TECHNICAL REPORT NO. LWL-CR-01S70

LIGHTWEIGHT, HAND-OPERATED BRACKISH WATER PURIFIER

by

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March 1974

Final Report

Contract No. DAAD05-72-C-0419

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U. S. ARMY LAND WARFARE LABORATORY
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER LWL-CR-01S70	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) LIGHTWEIGHT, HAND-OPERATED BRACKISH WATER PURIFIER		5. TYPE OF REPORT & PERIOD COVERED Final Report Jul 72 - Jan 74 6. PERFORMING ORG. REPORT NUMBER U-6061
7. AUTHOR(s) Richard H. Williams, David R. Fort, John V. Peck, Leonard Gapsun, John L. Richardson		8. CONTRACT OR GRANT NUMBER(s) DAAD05-72-C-0419
9. PERFORMING ORGANIZATION NAME AND ADDRESS Philco-Ford Corporation Fort Road Newport Beach, CA 92663		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Task No. 01-S-70
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Land Warfare Laboratory Aberdeen Proving Ground, MD 21005		12. REPORT DATE March 1974 13. NUMBER OF PAGES 86
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Water Purifier
Brackish Water Purifier
Sea Water Purifier
Manually Operated Water Purifier
Reverse Osmosis
Cellulose Acetate Membrane

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In response to a need expressed by US Military personnel operating in coastal areas, a lightweight, hand-operated brackish water purifier has been developed. This system utilizes a reverse osmosis cellulose acetate membrane for desalination.

A total of 15 brackish water purifier units were fabricated and tested. Design and performance goals were met. The unit weight and volume is 11 lbs. and 0.3 cu. ft. Performance goals were 250 cc of potable water per minute
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and a salt rejection of 90% based on a brackish water salt concentration of 5,000 ppm. Pumping input is 0.12 HP.

A seawater unit was also fabricated, which required that the water be pumped through twice. Design configuration the same as above. It provides potable water at 150 ppm from seawater concentration of 35,000 ppm.

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SECTION 1

INTRODUCTION

1.1 GENERAL BACKGROUND

There is a need for a lightweight hand operated water purifier for soldiers on patrol. Brackish water or otherwise non-potable contaminated water may be the only water source available; consequently soldiers must carry drinking water (approximately 12 pounds per day's use in the tropics) with them. A portable hand operated water purifier would increase the patrol's effectiveness and duration by making use of otherwise contaminated water sources, and reducing the water load a soldier must carry.

A system incorporating the principle of reverse osmosis (RO) was considered the most efficient means of water purification within the constraints of hand operation requirements, ease of portability, and desired output quantity and quality on the basis of a previous program (Reference 1).*

1.2 PROGRAM DEFINITION

A program was defined in terms of four phases, for the design development and test evaluation of the brackish water purifiers and a single sea water purifier.

<u>Phase I</u>: Design and fabricate a "model" hand-operated, brackish water purifier. This system was demonstration tested in order to qualify for acceptance within the preceding performance and design criteria.

<u>Phase II</u>: Design and fabricate four "prototype" hand-operated, brackish water purifiers in preparation for life tests.

<u>Phase III</u>: Long term tests were performed upon the four Phase II brackish water purifiers to determine reliability and life expectancy in terms of the stated performance criteria. Design modifications were made as required.

<u>Phase IV</u>: Ten brackish water purifiers and one sea water purifier were fabricated and qualification tested prior to shipment.

1.3 OBJECTIVES

The objectives of the program were to design and fabricate fifteen lightweight, hand operated brackish water purifiers. The final ten purifiers were held to the following design and performance goals (feed temperature of 77°F and feed solution of 5000 ppm NaCl).

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*Williams, R. H., <u>et al.</u>, "Final Report, Lightweight Reverse Osmosis Membrane Module", U. S. Army Land Warfare Laboratory Contract DAAD05-70-C-0256, Aeronutronic Publication No. U-4877, Newport Beach, California: Physics and Chemistry Laboratory, Advanced Development Operation, Aeronutronic Division, Philco-Ford Corporation (November 1970). Also published as U. S. Army Technical Report LWL-CR-17B69.

(a) Size: Maximum of 0.30 ft^3

(b) Weight: Maximum of 11 lb

(c) Output Quantity: Minimum of 250 ml/min = 95 gpd = 0.53 pints/min

(d) Output Purity: Salt Rejection of 90%

(e) Energy Input: Maximum 0.12 hp

(f) Reliability: Mean Gallonage Before Failure of 3600 at a Confidence Level of 90% (Reference 2)*

(g) Life Expectancy: ~3200 gallons (800 hrs at 250 ml/min output flow rate)

(h) Ease of Maintenance

A single sea water desalination unit was designed, fabricated and tested with the performance objective of potable water production from sea water in two passes. The size, weight and energy input requirements were held the same as for the above brackish water purifiers. The operating conditions, particularly the fractional recovery limit of 0.20, were derived from recent studies of saturation conditions for various sea water RO system concentrates.*

1.4 THEORY OF REVERSE OSMOSIS

Reverse osmosis is a process capable of separating or removing dissolved materials from solution. It is this ability to remove dissolved ionic materials which differentiates reverse osmosis from filtration operations. In the process of reverse osmosis, a feed stream, at high pressure, flows across the surface of a membrane. Some of the water in the feed stream is forced through the membrane, while most of the dissolved materials and all of the suspended materials do not pass through it. Thus, the entering feed stream is separated into two streams; a permeate stream which passed through the membrane and a concentrate stream which did not. Most of the water and very little of the dissolved material appears as the permeate. The concentrate stream is composed of the remainder of the water and all of the material rejected by the membrane.

To better understand the process of reverse osmosis, let us first consider the natural process of osmosis (Figure 1-1). If a semipermeable membrane, i.e., one which permits the passage of water but not of dissolved or suspended materials, is used to separate two solutions at a given temperature having different concentrations, water will flow from the less concentrated to the more concentrated solution, causing a build-up of pressure on the more concentrated side of the membrane. This flow of water through the membrane continues until the concentrations on both sides of the membrane are equal or until the pressure on the more concentrated side has increased to a point where no more water can flow through the membrane. This pressure is called the osmotic pressure difference and depends only on the types of materials in solution, the concentration difference across the membrane, and the temperature. The osmotic pressure is independent of the nature of the semipermeable membrane.

In reverse osmosis, a semipermeable membrane separates two solutions, with a pressure greater than the osmotic pressure difference applied to the more

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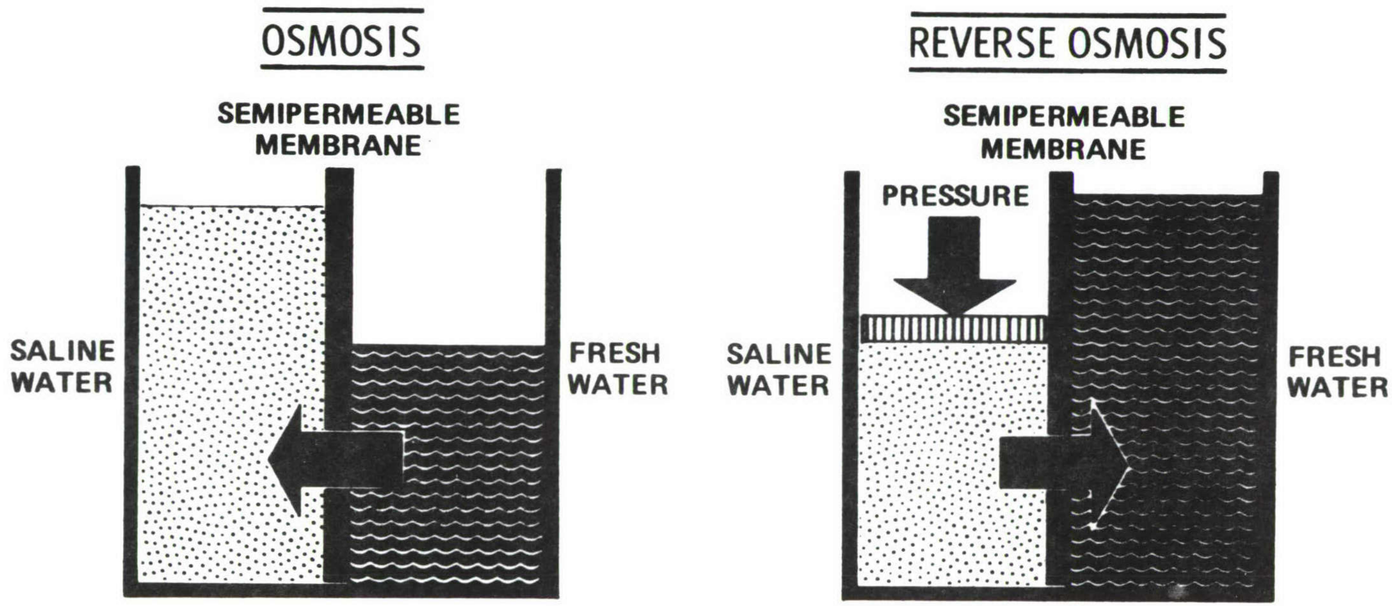
*Lipson, C. and Sheth, N., <u>Statistical Design and Analysis of Engineering Experiments</u>, McGraw Hill, 1973.



DRINKING WATER (U.S. PUBLIC HEALTH SERVICE STANDARD) = ≤ 500 PPM SALT SOLUTION

SOFTENED WATER = < 500 PPM SALT SOLUTION; MANY OF THE CALCIUM AND MAGNESIUM IONS REPLACED BY SODIUM IONS.

BRACKISH WATER = 500 TO 5,000 PPM SALT SOLUTION

SEA WATER = 30,000 TO 35,000 PPM SALT SOLUTION

FIGURE 1-1. COMPARISON OF OSMOSIS AND REVERSE OSMOSIS concentrated solution. The excess in applied pressure difference over the osmotic pressure difference causes water to flow from the more concentrated solution to the less concentrated one. This water flow is the reverse of that encountered in the normal osmotic process giving rise to the term "reverse osmosis". The membranes used in reverse osmosis systems are not completely semipermeable; they do allow the passage of a small amount of the dissolved materials. The amount of dissolved materials which pass through the membrane, i.e., those that are not rejected by the membrane, depends upon the membrane material and the processes used to manufacture the membrane, upon the types and concentrations of dissolved materials, and upon the operating conditions of the reverse osmosis system.

The RO process will remove suspended materials, but it has been found to be economically advantageous to remove most of these materials by normal filtration procedures prior to passing the feed stream into the RO system. The feed solution, after pretreatment filtration, is pressurized by a hand operated pump. At pressure levels of approximately 600 psig, it is passed into the four series connected membrane modules which contain several square feet of the tubular semipermeable membrane. The exact amount of membrane needed for a particular application depends upon the type of feed solution being treated and on the other operating parameters of the RO system. The membrane area is usually optimized for a particular application to give the desired flow rates and separations with a minimum of membrane area.

The semipermeable membrane is the heart of the RO system. Philco-Ford's membrane material is cellulose acetate. Membranes prepared from cellulose acetate are capable of high flux (high rate of permeate throughout) and high dissolved salt rejection. At the high pressures used in an RO system, the membrane gradually "compacts" giving a slightly lower product flux after the first few months of operation. Cellulose acetate can undergo hydrolysis with the loss of acetate groups. This hydrolysis is accelerated at high and at low values of pH. The minimum rate of hydrolysis occurs at a pH of approximately five. Loss of acetate groups of hydrolysis causes a decrease in the salt rejection capabilities of the membrane.

Philco-Ford nominal 1/4-inch membranes are manufactured with various permeabilities. This ability to vary the salt rejection and permeate flow rate of the membrane permits the fabrication of an RO system economically tailored for a given application.

The first equation of reverse osmosis describing the effect of pressure upon product quantity is:

$$J = A(\Delta P - \Delta \pi) \qquad (1)$$

where J is the product flux in cm/-sec, A is the permeate permeation coefficient in cm/atm-sec, ΔP is the applied pressure difference in atmospheres across the membrane, and $\Delta \pi$ is the osmotic pressure difference in atmospheres due to the concentration difference across the membrane. The permeate flux depends directly on the net pressure difference (the applied pressure minus the osmotic pressure) across the membrane. Increasing the net pressure difference will increase the product flow rate. RO systems generally operate in the pressure range of 400 to 700 psig where compaction of the membrane is minimized.

The second equation of reverse osmosis describing the salt or solute flow through the membrane is:

$$J_s = B(C_w - C_p) \tag{2}$$

where J_s is the salt flow in gm/cm^2-sec, B is the salt permeation coefficient in cm/sec, C_w is the concentration of salt in gm/cm^3 in the concentrate stream at the membrane/solution interface, and C_p is the concentration of salt in gm/cm^3 in the permeate stream. This equation shows that the salt flux depends only on the concentration difference across the membrane and is independent of the applied pressure. As the applied pressure is increased, the permeate flux increases but the salt flux remains essentially constant. The higher permeate flux with the same salt flux produces a larger volume of permeate with a better quality (lower salt content). Higher pressure therefore increases both the permeate quantity and the permeate quality. Pressure cannot be increased indefinitely, however. Higher pressure operation requires more energy input and a more substantial and costly high pressure pump and membrane pressure containment module structure. At higher pressures, the rate of membrane compaction increases and the permeate flux decreases more rapidly with time.

Two important operating characteristics of an RO system are the percent rejection of materials in the feed stream and the fractional recovery of feed water. The percent rejection, R, is defined by the equation:

$$R = 100(C_B - C_P)/C_B \tag{3}$$

where C_B is the bulk feed solution concentration and C_p is the permeate concentration. The individual rejections of dissolved material will depend upon such factors as membrane material and fabrication procedures, feed solution composition and concentration, feed solution pH, and RO operating parameters such as feed flow rate, pressure, and fractional recovery. In general, multivalent ions are more strongly rejected than monovalent ions and materials only partially dissociated in water, as, for example, ammonia and boric acid, are poorly rejected. Adjustment of pH to effect a greater dissociation of these materials will usually increase their rejection. Generally, higher rejections are achieved with increasing charge density of the ion.

