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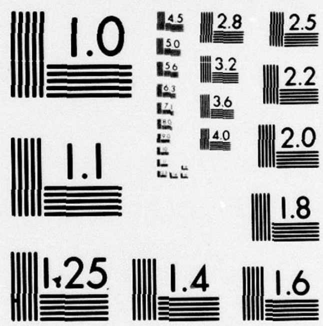

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DAVID W. TAYLOR NAVAL SHIP
RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

OPERATION OF A 2000 GALLON PER DAY REVERSE OSMOSIS DESALINATION SYSTEM ABOARD MONOB (YAG-61)

by

Joseph F. Pizzino

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December 1979

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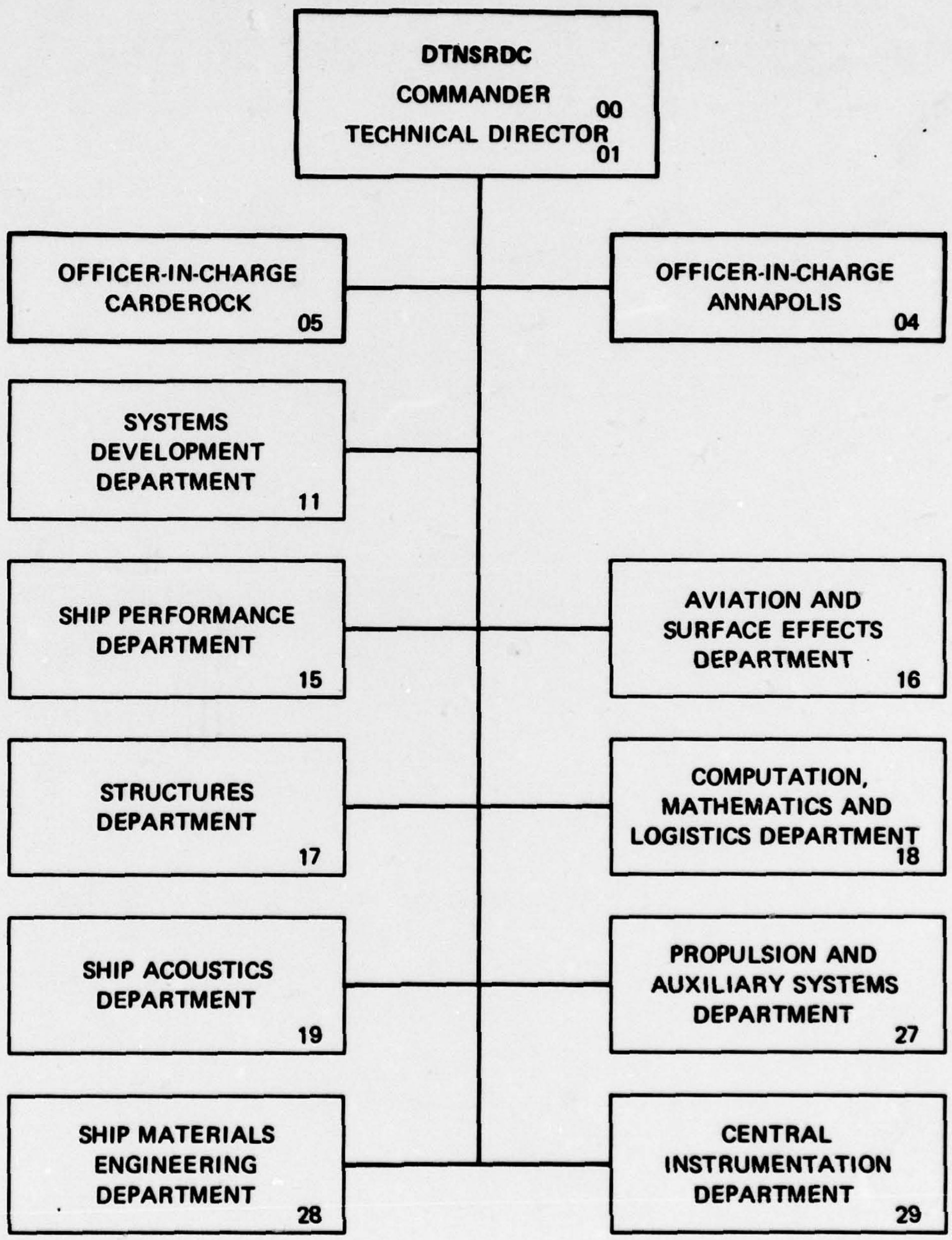
ABOARD MONOB (YAG-61)

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



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A seawater reverse osmosis desalination plant rated for 2000 gallons per day output was installed and operated aboard the MONOB (YAG-61) for shipboard evaluation. The reverse osmosis plant produced 2200 to 3200 gallons per day of potable water when operated between pressures of 650 and 800 pounds per square inch gage, respectively. The diatomaceous earth pre-filter performed reliably providing sufficiently high quality seawater filtrate to the reverse osmosis module. The overall reverse osmosis plant

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data after 480 operating hours showed no evidence of performance decline due to particulate fouling or calcium carbonate scaling. The reverse osmosis desalination plant power requirements aboard MONOB varied between 4.98 and 6.77 watt-hour per pound of freshwater produced. The fuel heat input requirements for a reverse osmosis plant were calculated to be 56 British thermal units per pound of freshwater for a ship that utilizes diesel electric generators, 91 British thermal units per pound for a ship that utilizes steam turbine generators, and 95.9 British thermal units per pound for a vessel that utilizes gas turbine generators.

Procurement of a 12,000 gallon per day desalination plant is recommended along with a continuing technical effort on filtration and high-pressure pumps to achieve specific advanced performance goals.

