	Parts per million
psi	Pounds per square inch
PVDF	Polyvinylidene Fluoride
SEM	Scanning Electron Microscopy
SERDP	Strategic Environmental Research & Development Program
TBD	To be determined
TMP	Transmembrane Pressure
UNDS	Uniform National Discharge Standards
WOT	Waste Oil Tank
yr	Year

Acknowledgments

This evaluation was sponsored by the Environmental Security Technology Certification Program (ESTCP) Weapons Systems and Platforms (WP). The financial support of the Environmental Security Technology Certification Program is hereby acknowledged. The ESTCP WP program manager is Mr. Bruce Sartwell. The work was performed by Naval Surface Warfare Center, Carderock Division (NSWCCD), Wastewater Management Branch (Code 633) and Membrane Technology and Research, Inc. The project team was Mr. David Maribo (Lead Investigator 2006-2010) and Ms. Holly Nestle (Lead Investigator 2002-2006). Dr. Alvin Ng and Dr. Hans Wijnmans participated from Membrane Technology and Research, Inc. The author particularly would like to acknowledge the officers and crew of the USS James E. Williams (DDG 95), where the shipboard testing was performed.

Executive Summary

A major source of overboard discharge from ships is oily wastewater (bilgewater), which collects in most machinery spaces and is generated in volumes too large for long-term storage. Ceramic oily waste membrane systems have been developed by Naval Surface Warfare Center, Carderock Division (NSWCCD), as a secondary treatment of the existing parallel-plate separator (OWS) effluent.

The objective of this demonstration was to improve fouling resistance and process reliability of these ceramic membrane systems using a nonporous polymer coating, thereby reducing life-cycle costs. A secondary objective was to improve acquisition cost of membranes through the use of polymeric spiral-wound membranes in lieu of ceramic.

A total of seven small-scale ceramic membranes were coated and tested for this evaluation. After trying different concentrations and thicknesses on the polymer, Pebax® 1074, one layer of 0.1% produced the required flux with a very low fouling rate. This was the chosen coating for subsequent tests of full-scale ceramic membranes.

This study has so far shown that coated ceramic membranes have at least doubled the life of uncoated membranes in the laboratory. Oil separation performance is equal, and the coating proved resistant to all contaminants. Spiral-wound polymeric membranes, however, could not pass the required amount of flux after the coating was applied, and so were deemed unsuitable for this application.

Full-scale coated membranes were then installed on USS JAMES E. WILLIAMS (DDG 95). Resistance data was sent by e-mail from the ship to NSWCCD for the first 21 hours. Then operational conditions did not permit e-mail contact until the 54-hour point. At that point, the membrane system broke down due to an electrical failure and no further run time was accomplished during the deployment, so long-term membrane lifetime at sea has not yet been determined. It is recommended that the membranes continue to be monitored until sufficient data is obtained.

1. Introduction

1.1 Background

A major source of overboard discharge from ships is oily wastewater (bilgewater), which collects in most machinery spaces and is generated in volumes too large for long-term storage. Ceramic oily waste membrane systems have been developed by Naval Surface Warfare Center, Carderock Division (NSWCCD), as a secondary treatment of the existing parallel-plate separator (OWS) effluent. The oily waste membrane system (OWMS) has demonstrated the ability to reliably produce effluent oil concentrations below environmental requirements.

Laboratory and shipboard evaluations of oily waste membrane systems to date have focused on ceramic membranes. Ceramic membranes were selected early in membrane system development for their chemical inertness and fouling resistant properties. Figure 1 is a picture of a full-scale ceramic membrane system on a DDG 51-class destroyer. The ceramic membranes typically account for one-fifth of the acquisition cost of a membrane system. These membranes contain small pores, which over time (typically one year of operation) will foul due to the highly variable bilge constituents, requiring membrane cleaning or replacement. Membrane cleaning and replacement are the leading drivers for membrane system life-cycle costs. While ceramic membrane technology has been demonstrated to be effective in meeting discharge requirements, its implementation has been limited by acquisition and lifecycle costs. Therefore, an alternative membrane technology, a nonporous polymer coating on the ceramic membrane, was identified to reduce membrane acquisition and life-cycle costs and provide a cost-effective solution for treating oily waste shipboard.

1.2 Objectives of Demonstration

The objective of the demonstration was to improve fouling resistance and process reliability of ceramic membrane modules used in the secondary treatment of oily wastewater by applying a nonporous polymer coating, called Pebax®, thereby reducing life-cycle costs. A secondary objective was to improve acquisition cost of membranes through the use of polymeric spiral-wound membranes in lieu of ceramic. Polymeric membranes are less costly than ceramic and the manufacturing process used to make spiral-wound membranes is conducive to application and control of the non-porous coating [1].

Bilgewater is a highly variable mixture of potable water and seawater, with contaminants from a number of sources. Typical contaminants may include fuels, oils, and hydraulic fluids, detergents and Aqueous Film Forming Foam (AFFF), incidental leaks from blackwater / graywater systems, and a wide variety of other substances, potentially including corrosion products, paints, and solvents. The type and amount of bilgewater contaminants vary widely based on a ship's operations, equipment performance, casualties, repairs, and other events. The generation rate of bilgewater ranges from tens of thousands of gallons per day on air-capable ships to less than 500 gallons per day on newer "dry bilge" combatants such as the *Arleigh Burke* Class. Larger,

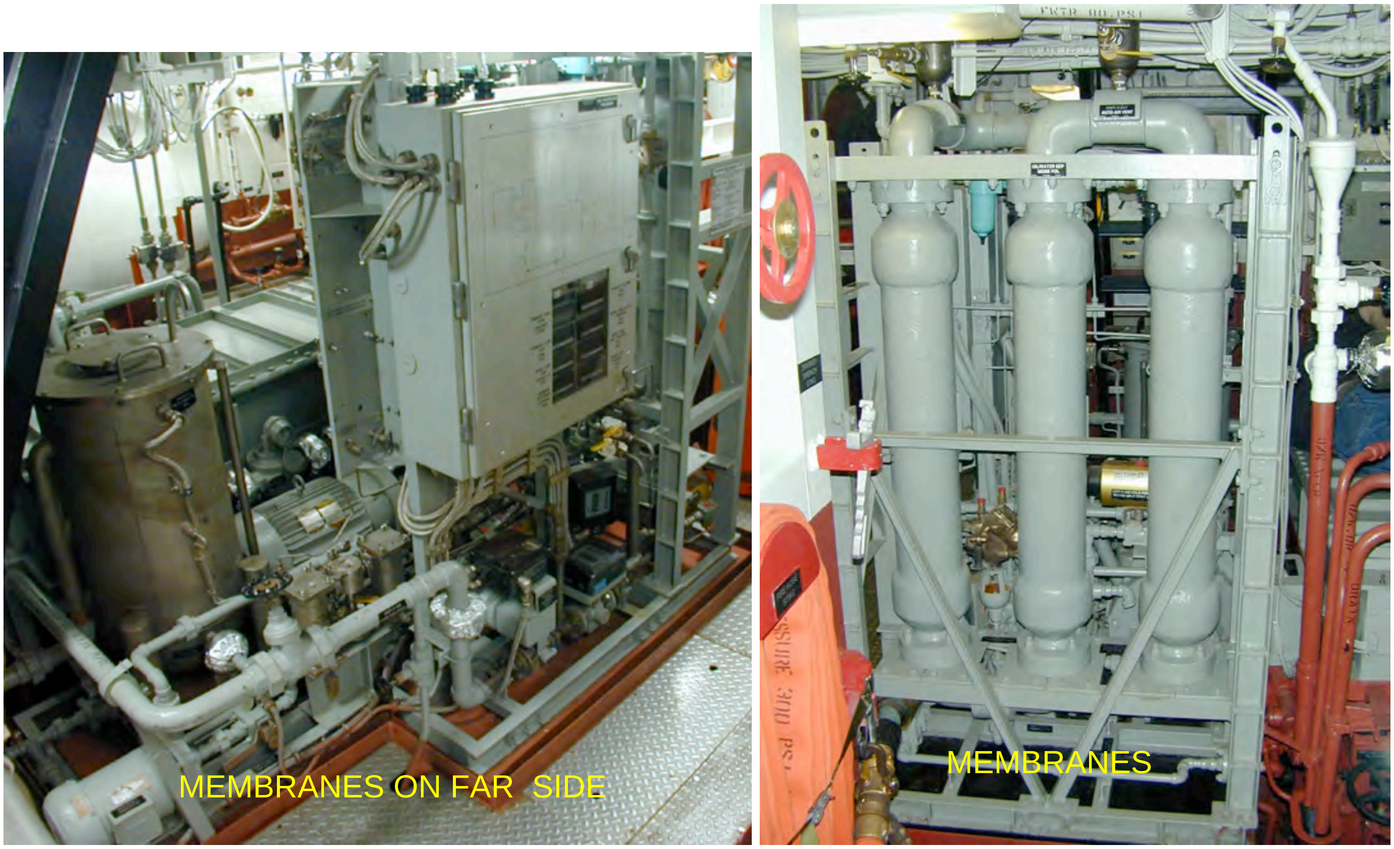


Figure 1. Oily Waste Membrane System Onboard DDG-class ship

older ships frequently produce large volumes of dilute waste, while newer, smaller ships generally produce smaller volumes of more concentrated waste.

The purpose of the demonstration was to validate the performance of the nonporous polymeric coating by small-scale evaluation of coated ceramic membranes, and if successful, follow up with a full-scale demonstration of a coated ceramic membrane in the laboratory and shipboard. The coated polymeric spiral-wound membranes were also to be tested in the laboratory and shipboard.

1.3 Regulatory Drivers

DoD Directive 6050.15 requires the heads of Federal Departments and agencies to prescribe standards for the prevention of pollution from ships for which they are responsible. The provisions of this Directive specifically provide for preventing oil pollution from DoD ships in accordance with 33 USC 1901-1911 (Act to Prevent Pollution from Ships, APPS). APPS implements the Protocol of 73/78 Relating to the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78). In addition to the DoD Directive, the U.S. Environmental Protection Agency's (EPA) Clean Water Act (CWA) prohibits discharge of oil or hazardous substances in harmful quantities into or upon navigable waters of the United States. MARPOL 73/78 and CWA are currently being implemented into the Coast Guard and Army by 33CFR151.10, which regulates vessels carrying oil and ballast water. Oil discharge over 15 ppm is prohibited. OPNAVINST 5090.1B CH-2 regulates Navy ships to the same discharge limit for bilgewater and other oily waste discharges.

Future discharge limits of oily waste for Armed Forces vessels will be regulated by Uniform National Discharge Standards (UNDS). Phase I of UNDS identified discharges and applicable Armed Forces vessels subject to UNDS regulation. A total of 7,170 Armed Forces vessels are applicable to UNDS. Also, the Administrator of EPA and the Secretary of Defense determined it was reasonable and practicable to require Marine Pollution Control Devices (MPCDs) for 25 of the 39 identified discharges, including compensated fuel ballast, dirty ballast, and surface vessel bilgewater/oil-water separator effluent. Phase II of UNDS will identify appropriate MPCDs for each discharge that requires control, and establish the MPCD performance standards. Membranes have been selected by UNDS as a potential MPCD for treatment of oily waste. As previously mentioned, major limitations of membrane technology have been membrane cost and membrane fouling, which directly impact lifecycle costs to process oily waste. New technologies are needed to address this limitation and provide a cost effective method for treating shipboard oily waste.

1.4 Stakeholder/End-User Issues

The purpose of this demonstration was to validate the polymer coated ceramic membrane and/or polymeric membrane performance under the operating parameters required by the shipboard Oily Waste Membrane System (OWMS). Currently, the military performance specifications MIL-PRF-32097 [2] for OWMS membrane modules have been finalized. The performance specification may be updated based on the degree of the demonstration’s success and cost benefits, and will provide DoD with a means for evaluating open competition for future implementation. It is anticipated membrane fouling and costs may be reduced by as much as 50%. This technology is applicable to all Navy ship classes. An additional benefit is the potential to remove additional constituents of concern from bilgewater discharge (bilgewater regulations may be expanded to address other constituents of concern such as metals, pesticides, etc.). It is possible that the nonporous membranes will produce cleaner effluent for overboard discharge. Additionally, other wastewater applications can be investigated for treatment including: gas turbine water wash, vehicle wash-down, and advanced base applications.

2. Technology Description

2.1 Technology Development and Application

The oily waste membrane system developed by NSWCCD utilizes ultrafiltration membranes to filter small-droplet and emulsified oil that has passed through a primary treatment system [3]. The pore sizes of the membranes are scaled to allow passage of small water molecules but not allow passage of very large molecules and particles, such as oil droplets and other contaminants. Please refer to Figures 2 and 3, below. Figure 2 is a slice of an actual membrane element. The holes visible in the ends are parallel passageways, called lumens, which extend all the way through from one end to the other. Figure 3 is a simplified representation of one of those lumens. The membrane element is mostly porous substrate, through which water passes quite easily. However, inside each lumen several layers of far-less porous material - 5 nanometer pore size - are applied. This is the membrane. Clean water passes through the pores in the membrane in a radial direction and is discharged overboard (permeate). Oil droplets emulsified in water and particulates that are too large to pass through ultrafiltration membranes are retained and concentrated in the membrane system (concentrate). The concentrate is periodically discharged from the system and stored for disposal ashore. Figure 4 is a 500X magnified SEM showing the actual appearance of the membrane layers.

The recirculation flow, also called cross-flow, is a flow parallel to the membrane surface. The purpose is to clean the membrane surface by shear. The velocity is approximately 10 ft/sec. (3.3 m/s).

Laboratory and shipboard evaluations by NSWCCD of oily waste membrane systems to date have focused on porous ceramic membranes, after comparison of several different types of ceramic and polymeric membranes [4].

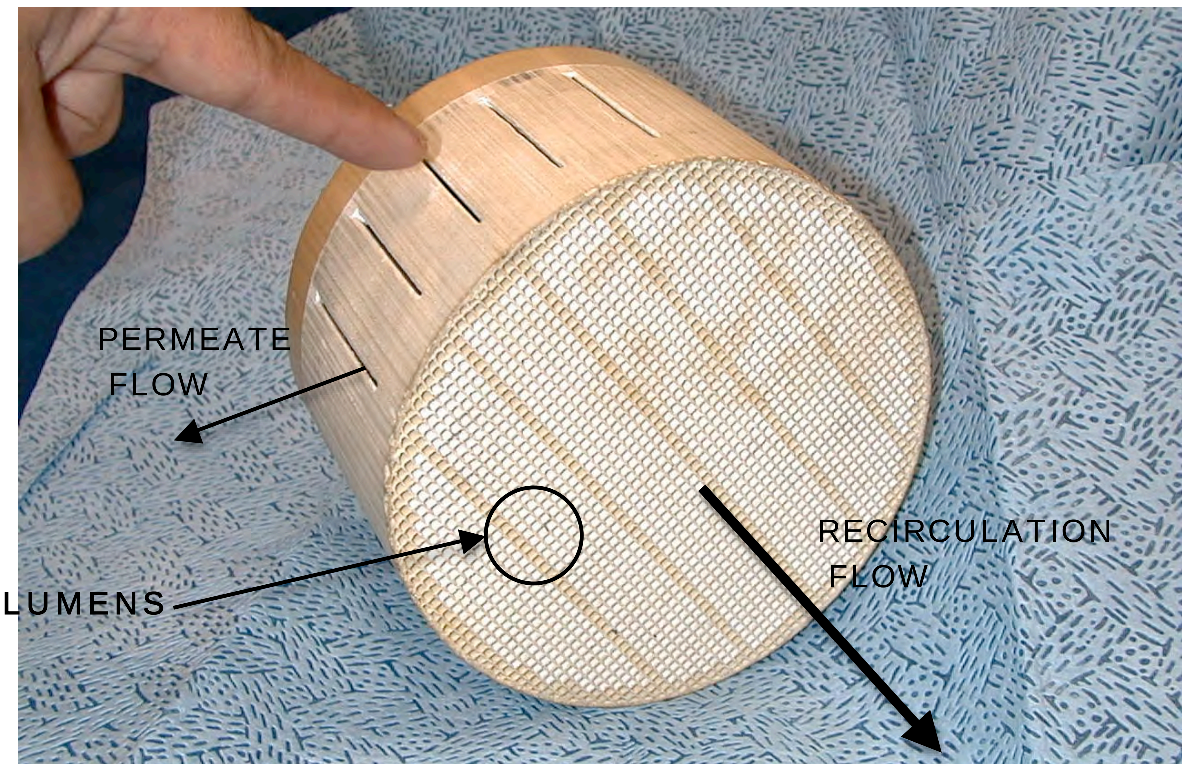


Figure 2. Ceramic Membrane Element (a short piece)