Low molecular weight, un-ionized, water soluble organic materials are poorly rejected. Organics with a molecular weight of greater than 200 are usually rejected, but this molecular weight should not be regarded as a fixed limit. Gases, when dissolved in the feed water and present in an undissociated form, are poorly rejected.

The second important characteristic of an operating RO system is the fractional recovery. The permeate fractional recovery is the fraction of the feed water that is recovered as permeate as defined by the equation:

$$F = Q_p/Q_{B_o} \tag{4}$$

where F is the fractional recovery, Q_p is the permeate flow rate, and Q_{Bo} is the feed flow rate. Fractional recoveries in the range of 60 to 90 percent are common. For minimum operating costs, the fractional recovery should be as high as practical. The maximum recovery possible in a particular application is determined by either the osmotic pressure of the concentrate stream or the solubility of materials within this stream.

As the fractional recovery increases, the concentration and hence the osmotic pressure of the materials in the concentrate stream increases. The net pressure available to force water through the membrane is equal to the difference between the applied pressure and the osmotic pressure differences. As the osmotic pressure difference increases, the permeate flow rate through a given membrane decreases.

With increasing concentrations of materials in the feed stream, the danger of exceeding the solubility of slightly soluble materials exists. Materials which are precipitated within the RO system can form as a scale or deposit on the membrane surface or in the flow passages. Such deposits can lead to decreased permeate flux and clogged passages. The susceptibility of an RO system to become fouled by this type of mechanism depends to a great extent upon the configuration of the flow conduit. Systems having open tubular flow passages which are operated under turbulent conditions are less susceptible to clogging. To prevent deposition of insoluble materials, the RO system is usually operated at fractional recoveries such that the solubility limits are not exceeded.

SECTION 2

DESIGN REVIEW

This section reviews the design of both the brackish water purifier and the seawater purifier. The design was conceived for these applications after consideration of the following criteria: (1) human factors required for pump operation, (2) specific RO membrane performance, and (3) requirements of the U.S. Army Land Warfare Laboratory. The compactness and weight of the unit were of key importance in the design of all components. All aspects of the system design were aimed toward accommodating economical high production fabrication processes even through the purifiers in the present program were fabricated on a limited number or prototype basis. All materials utilized were resistant to corrosion in a brackish water environment.

Environmental and human engineering factors were initially considered. Various in-field environments were envisioned which would bear on the design features such as the support pads, and impose performance interface requirements. The basic assumptions pertinent to in-field operation are:

(1) The feed water must be prefiltered to yield a turbidity of less than 10 JTU (Jackson Turbidity Units)* and particle size of less than 10 microns.

(2) The feed water should be essentially free of oxidizing agents, low in organics and biological activity and its pH and temperature levels should not be extreme. Refer to Section 5 for more specific feed water requirements for optimum system performance and membrane life.

(3) The surface upon which the unit is operated must have a bearing strength suitable for supporting a man, and it must be fairly level.

*JTU equivalence

(4) It is recommended that the purifier be operated at a site removed from a natural water source in order to reduce exposure to Army Personnel. A bucket or container capable of holding the prefilter should be available to transport the quantity of water to be processed.

Various aspects of this design which involved human engineering considerations are:

(1) Hand pump operation - The pump has to be operated in the manner most consistent with energy input requirements and operator efficiency and comfort. A system configuration which allows some versatility in modes of pump operation is desired. The present design incorporates these features. Two primary modes of pumping are possible: (1) The operator places his feet on the stabilizing foot pads and works the handle while standing in a slightly stooped erect position, (2) The operator kneels on the stabilizing pads while working the pump handle. The pump has also been operated from a prone position. The double ended pump handle provides for efficient power input. The operator is able to use both arms and to use them alternately to develop the necessary power. This minimizes fatigue because each arm is free to rest for half the pumping cycle.

(2) Purifier transportability and set-up - The purifier unit is designed to fold into a compact package which contributes to ease of transport. The stabilizing foot pads and the pump handles both fold along the periphery of the unit. The various folding components are physically attached to the unit at all times; hence they cannot be misplaced. The purifier can be prepared for operation simply by unfolding the foot pads and pump handles and connecting the feed inlet and permeate outlet lines.

2.1 STANDARD PURIFIER ASSEMBLY

2.1.1 OVERALL SYSTEM

The purifier assembly drawing is shown in Figure 2-1. The assembly is illustrated with the folded, or transportable mode, on one side of the centerline and the operational, or water processing mode, on the other side of the centerline.

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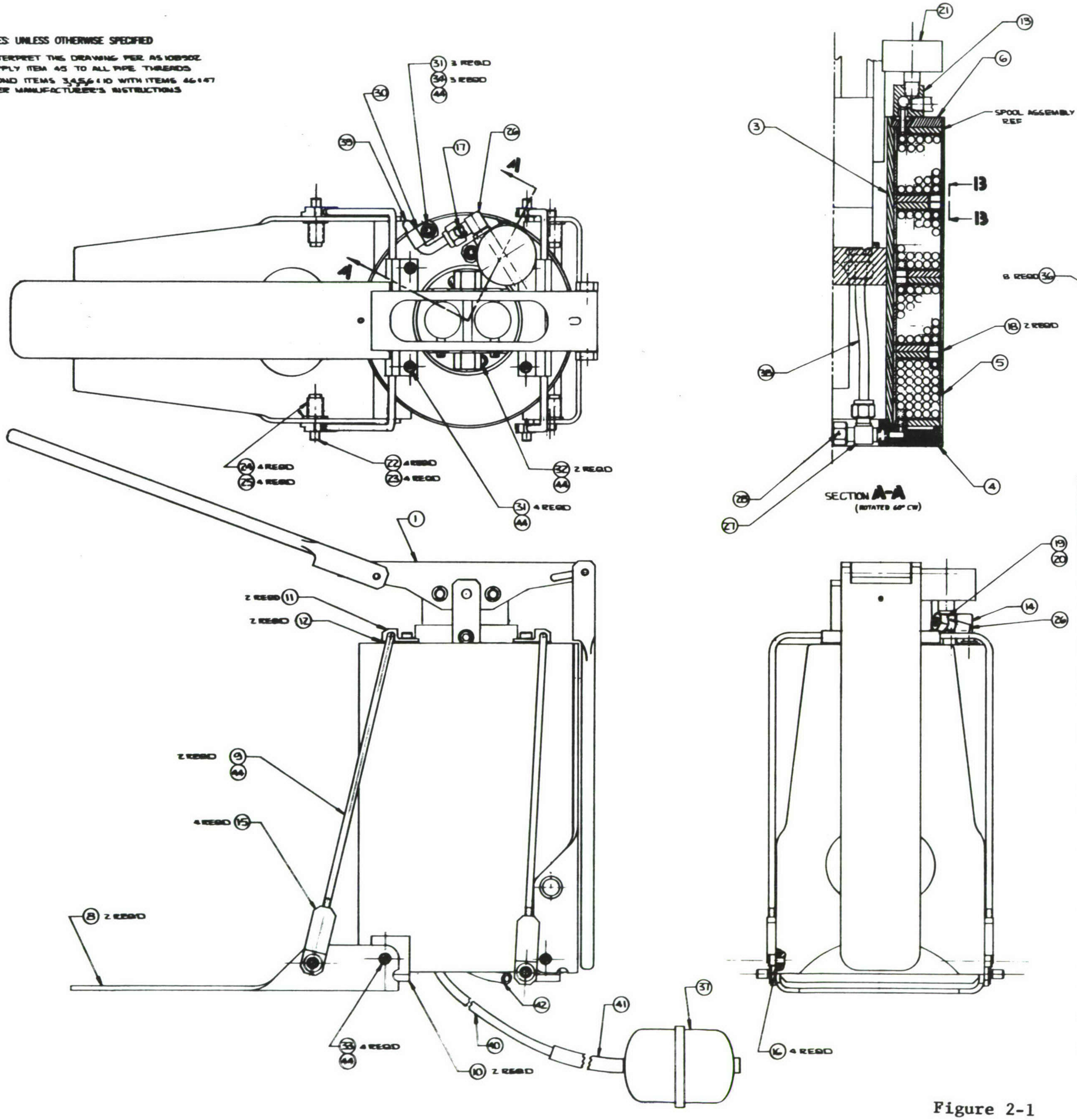

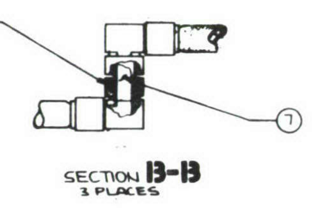

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AR		VERSAMID	HARDENER	SHELL CHEM.	47
AR		EPON 828	RESIN	SHELL CHEM.	46
AR			TAPE-THD. SEAL	TEFLON	45
AR		GRADE A	SEALING COMP.	LOCTITE	44
					43
1			TUBE-PERMEATE	5/16 OD × .062 WALL × 36.0 LG TYGON	42
1			TUBE-FILTER	3/8 OD × .062 WALL × 6.0 LG TYGON	41
1			TUBE-FEED	1/4 OD × .062 WALL × 72.0 LG TYGON	40
1			TUBE-CONC.	1/4 OD × .062 WALL × 6.0 LG TYGON	39
1			TUBE-HIGH PRESS.	1/4 OD × .062 WALL × 4.5 LG NYLON	38
1		MBY 2001-CC	FILTER ASSY	PALL TRINITY MICRO CORP	37
8		2-008	SEAL-O-RING	PARKER COMPOUND 674-70	36
					35
3		AN960C3	WASHER		34
4			SCREW-SOC. HD. CAP	#10-32 UNF × .38 LG. CRES	33
2			SCREW-SOC. HD. CAP	#10-24 UNC × 1.50 LG. CRES	32
7			SCREW-SOC. HD. CAP	#10-24 UNC × .38 LG. CRES	31
1		MS25281-4	CLAMP	NYLON	30
					29
1		ZY-400-P	PLUG	1/4 T NYLON SWAGELOK	28
1		ZY-400-3TMT	MALE RUN TEE	1/4 T × 1/4 T × 1/8 MPT NYLON SWAGELOK	27
2		ZY-400-2-2	ELBOW	1/4 T × 1/8 MPT NYLON SWAGELOK	26
4		15R10-1AD	RETAINING NUT	CAMLOC	25
4		15R1-1AE	RECEPTACLE	CAMLOC	24
4		15S11-2AE	RETAINING WASHER	CAMLOC	23
4		15S1-3-1AF	STUD ASSY	CAMLOC	22
1		PS63-1/8 CBM	GAUGE PRESSURE	U.S. GAUGE 0-1000 PSIG	21
1		0600 490024	PLUG ASSY-MOD.		20
1		0600 490023	RELIEF DIAPHRAGM		19
2		0600 490022	CLIP-SPOOL/END FITTING		18
1		0600 490021-3	ORIFICE		17
4		0600 490020	SPACER-PAD ATTACK		16
4		0600 490019	BLOCK-QUICK DISC. ASSY		15
1		0600 490018	CLAMP-HSG. ASSY		14
1		0600 490017-1	HOUSING ASSY		13
2		0600 490016-2	SUPPORT-ARM		12
2		0600 490016-1	SUPPORT ARM		11
2		0600 490015	BLOCK-REST PAD		10
2		0600 490014	ARM, STABILIZING PAD		9
2		0600 490013	PAD, REST		8
3		0600 490012	TUBE END FITTING		7
1		0600 490011	END CAP		6
1		0600 490010	SHELL, OUTER		5
1		0600 490009	BASE PLATE ASSY		4
1		0600 490008	TUBE ASSY		3
					2
1		0600 490001	PUMP ASSY		1

PARTS LIST

SEE ENGINEERING RECORDS FOR COMPLETE APPLICATION DATA

CONTRACT NO.

DR BY 10-16-72

CHK BY 10-23-72

10-23-72

DESIGN ACTIVITY APPROVAL

U.S. ARMY LAND WARFARE LABORATORY
ABERDEEN PROVING GROUND, MARYLAND 21005

LIGHTWEIGHT HAND OPERATED BRACKISH WATER PURIFIER - LWL

SIZE E | CODE IDENT NO. 09205 | 0600 490000 B

SCALE FULL | SHEET 1 OF 1

Figure 2-1

The purifier assembly consists of three basic units, (1) the pumping unit in the center which includes the pump, the handles and the accumulator, a set of four reverse osmosis membrane modules (in an annulus around the pump), and an external containment and support structure which includes the inner and outer shells, the endplates, the rest pads and the support arm assemblies with their quick disconnect fasteners.

The pumping unit draws the water in through the filter and pressurizes it, drives it into the membrane modules where some of the water permeates through and some continues on to be discharged through the orifice and out the concentrate effluent tube. The water which has permeated through the membrane wall is collected within the annulus between the inner and outer shells. It is then allowed to flow out the permeate line. The rest pads and support arm assemblies provide a means for stabilizing the assembly for efficient two stroke pumping.

2.1.2 SIZE AND WEIGHT SUMMARY

The purifier assembly, in the transportable configuration, has overall dimensions of 11.75 inches high and 6.25 inches x 7.25 inches in cross section. This yields a total envelope volume of 0.30 cubic feet.

The dry weight of the system (membrane drained of water) is 10.3 pounds. The wet weight of the system (water in membrane but not reservoir) is 12.6 pounds. These weights include all components and tubing, exclusive of the filter.*

The size and weights quoted above apply to both the brackish water and seawater units.