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LIST OF ABBREVIATIONS

Atm	Atmospheres
Btu/lb	British termal units per pound
° C	Degrees celsius
DE	Diatomaceous earth
gal/day	Gallons per day
gal/min	Gallons per minute
kw	Kilowatt
LSI	Langelier Saturation Index
NAVSEA	Naval Sea Systems Command
PI	Plugging index
ppm	Parts per million
psi	Pounds per square inch
psig	Pounds per square inch gage
PVC	Polyvinyl chloride
RO	Reverse osmosis
TDS	Total dissolved solids
Watt-hr/lb	Watt-hours per pound

ABSTRACT

A seawater reverse osmosis desalination plant rated for 2000 gallons per day output was installed and operated aboard the MONOB (YAG-61) for shipboard evaluation. The reverse osmosis plant produced 2200 to 3200 gallons per day of potable water when operated between pressures of 650 to 800 pounds per square inch gage, respectively. The diatomaceous earth prefilter performed reliably providing sufficiently high quality seawater filtrate to the reverse osmosis module. The overall reverse osmosis plant data after 480 operating hours showed no evidence of performance decline due to particulate fouling or calcium carbonate scaling. The reverse osmosis desalination plant power requirements aboard MONOB varied between 4.98 and 6.77 watt-hour per pound of fresh water produced. The fuel heat input requirements for a reverse osmosis plant were calculated to be 56 British thermal units per pound of fresh water for a ship that utilizes diesel electric generators, 91 British thermal units per pound for a ship that utilizes steam turbine generators, and 95.9 British thermal units per pound for a vessel that utilizes gas turbine generators.

Procurement of a 12,000 gallon per day desalination plant is recommended along with a continuing technical effort on filtration and high-pressure pumps to achieve specific advanced performance goals.

ADMINISTRATIVE INFORMATION

This report was completed as part of NAVSEA Task 17709, Task Area SO 382 002, Work Unit 1-2745-106. The program manager is Dr. F. Ventriglio, NAVSEA (SEA 05R14). All data taken in this report were taken in U.S. customary units.

BACKGROUND

Reverse osmosis desalination is a process whereby high-pressure seawater is forced through a semipermeable membrane to produce potable water. This Center has been developing this process for shipboard desalination for some time, and the results of extensive investigations of RO* membrane modules and feedwater pretreatment processes have been reported

*Definitions of abbreviations used are given on page v.

previously.[1,2*] This development process has advanced to the point where a 2000 gal/day RO desalination plant was installed on the Center's laboratory ship MONOB (YAG-61) for an at-sea evaluation. MONOB provides a good platform for the evaluation because its shipboard shock, vibration, and materials requirements are not as stringent as those on a combatant ship. Thus, the main emphasis could be placed on developing a workable potable water plant.

The objectives of the MONOB installation were to: (1) evaluate at-sea water production and quality, as well as power requirements of the RO process; (2) determine potential reliability/maintainability problems and develop solutions; and (3) investigate operator training requirements. This report details the results of the first year of operation of the 2000 gal/day RO desalination plant aboard MONOB.

NORMAL OPERATION OF REVERSE OSMOSIS PLANT

The 2000 gal/day RO desalination plant on MONOB is shown schematically in Figure 1.

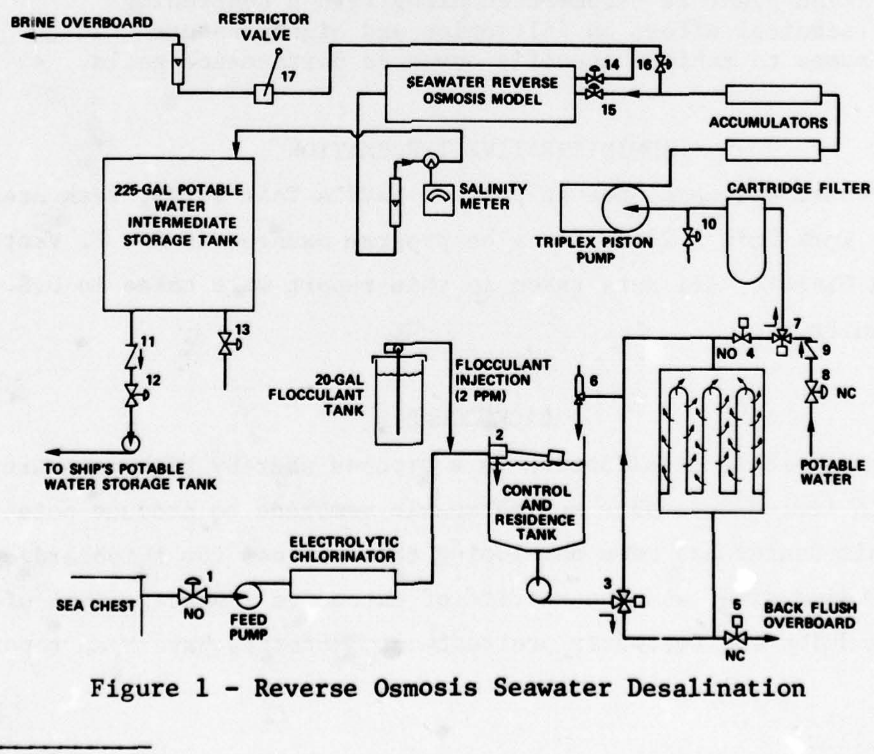


Figure 1 - Reverse Osmosis Seawater Desalination

*A complete list of references is given on page 23.