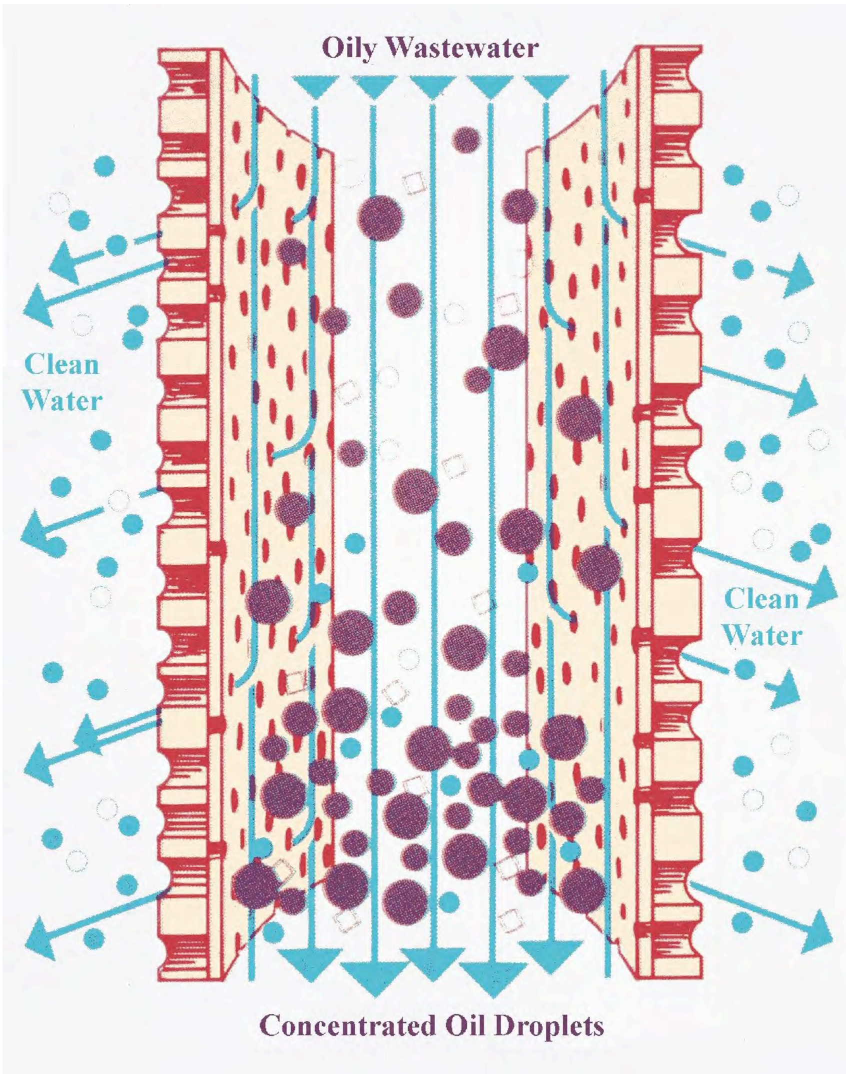
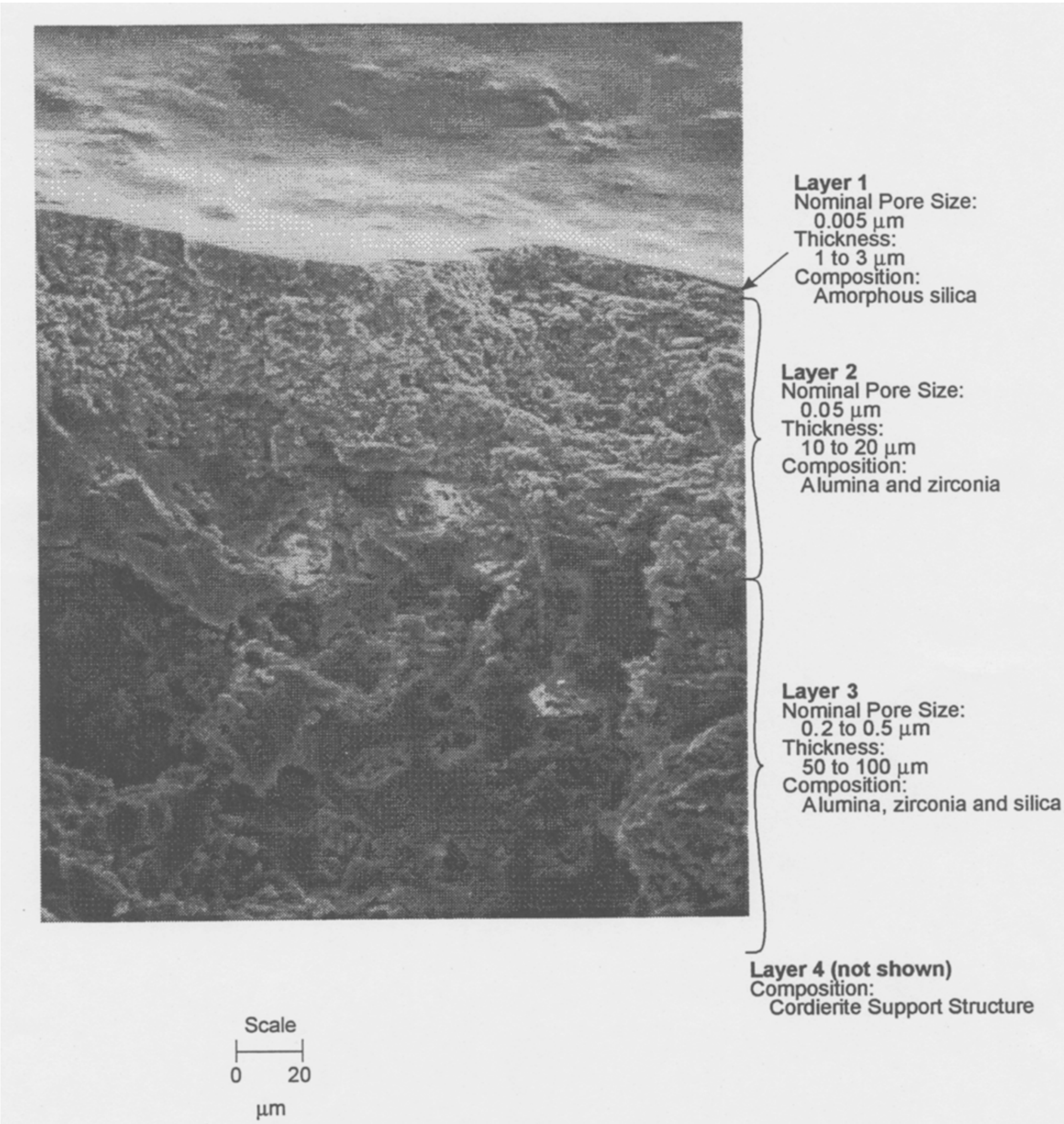


Figure 3. Principle of membrane separation, showing cross-section of one lumen.



Scanning Electron Microscope (SEM) image of the ceramic filter in cross-section. Magnification is 500x. Three of the four layers can be seen. The separation layer is the uppermost layer in the image.

Figure 4. Ceramic membrane layers without the non-porous polymer coating.

Membrane Technology and Research, Inc. (MTR), Menlo Park, CA, under a previous SERDP project [1] (CP1108, completed FY00) developed the application of a nonporous polymer coating to membranes used for bilgewater and graywater treatment. The polymer is called Pebax®. It is produced by Arkema, Inc. (formerly Atofina), Philadelphia, PA. It consists of polyamide-polyether copolymer blocks. It is hydrophilic and oil phobic (that is, it attracts water and repels oil), and provides superior strength, water flux, and very high resistance to internal and external fouling. It also has excellent resistance to a wide range of contaminants in wastewater including toluene, ethanol, and various detergents. The polymer is stable in the pH range of 2-12 and can withstand temperatures up to 70°C. The first phase of tests in the demonstration included the coating and testing of commercially available ceramic ultrafiltration modules with the fouling-resistant polymer. Figure 5 is a magnified drawing of a porous ceramic membrane with and without the nonporous coating. Over time, oils and other contaminants build up in the permeating pores, reducing the amount of permeable membrane area. With the nonporous polymer coating, oils and contaminants are unable to plug the membrane pores, and therefore extend the life of the membrane.

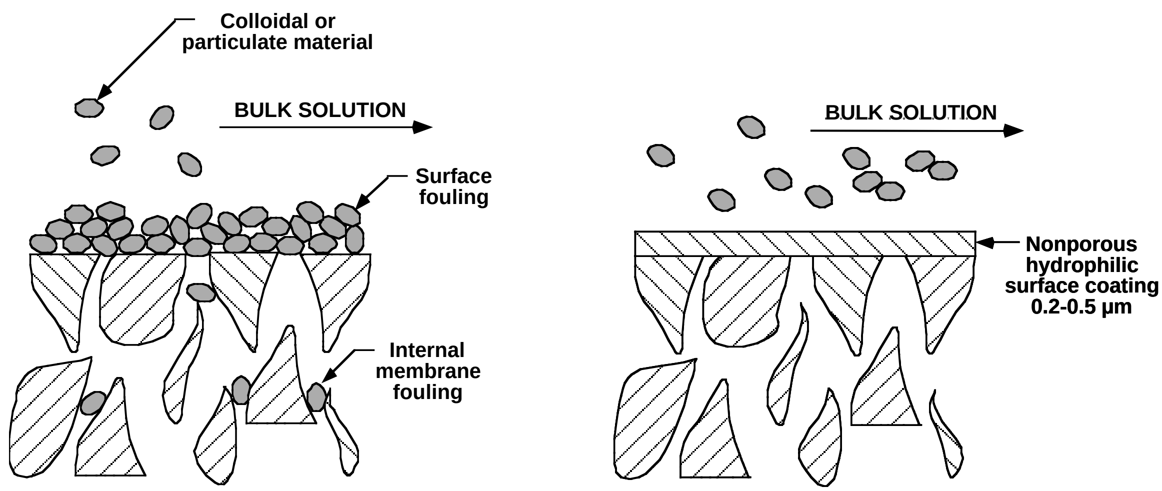


Figure 5. Membrane Surface with and without Polymer Coating

2.2 Previous Testing of Technology

Figure 6, from reference 1, shows a representative result of the long-term oil fouling tests carried out with ultrafiltration membrane modules, with and without MTR's polymer coating. The high initial pure water flux of the uncoated membrane is quickly lost on contact with an aqueous emulsion due to formation of a gel layer on the membrane surface [1], although the flux of the uncoated membrane was still higher than that of the coated membrane. After 7 or 8 days, fouling reduced the flux to less than that of the coated membranes. Flushing restores flux to a point, but never to the initial value. Eventually, flushing cannot restore a useful amount of flux. In contrast, very little fouling is observed with the membrane coated with the MTR polymer; the steady state water flux of this membrane is at least 200% higher than that of the uncoated membrane.

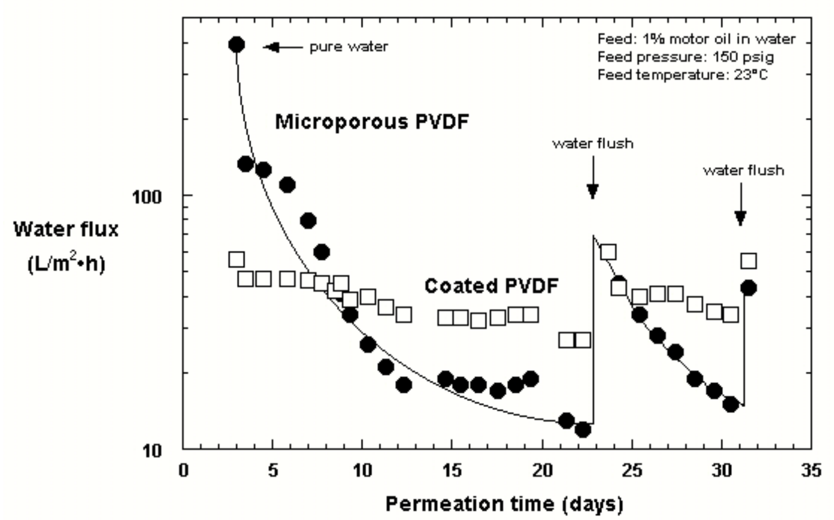


Figure 6. Water Fluxes of Coated and Uncoated Polymeric Membrane Modules as a Function of Permeation Time

Note: Feed solutions: pure water and 1% motor oil emulsion; feed temperature: 23°C; feed pressure: 150 psig. These were the conditions in reference 1 by MTR only, not in the Navy work.

Cross-flow velocity was varied from 2 to 4 m/s (6.6 to 13 ft/s) at NSWCCD in an effort to minimize fouling [5]. Below 6 ft/s flow is laminar and does no cleaning at all. Above 13 ft/s the membrane can peel off; pumps and other components get dramatically larger. So a cross-flow velocity of 10 ft/sec was shown to be an optimum. NSWCCD also studied the effect of flux on the life of ceramic membranes [6]. The work determined that the flux should be less than 60 gfd (102 L/m^2-hr), with 40 gfd (68 L/m^2-hr) being chosen as a conservative option.

MTR performed initial work [1] on the Pebax® coating using spiral-wound polymeric membranes. These membranes were redesigned to accept the coating. Parameters such as module rolling tension and spacer settings were varied, along with coating composition. Success was measured by the resulting flux, rejection of oil, and absence of defects. Ultimately, the entire module – that is, both the membrane and the housing – must be designed to fit within an existing shipboard membrane system.

2.3 Factors Affecting Cost and Performance

The factors affecting the cost and performance of coated membrane modules include the complexity of module configuration, the adhesion of the coating material to the substrate, the degree of flux reduction due to the presence of the coating layer, chemical stability of the coating and the ability of the redesigned modules to withstand the cross-flow velocity used in the system.

2.4 Advantages and Limitations of Technology

The nonporous technology offers several advantages. Application to ceramic membranes will reduce fouling, and thereby extend the membrane life and reduce life cycle costs. Use of the coated polymeric membrane would greatly reduce acquisition cost. The lighter weight of the polymeric would facilitate maintenance and installation, and the polymeric material is less prone to damage when transported or handled.

Another potential benefit is the potential to remove other constituents from bilgewater discharge (bilgewater regulations may be expanded to address other constituents, i.e. metals, pesticides, etc.). Because of the polymer coating, it is possible that the nonporous membranes will produce cleaner effluent for overboard discharge. In the future, other wastewater treatment applications will be investigated.

The coated ceramic and polymeric membranes offer more resistance to fouling but perhaps at the cost of flux. Flux is the rate of processed waste per unit of membrane area. The question of whether the operating mechanism of the nonporous coating reduces the flux through the membranes is to be answered by this work. If the flux were reduced, the required surface area of membranes would need to be increased. On the other hand, if the flux were not reduced, and life of the membranes is dramatically increased, then future systems might require fewer membranes while retaining acceptable life.

3. Demonstration Design

3.1 Performance Objectives

Table 1 lists the performance objectives that are essential for successful demonstration and validation of the nonporous polymer technology.

Table 1. Performance Objectives

Type of Performance Objective	**Primary Performance Criteria**	**Expected Performance (Metric)**
Quantitative[1]	System Interface Requirements	Maintain flow rate of 3.33 gpm (full-scale)
	Improve fouling resistance	Coated ceramic – ≤ 0.0027 psi/gfd/hr (~600 hours of operation) Coated polymeric – TBD (approximately ≤ 0.0034 psi/gfd/hr, ~600 hours of operation)
	Effluent quality	<15 ppm oil content in membrane permeate
	Material Stability and Compatibility	Polymer coating integrity does not degrade by more than 25% in coating coverage of the underlying support membrane
	Operating Costs Savings - With coated ceramic - With spiral -wound	 $4.0K/ship/yr $4.9K/ship/yr

The criteria include hydraulic performance of the coated membranes, meeting the environmental regulation, reduction of lifecycle costs and durability of the polymer coating. Sections 4.1 and 4.2 provide acceptance/rejection metrics of these performance criteria.

[1] The expected performance metrics (system interface requirements, improve fouling resistance, and effluent quality) are derived from the performance specification for membrane modules MIL-PRF-32097 [2] for the non-coated ceramic membranes already installed in the OSA OWMS-10. The resistance rates reflect the required extension of the operation period without regeneration from 300 hours to 600 hours.

3.2 Test Sites/Facilities

The coating and preliminary testing of the ceramic and polymeric membranes was performed at MTR. MTR has three pilot scale systems and five laboratory scale systems which were used for the preliminary performance tests during the coating optimization work. The optimized modules were then sent to NSWCCD for further evaluation.

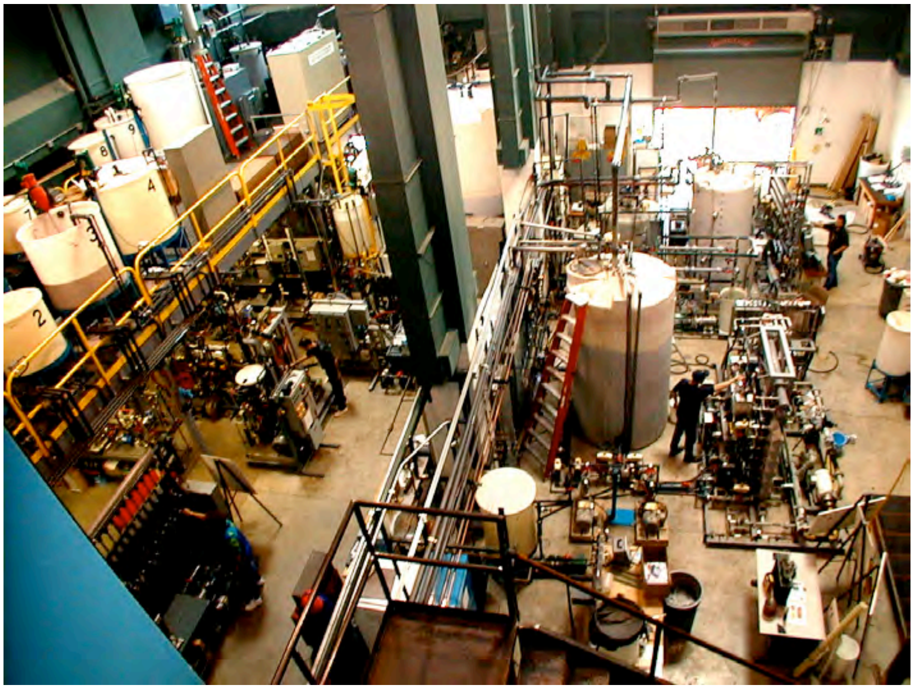


Figure 7 - Liquid waste laboratory at NSWCCD

Both small-scale and full-scale laboratory demonstrations of the coated membranes were performed at NSWCCD Carderock, West Bethesda MD, Liquid Waste Laboratory, Building 60, Room 175, (shown in Figure 7). The shipboard evaluation is taking place aboard the USS James E. Williams (DDG 95).

3.3 Summary of Previous Testing and Evaluation

3.3.1 Scale Factor

Membranes on LPD–class ships treat wastewater at a flux rate of 40 gallons/square foot/day (gfd), or 68 L/m^2-hr, based on the effect of flux on membrane life [6]. Therefore, small-scale (1.3 ft^2 membrane area) ceramic membrane elements process simulated oily wastewater at a rate of 0.05 gallons per minute (gpm), or 3.0 gallons per hour. A full-scale membrane element with approximately 120 ft^2 of membrane area processes oily wastewater at 3.3 gallons per minute.

3.3.2 Operating Parameters for Technology

The coated membranes processed 10 gpm at the same operating parameters as the non-coated ceramic membranes already installed in the open systems architecture (OSA) Oily Waste Membrane System, as described in the performance specification for membrane modules, MIL-PRF-32097 [2]. The three hydraulic parameters, membrane flux, cross-flow velocity and transmembrane pressure, were controlled during the testing.

Membrane permeate flux is the membrane flow rate divided by membrane area. Membrane systems evaluated at NSWCCD utilize three ceramic membrane modules with approximately 120 ft^2 of membrane area per membrane, requiring each module to produce 3.33 gal/min. A membrane permeate flux of 3.33 gal/min per 120 ft^2 of membrane area yields a flux rate of 40 gfd (gallons per foot-squared per day). The equation to calculate flux is:

$$F = \frac{Q_p}{A_m}$$

where F = Flux (gfd)
Q_p = Permeate Flow (gal/day)
A_m = Membrane Surface Area (ft^2)

Flux rate is *membrane flow for a given surface area*, allowing comparison of large and small-scale membranes. As mentioned previously, all membranes were required to initially meet the flux requirement for a 3.33 gpm system. Eventually fouling prevents full flow, but 40 gfd is the flux requirement when new.

But flux is not the whole story: it matters how much pressure is required to achieve the desired flux. Transmembrane pressure (TMP) is the average pressure drop through the membrane surface. This pressure difference drives water through the membrane. Pressure measurements before the membrane (P_I, concentrate in), after the membrane (P_O, concentrate out) and the permeate pressure, P_P, are used to calculate TMP. The concentrate in pressure and the concentrate out pressure remain relatively constant for each membrane; therefore, TMP is controlled by adjusting the permeate pressure, P_P. The equation for TMP is:

$$TMP = \frac{(P_I + P_O)}{2} - P_P$$

where TMP = Transmembrane Pressure (psi)
P_I = Feed/Concentrate (In) Pressure (psi)
P_O = Concentrate (Out) Pressure (psi)
P_P = Permeate Pressure (psi)

Resistance, the dependent variable, uses both TMP and flux to express the overall hydraulic life of a membrane as the *pressure required to produce a unit of flux*, or the psi needed to generate one gallon of permeate per one square foot of membrane area per day. A temperature correction factor is used in the equation to normalize flow to room temperature to eliminate the effect of viscosity changes in water with temperature. The equation for calculating resistance with the temperature correction factor to 68 degrees Fahrenheit is:

$$R = \frac{TMP}{F} * \frac{0.3 + 1.38e^{\frac{-68}{27.6}}}{0.3 + 1.38e^{\frac{-T}{27.6}}}$$

where: R = Resistance (psi/gfd)
TMP = Transmembrane Pressure (psi)
F = Flux (gfd)
T = Temperature in Test Loop (°F)

Resistance is a time-dependent performance criteria as listed in the membrane performance spec [2], requiring 300 hours of membrane operation with a resistance less than 1.63 psi/gfd for baseline non-coated ceramic membranes. A membrane with a surface area of 120 square feet at maximum transmembrane pressure (65 psi at operating parameters) and unable to maintain a 40 gfd flux rate (a processing rate of 3.3 gpm per membrane) has a resistance greater than 1.63 psi/gfd, and is then declared a failed membrane. By comparison, new membranes have a resistance of 0.3 to 0.7 psi/gfd. The 300-hour time period refers to approximately one year of membrane operation aboard an Arleigh Burke class ship [7], based on the bilgewater generation rate of 300-600 gal/day. Assuming (generously) a starting resistance of zero, the non-coated ceramic membrane rate of resistance increase (or fouling rate, R´) over the course of 300 hours would be 0.0054 psi/gfd/hr.