2.1.3 PUMP ASSEMBLY

The pump assembly drawing is shown in Figure 2-2. The pump has a dual alternating piston type of action. As shown, Parker molythane Poly-Pak seals provide the high pressure sealing and also act as cylinder wipers. They were chosen because of their wear resistance. Four check valves, two each at the cylinder inputs and outputs, are included within the pump body to provide necessary flow control. The pump and accumulator are directly connected in order to simplify interconnect fitting requirements. Both inlet and outlet connections to the pump are located in the base of the body for convenient access to the feed supply and the membrane module input. The pump actuating force is transmitted from pins in the handle rocker assembly to elongated holes within each of the two pistons. As shown in Figure 2-2, the pump handles are hinged so that they can be folded into a position which provides for compactness of the purification unit during transport.

2.1.4 RO MEMBRANE MODULE

A typical RO membrane module is viewed photographically in Figure 2-3. It consists of a lightweight plastic spool around which is placed approximately 41 feet of nominal 1/4 inch RO membrane and integral pressure support

*Units with Serial Nos. 006-015.

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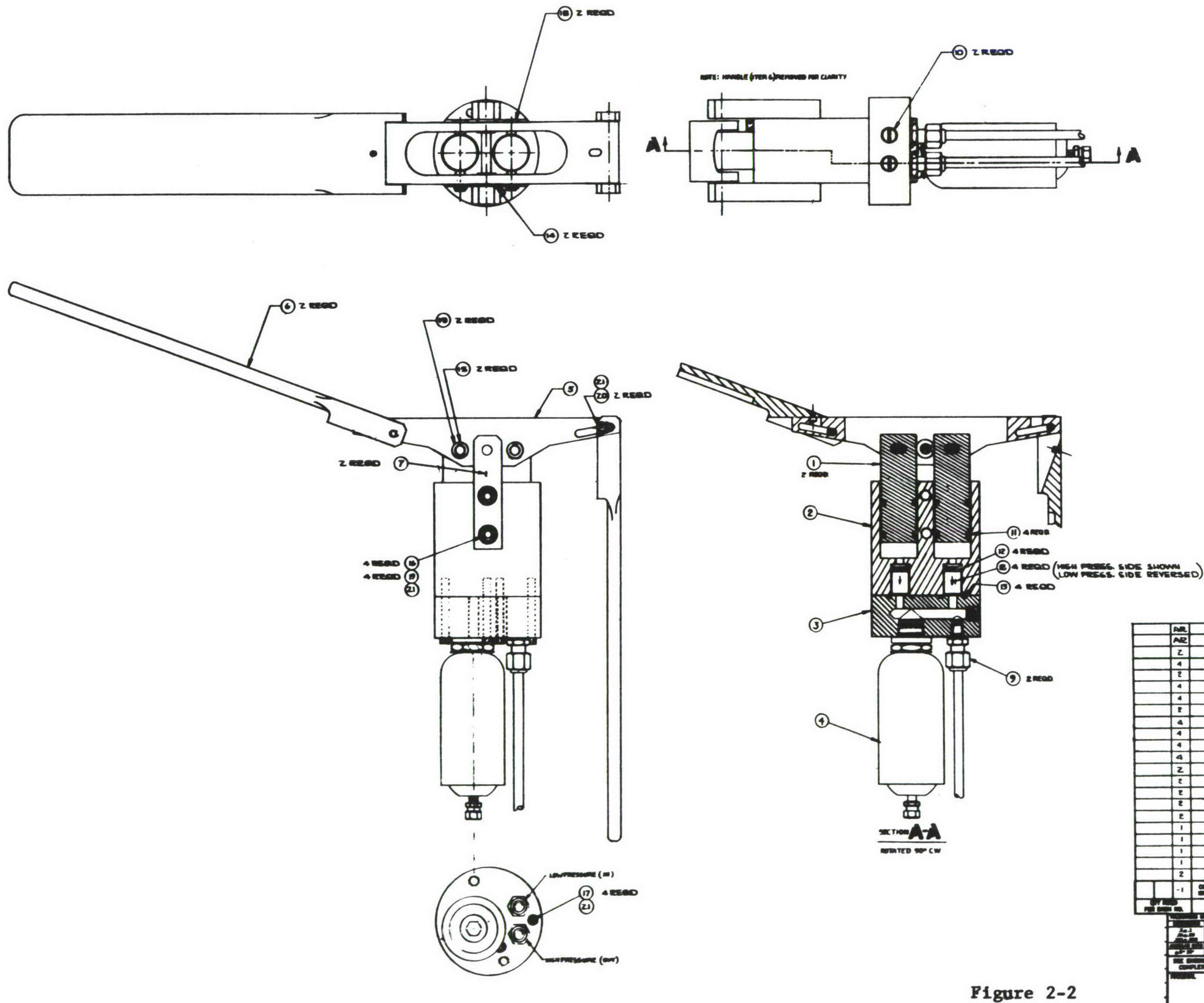

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	AR			TAPE-THD SEAL	TEFLON				22
	AR		GRADE A	SEALING COMPOUND	LOCTITE				21
	2			SETSCREW-HEX SOC	4-40 UNC x .19 LG CRES CUP POINT				20
	4		NAS 620 C4KL	WASHER					19
	2		MS9464-27	PIN, HEADED	.2AB DIA. x 1.690 GRIP CRES				18
	4			SCREW, CAP	10-24 UNC THD x 1.50 LG CRES				17
	4			SCREW, CAP	1/4-20 UNC THD x .75 LG CRES				16
	2			PIN, COTTER	.062 DIA x .50 LG CRES				15
	4		AN960C416	WASHER					14
	4		2-112	SEAL-O-RING	PARKER				13
	4		2-012	SEAL-O-RING	PARKER				12
	4		12500750	SEAL, POLYPAK	PARKER				11
	2			PLUG, PIPE	1/8-27 NPT 316 CRES				10
	2		Z4400-1-2	CONNECTOR, MALE	SWAGE-LOK				9
	2		C29498-4Q	CHECK VALVE	CIRCLE SEAL				8
	2		0600 490005	SUPPORT, PUMP HANDLE					7
	2		0600 490007	HANDLE ASSY.					6
	1		0600 490006	ROCKER ASSY.					5
	1		A70544-200	ACCUMULATOR	GREER-OLAER PRODUCTS-316 CRES				4
	1		0600 490003	HEAD					3
	1		0600 490002	HOUSING					2
	2		0600 490004	PISTON					1

PARTS LIST

SEE ENGINEERING RECORDS FOR COMPLETE APPLICATION DATA

CONTRACT NO.

U.S. ARMY LAND WARFARE LABORATORY
ABERDEEN PROVING GROUND, MARYLAND 21005

PUMP ASSY, LWL

SIZE E | CODE IDENT NO. 09205 | 0600 490001 A

SCALE: FULL | WT | SHEET 1 OF

Figure 2-2

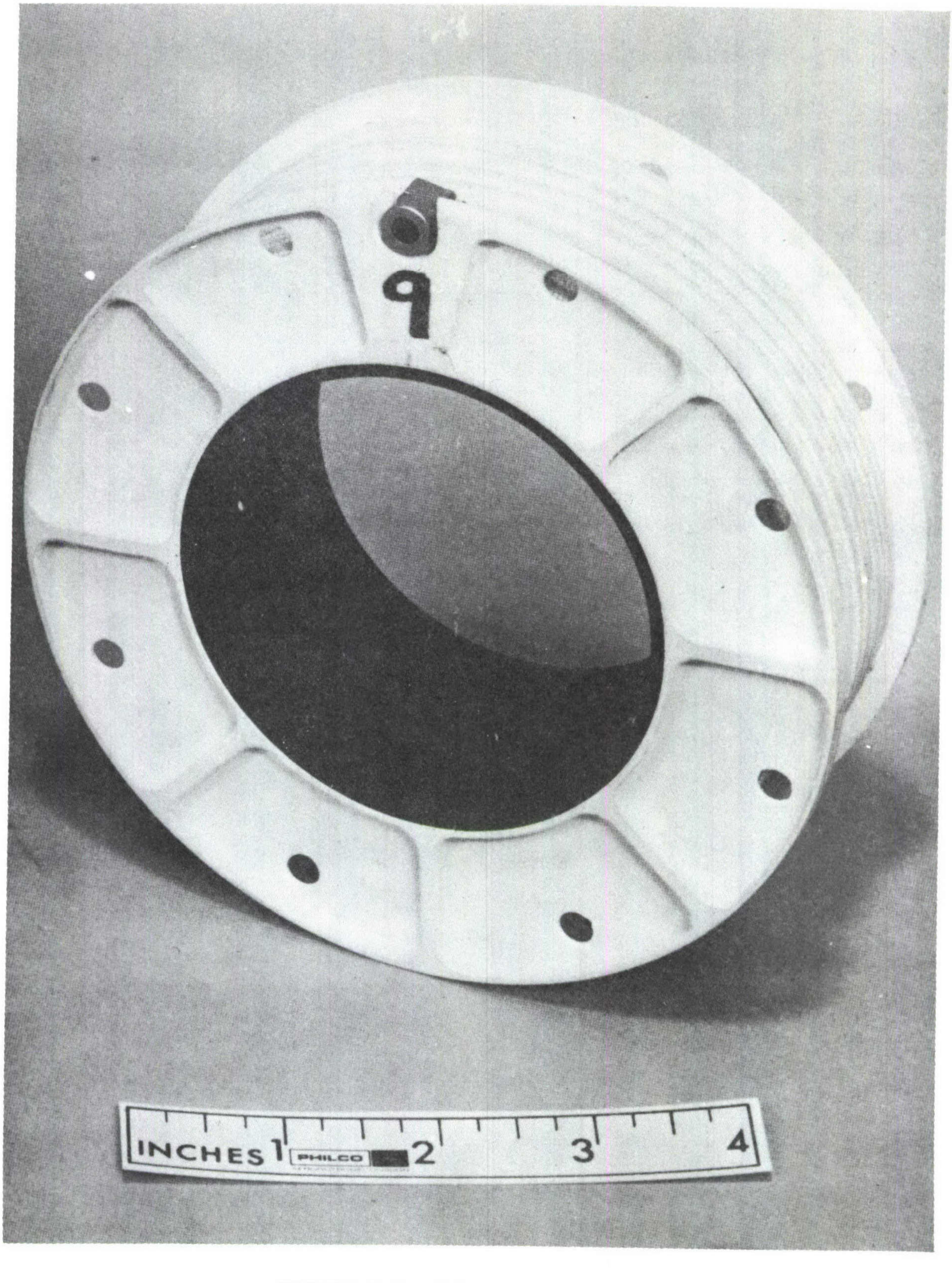

FIGURE 2-3. RO MEMBRANE MODULE

structure. Inlet and outlet fittings are on opposite sites to facilitate series connection. The modules are designed for ease and economy of assembly into series arrays. They are connected together with short lengths of stainless steel tubing.

2.1.5 INSTRUMENTATION AND FAIL-SAFE FEATURES

System instrumentation requirements are minimal for operation of the system. To provide an indication of the safe and efficient operating range, a pressure gauge, as shown in Figure 2-4, is mounted on top of the purifier assembly at the concentrate fitting. The normal operating range at 600 ± 20 psig is indicated by a green band. A red band indicates the abnormal pressure range from 620 to 1000 psig.

The relief diaphragm is a fail-safe device installed to protect against misuse of the purifier. It is a polycarbonate plastic disc, mounted in the capped elbow fitting on top of the purifier assembly (see Figure 2-4). It is designed to collapse (by virtue of its 0.002 inch thickness) at a pressure of about 1000 psig. This protects the membrane from excessive, continuing overpressure. The disc must be replaced after collapse.

2.1.6 MATERIALS OF CONSTRUCTION

The materials from which the purifier assemblies are fabricated provided corrosion resistance, lightweight, economy in manufacture, strength and durability. The pump head, housing and pistons are fabricated from acetal plastic. This material has high mechanical strength and fatigue endurance, natural lubricity, and excellent resistance to moisture. The handles, rocker assembly and the stabilizing arm supports are fabricated from a 2024 aluminum alloy for high strength and light weight. The rest pads are fabricated from a 6061 aluminum alloy. All of the aluminum parts are coated with a hard anodic coating to provide good wear and corrosion resistance. All other metal parts, including the accumulator, end fittings, interconnect tubes, stabilizing arms and concentrate fitting, are fabricated from Type 316 stainless steel and passivated to provide for good corrosion resistance in the anticipated operating environment. The inner tube assembly, the outer shell, and both the base and top plates were fabricated from PVC plastic because of its good impact resistance, ease of fabrication, light weight and corrosion resistance. The membrane module spool was fabricated from an ABS plastic which is more suited to the membrane helical forming process, which involves application of elevated temperatures. (The ABS has somewhat better elevated temperature properties than the PVC).*

2.2 SEAWATER PURIFIER ASSEMBLY

2.2.1 OVERALL SYSTEM

The seawater purifier assembly external configuration and component grouping is the same as the standard purifier assembly as described in Section 2.1 and shown in Figures 2-1, 2-2, 2-3 and 2-4. It consists of the same three basic

*Polyvinyl Chloride (PVC); Acrylonitrile Butadiene Styrene (ABS).