Under normal operation, seawater is brought in through the sea chest to an electrolytic chlorinator.[2] After 2 ppm of polymeric liquid flocculant is added, the chlorinated seawater flows to a control and residence tank. The control and residence tank performs several functions: (1) it provides a constant suction head for the diatomaceous earth (DE) filter pump; (2) it provides a residence time of approximately 3 minutes for reaction of the chlorine and the flocculant with the feed seawater; and (3) it is used for mixing diatomaceous earth and applying it to the filter during filter coating operations. Under normal operation, seawater flows from the control and residence tank through Valve 3 to the DE filter to the cartridge filter. The cartridge filter is used to prevent DE (which could pass through the DE filter) from entering the triplex piston pump and plugging the RO module. The filtered seawater is then pumped to an operating pressure of 650 to 800 psig (44.2 to 54.4 atm) prior to entering the hollow fiber seawater RO module via Valves 14 and 15. The plant operating pressure is regulated by a restrictor valve (Valve 17) through which the concentrated seawater (brine) is discharged overboard. RO permeate (freshwater) is fed to a 225-gallon intermediate storage tank for testing prior to being transferred to the ship's potable water tank. Approximately 20% of the feed seawater entering the RO plant is converted to potable quality water.

During plant start-up, water in the filter and residence tank is recirculated for the application of DE to the filter septum. Water flows from the control and residence tank to the DE filter via Valve 3 and then back to the control and residence tank via Valve 6 (Valve 4 is closed). Four pounds of DE are manually added to the control and residence tank. After approximately 15 minutes, the DE is fully coated on the filter septum as is evident by the improvement in the clarity of the seawater in the control and residence tank. Filtered seawater is then pumped to the remainder of the RO plant by opening Valve 4.

The RO system is normally started with Valves 14 and 15 closed and Valve 16 open in order to bypass the seawater RO module. A seawater filtrate plugging index test[1,3] (which is a quantitative measure of the filtrate particulate concentration) is performed on a seawater sample at Valve 10. After a satisfactorily low value of the plugging index is measured, pretreated feed seawater is fed to the RO module by opening Valves 14 and 15 and closing Valve 16. A plugging index test was required to ensure that RO feed seawater was suitably filtered. For future shipboard RO plants, this procedure would only be necessary for in-port operation.

To shut down the plant, the high-pressure pump is turned off, the DE filter is backwashed, and the high-pressure pump and RO module are flushed with potable water. Back-flushing is achieved by pumping seawater to the top of the DE filter via Valve 3 (Valve 4 closed) and dumping the wasted DE overboard via Valve 5. Flushing the high-pressure pump and RO module is achieved by opening Valve 9.

The electrolytic chlorinator and flocculant injection pump operate only when the DE filter is operating normally (i.e., when Value 4 is opened). All operating modes of the DE filter (i.e., back-flushing, recoating, and normal operation) are controlled manually by selector switches on an electrical control panel.

The MONOB RO plant is made up of two distinct, separately mounted, components: (1) the DE filter (control and residence tank, DE filter, and DE filter controls); and (2) the RO unit (RO module, high-pressure pump, chlorinator, flocculant injection pump, etc). The two components are located in two different areas of the machinery room on MONOB because of the unavailability of a large enough span to accommodate both units side by side. Figure 2 is a front view of the DE filter unit. Figure 3 is a rear view of the unit with the DE filter element in the foreground. This element is 4 feet tall by 1 foot in diameter. Figure 4 is a front view of the RO unit. Figure 5 shows the intermediate potable water storage tank with a small portable plugging index test unit located on the tank top.

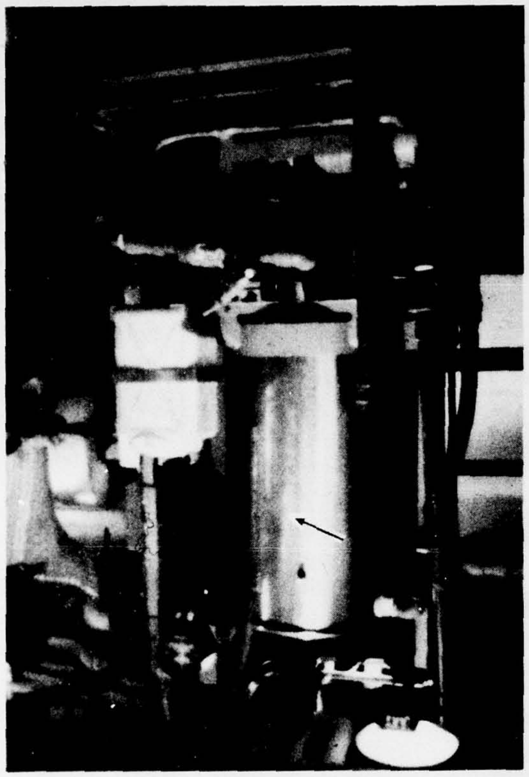


Figure 2 - Front View of Diatomaceous Earth Filter With Control and Residence Tank in Foreground (Arrow Indicates Control and Residence Tank)