The goal for coated ceramic membranes is to process 2.25 years before requiring regeneration, or approximately 600 hours: at least double the life. Membrane failure would still be at a resistance of 1.63 psi/gfd. For 600 hours of processing, however, the resistance rate is 0.0027 psi/gfd/hr (half).

The membranes processed the feed stream to a volume reduction factor of 100:1. Therefore, for every hundred gallons of oily waste, 99 gallons of clean membrane effluent (permeate) and one gallon of concentrated oil and other bilge contaminants are produced. On a ship, the concentrated waste is retained in a tank, and the permeate is pumped overboard. The 100:1 ratio of permeate to concentrate is used shipboard, and was maintained for this testing.

The only other parameter left is cross-flow velocity. Cross-flow velocity is the average flow rate of concentrated water flowing tangential to the membrane surface. Full-scale coated membranes were operated within the membrane design operation range of approximately 10 ft/s, or 3 m/s. For the small-scale demonstration, the membranes were processed at the same cross-flow velocity as full-scale. For the reasons mentioned in section 2.2, cross-flow velocity was not varied.

The membrane flux, cross-flow velocity, volume reduction factor, and TMP operating parameters were maintained and monitored manually by an operator in the laboratory demonstrations.

3.3.3. Phase I: Small-scale Laboratory Demonstration

MTR evaluated two candidate polymers: Pebax® 1074 and Pebax ®1657. The difference in the two polymers is their relative ratios of the hydrophilic and hydrophobic blocks (Pebax® 1074 has higher hydrophobic block content). The coating thickness was varied in the ultrathin range of 0.1 to 0.5 micrometers. The final coating thickness was based on its ability to sustain at least 75% of the long-term average flux of the uncoated membrane and its stability under exposure to varying temperatures, aggressive solvents, and shear by particulates in the feed stream.

A schematic of the test loop at NSWCCD Carderock is shown in Figure 8. A photograph is shown in Figure 9. The small-scale equipment accommodates two small-scale membranes for a side-by-side comparison of a ceramic membrane and a coated ceramic membrane.

The pressure at PG1 and PG2 was approximately 60 psi. The pressure at PG3 and PG4 was approximately 54 psi. The pressures at PG5 and PG6 varied from 0 to 38 psi, depending on the membrane coating. Thus, according to the TMP equation above, the TMP varied from 57 to 19 psi.

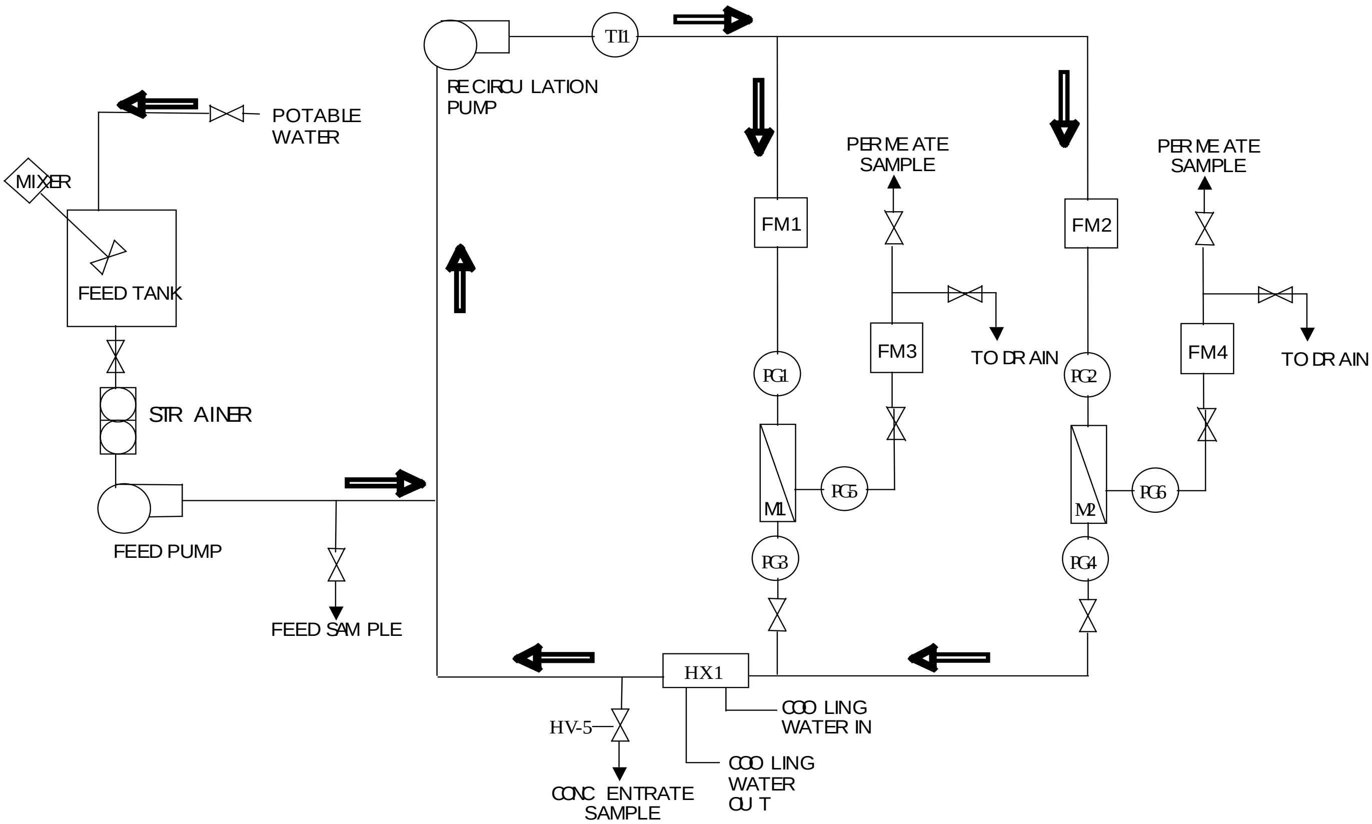


Figure 8. Schematic of the membrane test loop

Figure 9. Photograph of small-scale test loop

It was not necessary to vary cross-flow velocity, since the coating was expected to improve fouling resistance and increased cleaning would not be necessary. Also, these coated membranes are ultimately intended for systems that are already designed and installed shipboard. To change cross flow velocity on existing systems would be undesirable, since that would mean modifying a major pump.

The concentrations and components of the synthetic bilgewater mixture listed in Table 2 are within the membrane module performance specification for validation of membrane performance. The mixture contains oils, detergents, and solids typically found aboard ship. Additional contaminants used are listed in Table 3.

The small-scale laboratory tests were short-term permeation tests to demonstrate the effectiveness of the nonporous polymer coating on ceramic membranes prior to development of a full-scale coated ceramic membrane. Laboratory evaluations of membranes typically run 300 hours to demonstrate one year of shipboard life. The small-scale testing was not meant to verify the nonporous polymer coating long-term, but to decrease demonstration risk. Therefore, the small-scale testing ran for no more than 100 hours to demonstrate the effectiveness of the nonporous polymer coating. The fouling rate serves to extrapolate ultimate lifetime.

Table 2. List of Synthetic Bilgewater Constituents

Constituents	*Components*	*Concentrations*
Oil Mix #4 (100 mg/L)	Diesel Fuel Marine (MIL-F-16884) 2190 TEP Steam Turbine Lubricating Oil (MIL-PRF-17331) 9250 diesel lubricating oil (MIL-PRF-9000)	50 mg/L 25 mg/L 25 mg/L
Detergent Mix (25 mg/L)	General purpose nonionic detergent (MIL-D-16791G) Cleaning solvent (PD-680A Type III, MIL-PRF-680) Commercial detergent (Liquid Tide®)	12.5 mg/L 6.25 mg/L 6.25 mg/L
Solids (50 mg/L)	Fine Arizona test dust (ISO 12103-A2 fine test dust)	50 mg/L

Table 3. List of Bilgewater Contaminants for Laboratory Demonstration

Contaminant Class	*Component and Concentration in Feed Tank*
Oxidizer	0.50% Bleach, non-industrial
Soluble solvent	0.50% Acetone
Insoluble solvent	0.10% Paint thinner*
Seawater	3.50% ASTM synthetic seawater mixture

*Note: Due to the volume reduction factor of membranes, paint thinner will remain highly concentrated in the membrane loop until the end of the test sequence. Therefore, the initial concentration in the feed tank is reduced. The total feed tank volume will be 100 gallons for the closed loop testing.

3.4 Analytical/Testing Methods

Oil-in-water samples were analyzed using the EPA Method 1664. EPA Method 1664 is currently being used by Uniform National Discharge Standards (UNDS) to determine the permissible discharges of oily wastewater from DoD ships. Therefore, EPA Method 1664 was used for analysis of oil-in-water samples in this demonstration.

4. Results

4.1 Small-Scale Ceramic Membranes

A total of seven small-scale ceramic membranes were coated and tested for this evaluation. After trying different concentrations and thicknesses on the polymer, Pebax® 1074, one layer of 0.1% produced the required flux with a very low fouling rate. This was the chosen coating for subsequent tests of ceramic membranes. Following is the sequence of events that led to this choice.

Of the seven membranes tested, three passed the demonstration criteria as listed in Table 1 during short-term testing. Table 4 lists the membrane identification number, the concentration and number of layers of Pebax coating, and the initial clean water flux of the small-scale membrane. The first two coated membranes, B and C, did not meet the flux requirements of 40 gfd. Membrane D, #1222, did meet the 40 gfd criterion but was unable to process for 60 hours and maintain a resistance rate of increase less than 0.0024 psi/gfd/hour. This failure may have been caused by the relatively small difference between the maximum flux rate after the Pebax application and the required flux rate. With a 15 gfd difference between starting flux and required flux, only a small amount of fouling greatly affects membrane life, and therefore, the Mmembrane is unable to maintain a resistance rate less than 0.0024 psi/gfd/hour. To increase the flux, MTR, Inc. modified the coating application method to apply a thinner coating to the membrane surface. This method was applied to the remaining three coated membranes. Maximum flux rate for these membranes were at least double the required flux rate and therefore, able to meet the resistance rate.

Table 4. Hydraulic results

Id	*Membrane Manufacturer and Identification Number*	*Pebax 1074 Concentration and Coatings*	*Initial Clean Water Flux (CWF) (gfd)*	*Initial TMP (psi)*	*Initial Resistance (psi/gfd)*	*Hours Processed*	*Final flux (gfd)*	*Final TMP*	*Final Resistance*	*Reason: Resistance rate (psi/gfd/hour) (R´) or CWF*	*Pass/Fail**
A	Ceramem 1226	Uncoated (control)	>40	13	0.37	60	33	59	1.73	R´ = 0.0226	Failed
B	Corning 8081	Two layers of 0.5%	16	56	3.2	88	14.2	56	3.7	R´ = 0.0057 CWF < 40	Failed
C	Ceramem 1205	One layer of 0.2%	30	56	1.9	18	32	57	1.9	CWF < 40	Failed
D	Ceramem 1222	One layer of 0.1%	55	16	0.5	60	33.8	59	1.7	R´ = 0.0193	Failed
E	Ceramem 1269	One layer of 0.1%	99	23	0.6	117	38	27	0.8	R´ = 0.0010	Passed
F	Ceramem 1273	One layer of 0.1%	92	38	0.7	120	39.5	31	0.9	R´ = 0.0008	Passed
G	Ceramem 1274	One layer of 0.1%	83	20.5	0.6	64	37.9	22.5	0.7	R´ = 0.0012	Passed
H	Ceramem 1292	One layer of 0.1%	111	13	0.4	63.6	37.9	20	0.6	R´ = 0.003	Failed

*Note: Passing criteria is resistance increase (R´) of 0.0024 psi/gfd/hour or less AND must pass initial clean water flux (CWF) of 40 gfd or greater.

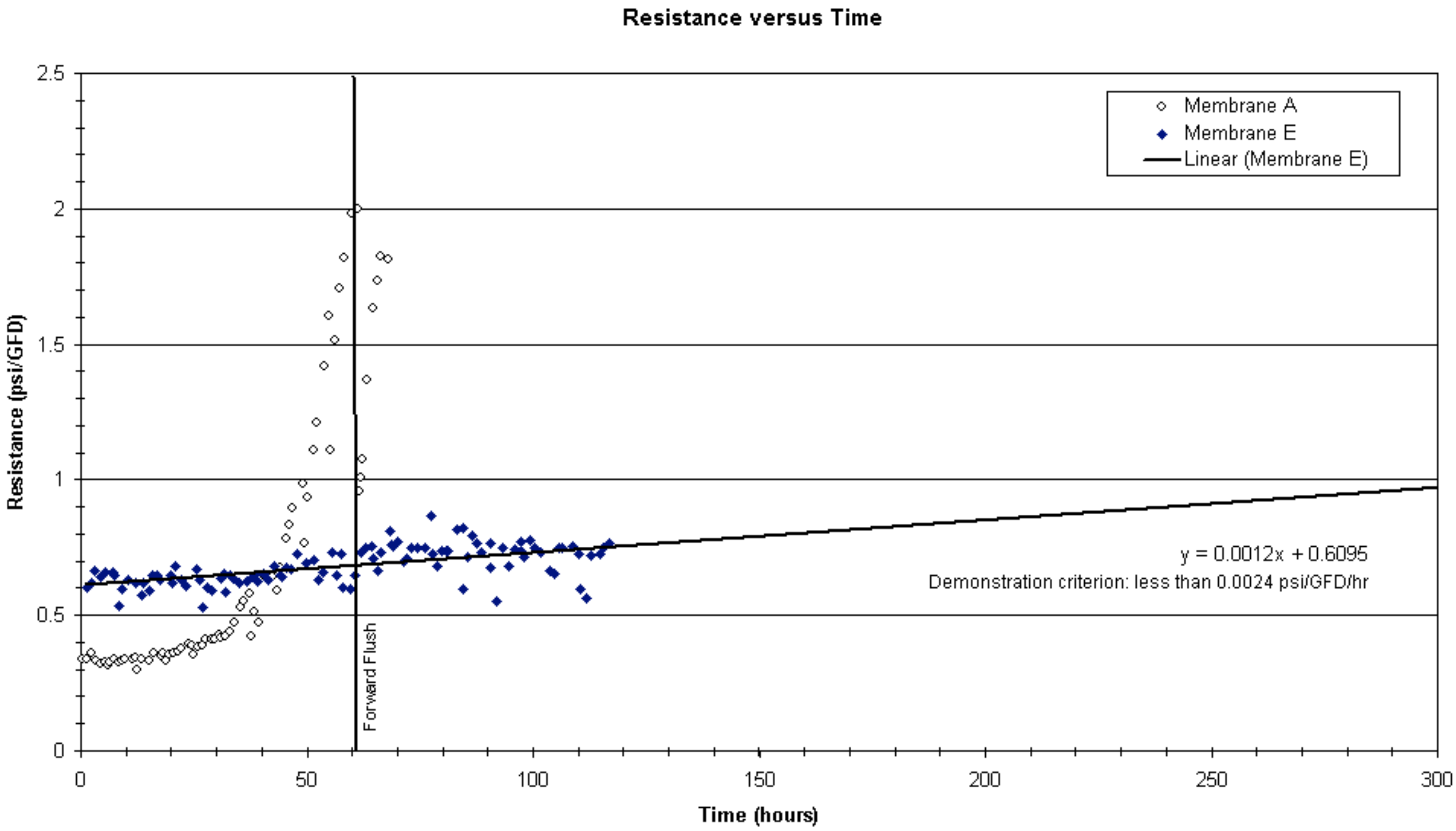


Figure 10. Graph of resistance versus time for uncoated (A) and coated (E) membranes.

Figure 10 graphs the control membrane's (Membrane A, uncoated) and coated Membrane E's resistance over time. Membrane resistance represents the life of membranes in terms of how much pressure is required to produce a flow rate through one square foot of membrane area. As shown in the graph, the initial resistance of the coated membrane was higher than the control. This was an expected result as the coating requires the system to "push" harder to produce the same flux rate. However, over time the resistance rate of the coated membrane flattens. After 45 hours, the uncoated membrane exceeds the resistance of the coated Membrane E before hydraulically failing at approximately 60 hours.

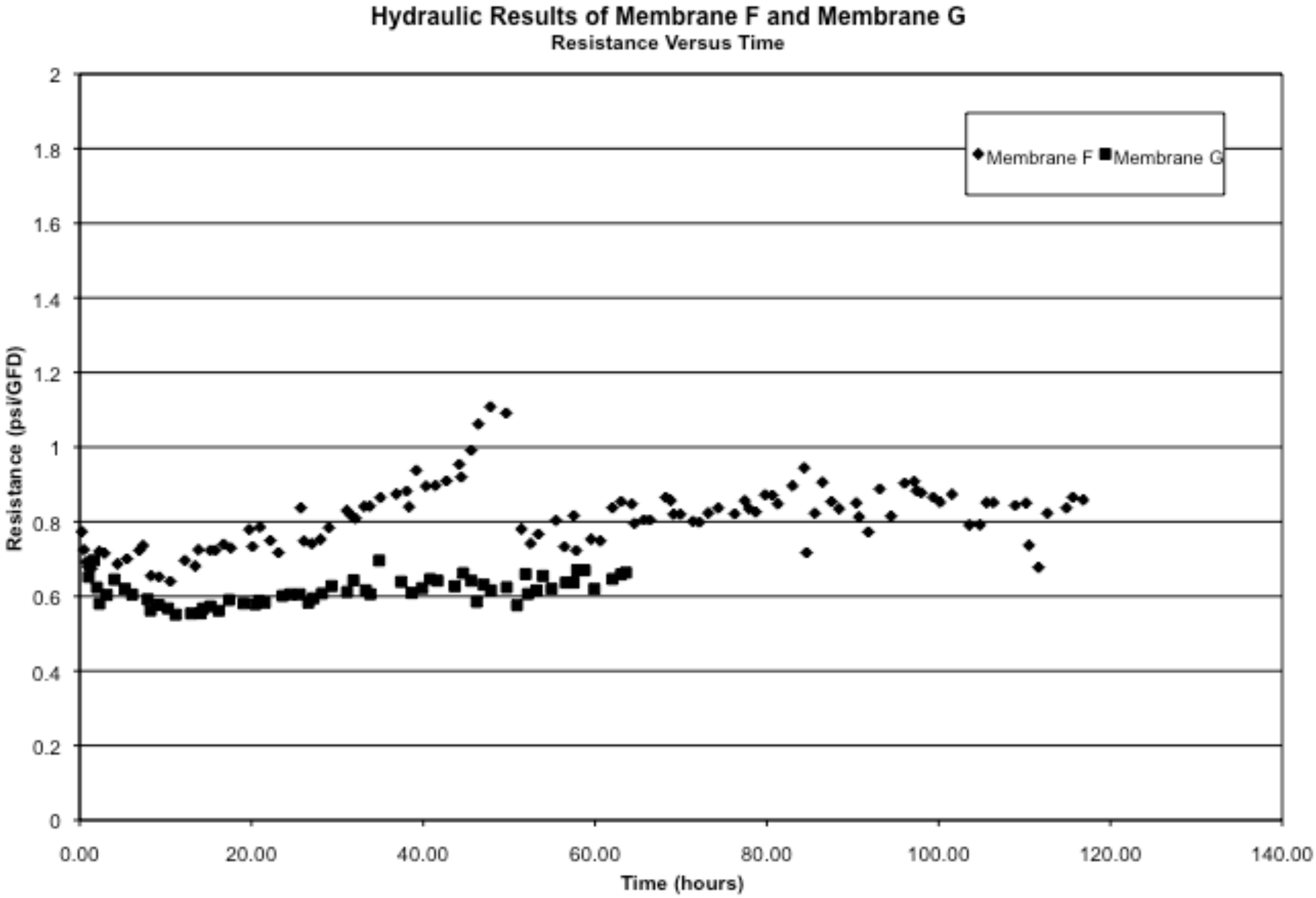


Figure 11. Resistance curves of Membranes F and G, both of which passed.