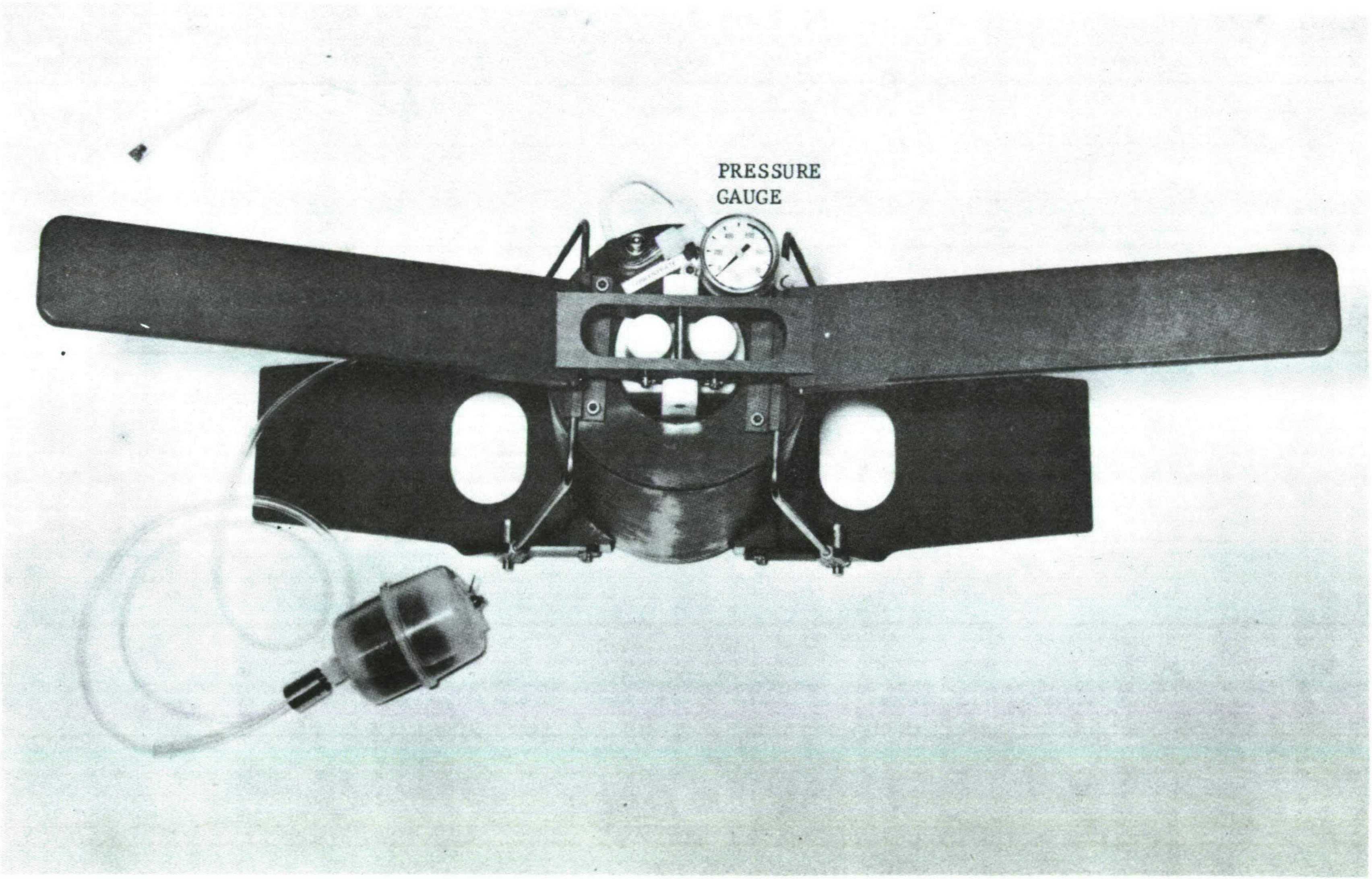

FIGURE 2-4. PURIFIER ASSEMBLY, TOP VIEW

units: the pumping unit, the set of four reverse osmosis membrane modules and the external containment and support structures. It also has an envelope volume of 0.30 cubic feet, a dry weight of 10.3 pounds and a wet weight of 12.6 pounds (exclusive of the filter assembly; units 006-015).

2.2.2 UNIQUE FEATURES

The two items which differentiate the seawater purifier from the standard purifier are the orifice diameter and the permselectivity of the membrane. Because of the low fractional recoveries in the first and second passes of the seawater purifier as compared to the standard purifier (0.20 and 0.40 versus approximately 0.60) there is a greater concentrate effluent flow rate. A larger diameter orifice was therefore required. A 0.014 inch diameter orifice was used in the seawater purifier versus a 0.012 inch diameter for the standard purifier.

The permselectivity of the membrane was determined by the required salt rejection performance. For the seawater purifier an overall (2 pass) salt rejection of approximately 99 percent is required, whereas for the brackish water purifier a salt rejection of only 90 percent is satisfactory for the production of potable water. The higher salt rejection is achieved at the expense of permeate flow rate, a condition inherent in RO membrane performance. Thus, the membrane is "tighter". The "tightness" is achieved by application of a programmed thermal annealing cycle to the membrane during the fabrication process. The tightness of the membrane was adjusted so as to achieve the performance characteristics required in the sea water purifier.

2.3 PERFORMANCE PREDICTION

The performance of the RO modules within the brackish water purifiers and the seawater purifier was originally predicted with a digital computer program. The program operates with permeation test data from zero fractional recovery membrane test cells, and extrapolates performance to finite fractional recovery levels and long tube lengths. Performance predictions will account for the effects of temperature and long term run time upon membrane permeabilities. The latter phenomenon is designated "compaction" i.e., the membrane permeation, particularly for water, decreases somewhat with long term operation (typically about 20 percent to 30 percent during a full year of 600 psig continuous operating pressure with standard cellulose acetate membranes). Table 1 is a summary of the brackish water unit performance predictions at initial operation (at two hours) and after 576 hours. This corresponds to cumulative production levels of 7 gallons and 3600 gallons. Cumulative production is a lifetime reliability requirement defined as the mean gallonage before failure with a statistical confidence level of 90 percent. All performance predictions are for a brackish feed solution containing 5000 ppm NaCl, at a standard temperature of 77°F (25°C). The performance after 576 hours meets or exceeds the minimum output quantity and purity requirements of 350 ml/min and 82.5 percent salt rejection, respectively. Brackish water purifier units 001 through 005 (comprising Phase I, II, and III of the program) were designed to these performance specifications.

TABLE 1. PERFORMANCE ESTIMATES - BRACKISH WATER PURIFIERS #001 THROUGH #006

A. Initial Standard Performance (Case LWL 6A)

Total Run Time	2 hr
Tube Length	160 ft
Tube Inside Diameter	0.166 inch
Membrane Internal Area	7.0 ft^2
Feed Velocity (Inlet)	2.25 ft/sec
Feed Flow Rate	218 gpd (0.152 gpm)
Operating Pressure	600 psig
Permeate (product) Flow	161 gpd (423 ml/min)
Permeate Concentration	862 ppm
Salt Rejection	83 percent
Average Flux	23.2 gpd/ft^2
Fractional Recovery	0.74
Pressure Drop	7.0 psi

B. Final Standard Performance (Case LWL 6B)

Total Run Time	576 hr
Tube Length	160 ft
Tube Inside Diameter	0.166 inches
Membrane Internal Area	7.0 ft^2
Feed Velocity (Inlet)	2.25 ft/sec
Feed Flow Rate	218 gpd (0.152 gpm)
Operating Pressure	600 psig
Permeate (product) Flow	136 gpd (357 ml/min)
Permeate Concentration	829 ppm
Salt Rejection	83 percent
Average Flux	19.5 gpd/ft^2
Fractional Recovery	0.62
Pressure Drop	9.0 psi

Table 2 lists final (576 hour) performance predictions for brackish water units 006 through 015, fabricated and tested in Phase IV of the program. Prior to Phase IV it was mutually agreed by the USALWL technical monitor and Philco-Ford personnel that these units should incorporate less permeable membranes in order to increase the salt rejection and permeate quality. The permeate output quantity and salt rejection performance goals were accordingly revised to 250 ml/min and 90 percent, respectively, for 77°F feed temperature and 5000 ppm NaCl feed solute.

Some additional margin over these performance predictions is provided by the installation of approximately six additional feet of membrane in each unit, for a total length of 166 feet.

Table 3 summarizes final (576 hour) conditions and corresponding performance predictions for the seawater purifier. Two pass operation is required for this system. The fractional recovery of the first pass is restricted to less than 0.20 in order to minimize susceptibility to saturation induced fouling. The second pass operating pressure was revised downward from 600 psig to 400 psig in actual operation in order to conserve input energy. The second pass permeate water quality in this case remained potable, as reported in Section 4.

TABLE 2. PERFORMANCE ESTIMATES - BRACKISH WATER PURIFIERS #007 THROUGH #015

A. Final Performance (Case LWL 9)

Total Run Time	576 hr
Tube Length	160 feet
Tube Inside Diameter	0.166 inch
Membrane Internal Area	7.0 ft^2
Feed Temperature	77°F (25°C)
Feed Velocity (Inlet)	2.25 ft/sec
Feed Composition	5000 ppm NaCl
Feed Flow Rate	218 gpd (0.152 gpm)
Operating Pressure	600 psig
Permeate (product) Flow	110 gpd (289 ml/min)
Permeate Concentration	474 ppm
Salt Rejection	91 percent
Average Flux	15.8 gpd/ft^2
Fractional Recovery	0.50
Pressure Drop	10 psi

TABLE 3. PERFORMANCE ESTIMATES - 2 PASS SEAWATER PURIFIER

A. First Pass Performance (Case LWL 10A)

Total Run Time	576 hr
Tube Length	160 feet
Tube Inside Diameter	0.166 inch
Membrane Internal Area	7.0 ft^2
Feed Temperature	77°F (25°C)
Feed Velocity (Inlet)	2.25 ft/sec
Feed Composition	35,000 ppm NaCl
Feed Flow Rate	218 gpd (0.152 gpm)
Operating Pressure	600 psig
Permeate (product) Flow	42 gpd
Permeate Concentration	5730 ppm
Salt Rejection	84 percent
Average Flux	6.1 gpd/ft^2
Fractional Recovery	0.19
Pressure Drop	15 psi

B. Second Pass Performance (Case LWL 10B)

Total Run Time	576 hr
Tube Length	160 feet
Tube Inside Diameter	0.166 inches
Membrane Internal Area	7.0 ft^2
Feed Temperature	77°F (25°C)
Feed Velocity (Inlet)	2.25 ft/sec
Feed Composition	5730 ppm NaCl
Feed Flow Rate	218 gpd(0.152 gpm)
Operating Pressure	600 psig
Permeate (product) Flow	108 gpd
Permeate Concentration	547 ppm
Salt Rejection	90 percent
Average Flux	15.5 gpd/ft^2
Fractional Recovery	0.49
Pressure Drop	10 psi

SECTION 3

FABRICATION PROCESS

The various unique processes for the fabrication and assembly of the purifier assemblies are discussed in this section.

3.1 RO MEMBRANE MODULE

The spool on which the membrane is wrapped is made by bonding together three individual pieces, each of which had been machined to the proper size and shape. In high rate production, it would be possible to injection mold the spool as two pieces and bond them together. The RO membrane tubing is cast from a modified cellulose acetate material and supported externally by a polyester flexible braided structure. Fittings are swaged onto each end of a membrane length to seal the membrane to the braid and to provide a means for joining a number of sections. The end fittings are fabricated from corrosion resistant non-toxic materials (316 stainless steel and plastic). They have shown excellent reliability and have operated at pressures in excess of 1500 psig without failure. The membrane-braid assembly is then processed and formed to a predetermined permselectivity, determined by the analytical procedures (of Section 2.3).

3.2 PUMP ASSEMBLY

The three plastic components of the pump assembly, the head, the housing and the pistons have been designed so that they could be molded for large quantity production. The two cavities in the housing into which the pistons fit and operate are finished to a smoothness of 8 microinches. This level of finish improves the life of the seals and reduces the amount of energy required to operate the purifier at 600 psig.

The handles and rocker assembly are machined from stock but in only slightly larger production quantities could be cast using permanent molds.

3.3 SUPPORT AND CONTAINMENT STRUCTURE

The support and containment components consist primarily of the inner tube assembly, the outer shell, the base and top plates, the rest pads and the stabilizing arm assemblies. These parts are all fabricated as individual pieces. However, for large quantity production, it would be possible to mold the inner tube assembly, the base plate and the rest pad attach block as one piece and the outer shell, the top plate and the orifice/relief valve housing as one piece. This would reduce cost and weight and simplify assembly.

3.4 RELIEF DIAPHRAGM

The relief diaphragm has been designed and fabricated to substitute for a more costly pressure relief valve. Since a pressure relief valve would be exposed to stagnant concentrate, its internal components would be susceptible to corrosion and unpredictable operation. The relief diaphragm is made from 0.040 thick polycarbonate with a section thinned down to 0.002. It is mounted within a nylon fitting and held in place with a nylon plug. Thus, all parts are plastic and not susceptible to corrosion. The fitting plug has a hole drilled in it to provide for pressure relief when the diaphragm breaks. The diaphragms are replaceable.

3.5 OVERALL ASSEMBLY

The purifier assembly is designed so that it can be assembled in modules. The pump assembly has all the components related to it. Only two bolts and a tube connection are required to install the pump assembly. The inner tube assembly and pump support and the base plate are bonded together. The RO membrane modules are slipped over the inner tube assembly and against the base plate with a small 316 stainless steel tube connecting the end fittings. The outer shell and top plate are then slipped over the RO modules and bonded into place. After the outer shell has been bonded, then the rest pad blocks can be bonded to the outer shell and base plate. The rest pads, stabilizing arms and stabilizing arm supports are attached with screws. Then, the pump is installed along with the pressure gauge, orifice fitting and relief diaphragm fitting. All the tube fittings on the purifier assembly are nylon because nylon is low cost, nontoxic, light weight, and corrosion resistant.

SECTION 4

TEST REVIEW

4.1 PHASE I MODEL TEST

4.1.1 OBJECTIVES

The model brackish water purifier (No. 001) fabricated in Phase I was qualification tested for conformance to desired permeate output quantity and purity, energy input and short term reliability. It was also inspected for size and weight, and operated by a Government representative. The goal of the above tests was to demonstrate the feasibility of the model purification unit with respect to pre-established design and performance goals.