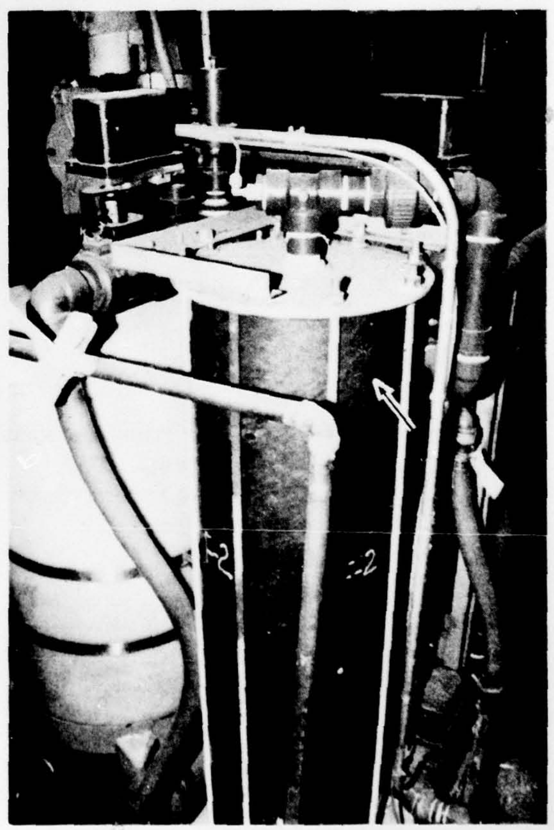
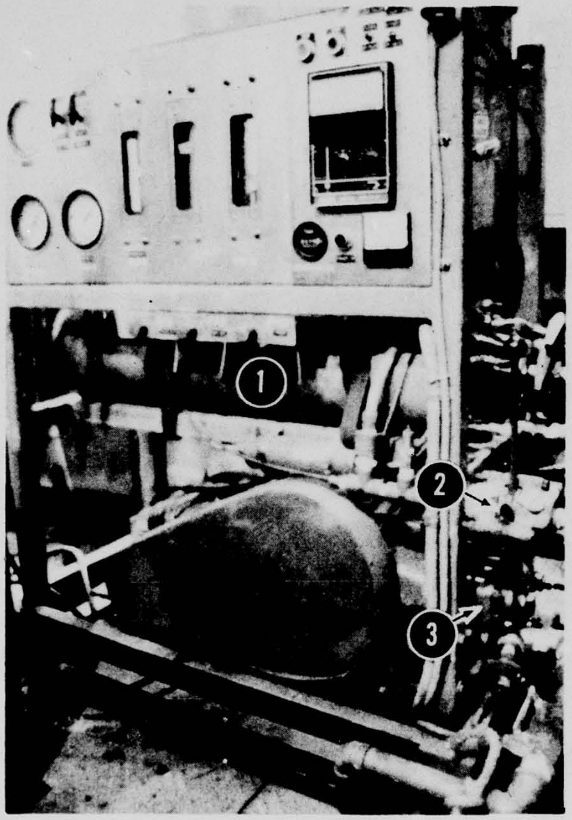


Figure 3 - Rear View of Diatomaceous Earth Filter With Filter Element in Foreground (Arrow Indicates Diatomaceous Earth Filter Element)



1 - Reverse Osmosis Module
2 - Back Pressure Valve
3 - High-Pressure Pump

Figure 4 - Front View of Reverse Osmosis Unit (Note High-Pressure Pump at Lower Right and Reverse Osmosis Module in Center)

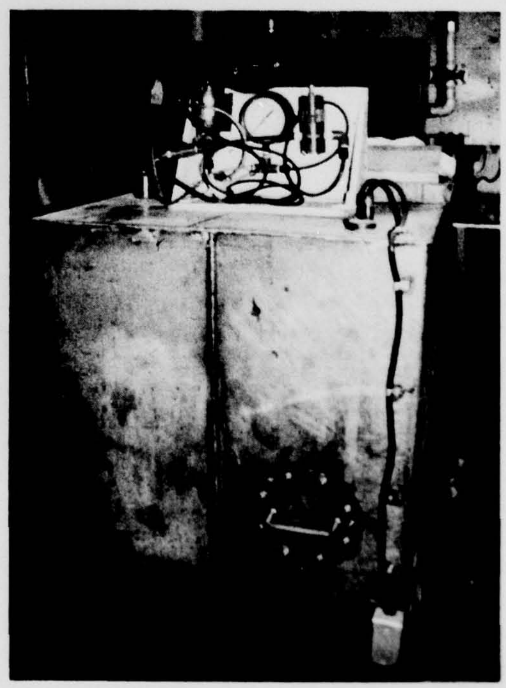


Figure 5 - 225-Gallon Potable Water Intermediate Storage Tank (Note Plugging Index Test Unit on Top of Tank)

During most of the time period covered by this report (November 1977 through January 1979), MONOB was stationed at Port Everglades, Florida. The mission of this ship is such that it is periodically at sea for 15 to 45 days. Existing ship potable water storage tanks are normally filled prior to leaving port. The RO plant is used to refill those tanks when the at-sea period is expected to exceed 25 days. Therefore, operating periods of the RO plant have generally been very short, i.e., 20 to 48 hours in duration. In addition to the at-sea operating hours, the plant has been run for test purposes while in port. In-port testing has been limited to 2- to 4- hour periods. The longest continuous at-sea run occurred when the ship's main propulsion plant became disabled while at sea, which necessitated running the RO system continuously for 113 hours.

pH CONTROL AND POTENTIAL MEMBRANE SEALING

One of the objectives of the Navy's RO desalination development program[1,2] has been to avoid the requirement to add acid for pH control to prevent calcium carbonate scaling. The saturation of calcium carbonate in seawater can be predicted by the Langelier Saturation Index[4] (LSI) as:

$$LSI = pH - pALk - pCa - K$$

where

- pH ≡ Log of the reciprocal of the hydrogen ion concentration
- pALk ≡ Log of the reciprocal of the alkylinity concentration
- pCa ≡ Log of the reciprocal of the calcium ion concentration
- K ≡ Constant based on the total ionic strength and temperature.