Two additional membranes, F and G, were coated to ensure the coating performance was reproducible. Membrane F and G were coated similarly to Membrane E, producing initial flux rates 92 gfd and 83 gfd, respectively. Their resistance graphs are shown in Figure 11. Their hydraulic performance duplicated the results seen with Membrane E, demonstrating that the coating process and results were reproducible. Interestingly, Membrane F, #1273, increased rapidly between hours 25 and 50. It surely would have failed. But then the resistance dropped sharply, yielding an overall resistance rate that was acceptable. One possible explanation is that there was some transient surface effect that eventually diminished. Also of note, is that the clean-water flux data taken at the end showed a lower resistance than at the beginning of the test. These were very good membranes.

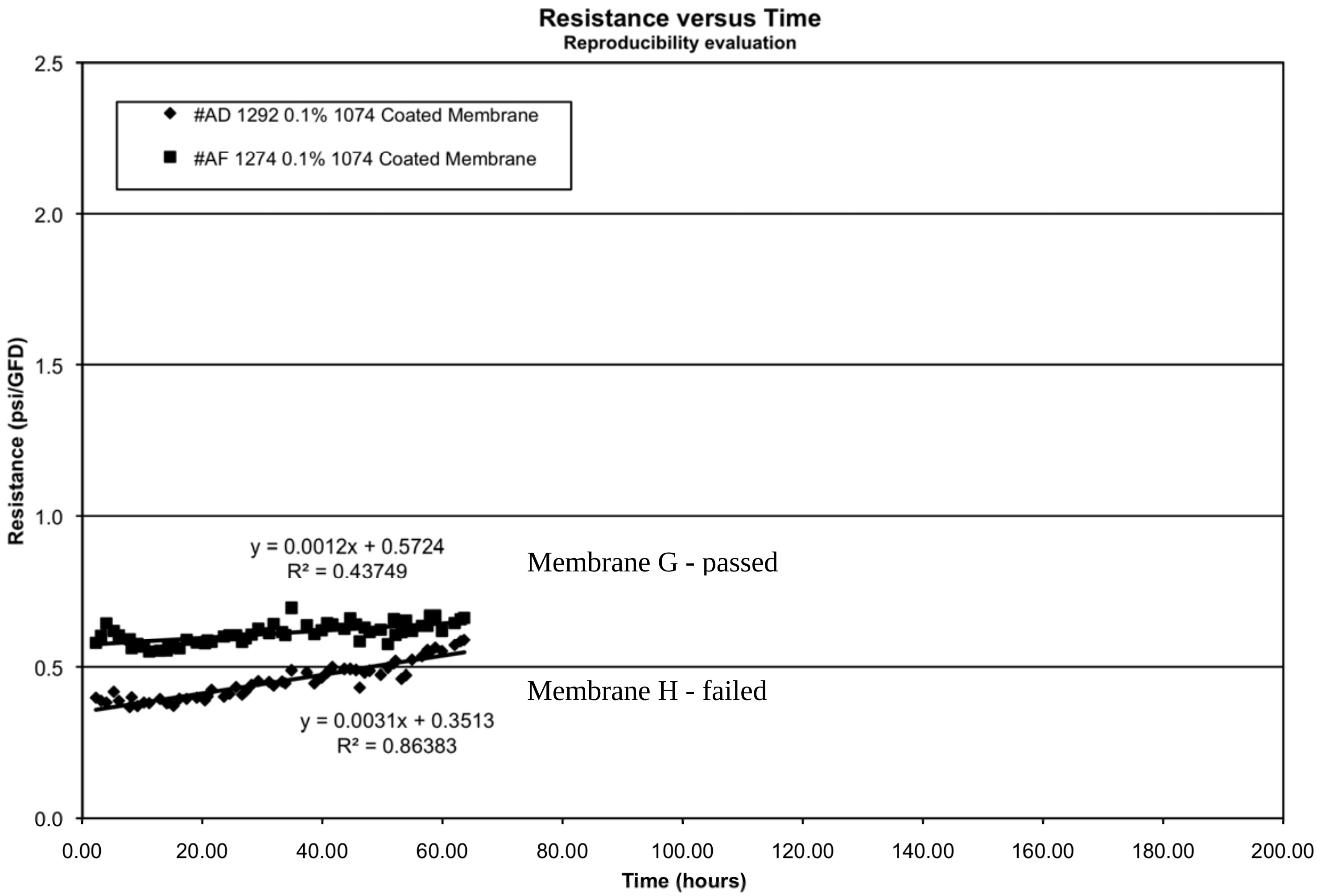


Figure 12. Membrane H, which failed, compared to Membrane G, which passed.

However, Membrane H, #1292, coated in the same way as membranes F and G, failed. The resistance curve of membrane H compared to that of Membrane G is shown Figure 12. Membrane H did not fail by much: the resistance increase rate was just a little too high – 0.003 instead of 0.0024. If the resistance had taken a drop as Membrane F did, it might have passed. That being said, the resistance of Membrane H started out lower than that of membrane G. This could indicate a less complete coating, allowing membrane-fouling agents into the pores. MTR's experience is with Pebax® application on spiral-wound polymeric membranes. Application to tubular ceramics was a completely new process, so some variability resulted. Hopefully a production-scale application process would result in more consistent performance. This type of data is not always clear-cut, but one layer of 0.1% Pebax® clearly showed the most promise.

Table 5. Small-Scale Ceramic Membrane Oil-in-Water Sampling Results

NSWC-SSES Sample No.	Identification	Date Sampled	Time	Petroleum Hydrocarbon mg/l {1}	Type
720-1	E #1269	04/18/03	8:37	2	Permeate
720-2	F #1273	04/18/03	8:38	4	Permeate
720-3	A #1226 (uncoated)	04/01/03	12:39	69	Feed
720-4	A #1226 (uncoated)	03/28/03	13:33	47	Feed
720-5	A #1226 (uncoated)	03/28/03	13:35	<2	Permeate
720-6	A #1226 (uncoated)	04/01/03	12:44	<2	Permeate
720-7	D #1222	03/28/03	13:34	<2	Permeate
720-8	D #1222	04/01/03	12:43	<2	Permeate
Received:	24-Apr-03		Extracted by:		
Analyzed:	26-Apr-03		EPA Method 1664 Rev. A		

NSWC-SSES Sample No.	Identification	Date Sampled	Time	Petroleum Hydrocarbon mg/l	Type
721-1	G #1274	06/30/03	13:02	4	Permeate
721-2	H #1292	06/30/03	13:01	3	Permeate
721-3	G and H	06/30/03	13:00	83	Feed
721-4	F #1273	05/02/03	10:43	2	Permeate
721-5		04/30/03	14:37	1361	Concentrate
721-6	E #1269	05/02/03	10:41	2	Permeate
721-7		04/08/03	14:05	1557	Concentrate
721-8	E and F	05/02/03	10:40	29	Feed
Received:	03-Jul-03		Extracted by:		
Analyzed:	21-Jul-03		EPA Method 1664 Rev. A		

Table 5 shows the oil-in-water sampling results for the small-scale membranes, as analyzed by NSWCCD-SSES Code 63. The permeate sample results are all 4 ppm oil or less. The concentrate and feed results are within range of what can be expected shipboard. As expected, the coating had no adverse effect on separation performance.

Scanning-Electron Microscope (SEM) readings of membrane F were taken after 120 hours of operation. Figure 13 shows the coated surface of the membrane. Although there is debris sitting on top of the membrane, there is no debris below the membrane surface in the pores because the coating prevents it. Debris on top of the membrane is considered reversible because it can usually be removed.

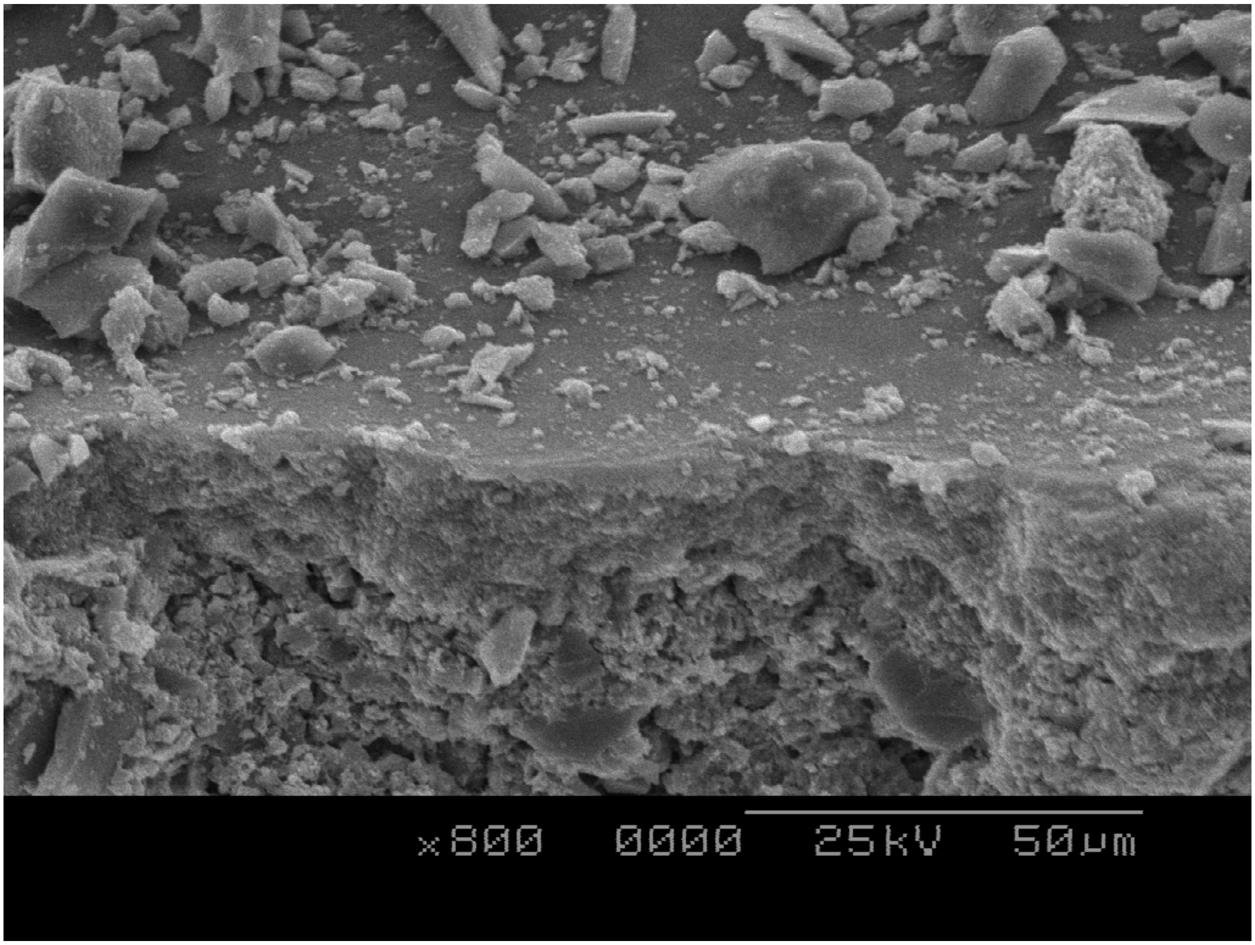


Figure 13. SEM of coated membrane surface after 120 hours of operation.

In addition to SEM, it was also planned to use Fourier Transform Infrared Reflectance (FTIR) to determine what foulants were present on the surface of a membrane. While this method had been used by MTR on spiral-wound polymeric membranes, it proved impractical on ceramics. Ceramics crumble when samples are cut, and it is very difficult to access the membrane within the small lumens. Surface analysis, including the measurement of coating thickness, is more conducive to spiral-wound membranes, because they consist of flat sheets. So coating thickness could not be directly measured, and foulants could not be analyzed.

4.2 Small-Scale Spiral-Wound Polymeric Membranes

Spiral-wound polymeric membranes did not show as much potential as the ceramic membranes. MTR was unable to produce a spiral-wound membrane capable of producing a flux rate high enough to meet a full-scale 3.3 gpm flow rate. Based on expected membrane area of a full-scale spiral-wound membrane and the required flow rate of 3.3 gpm, the spiral-wound membrane must maintain a flux rate of 28 gallons/ft^2/day (gfd). Ceramic membranes demonstrated an extended life with initial flux rates at least double of the required flux rate. Therefore, the initial flux rate of the coated spiral-wound membrane must be >50 gfd. Two types of membrane materials were used: Polyetherimide (PEI) and Polyvinylidene Fluoride (PVDF). The coated spiral-wound membranes produced flux rates of 18-35 gfd (uncoated spiral-wound membranes have an initial flux rate of ~95 gfd). There were no fouling curves of resistance over time taken because the initial flux was not sufficient. So there was no need to run the tests for a longer period.

The significant decrease in flux rate with the addition of the coating is more severe in the spiral-wound membranes than the ceramics due to the relative pore size of the two membranes. Ceramic membranes have a nominal pore size of 5-10 nm and spiral-wound membranes have a pore size of 10-100 nm. When the coating is applied to the membrane surface, the larger pores fill with the coating solution, where as the smaller pores are just “capped”, as illustrated in figure 14. The greater the coating thickness, the larger the area that water must pass through to

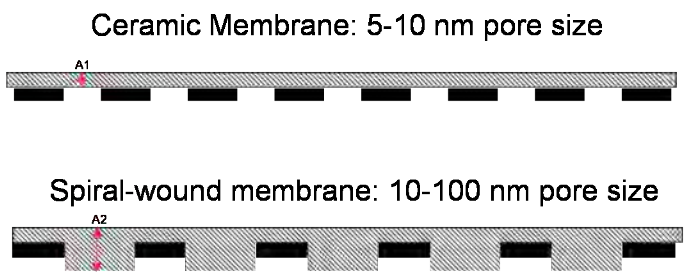


Figure 14. Coating behavior in ceramic membranes compared to spiral-wound membranes

permeate through the membrane. Therefore, the flux is significantly decreased in larger-pore sized spiral-wound membranes once the coating is applied.

With little success in improving flux rate by modifying coating techniques and coating concentrations, NSWCCD discontinued spiral-wound testing and focused on full-scale testing the ceramic membranes.

4.3 Full-Scale Laboratory Testing

After the success of ceramic coated membranes, full-scale membranes were coated with the same formula: one layer of 0.1% Pebax® 1074. The test apparatus is shown in Figure 15.

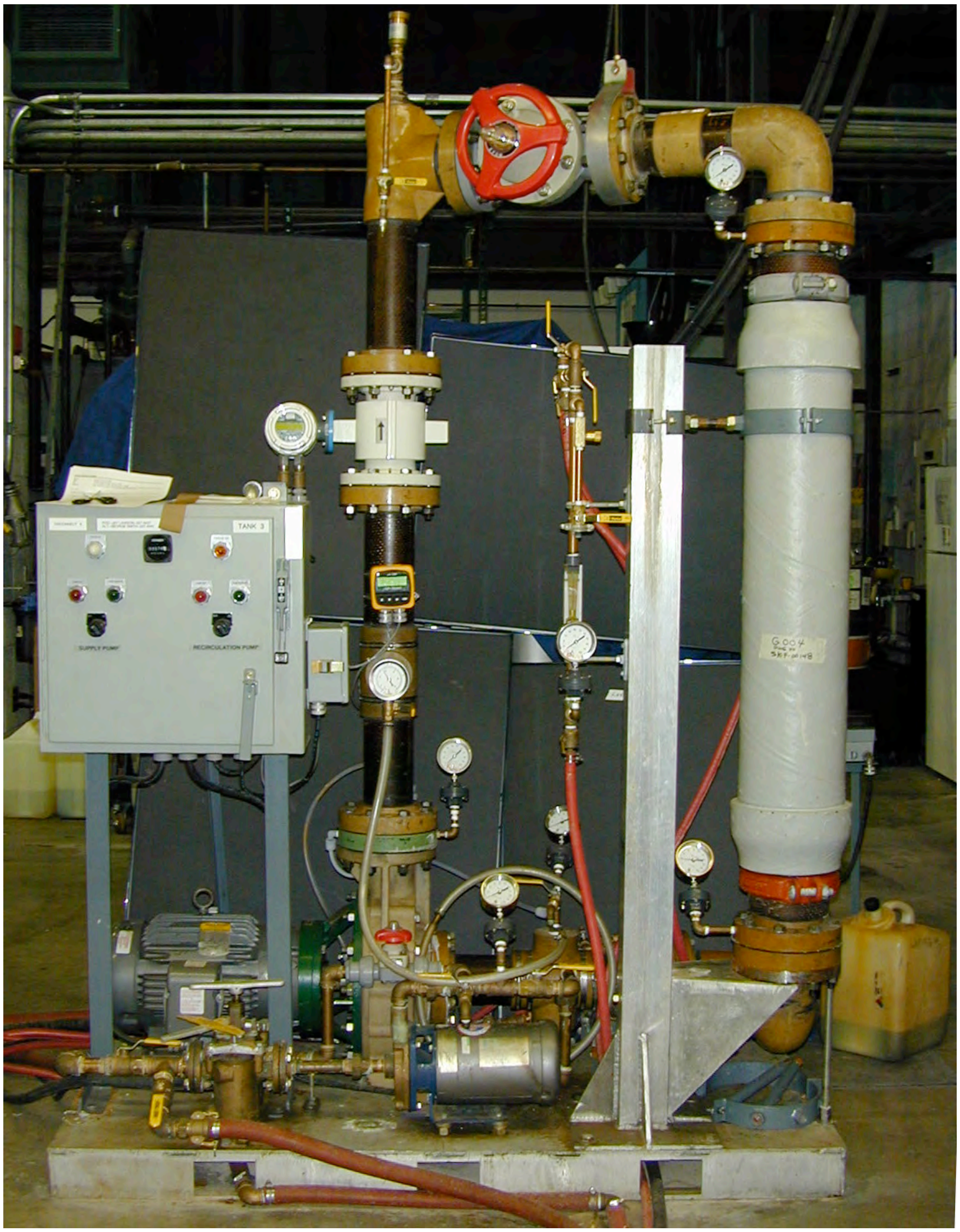


Figure 15. Full-Scale test rig.