4.1.2 EQUIPMENT AND PROCEDURES

The tests were performed with manual pumping, as would be expected in the field. A two gallon container of a brackish feed solution containing 5000 ppm NaCl was pumped through the purifier in a continuous run of approximately 20 minutes duration. Concentrate and permeate flow rates were monitored by timing their respective collection in graduated containers. The conductivity of the permeate and feed solutions was measured with a conductivity cell and bridge, and converted into equivalent dissolved solids concentrations. The pumping energy was computed from actuating force measurements made at the ends of the pump handles with a spring scale.

4.1.3 TEST RESULTS

The results of the model tests are presented in Table 4. Also shown for comparison are the respective design and performance specifications and goals.

TABLE 4. MODEL TESTS RESULTS

Quantity	Observations and Test Results	Specification	Goal
Size, ft^3	0.25	≤ 0.25	≤ 0.225
Weight, lb	10	≤ 11	≤ 9.5
Output Quantity, ml/min	487	≥ 350	≥ 500
GPD		≥ 133	≥ 190
Salt Rejection, %	83	≥ 82.5	≥ 92.5
Energy Input, HP	0.09	≤ 0.12	≤ 0.084

Based upon this data, approval was given to proceed with Phase II fabrication of four prototype brackish water purifiers which were to be life tested in Phase III of the program.

4.2 PHASE III LIFE TESTS

4.2.1 OBJECTIVES

The four purification units, serial numbers 002, 003, 004 and 005, fabricated and assembled in Phase II of the program, were subjected to a set of life tests over a three and one-half month period. The primary goal of the tests was to qualify the purification units for acceptance with respect to size, weight, performance (desalination quality, quantity of product output, and energy input requirements), and lifetime expressed in total gallonage of production. The specified design criteria and performance requirements led to a test evaluation program consisting of three major efforts: inspection, operation and life determination. The size, configuration and weight of the units were measured by inspection. Their operational performance was measured in terms of product water output flow rate, product water purity or desalination behavior, and energy input requirements. The life tests consisted of a continuation of the operational performance tests over the remainder of the Phase III test period.

4.2.2 TEST EQUIPMENT

The test equipment consisted of (1) an accessory power drive train suitable for long-term actuation of the pumps, (2) a re-circulating flow system consisting of containers for feed water and return lines for purifier product and concentrate streams, and (3) instrumentation and controls including those fail-safe devices required for periods of unattended operation of the system.

A pneumatic drive system was selected and designed for purifier pump actuation. The system is shown schematically in Figure 4-1. Filtered plant air at a mean pressure of 90 psig is the power source. The air is diverted alternately in a four-way valve to two pneumatic cylinders which alternately drive the pump

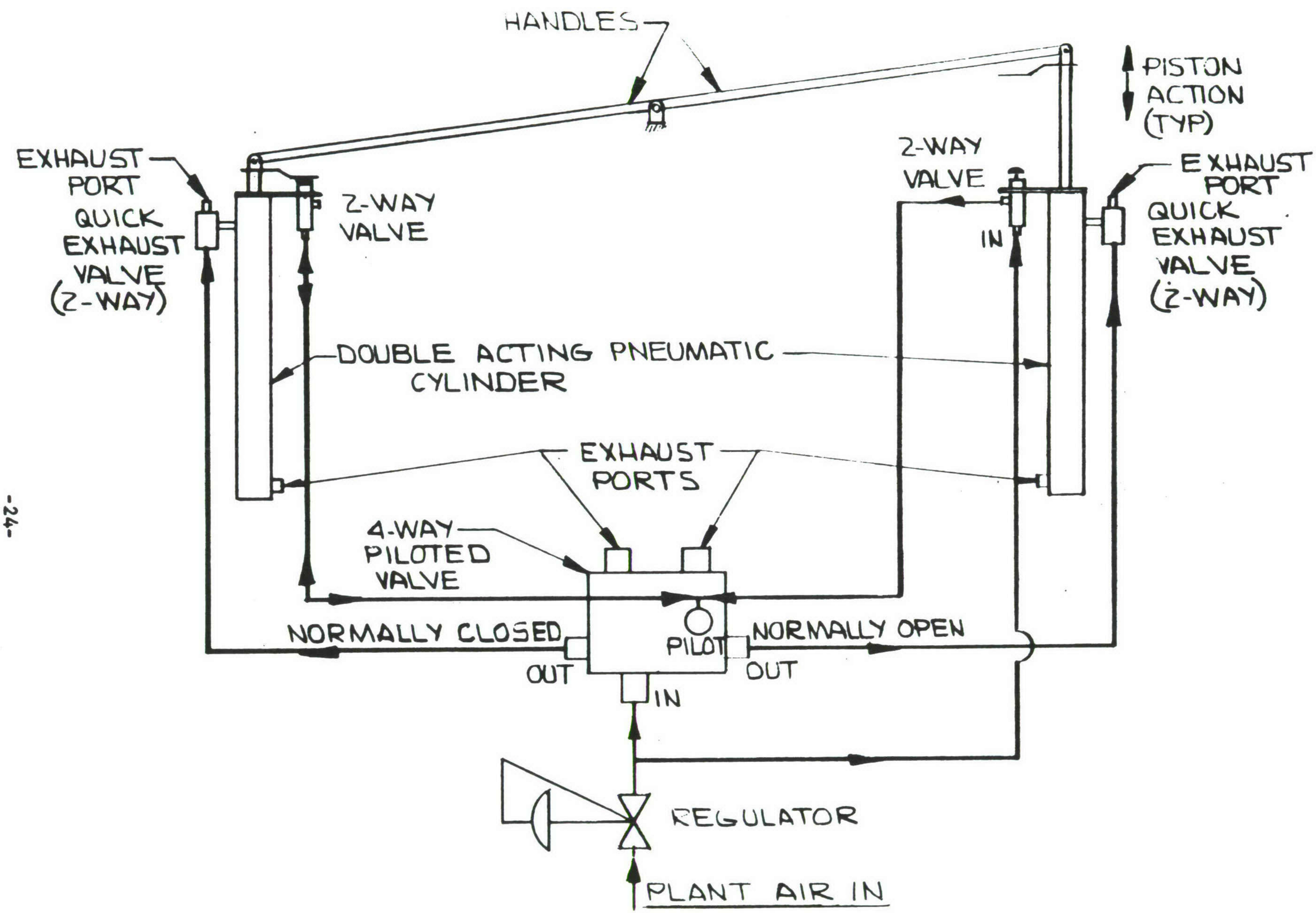

FIGURE 4-1. PNEUMATIC TESTER

from attachment points near the end of each handle. At the end of a downstroke the pump handle mechanically actuates a three-way control valve which transmits a pneumatic signal to the pilot operators on the four-way valve, thereby causing pressurization of the opposite cylinder. The pump handle is driven through a full 60 degree arc at a rate controlled by the supply air pressure. Both the angular displacement and the pumping rates required with hand operation can be duplicated with this drive system.

Figure 4-2 illustrates the four purification units under test with the pneumatically driven pumps and the re-circulating flow system. The common feed tank with return and feed lines is shown in the lower center. The four feed streams initially flow through a 10 micron cartridge filter which is submerged inside the feed tank. The second tank of water at the right-hand edge of the photograph serves only as a muffling system for the exhaust from the pneumatic drive cylinders.

The test system instrumentation included:

(1) Feed water thermometer.

(2) High pressure gauges (0-1000 psig) on each purifier unit.

(3) Conductivity cells and impedance bridges for recording feed water and permeate (product) conductivities and means for conversion into equivalent dissolved solids concentrations.

(4) Spring scale device to measure pump handle driving forces.

(5) Means for measurement of permeate, feed and concentrate stream flow rates (graduated vessels and stopwatches).

System controls and fail-safe features included:

(1) Pressure regulators for the air supply to each unit under test in order to control pumping rate and purifier operating pressure levels.

(2) Feed tank liquid low level switch which provides a signal to shut down the system in the event of leakage.

4.2.3 PHASE III TEST RESULTS

The following completed three-page test data log sheets for each of the purification units summarize results of the inspection, short-term operational performance test, and lifetime test portions of the test program. Double-underlined quantities are those specifically called for in the objectives section of the contract. Appropriate formulas are shown for quantities which must be computed.

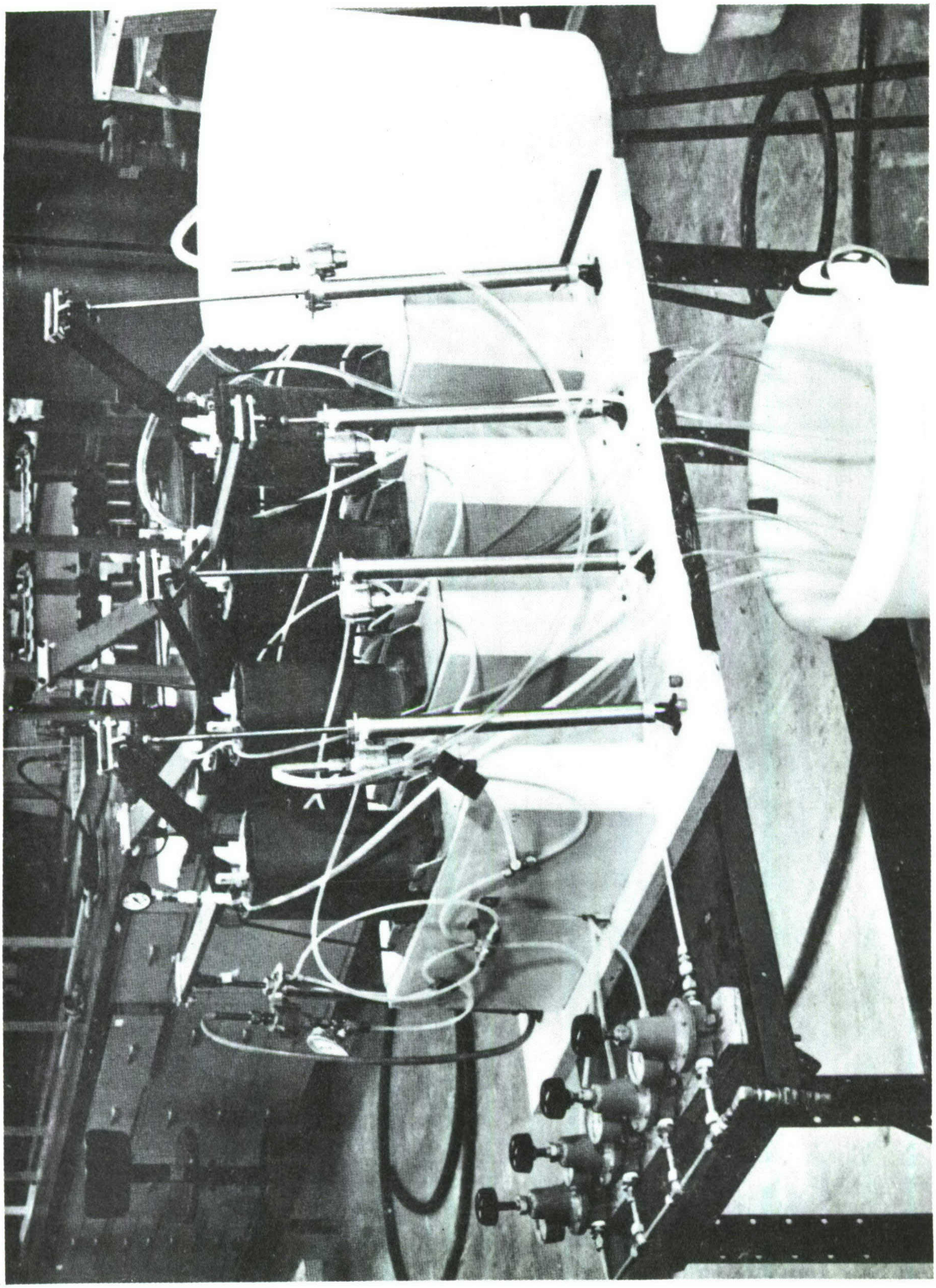

FIGURE 4-2. PURIFIERS UNDER TEST

TEST DATA LOG

LIGHTWEIGHT, HAND OPERATED BRACKISH WATER PURIFIER

General

Serial Number	002	
Model Number	85121	
Run Time	8	hr
Estimated Cumulative Production	46	gallons

I. INSPECTION

Overall Height	11.5	in.
Maximum Width	6.0	in.
Maximum Depth	7.0	in.
Cross-Sectional Area	36	$in.^2$
Overall Volume	414	$in.^3$
System Wet Weight	11	lb
System Dry Weight	10	lb

Materials:

Pump	Acetal Plastic
Pump Handle	2024 Aluminum
Accumulator	316 Stainless Steel; Rubber Bladder
Containment Shell	PVC Plastic
Fittings	Nylon
Lines	Nylon

II. OPERATION

1. Feed Water Type	5000 ppm NaCl	
2. Type of Pre-filtration	10 micron cartridge	
3. Pressure	600	psig
4. Feed Temperature	73	°F
5. Output Quantity:		
Permeate Volume Collected	370	ml
Collection Time	1.0	min

Permeate Flow Rate* (Q_p)	370	ml/min
Concentrate Volume Collected	190	ml
Collection Time.	1.0	min
Concentrate Flow Rate (Q_{BL}).	190	ml/min
Fractional Recovery ($Q_p/[Q_p + Q_{BL}]$). . . .	0.66	
6. Output Purity:		
Permeate Conductivity.	112	μmho
Permeate Concentration	650	ppm
7. System Purification Performance:		
Feed Conductivity.	780	μmho
Feed Concentration (C_{B_o})	5,320	ppm
Salt Rejection Rate ($1 - C_p/C_{B_o}$)	88	%
8. System Input Energy:		
Average Handle Force per Stroke (P). . . .	34	lb
Handle Lever Arm (L)	12	in.
Average Handle Torque per Stroke (PL). . .	408	in.-lb
Handle Angular Displacement per Stroke (θ)	1.05	radians/stroke
Pump Rate (N).	88	strokes/min
Energy Input Rate ($2.53PL\theta N\times10^{-6}$).	0.095	HP

*This quantity must be temperature corrected according to the following equation: $Q_{p(77°F)} = Q_p/[1 + 0.0162(T-77)]$, where $Q_{p(77°F)}$ is the temperature corrected permeate flow rate (ml/min), Q_p is the measured permeate flow rate and T is the feed temperature (°F).