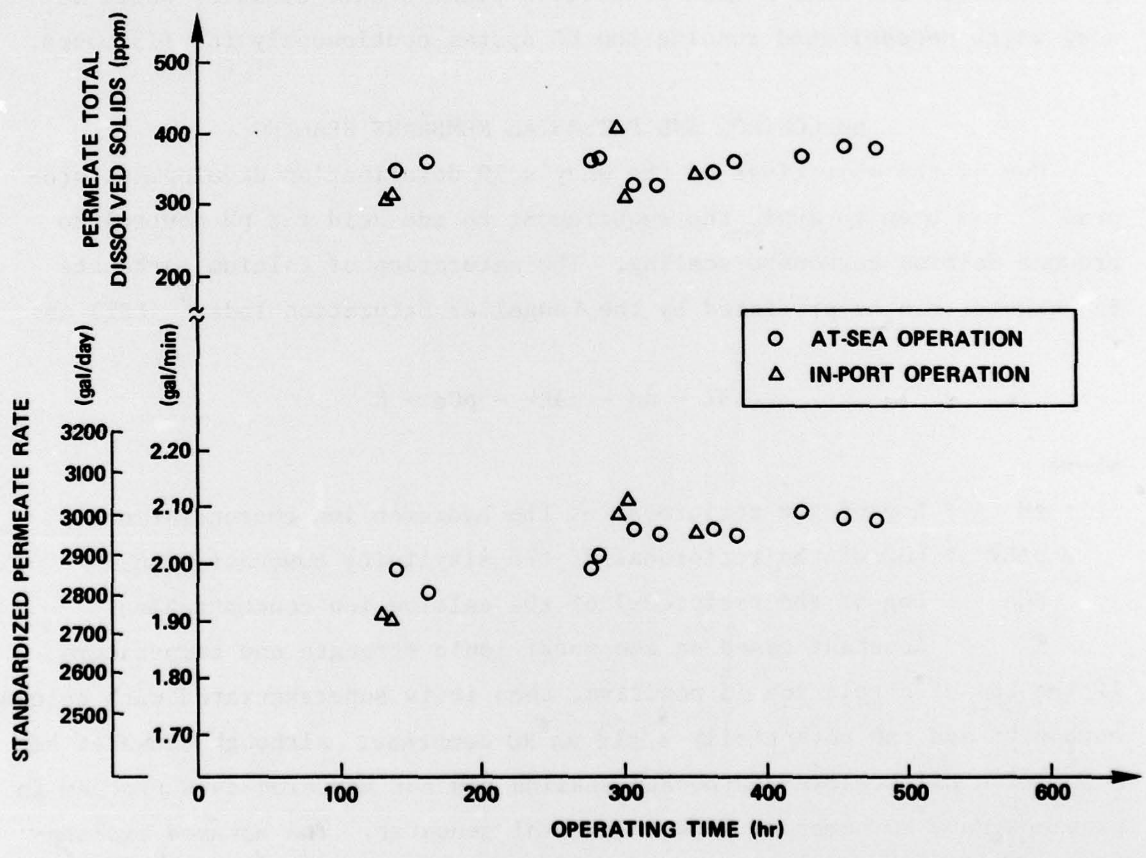
If the LSI of a solution is positive, then it is supersaturated with calcium carbonate and can potentially scale an RO membrane. Although seawater has a positive LSI, calcium carbonate scaling has not appeared as a problem in previous Navy RO membrane work on natural seawater. The assumed explanation is that the calcium carbonate apparently remains in the supersaturated state rather than precipitating.

As the salinity of seawater increases, the alkaline and calcium ion concentration will increase proportionately, and thus the LSI will increase as well. This was a major concern in the operation of the RO plant on

MONOB because open ocean water is generally more saline than the coastal water. Therefore, the possibility of calcium carbonate scaling of the MONOB RO plant was of great concern.

RESULTS AND DISCUSSION

The MONOB RO desalination plant has operated a total of 480 hours (approximately 18 start-ups and shutdowns). The results in terms of permeate rate and total dissolved solids versus time are given in Figure 6.



NOTE: PERMEATE RATE STANDARDIZED TO 70° F AND 35,000 PPM TDS SEAWATER CONDITION AND 800 PSIG OPERATING PRESSURE

Figure 6 - Permeate Rate and Permeate Total Dissolved Solids Versus Operating Time for the Reverse Osmosis Desalination Plant on MONOB (YAG-61)

Each point represents an average operating value for a given operating period. Since the plant was operated at varying pressures, temperatures, and seawater concentrations, permeate rate values were standardized to an operating pressure of 800 psig, a seawater temperature of 70° F (21.1° C), and a concentration of 35,000 ppm total dissolved solids.

MEMBRANE FOULING AND SCALING

The lack of decline of membrane output with operating time, as shown by Figure 6, provides evidence that membrane fouling from either seawater colloidal particulates or calcium carbonate scaling had not occurred. Particulate fouling was not expected since DE filtrate plugging index values observed at sea were low. Table 1 is a summary of average plugging index values of raw seawater and DE filtrate taken in port at Port Everglades, Florida, and at sea.