4.3.1 Full-Scale Results

The full-scale coated ceramic membranes equaled the non-coated membranes in flux and resistance. The resistance did not increase over the 300-hour duration of the test. The results are shown in Figure 16. Sample results averaged 2 to 3 ppm for both membrane types. By the end

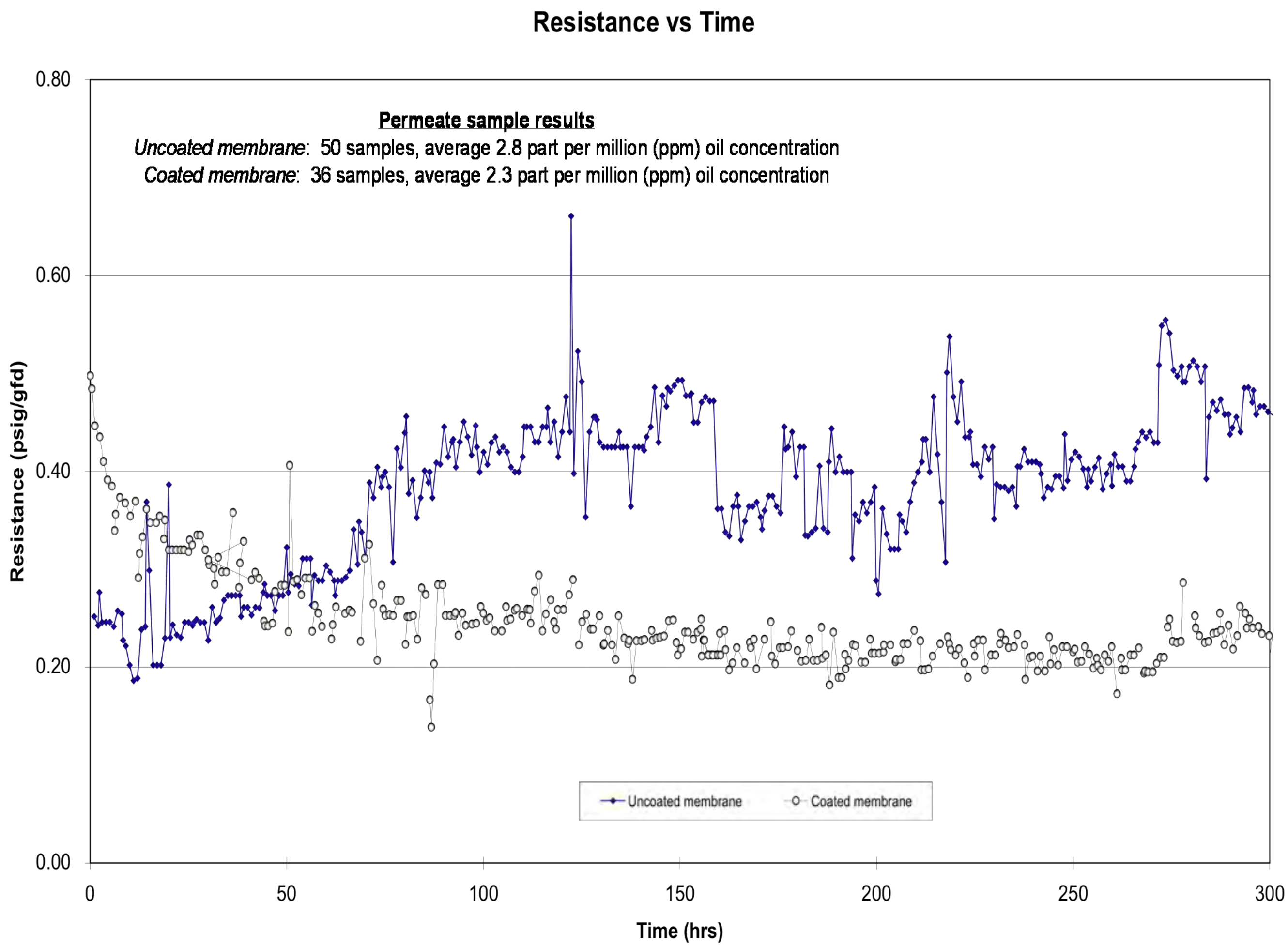


Figure 16. Resistance (psi/gfd) of full-scale membranes during laboratory test.

of the test the uncoated full-scale membranes had not failed, as the small-scale uncoated ones did; however, an overall upward trend in resistance is clearly present.

Feed and membrane effluent samples were taken every other run. This provided a representative sample population to determine membrane effluent quality over the demonstration with a 95% confidence. The results are shown in Table 6. The performance requirement for membranes is an oil concentration less than 15 ppm. The addition of the coating has no negative effect on membrane permeate. Of the permeate samples taken, none exceed 5 ppm oil.

Table 6. Full-Scale Ceramic Membrane Oil-in-Water Sample Results.

NSWC-SSES Sample No.	Customer Identification	Sample Type	Date Sampled	Time	Petroleum Hydrocarbon mg/l {1}
746-6	FSC-F-03	Feed	01/15/08	10:28	79
747-3	FSC-F-11	Feed	02/05/08	10:55	153
747-8	FSC-F-09	Feed	01/27/08	14:48	103
749-1	FSC-F-17	Feed	02/19/08	10:08	122
750-4	FSC-F-22	Feed	02/28/08	14:03	126
752-3	FSC-F-34	Feed	03/24/08	11:03	177
752-8	FSC-F-29	Feed	03/12/08	13:36	92
746-1	FSC-P-01	Permeate	01/13/08	15:26	<2
746-2	FSC-P-02	Permeate	01/14/08	14:04	<2
746-3	FSC-P-04	Permeate	01/16/08	14:23	<2
746-4	FSC-P-03	Permeate	01/04/04	10:30	<2
746-5	FSC-P-05	Permeate	01/16/08	9:20	<2
746-7	FSC-P-06	Permeate	01/22/08	13:41	<2
746-8	FSC-P-07	Permeate	01/23/08	9:11	<2
747-1	FSC-P-13	Permeate	02/11/08	12:00	<2
747-2	FSC-P-12	Permeate	02/10/08	13:37	<2
747-4	FSC-P-10	Permeate	02/05/08	10:57	2
747-5	FSC-P-11	Permeate	02/05/08	14:18	<2
747-6	FSC-P-08	Permeate	01/27/08	10:40	<2
747-7	FSC-P-09	Permeate	01/27/08	14:43	<2
749-2	FSC-P-14	Permeate	02/12/08	12:29	<2
749-3	FSC-P-16	Permeate	02/18/08	13:07	<2
749-4	FSC-P-17	Permeate	02/19/08	10:05	<2
749-5	FSC-P-20	Permeate	02/24/08	13:44	<2
749-6	FSC-P-19	Permeate	02/21/08	12:55	<2
749-7	FSC-P-18	Permeate	02/20/08	13:36	<2
749-8	FSC-P-15	Permeate	02/13/08	13:00	<2
750-3	FSC-P-24	Permeate	03/03/08	9:40	*
750-5	FSC-P-23	Permeate	03/02/08	12:48	*
750-6	FSC-P-22A	Permeate	02/28/08	14:00	*
750-7	FSC-P-21	Permeate	02/27/08	12:46	<2
750-8	FSC-P-22	Permeate	02/28/08	8:55	<2
751-1	FSC-P-25	Permeate	03/05/08	11:10	<2
751-2	FSC-P-26	Permeate	03/09/08	14:03	*
751-3	FSC-P-29	Permeate	03/12/08	13:33	3
751-4	FSC-P-28	Permeate	03/11/08	14:19	<2
751-6	FSC-P-27	Permeate	03/10/08	12:14	*
752-1	FSC-P-32	Permeate	03/18/08	10:43	7
752-2	FSC-P-35	Permeate	03/25/08	13:03	4
752-4	FSC-P-31	Permeate	03/17/08	17:54	3
752-5	FSC-P-34	Permeate	03/24/08	11:05	<2
752-6	FSC-P-30	Permeate	03/16/08	12:58	<2
752-7	FSC-P-33	Permeate	03/19/08	13:00	<2
751-7	FSC-C-29	Quality Cntl	03/11/08	9:35	3883
751-5	FSC-F-23	Quality Cntl	03/02/08	12:52	397
750-1	FSC-P-20A	Quality Cntl	02/24/08	15:04	3
750-2	FSC-P-25A	Quality Cntl	03/04/08	11:12	8
751-8	FSC-P-21A	Quality Cntl	02/27/08	0:00	<2

	Feed	Permeate
Average	122	2.25
Median	122	2
95%	169.8	3.25
Count	7	36

4.3.2 Chemical Stability

The contaminants listed in Table 3 (bleach, acetone, paint thinner, and sea-salt) were added to the standard oily water influent at various times. The reaction of the membranes is shown below in Figure 17. It can be seen that there was no effect on membrane resistance when the contaminants were added. If the stability of the polymer coating had been affected, i.e., if any of the coating had been lost, than there would have been a momentary decrease in resistance, followed by a steady increase, as the no-longer-protected membrane pores started to fill with foulants.

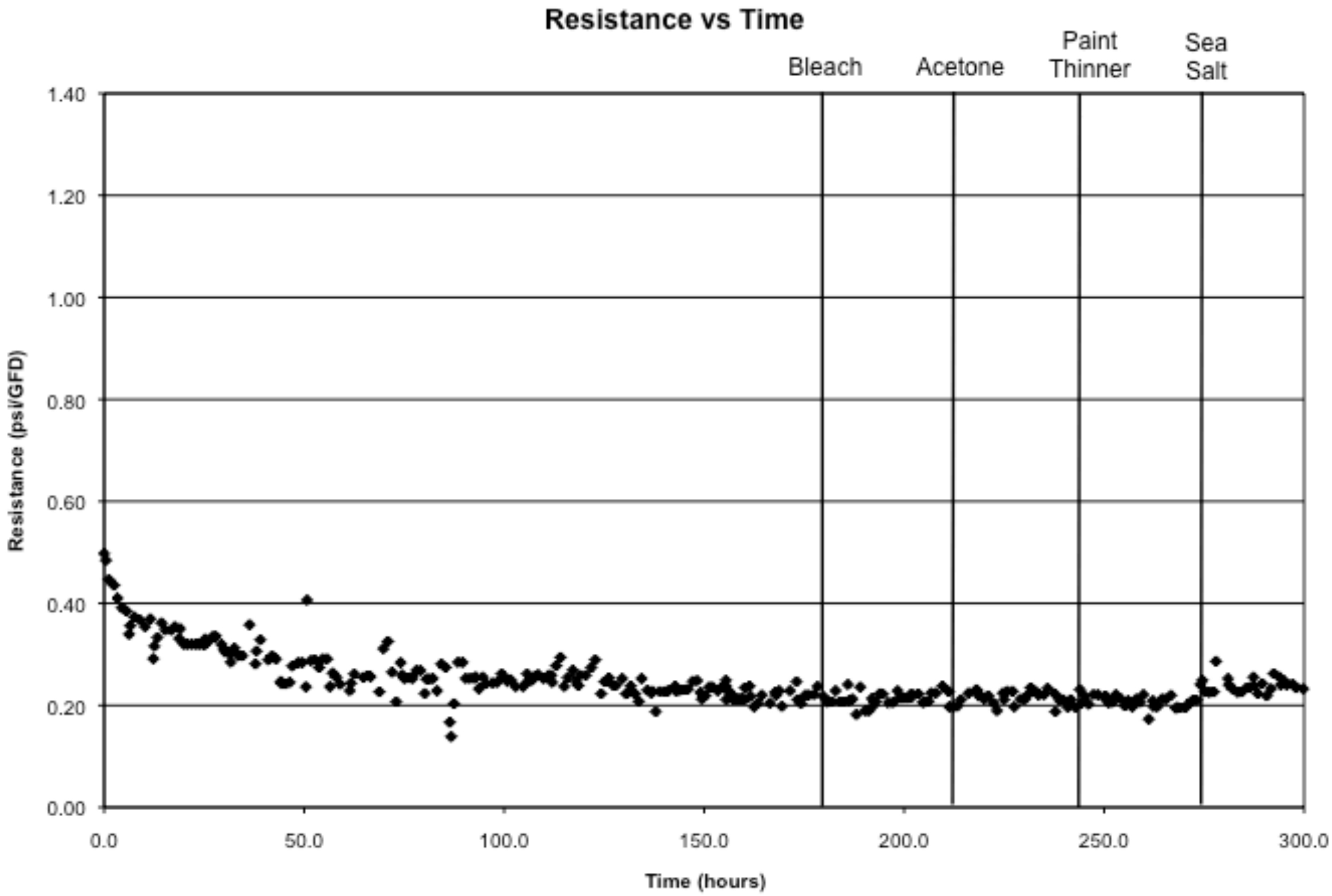


Figure 17. Chemical stability tests of full-scale membrane with polymer coating

4.4 Shipboard Evaluation

Three coated membranes were installed in the 5-gpm membrane system manufactured by AAE on the USS James E. Williams (DDG 95) in April 2009. The Pebax® coating was applied to new membranes that are normally installed in the system, so there were no major changes. The only physical change was to eliminate an automatic cleaning procedure called a back-flush. This modification required a small piping change, and a minor programming change.

4.4.1 Equipment Description

A basic schematic of an oily waste treatment system on a Navy ship is shown in Figure 18.

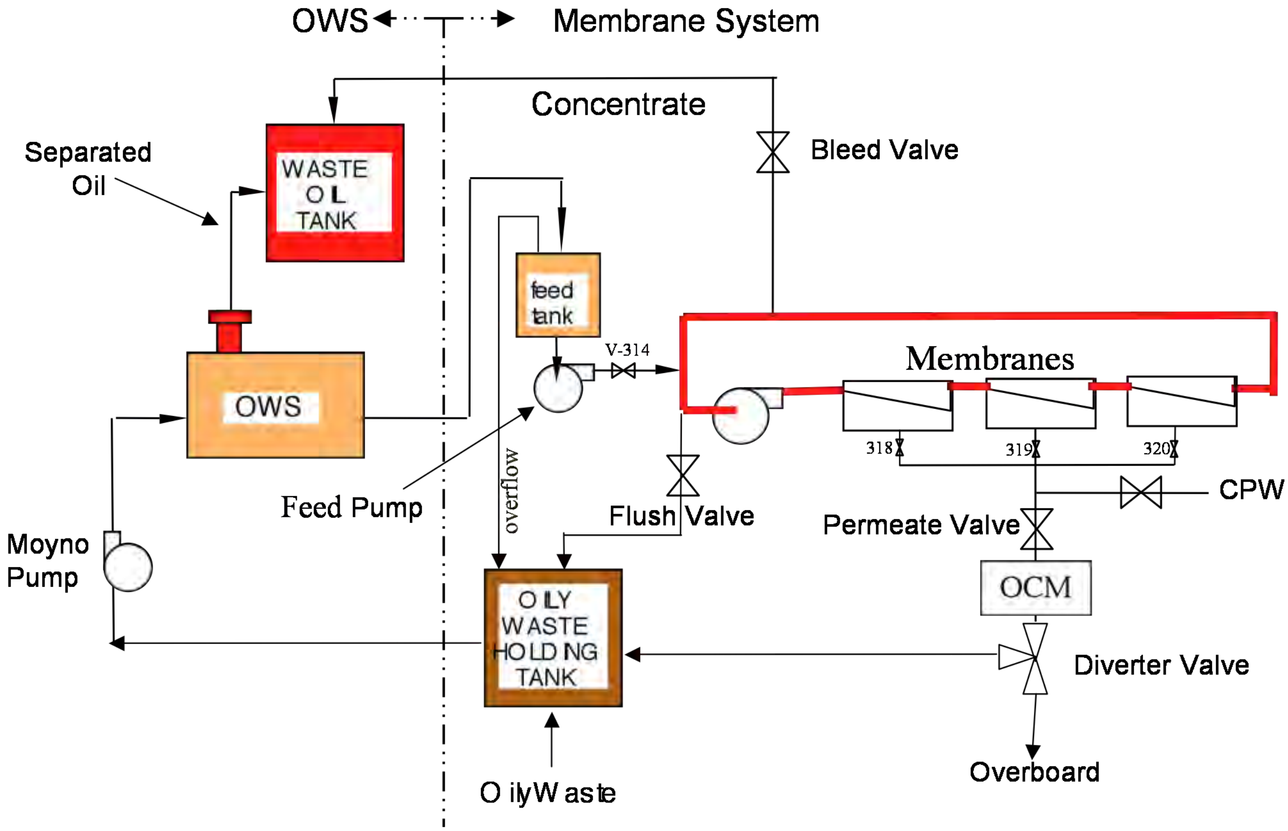


Figure 18. Basic oily waste treatment system on a Navy ship

Oily waste is pumped from various spaces where it accumulates into the Oily Waste Holding Tank (OWHT). When the OWS is turned on, the Moyno pump draws the oily waste from the OWHT through the OWS.

The OWS is a parallel-plate separator that performs primary separation. That is, it separates bulk and large-droplet oil (typically 90-98% of the oil) from the water and sends the oil to the Waste Oil Tank (WOT). The remaining small-droplet and/or emulsified oil proceeds onward with the water to the membrane system.

When oily water enters the membrane system's feed tank, operation automatically starts. The feed pump pumps the oily water into the recirculation loop at a rate of 5 gpm. The contents of the recirculation loop flow continuously across the membrane surface, providing cleaning action via shear. At the same time, water permeates through the membrane surface, escaping the recirculation loop at a rate controlled by the permeate valve, nominally about 5 gpm. The much cleaner water, now called permeate, then proceeds overboard. The oil, which is a much larger molecule, cannot fit through the membrane pores, and remains in the recirculation loop.

Meanwhile, the oil concentration in the recirculation loop has been increasing, since water has been escaping, but not oil. Every 10 minutes the bleed valve opens and releases 1% of the amount of oily waste already processed to the WOT. The contents of the WOT are supposed to be held on board until the ship returns to port.

When the OWS shuts down, the membrane system automatically shuts down after performing an automatic cleaning of the membranes, called back-flushing. To clean, both pumps turn off, the potable water supply valve opens and the flush valve opens. Referring to Figure 18, the reader can see that potable water then would flow through the membranes into the recirculation loop, in the reverse direction from normal processing. This action cleans the membranes, reducing the amount of debris that accumulated in the membrane pores during the last run. The contents of the recirculation loop flow out through the flush valve to the OWHT, for later reprocessing. After 5 minutes, both valves close and the system stands by for the next run. For complete detailed description of the membrane system, refer to the technical manual [8].

For this evaluation of the coated membranes, the back-flush operation was disabled. Back-flushing would blow the coating off the membrane surface. Back-flushing should not be necessary anyway, since the membranes are not supposed to foul. However, it may be undesirable to have the membranes immersed in concentrated oily waste for days or weeks between runs. Therefore, it was decided to automatically flush the concentrate from the loop at the end of every run, replacing it with clean water. The difference is that there will be no reverse flow through the membranes. The minor piping changes necessary are shown in Appendix B - a complete piping and instrumentation diagram of the membrane system. Normal operation will still be automatic. The only difference is that the operator will have to change the position of the added 3-way valve in order to fill the system after any disassembly for maintenance or repair.

The membranes, which are Corning dense-pack ceramic membranes, have been coated with one layer of 0.1% Pebax® 1074 by MTR. Then they were shipped to AAE, where they were inserted into the same type of housings that are used in the 5-gpm membrane system that is already installed on WILLIAMS.