TEST DATA LOG (Continued)

III. LIFETIME

UNIT NO. 2

Run Time (Hr)	Cumulative Production (Gallons)	Permeate Flow Rate (ml/min)	Feed Concen (ppm)	Permeate Concen (ppm)	Salt Rejection (%)	Energy Input (HP)-(strokes/min)
2	11.42	360	5320	700	87	0.081-76
8	45.7	360	5320	660	88	0.081-76
24	159	400	5525	1000	82	0.085-80
48	325	400	5525	1000	82	0.085-80
86	574	380	5020	700	86	0.085-80
163	1013	360	5020	700	86	0.102-96
188	1156	360	5020	700	86	0.102-96
229	1390	360	5020	700	86	0.085-80
290	1777	400	5025	860	82	0.104-98
338	2082	400	5025	850	83	0.104-98
392	2425	400	5025	850	83	0.106-100
458	2821	380	5315	800	85	0.110-104
482	2965	380	5320	800	85	0.102-96
548	3361	380	5320	800	85	0.102-96

TEST DATA LOG

LIGHTWEIGHT, HAND OPERATED BRACKISH WATER PURIFIER

GENERAL

Serial Number	003	
Model Number	85121	
Run Time	8	hr
Estimated Cumulative Production	43	gallons

I. INSPECTION

Overall Height	11.5	in.
Maximum Width	7.0	in.
Maximum Depth	6.0	in.
Cross-sectional Area	36	$in.^2$
Overall Volume	414	$in.^3$
System Wet Weight	11	lb
System Dry Weight	10	lb

Materials:

Pump	Acetal Plastic
Pump Handle	2024 Aluminum
Accumulator	316 Stainless Steel; Rubber Bladder
Containment Shell	PVC Plastic
Fittings	Nylon
Lines	Nylon

II. OPERATION

1. Feed Water Type	5000 ppm NaCl	
2. Type of Pre-filtration	10 micron cartridge	
3. Pressure	600	psig
4. Feed Temperature	74	°F
5. Output Quantity:		
Permeate Volume Collected	330	ml
Collection Time	1.0	min

TEST DATA LOG (Continued)

Permeate Flow Rate* (Q_p)	330	ml/min
Concentrate Volume Collected	140	ml
Collection Time	1.0	min
Concentrate Flow Rate (Q_{B_L})	140	ml/min
Fractional Recovery ($Q_p/[Q_p + Q_{B_L}]$)	0.70	
6. Output Purity:		
Permeate Conductivity	112	μmho**
Permeate Concentration	650	ppm
7. System Purification Performance:		
Feed Conductivity	780	μmho**
Feed Concentration (C_{B_o})	5320	ppm
Salt Rejection Rate ($1 - C_p/C_{B_o}$)	87.8	%
8. System Input Energy:		
Average Handle Force per Stroke (P)	34	lb
Handle Lever Arm (L)	12	in.
Average Handle Torque per Stroke (PL)	408	in.-lb
Handle Angular Displacement per Stroke (θ)	1.05	radians/stroke
Pump Rate (N)	62	strokes/min
Energy Input Rate ($2.53PL\theta N\times10^{-6}$)	0.066	HP

* This quantity must be temperature corrected according to the following equation: $Q_{p(77°F)} = Q_p/[1 + 0.0162(T-77)]$, where $Q_{p(77°F)}$ is the temperature corrected permeate flow rate (ml/min), Q_p is the measured permeate flow rate and T is the feed temperature (°F).

**All conductivity readings are at 25°C.

TEST DATA LOG (Continued)

III. LIFETIME UNIT NO. 3

Run Time (Hr)	Cumulative Production (Gallons)	Permeate Flow Rate (ml/min)	Feed Concen (ppm)	Permeate Concen (ppm)	Salt Rejection (%)	Energy Input (HP)-(strokes/min)
2	11.72	370	5060	710	86	0.076-71
8	43.1	330	5320	610	90	0.066-62
19	117	400	5025	1000	80	0.066-62
49	308	400	5025	1000	80	0.077-62
107	659	370	5020	700	86	0.077-72
126	770	370	5020	700	86	0.077-72
195	1170	365	5315	860	84	0.094-88
246	1466	365	5315	860	84	0.094-88
271	1611	365	5320	860	84	0.094-88
343	2028	365	5320	860	84	0.094-88
412	2428	365	5320	860	84	0.094-88

TEST DATA LOG

LIGHTWEIGHT, HAND OPERATED
BRACKISH WATER PURIFIER

GENERAL

Serial Number.	004	
Model Number	85121	
Run Time	8	hr
Estimated Cumulative Production.	33	gallons

I. INSPECTION

Overall Height	11.5	in.
Maximum Width.	7.0	in.
Maximum Depth.	6.0	in.
Cross-sectional Area	36	$in.^2$
Overall Volume	414	$in.^3$
System Wet Weight.	11	lb
System Dry Weight.	10	lb

Materials:

Pump	Acetal Plastic
Pump Handle.	2024 Aluminum
Accumulator.	316 Stainless Steel; Rubber Bladder
Containment Shell.	PVC Plastic
Fittings	Nylon
Lines.	Nylon

II. OPERATION

1. Feed Water Type.	5000 ppm NaCl	
2. Type of Pre-filtration	10 micron cartridge	
3. Pressure	600	psig
4. Feed Temperature	23	°F
5. Output Quantity:		
Permeate Volume Collected.	340	ml
Collection Time.	1.0	min

TEST DATA LOG (Continued)

Permeate Flow Rate* (Q_p)	340	ml/min
Concentrate Volume Collected	255	ml
Collection Time	1.0	min
Concentrate Flow Rate (Q_{BL})	255	ml/min
Fractional Recovery ($Q_p/[Q_p + Q_{BL}]$) . . .	0.57	
6. Output Purity:		
Permeate Conductivity	81	μmho
Permeate Concentration	475	ppm
7. System Purification Performance:		
Feed Conductivity	780	μmho
Feed Concentration (C_{B_o})	5320	ppm
Salt Rejection Rate ($1 - C_p/C_{B_o}$)	91.1	%
8. System Input Energy:		
Average Handle Force per Stroke (P) . . .	34	lb
Handle Lever Arm (L)	12	in.
Average Handle Torque per Stroke (PL) . .	408	in.-lb
Handle Angular Displacement per Stroke (θ)	1.05	radians/stroke
Pump Rate (N)	74	strokes/min
Energy Input Rate ($2.53PL\theta N\times10^{-6}$)	0.079	HP

*This quantity must be temperature corrected according to the following equation: $Q_{p(77°F)} = Q_p/[1 + 0.0162(T-77)]$, where $Q_{p(77°F)}$ is the temperature corrected permeate flow rate (ml/min), Q_p is the measured permeate flow rate and T is the feed temperature (°F).

TEST DATA LOG (Continued)

III. LIFETIME UNIT NO. 4

Run Time (Hr)	Cumulative Production (Gallons)	Permeate Flow Rate (ml/min)	Feed Concen (ppm)	Permeate Concen (ppm)	Salt Rejection (%)	Energy Input (HP)-(strokes/min)
2	11.1	350	5025	540	89	0.077-72
8	32.7	340	5320	475	91	0.068-64
18	103	350	5525	600	89	0.079-74
48	285	380	5025	900	82	0.079-74
119	715	380	5025	900	82	0.079-74
148	891	380	5025	900	82	0.079-74
177	1067	380	5025	900	82	0.079-74
246	1505	410	5025	860	82	0.092-86
279	1715	400	5025	860	82	0.092-86
347	2147	405	5315	900	83	0.092-86
420	2611	400	5320	900	83	0.092-86

TEST DATA LOG

LIGHTWEIGHT, HAND OPERATED BRACKISH WATER PURIFIER

GENERAL

Serial Number	005	
Model Number	85121	
Run Time	8	hr
Estimated Cumulative Production	35	gallons

I. INSPECTION

Overall Height	11.5	in.
Maximum Width	7.0	in.
Maximum Depth	6.0	in.
Cross-sectional Area	36	$in.^2$
Overall Volume	414	$in.^3$
System Wet Weight	11	lb
System Dry Weight	10	lb

Materials:

Pump	Acetal Plastic
Pump Handle	2024 Aluminum
Accumulator	316 Stainless Steel; Rubber Bladder
Containment Shell	PVC Plastic
Fittings	Nylon
Lines	Nylon

II. OPERATION

1. Feed Water Type	5000 ppm NaCl	
2. Type of Pre-filtration	10 micron cartridge	
3. Pressure	600	psig
4. Feed Temperature	74	°F
5. Output Quantity:		
Permeate Volume Collected	270	ml
Collection Time	1.0	min

Permeate Flow Rate* (Q_p)	270	ml/min
Concentrate Volume Collected	220	ml
Collection Time	1.0	min
Concentrate Flow Rate (Q_{B_L})	220	ml/min
Fractional Recovery ($Q_p/[Q_p + Q_{B_L}]$) . . .	0.55	
6. Output Purity:		
Permeate Conductivity	73	μmho
Permeate Concentration	440	ppm
7. System Purification Performance:		
Feed Conductivity	750	μmho
Feed Concentration (C_{B_o})	5090	ppm
Salt Rejection Rate ($1 - C_p/C_{B_o}$)	91.4	%
8. System Input Energy:		
Average Handle Force per Stroke (P) . . .	34	lb
Handle Lever Arm (L)	12	in.
Average Handle Torque per Stroke (PL). . .	408	in.-lb
Handle Angular Displacement per Stroke (θ)	1.05	radians/stroke
Pump Rate (N)	63	strokes/min
Energy Input Rate ($2.53PL\theta N \times 10^{-6}$)	0.067	HP

*This quantity must be temperature corrected according to the following equation: $Q_{p(77°F)} = Q_p/[1 + 0.0162(T-77)]$, where $Q_{p(77°F)}$ is the temperature corrected permeate flow rate (ml/min), Q_p is the measured permeate flow rate and T is the feed temperature (°F). The 270 ml/min output flow rate (less than the 350 ml/min limit stated in the contract) is per agreement with the USA/LWL Technical Supervisor and was required in order to produce a unit with higher salt rejection.

TEST DATA LOG (Continued)

III. LIFETIME

UNIT NO. 5

Run Time (Hr)	Cumulative Production (Gallons)	Permeate Flow Rate* (ml/min)	Feed Concen (ppm)	Permeate Concen (ppm)	Salt Rejection (%)	Energy Input (strokes/min) (HP)
2	8.9	280	5320	660	88	0.067-63
8	34.6	270	5090	450	91	0.067-63
24	114	290	5090	650	87	0.078-74
65	303	290	5090	640	87	0.071-68
132	611	290	5090	640	87	0.074-70
156	721	290	5090	640	87	0.074-70
178	822	290	5090	640	87	0.074-70
248	1178	290	5025	700	86	0.089-84
295	1404	300	5025	700	86	0.089-84

*The permeate flow rates (less than the 350 ml/min limit stated in the contract) are per agreement with the LWL Technical Supervisor and were required in order to produce a unit with higher salt rejection.

4.2.4 CONCLUSIONS

The Phase III test program has demonstrated that the four prototype purification units 002, 003, 004 and 005 have met design and performance criteria for size, weight, product output flow rate and quality, and input pumping energy. The lifetime tests showed that system performance in terms of product output flow rate and quality and input energy could be sustained over long test periods of from 295 hours to 548 hours, corresponding to total actual production levels of 1404 gallons to 3361 gallons (given a filtered feed water solution of 5000 ppm NaCl). The maintenance required in this period would typically consist of cartridge filter replacement at intervals determined by feed water turbidity, and possible pump piston seal replacement at approximately 400 hour intervals. The latter is a straightforward operation which can be completed without detaching the pump in only 15 minutes.

The life tests led to some minor design changes and materials specification changes introduced to improve long-term performance and reduce maintenance requirements. These changes are incorporated in the final set of design drawings and in all brackish units (No. 006 through No. 015) and the seawater unit fabricated in Phase IV of the program. The major changes consisted of:

(1) Installation of dual seals upon each plunger. Poly Pak Seal 12500750 is specified.

(2) Substitution of stainless steel for aluminum for the arm supports (part 85105).

(3) Doubling the width of the pump rocker arm support (part 85089) to reduce bearing wear.

(4) Incorporation of a positive means of connecting the arm supports into the stabilizing foot pads with quick disconnect devices.