TABLE 1 - PLUGGING INDEX VALUES FOR FILTERED AND UNFILTERED SEAWATER AT SEA AND IN PORT AS TAKEN ON MONOB (YAG-61)

Ship Location	Seawater Sample Location	PI_{15}
In Port	DE filtrate	2.70
In Port	Raw seawater	∿6.5
At Sea	DE filtrate	1.30
At Sea	Raw seawater	5.87

Seawater colloidal particulate content is lower in the open ocean than in harbor water. This was also reflected in the significantly longer periods that the DE filter was operated continuously at sea with minimal increase in pressure drop. For example, operated at sea, the DE filter operated for 113 hours as compared to 2.4 hours of operating in port for the same pressure drop. Calcium carbonate scaling was another major concern since open-ocean salinities rose to values as high as 42,800 ppm of total dissolved solids with a pH of approximately 8.0. This combination of pH and salinity gives a highly positive LSI which would indicate a tendency of the calcium carbonate to precipitate. There are two conditions which may have helped to discourage membrane scaling. First, since precipitation is a time-dependent phenomenon, it is possible that scale is occurring downstream after the brine leaves the RO module. This will be checked during subsequent inspection of the brine overboard piping. Second, precipitation is also influenced by the availability of particulate matter in the water to furnish nucleation sites. Since the water has been extensively filtered prior to entering the RO module, it is possible that the lack of nucleation sites has tended to discourage scale formation. Permeate quality was constantly maintained at acceptable total dissolved solids levels (below 500 ppm), and chlorine concentrations of 0.2 to 0.8 ppm were continuously achieved during operation. However, permeation of the membrane by chlorine generally did not occur until at least 30 to 60 minutes after the membrane has been exposed to the chlorinated feed seawater.

MECHANICAL PROBLEMS

When the RO plant was installed aboard MONOB, the weakest mechanical components of the plant were considered to be the DE filter (because of its relative complexity) and the high-pressure pump. It was recognized that in order for the shipboard experience to be judged successful, the RO plant would have to demonstrate overall reliability. Thus, a significant amount of effort was placed on monitoring the DE filter and high-pressure pump.

Diatomaceous Earth Filter

During the initial operation of the plant at the Center, problems with the DE filter unit were encountered and corrected. The major problem was that the polyvinyl chloride (PVC) motorized ball valves tended to seize from DE (particles) in the ball seals. This resulted in the shearing of the PVC valve stems. Replacement of all PVC ball valve stems with type 316 stainless steel stems solved the problem. A recent check of the interior of the valves indicated that PVC balls, fluorocarbon seals, and PVC valve bodies were in good running condition, and that the DE apparently has had little affect on these components.

Another problem initially encountered during the early operation was that of air being drawn into the DE filter pump suction and preventing the unit from performing satisfactorily. In some experiences with Severn River water, acceptably low plugging index values could not be obtained until a silicone sealant had been applied around the DE filter pump suction strainer.

Since the RO plant was installed aboard MONOB, no major problems associated with the operation of the filter have occurred. One small problem was a relief valve (Valve 6) that had to be modified slightly to make it operate smoothly. Overall, DE filtration has proven to be a reliable method for providing high quality filtered water both in port and at sea.

High-Pressure Pump

The high-pressure pump used in the RO plant is a triplex piston pump with the suction valves as an integral part of the pistons. The piston pump suction seals are glycerine-lubricated by automatic feed drippers. Pump selection was based upon: (1) minimum size and weight, (2) availability in corrosion-resistant construction materials, and (3) ability to operate without oil or grease lubrication. One of the drawbacks of the pump has been the high airborne-noise levels generated. Airborne-noise level readings operating in an open test floor area were as high as 94 decibels.

During laboratory testing, the high-pressure pump was run to determine the maximum number of operating hours that could be expected without major repairs. It was concluded that a maximum of 500 operating hours could be expected from this pump between overhauls. The type 316 stainless steel valves were found to be the weakest part of the pump because of susceptibility to pitting in stagnant seawater. This problem has since been reduced by flushing the pump with potable water on plant shutdown.

The major problem with the pump which arose during operation of the RO plant on MONOB was the inconsistency of the lubricators dripping glycerine onto the piston shaft. Though no failure attributable to this problem occurred, it was an annoying problem for the operator. The lubricators which have a needle valve type of adjustment were either running out of lubricant very quickly or failing to lubricate at all. To ensure that the inlet seals were well lubricated, operators were instructed to open the needle valves on the lubricators as far as possible and to fill the lubricators hourly.

During an in-port test run of the plant, a shutdown of the pump occurred when one of the piston seals was cut up by a badly chipped, shrome-plated cylinder wall. During a previous repair of the pump, a replacement cylinder having chromium plating was inadvertently installed. Replacement cylinders had been ordered without plating, but the manufacturer had inadvertently supplied one with chromium plating.

High-Pressure Hose

Another problem which occurred to the RO plant was failure of the reinforced fluorocarbon hose which connects the resiliently mounted high-pressure pump to the RO module. This problem, which occurred twice, was a result of improper installation and poor assembly. On the first failure, the hose was installed as shown in Figure 7a, which allowed chaffing on itself during pump operation and eventually caused a failure. Figure 7b shows two correct methods for hose installation which are provided in NAVSHIPS Note 9480. The other failure occurred at the hose end connection as a result of poor assembly of the end fitting onto the hose. Specific equipment needed for making proper hose connections has since been procured for future use. As an alternative, it is possible to procure hose from the manufacturer with end fittings already installed, which should provide even better reliability.