4.4.2 Procedure

Operation of the membrane system is unchanged from the normal operating procedure, called the Engineering Operating and Sequencing System (EOSS) in the NAVY, with the exception of one valve that has to change position for filling the system after maintenance. The revised EOSS and the Maintenance Requirements Cards (MRC) for filling the system are furnished as Appendix C.

4.4.3 Results

The ship deployed in April 2009. Resistance data was sent by e-mail from the ship to NSWCCD for the first 21 hours. Then operational conditions did not permit e-mail contact until the 54-hour point. At that point, the membrane system broke down due to failure of the EMI filter. The ship was unable to obtain the correct replacement part, so no further run time was accomplished during the deployment. The membrane resistance increased from 0.4 to 0.7 psi/gfd. The data points are shown in Figure 19. Using the existing data, the projected fouling rate would be 0.0024 psi/gfd over the course of 54 hours: exactly the pass/fail level. But the intermediate

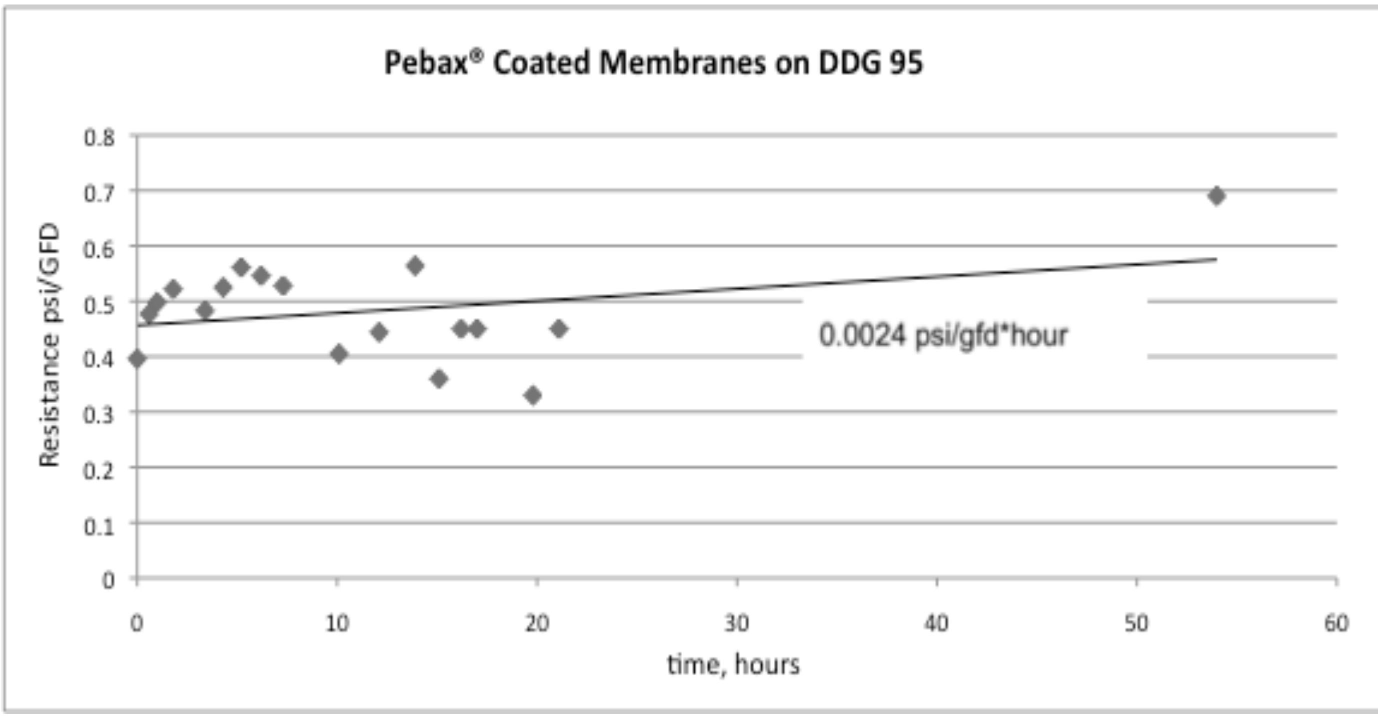


Figure 19. Shipboard Membrane Resistance of Full-Scale Coated Ceramic Membranes

resistance values between 21 and 54 hours are not known, so it would be desirable to acquire more data points to better establish a trend.

The replacement part was then installed and the system ran for 41 more hours, resulting in a total of 95 hours. Unfortunately, it is not known what the resistance value was over this time period either, because the operators did not record it and displayed data is only valid when the system is running. The system cannot be run as of this writing because the ship loaned some parts from the membrane system to another ship. As soon as possible NSWCCD will return to the ship and observe the resistance during operation. The data will then be up to 95 hours.

5. Cost Assessment

5.1 Cost Reporting

For this demonstration, the Environmental Cost Analysis Methodology (ECAM) was applied to gauge the potential cost savings of implementing coated ceramic membrane technology for shipboard oily wastewater treatment processes. The cost assessment was completed by Concurrent Technologies Corporation (CTC). CTC developed ECAM under direction of the National Defense Center for Environmental Excellence (NDCEE). The cost assessment was produced prior to the commencement of testing. Some changes have been made based on the test results.

In an effort to appropriately assign cost impacts to activities, materials, and other factors that control costs, flow diagrams are typically developed for the proposed process and the current process to be evaluated. However, for this ECAM the overall process (oily waste membrane treatment system) is not changing. Rather only one specific component (the type of membrane) is being investigated. Therefore, flow diagrams were not developed.

Also, only the initial investment costs of purchasing the initial membranes (as required for the first year of operation - year 0) and the associated annual operating costs (regeneration and re-coating, as applicable) were compared. The baseline technology currently uses non-coated ceramic membranes. Alternative #1 is the ceramic membranes with the applied nonporous coating. Prior to testing, there was a second alternative: coated spiral-wound polymeric membranes. As discussed earlier, testing revealed that these polymeric membranes were not conducive to the coating, so they have been removed from the cost analysis.

The total lifetime of the study was set for 15 years. The initial purchase of the membranes was calculated as the initial investment cost for the baseline and the alternative. In addition, within this timeframe, the membranes would presumably have to be replaced, regenerated, and where applicable, re-coated. These costs were calculated and included in the total operating costs, as appropriate. This is still a preliminary cost analysis since limited data has been obtained. The actual data for membrane lifetime and regeneration and re-coating lifetimes are as yet unknown. NSWCCD personnel supplied the baseline and alternative data, including materials costs, environmental, health and safety data, and disposal costs. Data related to the proposed membrane technologies was based on previously published data, best engineering judgment, and personal experience of those directly involved with operation of membrane technologies. The lifetime performance data for the membranes have been estimated for this preliminary analysis. Therefore, a high-end (pessimistic) estimate with lower lifetime performance factors, increased maintenance operations and regeneration occurring at a depot was evaluated in addition to a low-end (optimistic) estimate with higher lifetime performance factors, decreased maintenance operations, and regeneration occurring onboard ship. **Table** 7 summarizes the data used for the ECAM analysis.

Table 7. Summary of Input Parameters Used for the Cost Comparison

Category	Input Parameter	**Current (Baseline) Material/Process** Ceramic Membrane		**Alternative:** Ceramic Membrane with nonporous coating	
Operating Detail	Membranes/ Ship	3		3	
	Ships/Fleet	57		57	
		High	**Low**	**High**	**Low**
Operating Detail	New Membrane Life	1	1	2.25	2.25
	Regeneration Life	1	1	2.25	2.25
	# of Regenerations per Membrane	2	4	1	2
	Re-coating Life	NA	NA	2.25	2.25
	# of Re-coatings Per Membrane	NA	NA	1	1
Material Costs	New Membrane	$20,000/ membrane	$16,000/ membrane	$20,000/ membrane	$16,000/ membrane
	Coating costs (application to new membrane)	NA	NA	$500/ membrane	$500/ membrane
Regeneration Costs * First regeneration lasts 2 years and the second only lasts 1 year.	Chemical costs	$100/ membrane	$100/ membrane	$100/ membrane	$100/ membrane
	Ship Force Labor	2 sailors	3 sailors	2 sailors	3 sailors
		$50/hr	$50/hr	$50/hr	$50/hr
		4 hrs/sailor	8 hrs/sailor	4 hrs/sailor	8 hrs/sailor
	Personal Protective Equipment (PPE)	$50/team/ membrane	$100/team/ membrane	$50/team/ membrane	$100/team/ membrane
	Shipping Costs	$590/membran	NA	$590/membrane	NA
	Depot Labor	1 worker	NA	1 worker	NA
		20 hrs/worker	NA	20 hrs/worker	NA
		$65/hr	NA	$65/hr	NA
Waste Treatment Costs (for Regeneration)	Water required/used	360 gal	360 gal	360 gal	360 gal
	Potable (Clean) Water Cost	$0.01/gal	$0.01/gal	$0.01/gal	$0.01/gal
	Oily Wastewater (Dirty) Disposal Cost	$0.10/gal	$0.10/gal	$0.10/gal	$0.10/gal
Costs associated with regeneration prior to re-coating	Chemical costs	NA	NA	$100/membrane	$100/membran
	Ship Force Labor	NA	NA	2 sailors	3 sailors
		NA	NA	$50/hr	$50/hr
		NA	NA	4 hrs/sailor	8 hrs/sailor
	Personal Protective Equipment (PPE)	NA	NA	$50/team/ membrane	$100/team/ membrane
	Shipping Costs	NA	NA	$590/ membran	NA
				1 worker	NA
				20 hrs/worker	NA
				$65/hr	NA
Waste Treatment Costs (for re-coating)	Water required/used	NA	NA	360 gal	360 gal
	Potable (Clean) Water Cost	NA	NA	$0.01/gal	$0.01/gal
	Oily Wastewater (Dirty) Disposal Cost			$0.10/gal	$0.10/gal
Re-Coating Costs	Coating & associated material	NA	NA	$500/membrane	$500/membrane
	Labor costs	NA	NA	3 workers	3 workers
				12 hrs/worker	12 hrs/worker
				$65/hr	$65/hr

NA = not applicable

The ECAM tool is designed to evaluate initial capital costs and annual operating costs between various processes/technologies. As stated earlier, for this particular ECAM, the technologies being evaluated are "drop-in" alternatives to the baseline, which require no capital equipment investments. The first purchases of membranes were the only capital costs evaluated. The associated costs with the differences in the lifetime of the membrane and associated maintenance costs (i.e., regeneration and re-coating costs) were calculated and evaluated as the annual operating costs. Utilizing the operating detail, as outlined in Table 7, a schedule for new membrane purchase and regeneration/re-coating activities was developed. Based on the schedule the associated costs for those operations were divided out for a total of 15 years to obtain the annual operating costs. Thus, even if a membrane was not to be replaced or regenerated/re-coated for a particular year, there was still an assigned operation cost for that year. Table 8 outlines the activities, as calculated for the 15-year study period.

Table 8. Summary of Activities Included in Cost Analysis

Activities Required for 15-year Study Period	Baseline		Alternative #1	
	High	Low	High	Low
Initial membrane purchases (capital cost)	1	1	1	1
New membrane replacements	4	2	2	1
Regeneration of existing membranes	10	12	2	3
Re-coating (includes regeneration prior to) of existing membranes	NA	NA	2	2

NA = not applicable

The ECAM results revealed that the proposed technology alternatives have the potential to reduce operating and maintenance costs associated with the oily wastewater treatment process. A summary of the estimated capital and operating costs associated with replacing the current ceramic membrane with the alternative membrane technologies and the calculated indicators of profitability are shown in Table .

The results of the economic analysis performed by CTC show that, if implemented, the proposed membrane technologies are more cost effective to operate than the current membrane technology on an annual basis. The ceramic membranes with applied nonporous coating will yield a payback on investment within the first year of implementation.

For the coated ceramic membrane, the reduction in operating costs associated with maintenance (regeneration and replacement) of the membranes directly offsets the slight increase in capital costs for the nonporous coating.

Table 9. Financial Implications of Implementing New Membrane Technologies to Replace the Current Ceramic Membranes - High-end and Low-end Estimates

Category	Financial Analysis Results			
	Baseline		Alternative	
	High	Low	High	Low
Initial Investment Required (Capital Costs)	$3,420,000	$2,736,000	$3,505,500	$2,821,500
Estimated Annual Operating Costs (per year)	$1,194,674	$561,737	$645,222	$332,059
Indicators of Profitability [a]				
Discounted Payback Period (year)	----	----	0.16	0.38
Net Present Value - Years 0-1 ($)	----	----	446,400	136,841
Net Present Value - Years 0-15 ($)	----	----	6,333,735	2,597,821
Internal Rate of Return - Years 0-1 (%)	----	----	542.6	168.6
Internal Rate of Return - Years 0-15 (%)	----	----	642.6	268.6

[a] These values were calculated with Pollution Prevention Financial Analysis and Cost Evaluation System (P2/FINANCE). This software, which is recommended by the ECAM, is proprietary and copyrighted by Tellus Institute of Boston, Massachusetts. A 15-year analysis and 3.3% discount rate were assumed.

5.2 Cost Analysis

Upon completion of testing of the membranes, the ECAM should be revisited to incorporate the actual lifetime performance factors to yield more accurate estimates as to the cost savings of implementing the proposed technologies. Not enough shipboard data has yet been obtained to revisit the analysis.

5.2.1 Cost Comparison

As mentioned in the Section 5.1, the cost of the nonporous coated ceramic and polymeric membrane will be compared to the non-coated commercially available ceramic membranes currently used in the existing oily waste membrane systems. Costs for the membrane, membrane housing, and coating costs should continue to be monitored.

5.2.2 Cost Drivers

The highest cost driver for the nonporous membrane is membrane acquisition and regeneration costs. The baseline non-coated ceramic membrane and the coated ceramic membrane costs are nearly equivalent. However, the extended life of the coated ceramic membrane is expected to reduce the total life cycle cost. Put another way, if a $500 coating doubles the life of a $20,000 membrane, the investment is well worth it.

6. Conclusions and Recommendations

This study has so far shown that ceramic membranes coated with one layer of 0.1% Pebax® 1074 have at least doubled the life of uncoated ceramic membranes in the laboratory. Oil separation performance is equal. The pressure required to drive fluid through the coated ceramic membranes is no greater than that for uncoated membranes. So upgrading would be simple. The sea-trial of the ceramic membranes is ongoing.

The coating on spiral-wound polymeric membranes does not meet the Navy's needs because the required flow rate cannot be achieved for the same trans-membrane pressure. Polymeric membranes with the coating would require a much larger membrane system: more membrane surface area and larger pumps. A simple change-out would not be possible.

Fifty-four hours of operation was obtained during the first deployment of the sea trial. An electronic failure prevented further data collection. It is recommended that the membranes remain on the ship to collect data once the system is repaired. It could be years until the coated membranes' life is exhausted, so this evaluation should extend at least until a fouling rate can be established. Then a lifetime could be extrapolated. Cost would be minimal. The only effort involved would be to communicate by e-mail with the ship, with occasional visits. NSWCCD has personnel on-site at the ship's homeport, so travel expenses would be minimal.

Membranes are expensive, so any method of extending their life is desirable. Membranes that do not foul are advantageous compared to membranes that require cleaning with detergent, since cleaning is an extra burden for the operator. In addition, two membranes might provide sufficient lifetime for future 5-gpm systems, rather than the current three. Such a configuration would also allow a smaller recirculation pump, resulting in a smaller, lower-cost, lower-maintenance system.

7. References

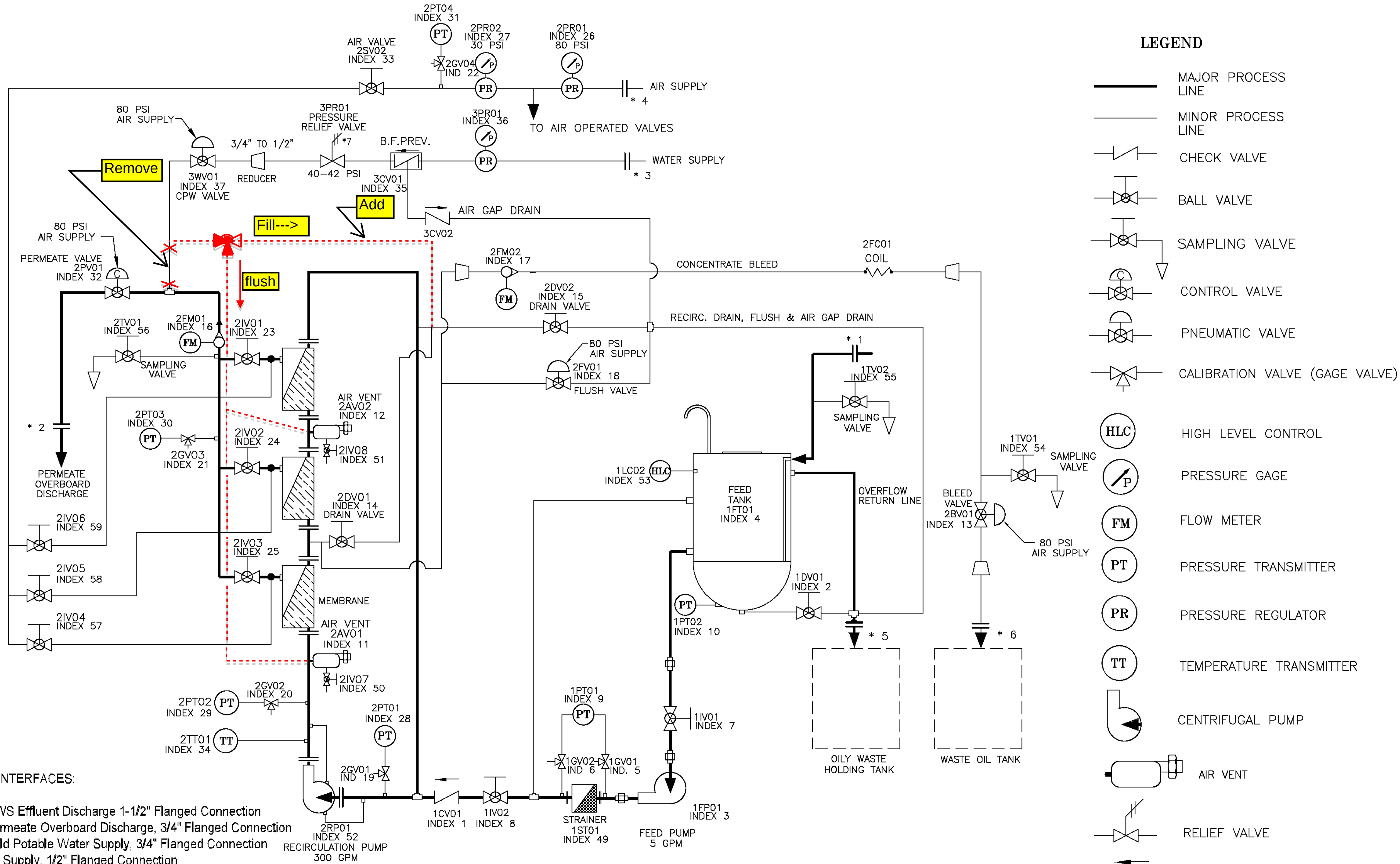
1. Membrane Technology and Research, Inc, *Novel Nonporous Fouling-Resistant Composite Nanofiltration Membrane and Membrane Separation Systems for Wastewater Treatment Important for CPSON5/PPSON1: Minimization of Oily and Non-Oily Wastewater*. Final Report, Subcontract no. 97-1493-01, (July 2001).
2. *Filtration Module, Oily Waste Membrane Type*. MIL-PRF-32097, (15 February 2002).
3. Nestle, H. L., *Development of Membrane Technology and Oily Waste Membrane Systems,* NSWCCD-63-TM-2001/118, (June 2001).
4. Stefanko, Jerome and Owsenek, Brian, *Design and Testing of Oily Waste Treatment Systems: Performance of Staged Membrane Polishing Systems*, NSWCCD-TR-63-96/25, (January 1997).
5. Loehe, Joseph R, Merkle, Andrew C, and Stefanko, Jerome S., *Ship Impact of Ultrafiltration Membrane Oily Wastewater Polishing Systems: Membrane Test Results, Computer Design Program, and Tradeoff Study",* NSWCCD-TR-63-CR—97/26, (August 1997).
6. Owsenek and Tompkins, *"Laboratory Testing of Ultrafiltration Membrane Oily Wastewater Polishing Systems: Effects of Flux on Ceramic Membrane Performance"*, NSWCCD-TR-63-69/36 (March, 1997).
7. *McAleavy, P.F. and Hoffman, S.P., Tompkins, K.T., and Schmitt, R.F., "In-Port Oily Wastewater Generation on USS ARLEIGH BURKE (DDG 51)", NSWCCD-TR-63-96/37, November 1996.*
8. *Technical Manual for 5 gpm Membrane Oily Water Separator (OWS) Polishing System AAE Model 740956*, S9593-DL-MMA-010.