4.3 PHASE IV QUALIFICATION TESTS

4.3.1 STANDARD BRACKISH WATER PURIFIERS

These tests were performed upon brackish water purifier units No. 006 through No. 015 as a means for qualification for shipment. Table 5 summarizes the test results. Each unit was run approximately two hours upon the pneumatically driven test apparatus shown in Figure 4-2. Tests were made with a feed solution of 5000 ppm NaCl and a feed temperature of 68°F (20°C). Salt rejection performance ranged from 92 percent (Unit No. 007) to 95 percent (Unit Nos. 011, 012) and permeate output flow rates (temperature corrected to 77°F) ranged from 281 ml/min (Unit No. 009) to 355 ml/min (Unit No. 014). The temperature permeate corrected flow rates and salt rejections are greater than the respective goals of 250 ml/min and 90 percent. As shown, all units were operated well within the limiting pumping energy of 0.12 HP. The "wet" weight of these

TABLE 5. LIGHTWEIGHT, HAND OPERATED BRACKISH WATER PURIFIER PERFORMANCE SUMMARY (Contract DAAD05-72-C-0419)

OPERATING CONDITIONS:

P_o = 600 psig

T_o = 68°F (20°C) unless otherwise specified

Run Time = 2 hours

PERFORMANCE:

Unit Serial Number	Q_{B_o} (GPM)	Q_p (GPM)	Q_p (GPD)	Q_p (ml/min)	Q_p @77°F (ml/min)	Q_p (pints/min)	J (GFD)	F —	C_{B_o} (ppm)	C_p (ppm)	R (%)	N (strokes/min)	E (HP)
006	0.115	0.071	103	270	309	0.57	14.1	0.62	5,000	300	94	60	0.0666
007	0.121	0.079	114	300	344	0.63	15.6	0.65	5,000	400	92	64	0.0710
008	0.133	0.069	99	260	298	0.55	13.6	0.52	5,000	300	94	78	0.0866
009	0.099	0.065	93	245	281	0.52	12.8	0.65	5,000	370	93	66	0.0733
010	0.120	0.073	105	275	315	0.58	14.9	0.60	5,000	345	93	66	0.0733
011	0.149	0.081	116	305	349	0.65	15.9	0.54	5,000	270	95	84	0.0932
012	0.157	0.079	114	300	344	0.64	15.6	0.50	5,000	270	95	88	0.0977
013	0.139	0.082	118	310	355	0.66	16.8	0.59	5,000	310	94	72	0.0799
014	0.146	0.082	118	310	355	0.66	16.8	0.58	5,000	310	94	72	0.0799
015	0.127	0.071	103	270	309	0.57	14.1	0.56	5,000	290	94	68	0.0755

units was recorded as 12.6 lb, exclusive of the filter, but including feed and product lines. This corresponds to a "dry" weight of 10.3 lb, which is less than the specified "dry" weight limit of 11 lb. The "wet" and "dry" weights refer to conditions wherein the membrane tubing is respectively filled and emptied of water.

4.3.2 SEAWATER PURIFIER

The seawater unit was tested with a simulated seawater feed solution of 35,100 ppm NaCl. The test results are included in Table 6 for both passes and for overall performance. The permeate from the first pass is collected, then fed through the purifier to produce potable water. The tests demonstrate that very good quality potable water (TDS of 150 ppm) could be attained with this system operating in two passes. The pressure in the first pass was maintained at 600 psig, identical to the design operating pressure for the standard brackish water purifiers. In the second pass the pressure was reduced to 400 psig in order to conserve energy and to permit operation at a comfortable pumping rate. It is recommended that these respective operating pressures be maintained on subsequent operations. These results have demonstrated the feasibility of seawater desalination with 2-pass operation of a lightweight hand-operated reverse osmosis purification unit.

TABLE 6. SEAWATER UNIT 001 - PERFORMANCE ON SIMULATED SEAWATER

Variable	First Pass (Run 122073-5)	Second Pass (Run 122673-1)
P_o	600 psig	400 psig
C_{B_o}	35,100 ppm	3,500 ppm
Q_{B_o}	0.102 GPM	0.13 GPM
N	72 strokes/min	80 strokes/min
Q_p	82 ml/min or 31.2 GPD or 0.173 pints/min	201 ml/min or 76.7 GPD or 0.425 pints/min
C_p	3,500 ppm	150 ppm
R	90.0 percent	95.6 percent
F	0.20	0.40

R overall = 99.6 percent

F overall = 0.08

Q_p overall = 31.0 ml/min, 11.8 gpd, 0.0653 pints/min (assuming no delay between 1st & 2nd passes)

SECTION 5

OPERATION DESCRIPTION

The normal operation sequence of the Purifier Assembly for the production of potable water from either brackish or seawater is outlined in detail within this section. This section also presents detailed discussions of the proper procedures to be used in cleaning, storing, transporting and maintaining the Purifier Assembly. As part of the Operating Summary, a list of precautions to be exercised prior to, during, and after the use of the Purifier Assembly is presented.

5.1 NOTES OF CAUTION

The lightweight, hand operated water purifier is a sturdy, reliable, well-performing unit when operated in proper fashion. However, to insure optimum performance and maximum lifetime, there are some notes of caution to be observed. These are as follows:

(1) Do not exceed a pressure of 650 psig.

(2) Do not operate without nominal ten micron or finer particulate prefilter. The supplied filter contains activated carbon for the limited removal of chlorine and organic materials.

(3) Always flush with at least 1/2 gallon of clean potable water after testing (RO permeate water may be used).

(4) Always fill with potable water (RO permeate) for storage.

(5) Feed conditions for optimum performance and service life.

Listed below are general conditions in which reverse osmosis membrane performance is optimized, membrane life is extended, and membrane cleaning frequency is minimized. Should actual conditions vary from these conditions, certain pretreatment equipment may be required or purifier performance may be affected.

- o pH Level* - Between 4.0 and 6.0 for best long-term performance. Do not operate at pH levels less than 3.0 and greater than 8.0.

- o Feed Water Temperature* - Operating range capability is between 35°F and 100°F. Optimum range is between 68°F and 82°F.

- o Free Residual Chlorine or other oxidizing agents - Less than 0.3 ppm

- o Suspended Solids, Turbidity and Grit - Use of a 10 micron particulate prefilter will eliminate the larger suspended solids and the grit. Smaller colloidal and particulate suspensions will contribute to membrane fouling and increase cleaning frequency. A feed fouling index of 3.33 min^{-1} (refer to Appendix A) or less is known to deliver acceptable performance in an RO module whose flow passages are only one-thirtieth the size of those in the brackish water purifier. Since fouling tendency is reduced with larger passage sizes, tolerance to feeds with higher fouling indices than 3.33 min-1 is anticipated.

- o Iron and Manganese - Less than 1.0 ppm. Iron and manganese fouling will reduce membrane performance; flush cleaning with 2 weight percent ammonium citrate solution is recommended.

- o Organics - Generally not to exceed 10 ppm depending on organic type. Low molecular weight organics (MW < 150) can swell the membrane and decrease its salt rejection characteristics. Highly reactive organics, such as some pesticides, can chemically attack the membrane surface and decrease the membrane's salt rejection properties even though the pesticide may be present in the feed in very low concentrations (< 1 ppm). These effects are usually not noticed until after several thousand hours of stream (or use) time. The hand unit is designed for much smaller use times.

- o Oil and Grease - Less than 1 ppm

- o Surfactants - Depending on characteristic, may affect performance

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*Pertinent for storage as well

- o Waters of high biological activity should be chlorinated and filtered. If free residual chlorine exceeds 0.3 ppm, treatment with activated carbon for best long-term membrane service is required. (The pre-filter supplied with each unit has a small activated carbon section.)

5.2 PURIFICATION MODE-BRACKISH WATER

The purifier operation is described in sequence, starting with the unit in the folded transportable configuration. Reference to Figures 5-1, 5-2 and 5-3 will assist in understanding the descriptions.

(1) Remove the elastic constraining cord.

(2) Lock the pump handles into their extended configuration by sliding the foldable portion toward the centerline of the unit.

(3) Rotate the stabilizing foot-pads outward through 90 degrees.

(4) Lock each foot-pad into position by fixing the support arms into the receptacles on the sides of the foot-pads. There is a lock-detent mechanism at the end of each support arm to make the connection.

The purifier is now in the proper orientation for water processing.

(5) Insert the permeate line (vinyl tubing) from the labeled permeate fitting inside the base of the purifier into a collection container.

(6) Assure that the orifice and the relief diaphragm are installed in the nylon elbow fittings upon the top of the purifier. The orifice is installed in the elbow fitting attached to the labeled concentrate line.

(7) The pump is operated slowly at first (less than 60 strokes per minute) until the air entrained in the various lines and components is eliminated. Entrained air can be observed as bubbles in the concentrate effluent line at the purifier. Do not attempt high pressurization (greater than 50 psig) until entrained air is eliminated.

(8) Continuation of the pumping at a rate of approximately 60 to 90 strokes per minute will cause system pressurization to 600 psig and initiation of water purification. Adjust the pumping rate as necessary to maintain the 600 psig operating pressure. Total pumping time will depend upon the process water requirements.