OPERATOR COMPATIBILITY

Before operating the RO plant on MONOB, an operating manual was provided to the ship. The manual included a step by step start-up, shutdown, and operating procedure for the plant, a maintenance chart, a trouble-shooting chart, and a list of all parts. An initial in-port and an at-sea demonstration was given on how to operate the plant. Operation of this plant on MONOB was somewhat more complicated than would be expected with a production shipboard RO plant because: (1) plugging index data would not necessarily be a prerequisite for start-up of an RO plant, (2) a rather

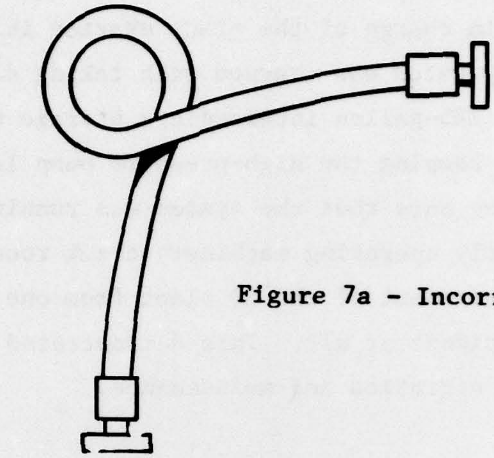


Figure 7a - Incorrect 90° Bend

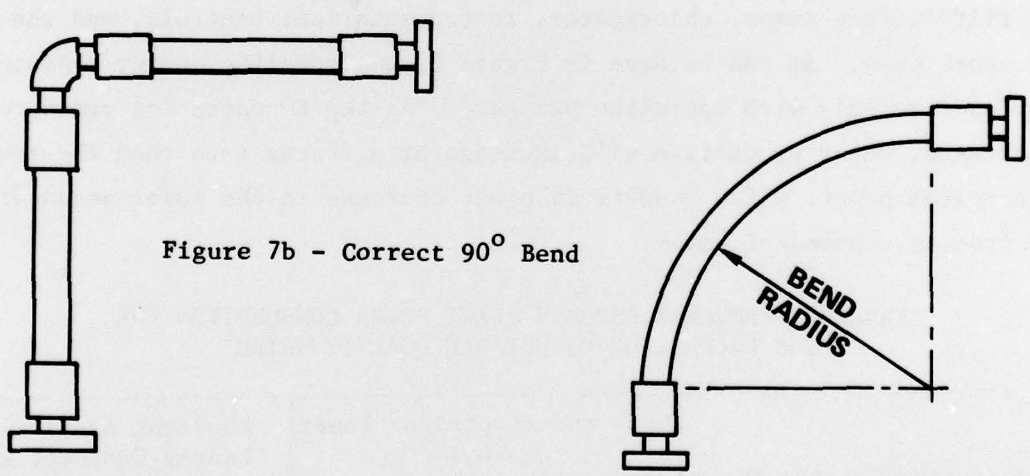


Figure 7b - Correct 90° Bend

Figure 7 - Incorrect and Correct 90° Hose Installations (Note that the incorrect installation as shown in 7a above, as installed aboard MONOB, allows chaffing between contacting hose surfaces)

high maintenance, high-pressure pump was used, and (3) a much greater amount of data was required as part of the normal operation than would be expected on a production unit. Except for one at-sea operating period, the complete operation of the RO plant has been handled by the MONOB crew.

Operation of the RO plant fell into the normal operating routine of the ship. The man in charge of the plant started it up and shut it down. The engineer on duty watch was charged with taking data, transferring potable water from the 225-gallon intermediate storage tank to the ship potable water storage tank, keeping the high-pressure pump lubricators filled with glycerine, and making sure that the system was running satisfactorily. This was done during hourly operating machinery check rounds.

Transfer of assignment of the RO plant from one crewman to the other occurred with no incident at all. This demonstrated the relative simplicity of the RO plant for operation and maintenance.

REVERSE OSMOSIS PLANT POWER REQUIREMENTS

Electrical power requirements of the RO plant as a function of pressure were determined with an industrial power analyzer. Table 2 shows power measurements made for the high-pressure pump and the total plant including the DE filter, feed pumps, chlorinator, instrumentation, controls, and the high-pressure pump. As can be seen in Figure 8, the specific energy consumption varies inversely with operating pressure. As the RO operating pressure is increased, water production will increase at a faster rate than the required electrical power, which results in a net decrease in the power necessary to produce a pound of water.

TABLE 2 - REVERSE OSMOSIS PLANT POWER CONSUMPTION FOR THE PRODUCTION OF POTABLE QUALITY WATER

Operating Pressure (psig)	Potable Water Production (gal/day)	Measured Electrical Power (kw)		RO Plant Specific Energy Consumption (watt-hr/lb of water)	
		RO High-Pressure Pump	Total Plant	RO High-Pressure Pump	Total Plant
800	3220	5.07	6.68	4.54	5.98
740	2900	4.78	6.37	4.75	6.33
650	2460	4.18	5.78	4.89	6.77

Note: Seawater salinity = 33,800 ppm total dissolved solids.
Seawater temperature = 76.1° F.