Appendix A
Points of Contact

Name	Organization Name Address	**Phone** **E-mail**	**Role in Project**
David Maribo	NSWCCD Code 633 9500 MacArthur BLVD W. Bethesda MD 20817	301-227-5220 David.Maribo@Navy.mil	Principal Investigator
Alvin Ng	Membrane Technology and Research, Inc 1360 Willow Rd. Menlo Park, CA 94025	650-328-2228 x156 NgAlvin@MTRinc.com	Co-Investigator
Bruce Sartwell	ESTCP Program Office 901 N Stuart St. Suite 303 Arlington, VA 22203	703-696-2128 Bruce.Sartwell@OSD.mil	Sponsor
Rick Ruediger	NSWCCD Code 63	301-227-1668 Richard.Ruediger@Navy.mil	Department Head, Code 63
Steve Verosto	NSWCCD Code 633	301-227-5182 Stephan.Verosto@Navy.mil	Technical Area Leader
Holly Nestle	NAVSEA 05P25	202-781-3291 Holly.Nestle@navy.mil	Former Principal Investigator

Appendix B.

Piping and Instrumentation Diagram of the AAE 5-gpm Oily Waste Ultrafiltration System



SHIP INTERFACES:

*1- OWS Effluent Discharge 1-1/2" Flanged Connection
*2- Permeate Overboard Discharge, 3/4" Flanged Connection
*3- Cold Potable Water Supply, 3/4" Flanged Connection
*4- Air Supply, 1/2" Flanged Connection
*5- Oily Waste Holding Tank, 1 1/2" Flanged Connection
*6- Waste Oil Tank, 3/4" Flanged Connection
*7- Pressure Relief Valve, 3/4" Brazed Union Connection

Figure 3. Piping and Instrumentation Diagram for AAE 5-gpm Membrane System revised to show changes for non-fouling membranes

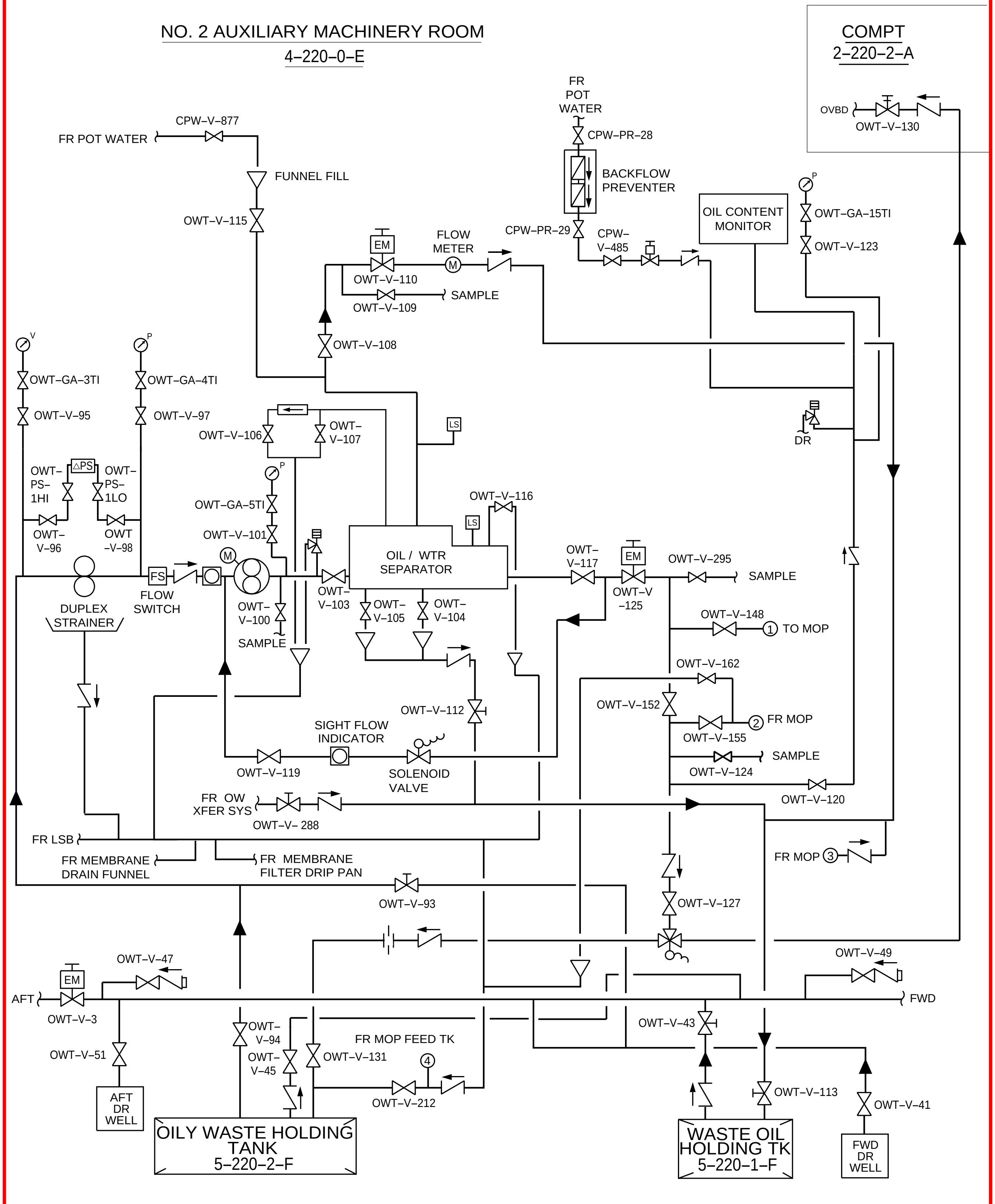
from tech manual S9593–DL–MMA–010 for AAE 5-gpm Membrane System

Appendix C

EOSS for Operation of the OWS and Oily Waste Ultrafiltration System (Modified)

DIAGRAM FOR OILY WATER SEPARATOR/ MEMBRANE POLISHER SYSTEM

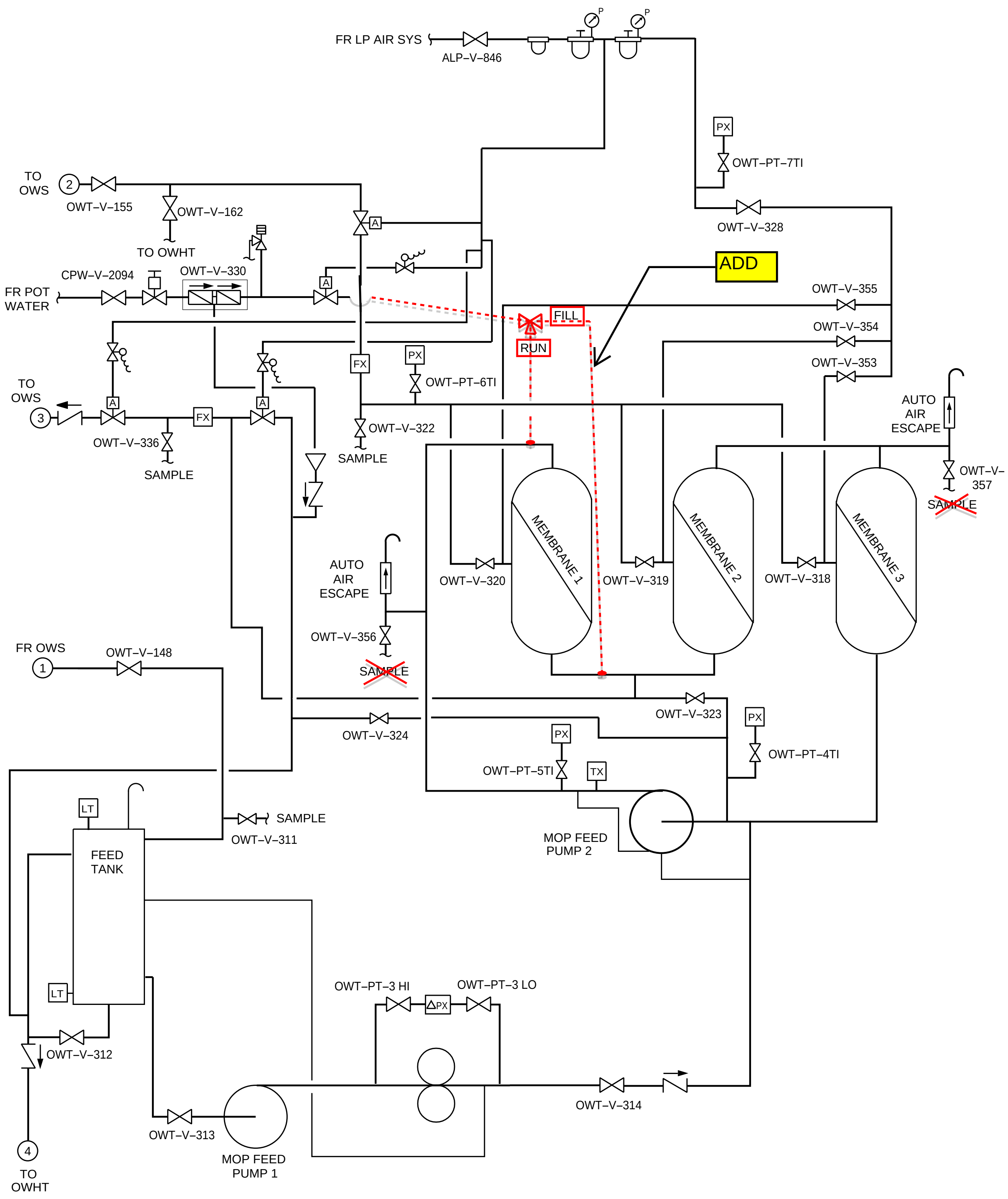
ID. NO. DOWS



Page 2 of this EOSS drawing modified for temporary installation of non-fouling membranes. Re: SCD 4242

NAVSSES EOSS FORM 082–38

DIAGRAM FOR OILY WATER SEPARATOR/ MEMBRANE POLISHER SYSTEM



EOSS modified for temporary installation of non-fouling membranes. Re: SCD 4242

COMPONENT PROCEDURE | **C. P. NO.**

OIL/WATER SEPARATOR | OWS

C. P. DESCRIPTION

PREPARING FOR OPERATION
PLACING IN OPERATION (WITH POLISHER)
PLACING IN OPERATION (WITH POLISHER BYPASSED)
AUTOMATIC CLEANING OF POLISHER
STOPPING

PROCEDURE

NOTE: Numbers refer to valves as numbered on diagram DOWS.

NOTE: Use only short-lived detergents (MIL-D-16791) or Allied P-98 to clean bilges and machinery.

PREPARING FOR OPERATION

1. Ensure the following valves are shut:

	Valve Number
a. Separator tank drains.	OWT-V-105 OWT-V-104
b. Separator waste oil vent.	OWT-V-116
c. Separator tank manual vent.	OWT-V-107
d. Separator priming valve.	OWT-V-115
e. Separator inlet and outlet sample connections.	OWT-V-100 OWT-V-109
f. Oily waste transfer header cutout.	OWT-V-93
g. Membrane polisher permeate discharge drain.	OWT-V-162
h. Freshwater supply to oil content monitor and backflow preventer inlet and outlet.	CPW-V-485 CPW-PR-28 CPW-PR-29
i. OWS effluent sample.	OWT-V-295
j. Feed tank drain.	OWT-V-312
k. Retentate (bleed) sample.	OWT-V-336
l. Air supply to membrane polisher blowout.	OWT-V-328

EOSS modified for temporary installation of non-fouling membranes. Re: SCD 4242

PROCEDURE

	Valve Number
m. Membrane system vent and drain.	OWT-V-324 OWT-V-323
n. Membrane polisher inlet/outlet samples.	OWT-V-356 OWT-V-357 OWT-V-124 OWT-V-311 OWT-V-322
o. Air supply cutouts for membrane blowout.	OWT-V-353 OWT-V-354

Note: These valves are for draining and filling the system, not sampling.

Ensure that the 3-way FILL/RUN valve is in the RUN position. FILL/RUN

2. Ensure the separator pump priming valve is open 1/4 turn.	OWT-V-119
3. Ensure the following valves are open:	
a. Separator tank influent inlet.	OWT-V-103
b. Separator tank water outlet.	OWT-V-117
c. Separator tank drain line stop to waste oil holding tank.	OWT-V-112
d. Separator tank automatic vent isolation.	OWT-V-106
e. Separator water discharge.	OWT-V-127
f. Separator water discharge to oil content monitor.	OWT-V-120
g. OCM inlet pressure gauge cutouts.	OWT-V-123 OWT-GA-15TI
h. Separator waste oil discharge.	OWT-V-108
i. Waste oil holding tank inlet from separator.	OWT-V-113
j. Duplex strainer IN pressure gauge cutouts.	OWT-V-95 OWT-GA-3TI
k. Duplex strainer OUT pressure gauge cutouts.	OWT-V-97 OWT-GA-4TI
l. Duplex strainer differential pressure switch isolations and cutouts.	OWT-V-96 OWT-PS-1HI OWT-V-98 OWT-PS-1LO

PROCEDURE

	Valve Number
m. Influent pump discharge pressure gauge cutouts.	OWT-V-101 OWT-GA-5TI
n. Pressure transducer cutouts.	OWT-PT-4TI OWT-PT-5TI OWT-PT-6TI OWT-PT-7TI OWT-PT-3HI OWT-PT-3LO
o. Fresh water fill.	CPW-V-2094
p. Air supply to membrane polisher.	ALP-V-846
q. OWHT inlet from drains.	OWT-V-212
4. Align suction from oily waste holding tank (5-220-2-F):	
a. Open oily waste holding tank suction valve.	OWT-V-94
b. Open oily waste holding tank inlet cutout valve.	OWT-V-131
5. Open water overboard discharge valve in compartment 2-220-2-A.	OWT-V-130

PLACING IN OPERATION (WITH POLISHER)

1. Ensure membrane system bypass valve is shut.	OWT-V-152
2. Ensure the following valves are open:	
a. Membrane system feed tank fill cutout.	OWT-V-148
b. Membrane system feed pump suction and discharge.	OWT-V-313 OWT-V-314
c. Membrane polisher outlet valves.	OWT-V-318 OWT-V-319 OWT-V-320
d. Membrane system permeate discharge.	OWT-V-155

3. To activate the system, the system must be primed. If system is primed, proceed to Step 4. If system is **not** primed, proceed as follows:

a. Ensure motor Operated valves are shut; if **not**, manually shut valves.	OWT-V-110 OWT-V-125
b. Open separator priming valve.	OWT-V-115

PROCEDURE

	Valve Number
c. Open separator waste oil vent valve.	OWT-V-116
d. Open separator tank manual vent valve.	OWT-V-107
e. Open priming water source and commence to fill oil/water separator tank.	CPW-V-877
f. When water flows from separator waste oil vent valve, shut vent valve.	OWT-V-116
g. When water flows from separator tank vent valve:	
(1) Shut priming water source and commence to fill oil/water separator tank.	CPW-V-877
(2) Shut priming water fill valve.	OWT-V-115
(3) Shut separator tank vent valve.	OWT-V-107
h. Return motor-operated valves to normal, if manually shut.	OWT-V-110 OWT-V-125

4. Report to EOOW, "Oil/water separator aligned for operation."

5. Ensure membrane system MAIN PANEL POWER switch is in the ON position.

6. Ensure the EMERGENCY STOP pushbutton on the MEMBRANE OWS POLISHING SYSTEM CONTROL PANEL is not depressed.

7. Turn membrane system MAIN PANEL SYSTEM switch to the AUTO position.

8. Verify "POWER ON" and valve position indicator lights are illuminated.

NOTE: Proceed to step 10. to place oily waste separator into manual mode of operation.

9. Place the oil/water separator into automatic mode of operation as follows:

NOTE: In the Automatic Mode, the ON/OFF pumping cycle is controlled by the liquid level sensors located in the oily waste holding tank (5-220-2-F). Separator pump will start only if liquid level in oily waste holding tank is above the upper sensor.

NOTE: When the holding tank level is between the upper and lower sensors, the oil/water separator is in a standby mode.

After membrane system has entered the PROCESSING mode, record RESISTANCE of the membranes. The resistance may be read from the meter on the panel on the side of the membrane system. It is labeled RESISTANCE. Record HOURS and PERMEATE TOTAL FLOW from meters located on the same panel. E-mail to David. Maribo@Navy,mil.

PROCEDURE

CAUTION: THE SYSTEM MAY **NOT** PRODUCE A LEGALLY ACCEPTABLE OIL FREE WATER EFFLUENT IF THE WATER TO BE PROCESSED HAS BEEN CONTAMINATED WITH STABLE EMULSIONS OF OIL, SIGNIFICANT QUANTITIES OF LONG-LIVED DETERGENTS OR AFFF.

CAUTION: DO **NOT** OPERATE THE OIL CONTENT MONITOR IN THE MANUAL POSITION. ANY LOSS OF FLOW WILL DAMAGE THE SAMPLING SENSOR ASSEMBLY.

a. Open OCM Sample Sensor door and position the OPERATION SELECTOR switch to the AUTO position by pulling toggle out and then push up.

b. Position OCM ALARM LIMIT SELECTOR switch to the REMOTE position by pulling toggle out and then push to center.

c. Shut Sample Sensor door.

d. Place OWS MODE SELECTOR SWITCH in the AUTO position on the separator control panel.

e. Verify "SYSTEM RUNNING" indicator illuminates. This occurs up to 2 minutes from pump start. Separator water discharge valve and oil discharge valve will "OPEN/CLOSE" during system operation.

f. When OCM inlet pressure is 5 to 25 PSIG, OCM will operate automatically. Membrane system starts when feed tank level is 12 gallons or higher.

g. Verify "OCM POWER" indicator illuminates.

h. Set REMOTE INDICATOR ASSEMBLY alarm limit by depressing the PUSH TO CHANGE ALARM LIMIT pushbutton in CCS TO 15 ppm (assistance required).