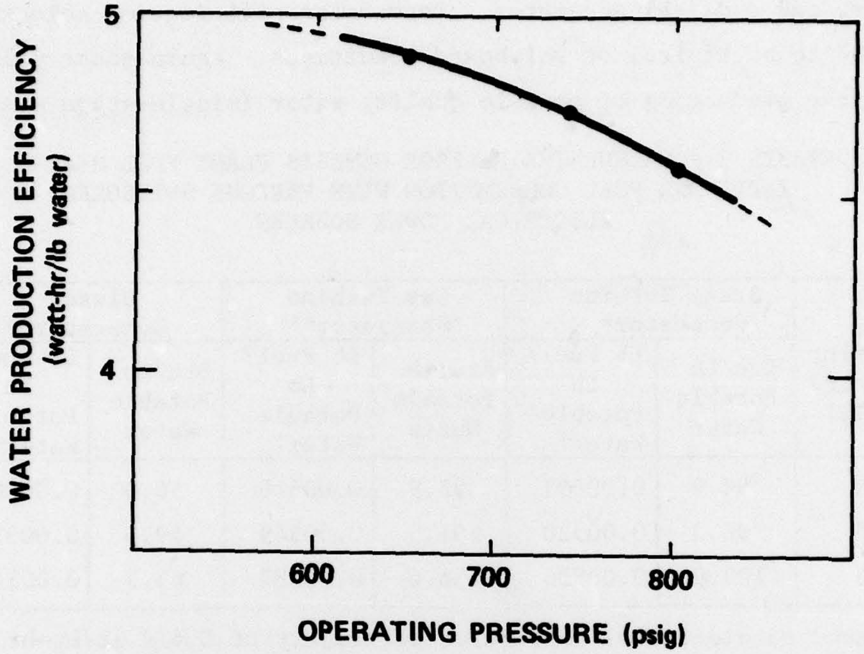


Figure 8 - Specific Power Consumption

It must be emphasized that these power requirements are for a single-stage RO plant which produces potable quality water (200 to 500 ppm total dissolved solids). Additional power would be required to produce boiler feedwater (4 to 6 ppm total dissolved solids) because a second-stage RO unit would be required. The additional stage would require approximately 15% of that power required for Stage 1. For example, the single-stage RO plant operated at 800 psig required 4.54 watt-hr/lb of water produced. An additional second stage operated at 400 psig operating pressure and at a 67% recovery would require 0.68 watt-hr/lb of water produced. Therefore, the total high-pressure pumping power necessary to produce boiler feedwater would be 5.22 watt-hr/lb of water produced.

The values from Table 2 were used to calculate expected total fuel heat input and fuel consumption to produce 1 pound of potable water. Values are provided in Table 3 in terms of Btu/lb of potable water as well as pounds of fuel per pound of water. These requirements were calculated for the three types of shipboard generating equipment that are used today to provide electrical power: a steam turbine generator, a gas turbine generator, and a diesel generator. Conversion efficiencies selected were considered to be typical of shipboard conditions. Again these values are based on the production of potable quality water (single-stage system).

TABLE 3 - CALCULATED REVERSE OSMOSIS PLANT FUEL HEAT INPUT AND FUEL CONSUMPTION WITH VARIOUS SHIPBOARD ELECTRICAL POWER SOURCES

RO Operating Pressure (psig)	Steam Turbine Generator*		Gas Turbine Generator**		Diesel Generator***	
	Btu/Lb Potable Water	Lb Fuel/ Lb Potable Water†	Btu/Lb Potable Water	Lb Fuel/ Lb Potable Water†	Btu/Lb Potable Water	Lb Fuel/ Lb Potable Water†
800	90.9	0.00491	95.9	0.00518	56.0	0.00303
740	96.2	0.00520	101.5	0.00549	59.3	0.00321
650	102.9	0.00556	108.6	0.00587	63.5	0.00343

*Based on electrical conversion efficiency of 0.616 lb/hp-hr of fuel.
**Based on electrical conversion efficiency of 0.650 lb/hp-hr of fuel.
***Based on electrical conversion efficiency of 0.380 lb/hp-hr of fuel.
†Heat fuel requirements based on fuel heating value of 18,500 Btu/lb.

The data in Table 3 indicate that a substantial reduction in shipboard fuel consumption and energy requirements for the production of water is possible when RO is substituted for present distillation plants (which consume approximately 0.0235 pound of fuel to produce a pound of water[5] based on a fuel heating value of 18,500 Btu/lb fuel). The RO system would consume no more than 0.00518 pound of fuel to obtain the same amount of water (using electricity from the gas turbine generator). Clearly, the RO desalination system can produce potable water using five to eight times less fuel.

CONCLUSIONS AND RECOMMENDATIONS

The 2000 gal/day RO desalination plant on MONOB has performed satisfactorily and reliably, providing the ships crew with potable water.

No evidence of membrane fouling or scaling has been detected during the 480 operating hours. Seawater particulate levels measured at sea were much less severe than those encountered on coastal seawater in previous work. This indicates that the stringent pretreatment requirements thought necessary for RO application may be relaxed for at-sea operation. Future work in the area of pretreatment will include the investigation of alternative methods of filtration, primarily multimedia filtration, which is less complex and simpler to operate and maintain. Furthermore, the absence of calcium carbonate scaling, even at high seawater total dissolved solids levels, simplifies the development of a desalination plant which does not require acid feed pretreatment.

RO plant measured power consumption was found to be low as compared with the distillation systems used in the fleet today. It is concluded that considerable fuel savings would result from fleet wide application of RO for shipboard desalination.

An area of continuing concern is the development of high-pressure pumps to feed the RO process. Such pumps should include the following features:

1. Non-oil- or non-grease-lubricated to prevent membrane damage
2. Constructed of seawater corrosion-resistant materials
3. Long life between overhauls (greater than 3000 hours)
4. Positive displacement to achieve high pressure and high efficiency
5. Low vibration and low airborne noise
6. Relatively low maintenance.

The pump on the MONOB RO plant did not completely satisfy these requirements because of its high maintenance and high noise levels. The Center is currently investigating modifications which can be made to commercially available plunger-type pumps to achieve many of the features listed above. Results to date have led to considerable improvement in pump seal and valve reliability. Future work on MONOB will include the installation of a new pump incorporating many of the recently developed improvements.

The high level of success achieved with operation of the RO plant aboard MONOB raises the expectation that operation of a production-type RO plant aboard ship should be equally successful. Ship personnel qualified to operate distiller equipment should (when properly trained) be able to handle RO equipment without major difficulties.

Based upon the successful operation of the MONOB reverse osmosis desalination plant, it is recommended that the currently planned procurement of a 12,000 gal/day preproduction prototype system be implemented on schedule. A continued technical effort to improve filtration and high-pressure pump technology is recommended to ensure an RO desalination system with high reliability and good maintainability.

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