NOTE: If separator **cannot** achieve 15 PPM and operating more than 12 nautical miles from shore, OCM ALARM LIMIT SELECTOR can be set to 70 PPM per latest OPNAVINST 5090.1B.

CAUTION: THE DIFFERENCE IN PRESSURE BETWEEN THE STRAINER IN AND STRAINER OUT READINGS **CANNOT** EXCEED 2.5 PSI

NOTE: The backflow preventer (OWT-V-330) should be checked once per run to ensure that it is **not** dumping. Check troubleshooting section of technical manual if dumping.

PROCEDURE

Design Operating Data

	MAXIMUM
OWS	
Strainer In	9" Hg
Strainer Out	9" Hg
Tank Pressure (with pump operating)	25 PSIG
POLISHER	
Strainer In	60 PSIG
Strainer Out	60 PSIG

i. Report to EOOW, "Oil/water separator and polisher are in AUTOMATIC MODE operation."

10. Place the oily waste separator into manual mode of operation as follows:

NOTE: In the Manual Mode, the operator controls pump startup and shutdown.

CAUTION: THE SYSTEM MAY **NOT** PRODUCE A LEGALLY ACCEPTABLE OIL FREE WATER EFFLUENT IF THE WATER TO BE PROCESSED HAS BEEN CONTAMINATED WITH STABLE EMULSIONS OF OIL, SIGNIFICANT QUANTITIES OF LONG-LIVED DETERGENTS OR AFFF.

CAUTION: DO **NOT** OPERATE THE OIL CONTENT MONITOR IN THE MANUAL POSITION. ANY LOSS OF FLOW WILL DAMAGE THE SAMPLING SENSOR ASSEMBLY.

a. Open Sampling Sensor door and position OPERATION SELECTOR SWITCH to the AUTO position by pulling toggle out and then push to up.

b. Position ALARM LIMIT SELECTOR switch to the REMOTE position by pulling toggle out then push to center.

c. Shut Sampling Sensor door.

d. Place MODE SELECTOR SWITCH to MANUAL position on the separator control panel.

e. Depress PUSH TO RUN pushbutton on separator control panel.

f. Verify "SYSTEM RUNNING" Indicator illuminates. This occurs at up to 2 minutes from pump start. Separator water discharge valve and oil discharge valve will cycle "OPEN/CLOSE" during system operation.

PROCEDURE

g. When OCM inlet pressure is 5 to 25 PSIG, verify "OCM POWER" indicator illuminates. Membrane system starts when feed tank level is 12 gallons or higher.

h. Set REMOTE INDICATOR ASSEMBLY alarm limit by depressing the PUSH TO CHANGE ALARM LIMIT pushbutton in CCS TO 15 ppm (assistance required).

NOTE: If separator **cannot** achieve 15 PPM and operating more than 12 nautical miles from shore, OCM ALARM LIMIT SELECTOR can be set to 70 PPM per latest OPNAVINST 5090.1B.

CAUTION: THE DIFFERENCE IN PRESSURE BETWEEN THE STRAINER IN AND STRAINER OUT READINGS **CANNOT** EXCEED 2.5 PSI.

NOTE: The backflow preventer (OWT-V-330) should be checked once per run to ensure that it is **not** dumping. Use trouble shooting section of technical manual if dumping.

Design Operating Data

	Maximum
OWS	
Strainer In	9" Hg
Strainer Out	9" Hg
POLISHER	
Strainer In	60 PSIG
Strainer Out	60 PSIG

i. Report to EOOW, "Oil/water separator is in MANUAL MODE operation."

PLACING IN OPERATION (WITH POLISHER BYPASSED)

1. Ensure the following valves are shut:

	Valve Number
a. Membrane system permeate discharge.	OWT-V-155
b. Membrane system feed tank fill.	OWT-V-148

2. Open the membrane system bypass valve is open. OWT-V-152

3. To activate the system, the system must be primed. If system is primed, proceed to Step 4. If system is **not** primed, proceed as follows:

a. Ensure motor Operated valves are shut: if **not**, manually shut valves. OWT-V-110 OWT-V-125

Step	Valve Number
b. Open separator priming valve.	OWT-V-115
c. Open separator waste oil vent valve.	OWT-V-116
d. Open separator tank manual vent valve.	OWT-V-107
e. Open priming water source and commence to fill oil/water separator tank.	CPW-V-877
f. When water flows from separator waste oil vent valve, shut vent valve.	OWT-V-116
g. When water flows from separator tank vent valve:	
(1) Shut priming water source and commence to fill oil/water separator tank.	CPW-V-877
(2) Shut priming water fill valve.	OWT-V-115
(3) Shut separator tank vent valve.	OWT-V-107
h. Return motor-operated valves to normal, if manually shut.	OWT-V-110 OWT-V-125

4. Report to EOOW, "Oil/water separator aligned for operation."

5. Ensure membrane system MAIN PANEL POWER switch is in the OFF position.

6. Verify "OWS POWER ON" and valve position indicator lights are illuminated.

NOTE: Proceed to step 8. to place oily waste separator into manual mode of operation.

7. Place the oil/water separator into automatic mode of operation as follows:

NOTE: In the Automatic Mode, the ON/OFF pumping cycle is controlled by the liquid level sensors located in the oily waste holding tank (5-220-2-F). Separator pump will start only if liquid level in oily waste holding tank is above the upper sensor.

NOTE: When the holding tank level is between the upper and lower sensors, the oil/water separator is in a standby mode.

CAUTION: THE SYSTEM MAY **NOT** PRODUCE A LEGALLY ACCEPTABLE OIL FREE WATER EFFLUENT IF THE WATER TO BE PROCESSED HAS BEEN CONTAMINATED WITH STABLE EMULSIONS OF OIL, SIGNIFICANT QUANTITIES OF LONG-LIVED DETERGENTS OR AFFF.

PROCEDURE

CAUTION: DO **NOT** OPERATE THE OIL CONTENT MONITOR IN THE MANUAL POSITION. ANY LOSS OF FLOW WILL DAMAGE THE SAMPLING SENSOR ASSEMBLY.

a. Open OCM Sample Sensor door and position OPERATION SELECTOR switch to the AUTO position by pulling toggle out and then push up.

b. Position ALARM LIMIT SELECTOR switch to the REMOTE position by pulling toggle out and then push to center.

c. Shut Sample Sensor door.

d. Place OWS MODE SELECTOR SWITCH in the AUTO position on the separator control panel.

e. Verify "SYSTEM RUNNING" indicator illuminates. This occurs up to 2 minutes from pump start. Separator water discharge valve and oil discharge valve will "OPEN/CLOSE" during system operation.

f. When OCM inlet pressure is 5 to 25 PSIG, OCM will operate automatically.

g. Verify "OCM POWER" indicator illuminates.

h. Set REMOTE INDICATOR ASSEMBLY alarm limit by depressing the PUSH TO CHANGE ALARM LIMIT pushbutton in CCS TO 15 ppm (assistance required).

NOTE: If separator **cannot** achieve 15 PPM and operating more than 12 nautical miles from shore, OCM ALARM LIMIT SELECTOR can be set to 70 PPM per latest OPNAVINST 5090.1B.

CAUTION: THE DIFFERENCE IN PRESSURE BETWEEN THE STRAINER IN AND STRAINER OUT READINGS **CANNOT** EXCEED 2.5 PSI

Design Operating Data

	Maximum
OWS	
Strainer In	9" Hg
Strainer Out	9" Hg
Tank Pressure (with pump operating)	25 PSIG

i. Report to EOOW, "Oil/water separator operating in AUTOMATIC MODE."

8. Place the oily waste separator into manual mode of operation as follows:

PROCEDURE

NOTE: In the Manual Mode, the operator controls pump startup and shutdown.

CAUTION: THE SYSTEM MAY **NOT** PRODUCE A LEGALLY ACCEPTABLE OIL FREE WATER EFFLUENT IF THE WATER TO BE PROCESSED HAS BEEN CONTAMINATED WITH STABLE EMULSIONS OF OIL, SIGNIFICANT QUANTITIES OF LONG-LIVED DETERGENTS OR AFFF.

CAUTION: DO **NOT** OPERATE THE OIL CONTENT MONITOR IN THE MANUAL POSITION. ANY LOSS OF FLOW WILL DAMAGE THE SAMPLING SENSOR ASSEMBLY.

a. Open Sampling Sensor door and position OPERATION SELECTOR SWITCH to the AUTO position by pulling toggle out and then push to up.

b. Position ALARM LIMIT SELECTOR switch to the REMOTE position by pulling toggle out then push to center.

c. Shut Sampling Sensor door.

d. Place OWS MODE SELECTOR SWITCH in the MANUAL position on the separator control panel.

e. Depress PUSH TO RUN pushbutton on separator control panel.

f. Verify "SYSTEM RUNNING" Indicator illuminates. This occurs at up to 2 minutes from pump start. Separator water discharge valve and oil discharge valve will cycle "OPEN/CLOSE" during system operation.

g. When OCM inlet pressure is 5 to 25 PSIG, OCM will operate automatically.

h. Set REMOTE INDICATOR ASSEMBLY alarm limit by depressing the PUSH TO CHANGE ALARM LIMIT pushbutton in CCS TO 15 ppm (assistance required).

NOTE: If separator **cannot** achieve 15 PPM and operating more than 12 nautical miles from shore, OCM ALARM LIMIT SELECTOR can be set to 70 PPM per latest OPNAVINST 5090.1B.

CAUTION: THE DIFFERENCE IN PRESSURE BETWEEN THE STRAINER IN AND STRAINER OUT READINGS **CANNOT** EXCEED 2.5 PSI

Design Operating Data

	Maximum
OWS	
Strainer In	9" Hg

PROCEDURE

	Maximum
OWS	
Strainer Out	9" Hg
Tank pressure (with pump operating)	25 PSIG

i. Report to EOOW, "Oil/water separator is in MANUAL MODE operation."

AUTOMATIC CLEANING OF POLISHER

Note: this procedure should not be necessary with the non-fouling membranes installed. Please call of e-mail David.Maribo@Navy.mil 301-227-5220 before initiating.

CAUTION: IN THE EVENT OF MAJOR SYSTEM MALFUNCTION OR LEAKAGE, THE MEMBRANE SYSTEM SHOULD BE IMMEDIATELY STOPPED BY TURNING THE MEMBRANE SYSTEM SWITCH TO THE OFF POSITION AND TURN THE POWER SWITCH OFF.

NOTE: Ensure the OWHT level is less than 1800 gallons and **not** being filled by another source. As water will be drained to the OWHT during cleaning, monitor level in OWHT during this process.

NOTE: This operation will take just over six hours to complete. Ensure the polisher system will **not** be needed in order to provide ample time to perform this task.

NOTE: The backflow preventer should be checked at least once per cleaning cycle to ensure it is **not** dumping. If it is dumping, secure system and use troubleshooting section of technical manual.

NOTE: The membrane polisher system valves must be aligned for operation. When required, perform the PREPARING FOR OPERATION and steps 1-5 of the PLACING IN OPERATION (WITH POLISHER) sections.

	Valve Number
1. Ensure the potable water flush supply valve is open.	CPW-V-2094

2. Report to EOOW, "Polisher aligned for auto cleaning."

3. Place membrane SYSTEM SWITCH in the ~~AUTO~~ OFF position and depress the CLEAN pushbutton.

4. Allow system to run in the clean mode for six hours, monitoring hourly. The system will automatically stop after six hours.

PROCEDURE

CAUTION: IF OWHT LEVEL EXCEEDS 2400 GALLONS DURING A CLEAN CYCLE, STOP THE CLEAN CYCLE BY TURNING SYSTEM SWITCH TO OFF POSITION. DO **NOT** RESUME CLEANING OF MEMBRANE UNTIL OWHT LEVEL IS BELOW 1800 GALLONS.

NOTE: System will automatically maintain loop temperature between 120°F and 160°F by opening and shutting flush valve MOP-V-17 and cycling the recirculation pump on off as needed. This process allows hot water to drain out and relatively cool water from the flush system in.

5. After six hours of running in clean mode the system will stop cleaning and return to "STANDBY TO RUN" status.

6. Ensure membrane SYSTEM SWITCH is in the AUTO position and "STANDBY TO RUN" light is illuminated.

7. Report to EOOW, "Oil polisher is in standby mode."

STOPPING

Before stopping, record RESISTANCE of the membranes. The resistance may be read from the meter on the panel on the side of the membrane system. It is labeled RESISTANCE. Record HOURS and PERMEATE TOTAL FLOW from meters located on the same panel. E-mail to David.Maribo@Navy,mil.

NOTE: OCM will automatically turn off when system loses pressure.

1. When stopping OWS with the polisher in operation perform the following:

CAUTION: THE ~~BACK~~ FLUSH IS AN IMPORTANT MEMBRANE OPERATION. THE SYSTEM SHOULD BE PERMITTED TO FLUSH AFTER EVERY PROCESSING RUN, UNLESS POTABLE WATER CONSERVATION IS DEEMED TO BE A HIGHER PRIORITY THAN PREVENTING MEMBRANE FOULING.

a. If system is in Manual Mode or Automatic Mode and liquid level in the oily waste holding tank is between the upper and lower sensors, shut down the system as follows:

(1) Depress OWS STOP/SECURE ALARM pushbutton.

(2) Verify the OWS influent pump stops and "SYSTEM RUNNING" indicator extinguishes.

(3) Verify OWS water discharge valve and oil discharge valve "CLOSE" indicator illuminates.

(4) Place OWS MODE SELECTOR SWITCH to the OFF position.

b. If system is in Automatic Mode and liquid level in the oily waste holding tank is above the upper sensor, shut down the system as follows:

(1) Depress and hold OWS STOP/SECURE ALARM pushbutton until water discharge valve and oil discharge valve "CLOSE" indicator illuminates.

PROCEDURE

(2) While still depressing pushbutton, place OWS MODE SELECTOR SWITCH in OFF position.

c. The membrane SYSTEM SWITCH should normally be left in the AUTO position. However at the EOOW discretion, the membrane SYSTEM SWITCH may be placed in the OFF position after flush cycle is finished as indicated by the illuminated "STANDBY TO RUN" status light.

2. When stopping OWS with the polisher bypassed perform the following:

a. If system is in Manual Mode or Automatic Mode and liquid level in the oily waste holding tank is between the upper and lower sensors, shut down the system as follows:

(1) Depress OWS STOP/SECURE ALARM pushbutton.

(2) Verify the OWS influent pump stops and "SYSTEM RUNNING" indicator extinguishes.

(3) Verify OWS water discharge valve and oil discharge valve "CLOSE" indicator illuminates.

(4) Place OWS MODE SELECTOR SWITCH in the OFF position.

b. If system is in Automatic Mode and liquid level in the oily waste holding tank is above the upper sensor, shut down the system as follows:

(1) Depress and hold OWS STOP/SECURE ALARM pushbutton until water discharge valve and oil discharge valve "CLOSE" indicator illuminates.

(2) While still depressing pushbutton, place OWS MODE SELECTOR SWITCH in the OFF position.

3. If securing the system for maintenance or long periods of time, shut the following valves:

	Valve Number
a. Oily water inlet.	OWT-V-103
b. Separator water discharge.	OWT-V-117

4. Report to EOOW, "Oil/water separator is stopped."

Note: This MRC modified for the temporary installation of non-fouling membranes IAW SCD 4242

DISTRIBUTION STATEMENT D:

Distribution authorized to DOD components and DOD contractors only; Critical Technology; February 2004. Other requests for this document shall be referred to Naval Sea Systems Command (SEA 04RM). Destroy by any method that will prevent disclosure of contents or reconstruction of the document.

DATE: February 2004 **MIP SERIES:** 5932 **PERIODICITY:** SU-2

LOCATION:

SHIP SYSTEM: Special Purpose Systems 590
SYSTEM: Environmental Pollution Control Systems 593
SUB SYSTEM: Oil Pollution Control System 5932
EQUIPMENT: Membrane OWS Polishing System

RATE	MAN-HOURS	RATE	MAN-HOURS	RATE	MAN-HOURS
EN/GSM3	0.3				

TOTAL MAN-HOURS: 0.3 **ELAPSED TIME:** 0.3

MAINTENANCE REQUIREMENT DESCRIPTION

1. Fill Membrane OWS Polishing System.

SAFETY PRECAUTIONS

1. Forces afloat comply with NAVOSH Program Manual for Forces Afloat, OPNAVINST 5100.19 series.

TOOLS, PARTS, MATERIAL, TEST EQUIPMENT

NONE

PROCEDURE

1. **Fill Membrane OWS Polishing System.**
   a. Adjust air pressure regulator 2PR01 to 85 PSI.
   b. Adjust air pressure regulator 2PR02 to 30 PSI.
   c. Adjust cold potable water (CPW) regulator 3PR01 to 35 PSI.
   d. Shut drain valves 2DV01, 2DV02 and 2TV01.
   e. Shut sampling valves 1TV01, 1TV02 and 2TV01.
   f. Shut vent valves 2IV07 and 2IV08.
   g. Open calibration valves 1GV01, 1GV02, 2GV01, 2GV02, 2GV03, and 2GV04.
   h. Shut air valves 2SV02, 2SV04, 2SV05 and 2SV06.
   i. Open valves 1IV01 and 1IV02.
   j. Ensure all manual actuation switches (S8, S9, S10 and S11) are set to "OFF"; ensure switch S3 is set to "OFF".
   k. Remove safety tag; set main power switch S1 to "ON".

Place the 3-way FILL/RUN valve is in the FILL position.

NOTE 1: If permeate or bleed flowmeter flowtubes are empty, their electrical output will fluctuate. This may result in the following conditions: Approximately 8 seconds after power is turned on, a sensor failure alarm may occur. If so, the SENSOR FAILURE lamp will illuminate and the FAILURE INDICATOR lamp will flash number of times corresponding to permeate or bleed flowmeter. ALARM lamp on remote indicator panel will illuminate and audible alarms from remote indicator panel will sound. Press SILENCE pushbutton S7 to silence alarms. DO NOT push RESET S6 until main system is filled and flowmeters are indicating a steady zero.

l. Set CPW VALVE switch S8 to ″ON″ to fill recirculation loop.

NOTE 2: Loop is filled when PERMEATE, RECIRC. PUMP OUTLET, and RECIRC. PUMP INLET PRESSURE all indicate CPW line pressure of 25 - 35 PSI.

m. Increase setting on CPW pressure regulator to 25 - 35 PSI, if necessary.
n. Set FLUSH VALVE switch S10 to ″ON″.

NOTE 3: FLUSH VALVE indicator lamp will illuminate. After approximately 10 seconds, the PERMEATE FLOW RATE meter will indicate 4 - 6 GPM.

o. Set FLUSH VALVE switch S10 to ″OFF″.

NOTE 4: PERMEATE FLOW RATE meter will indicate a steady reading of approximately 0.0 GPM.

Place the 3-way FILL/RUN valve is in the RUN position.

NOTE 5: BLEED VALVE indicator lamp will illuminate. Bleed flowmeter will indicate approximately 0.5 GPM.

q. Set BLEED VALVE switch S8 to ″OFF″.
r. Set BLEED VALVE switch S9 to ″ON″ after 10 seconds.
s. Set CPW VALVE switch S8 to ″OFF″.

NOTE 6: Recirculation loop is now filled.

NOTE 7: Recirculation loop should always be completely filled or completely empty to prevent separated oil from accumulating on and/or fouling membrane surfaces.

t. Return equipment to readiness condition.