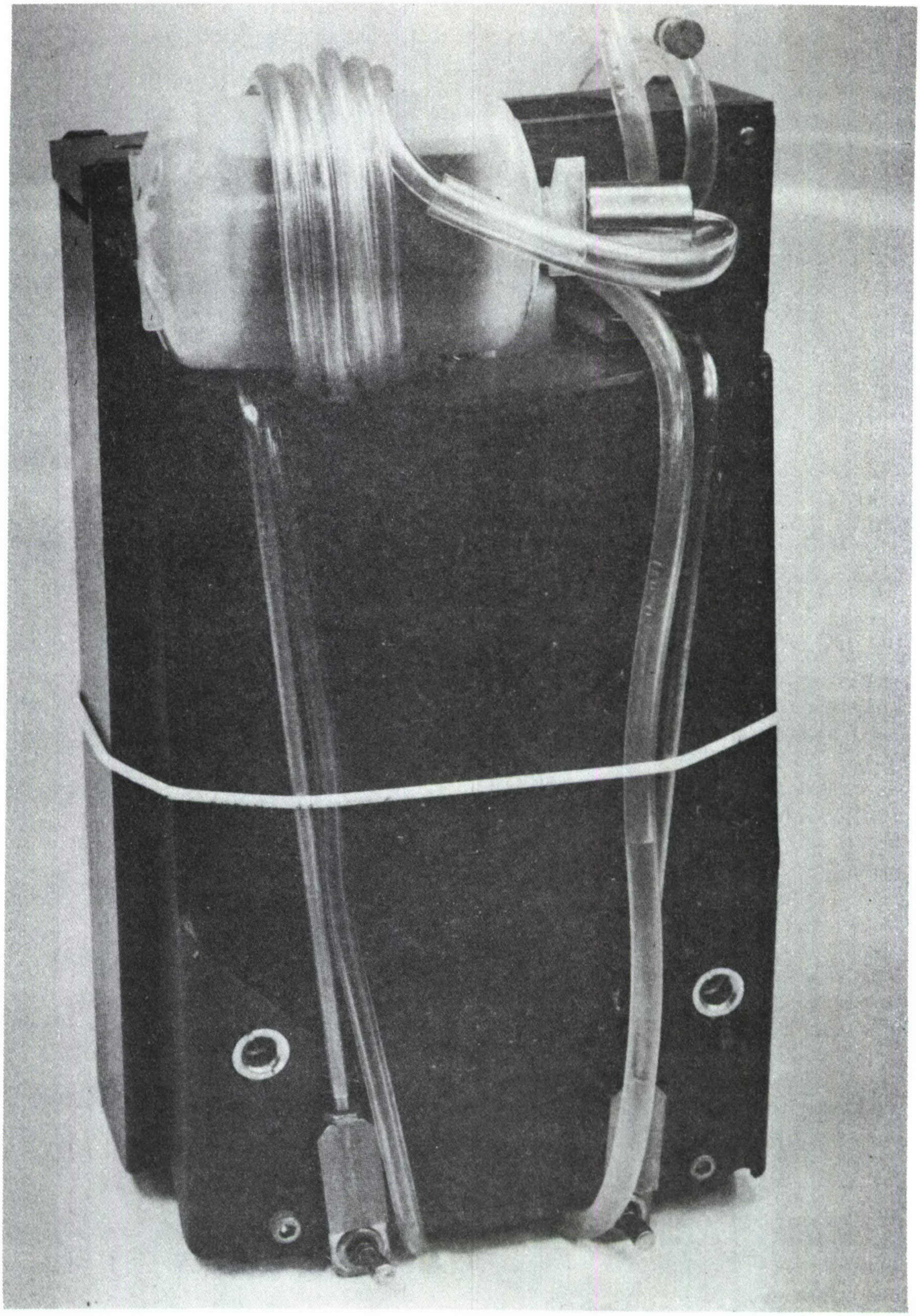

FIGURE 5-1. PURIFIER ASSEMBLY - TRANSPORTABLE CONFIGURATION

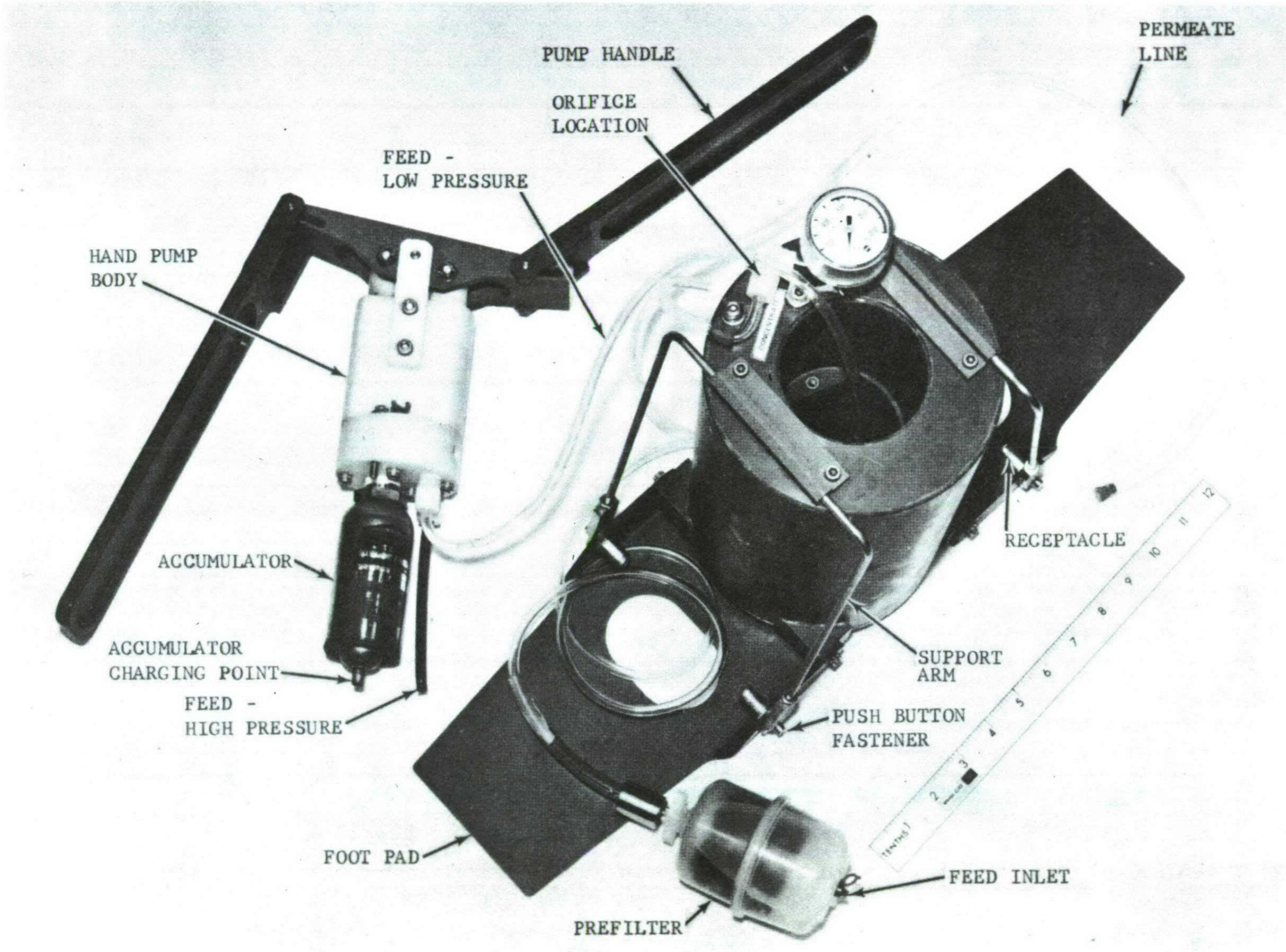

FIGURE 5-2. PURIFIER ASSEMBLY/PUMP ASSEMBLY

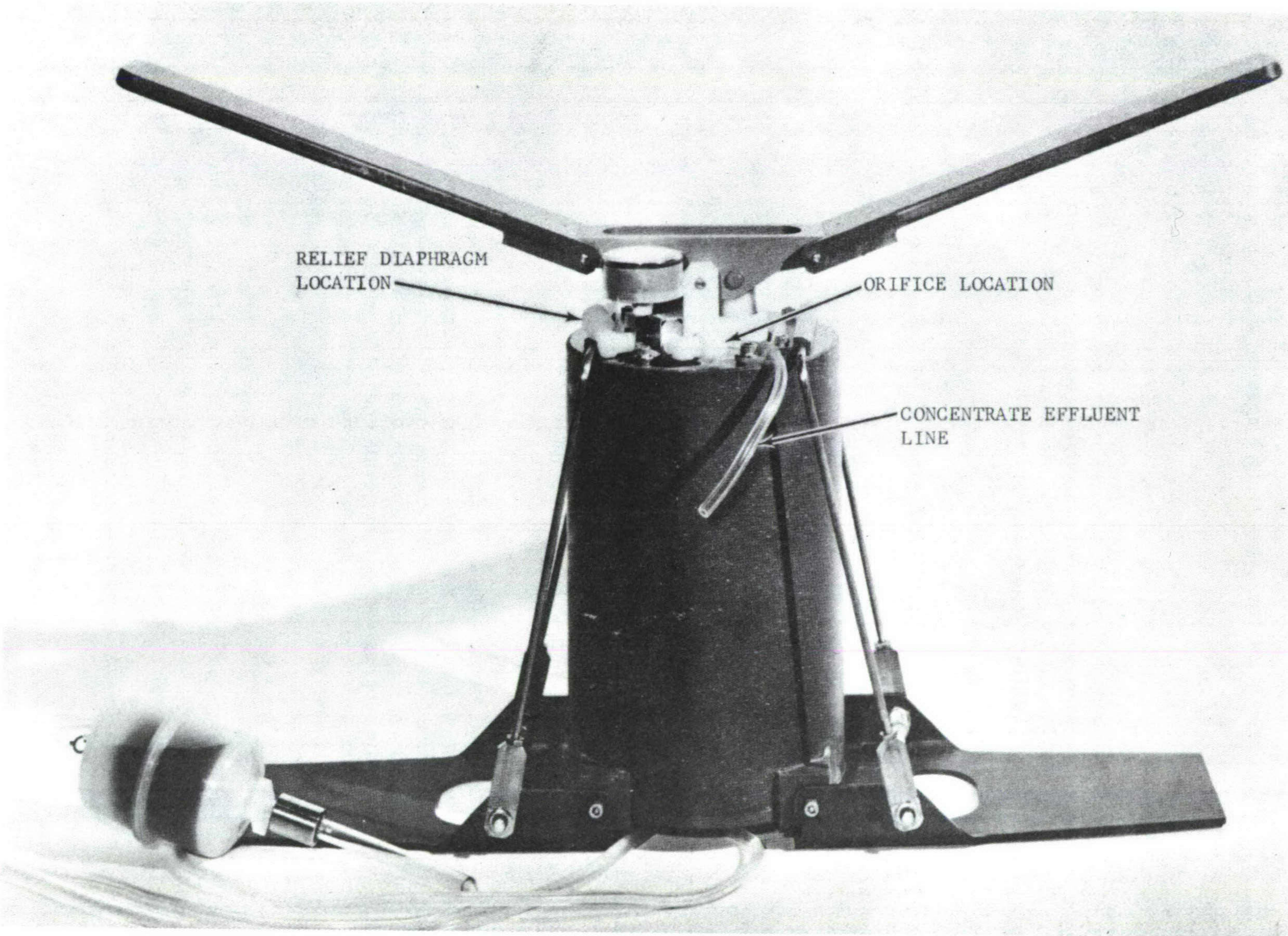

FIGURE 5-3. PURIFIER ASSEMBLY - OPERATING CONFIGURATION

(9) For the best system performance, a pumping rate should be maintained which will produce 600 psig pressurization as shown on a pressure gage attached at top of unit. The occurrence of concentrate flow through the relief diaphragm port indicates the optimum working pressure, 600 psig, has been exceeded. Do not continue operation until the relief diaphragm has been replaced with a new one.

(10) At the end of an operating cycle, the membrane modules should be flushed by loosening or removing the orifice and pumping feed water through the system. This is accomplished by loosening the B-nut on the nylon elbow fitting containing the orifice.

5.3 PURIFICATION MODE - SEAWATER

To desalt seawater with the purifier requires a two-pass operation; i.e., the permeate is collected from the first pass, then supplied as feed water in a second pass.

(1) Setup

The setup of the purifier is the same as for its use on brackish water as described in steps (1) through (6) above, except that two collection containers are required. The collection container for the first pass must have a capacity equal to approximately 2-1/2 times the desired quantity of potable water from the second pass.

(2) First Pass Operation

The first operation is as described above for the brackish water purifier in steps (7), (8), and (9). During the first pass operation the permeate is being collected in the larger container. When the container is almost filled, the pumping should be stopped and the internal permeate compartment and line should be drained into the container. (The bottom of the purifier must be held above the water level in the collection container).

(3) Second Pass Operation

(a) Transfer the prefilter and inlet line into the first pass permeate collection container.

(b) Transfer the permeate line into a final drinking water collection container.

(c) Pump at a rate of approximately 80 strokes per minute in order to pressurize the system to 400 psig. Adjust the pumping rate as necessary to maintain the 400 psig operating pressure.

(d) Continue pumping (maintain 400 psig operating pressure) until either the permeate collection container is filled or the feed container is depleted.

(4) Flush

At the end of an operating cycle, the membrane modules should be flushed with potable water containing low free residual chlorine (< 0.3 ppm). This is most easily accomplished by approximately 1/2 gallon of final permeate water (or equivalent) through the purifier at relatively low pressure (less than 100 psig). It will be necessary to reduce the pumping rate considerably.

5.4 VARIATION OF THE OPERATING PRESSURE

The output flow of the purifier is approximately proportional to pumping rate and the operating pressure. The standard operating pressure, 600 psig, is fixed by the orifice assembly and rate of pumping. Operating pressures in excess of 600 psig can be achieved by increased rates of pumping; however, operation at pressures greater than 600 psig is not recommended. Irreversible RO membrane damage can occur with continued operating in the pressure range of 700 psig to 800 psig. For this reason a pressure relief diaphragm with a nominal burst pressure of 1000 psig has been incorporated into the system. Operating pressures less than 600 psig can be obtained at reduced pumping rates. This mode of operation is not recommended, however, except for the second pass of the seawater purifier because both the quantity and quality of output will be reduced.

5.5 PURIFIER CLEANING

A normal occurrence during the use of the purifier is the accumulation on the membrane surfaces of either salts or other solid materials which have been removed from the feed water. The tendency for a feed water to coat or "foul" the membrane surface can be measured by the Percent Plugging and Fouling Index Test (see Appendix A).

There are three methods available for removing the foulants from the membrane surfaces. These methods, in order of preference, include high velocity flushing of the membrane surfaces, cleaning involving the use of either chemicals or detergents, and plug cleaning of the membrane surfaces. The procedures to be used in these three methods are outlined below.

5.5.1 FLUSH CLEANING

Loosely held precipitates on the membrane surface can quite often be flushed off the membrane by a high velocity water flow at low pressure. The procedure is as follows:

(1) Remove the orifice from its fitting but reattach the concentrate effluent line.

(2) Flush the system with clean water for approximately 15 minutes. This can be accomplished either by direct application of pressurized tap water to the feed inlet tee at the bottom of the purifier interior by removing the cap and attaching a line, or in the field, by operation of the hand pump with the cleanest, least saline feed water available. The pump rate should be preferably 90 to 120 strokes per minute.

(3) Reinstall the orifice and reattach the concentrate effluent line.

5.5.2 CHEMICAL CLEANING

Due to the time consuming nature of chemical cleaning, the preceding method is preferable in most instances. However, in some cases it will be advisable, if not necessary, to include chemical cleaning as part of the flux restorative operation. The preparation of the purification unit for this operation is identical to that used in the preparation of plug cleaning except that the filter on the feed inlet line must be removed. The method differs in that a porous plug is not included as part of the operation and water is not used as the solution to force the plug through the module. Rather, a container of cleaning solution is pumped (by the hand pump) through the system in a recirculating fashion. The outflow from the system is put back into the container to maintain a source of cleaning fluid. After circulating the cleaning solution (at a preferred pumping pressure of 20 to 40 psig) through the module for a prescribed period of time, the system can be put back into operation after rinsing out the cleaning solution and then reinstalling the filter. There are several fouling situations for which chemical cleaning can be considered as an alternative. These are listed below:

(1) <u>Scale Formation</u>

The two principal sources of scaling in most waters are either calcium carbonate or calcium sulfate. When operating at high fractional recovery using feeds that have appreciable concentrations of calcium sulfate in the downstream part of the RO system where the concentration has exceeded, the calcium sulfate solubility limit, by a significant margin. In most cases, this precipitate can be re-dissolved by operation at a lower fractional recovery for a period of time. In the case of severe scale formation and fouling, the system could be prepared for a plug cleaning operation.

The calcium sulfate scale can also be removed by circulating a high concentration sodium chloride solution through the system (1 or 2 percent NaCl by weight). The high ionic strength of this solution and its relatively low calcium sulfate content will cause the scale in the membrane surface to readily dissolve. This is a time-consuming operation but may have virtue in situations where the scale formation is excessive.

(2) Hydrous Metal Oxides

The complexing ability of citrate can be used to remove ferric and aluminum hydroxide deposits. A two percent by weight aqueous solution of ammonium citrate can be recirculated through the purifier system. This treatment will also remove a portion of manganese deposits present and manganic oxide (Mn_2O_3 or Mn_3O_4). Manganic oxide and manganese dioxide can be removed by treatment with a reducing agent such as catalyzed sodium sulfite. Manganese as well as ferric precipitates are reduced to the soluble manganous and ferrous forms respectively.

(3) Organics

Organic materials such as oils and greates significantly decrease the water flux of cellulose acetate membranes. When using feeds which have trace quantities of oils and greases, the most effective method of handling these materials is to use adequate pretreatment which may include activated carbon absorption, anthracite coal-sand filtration preceded by coagulation with alum, and possibly even diatomaceous earth filtration. In the event that the membranes become coated with oils or greases, these materials are best removed by recirculating warm 0.2 to 0.5 percent by weight laundry or dishwashing detergent solution through the system. Most detergents are quite alkaline. To prevent hydrolysis of the membranes, the pH of the detergent solution must be reduced to a value of 6 to 7 by the addition of a suitable acid before the solution is used.

5.5.3 PLUG CLEANING

For foulants that cannot be removed by flushing alone, or by chemical cleaning, removal of foulants by wiping the membrane surface with a porous plastic plug quite often is very effective. This procedure should be used only after flush and chemical cleaning have been attempted.

(1) Always flush and chemical clean first, then use the following procedure for additional cleaning as required.

(2) Remove the orifice from its fitting but reattach the concentrate effluent line.

(3) Insert the porous cleaning plug into the tee at the bottom of the purifier interior by removing the cap and pushing the plug past the tube from the pump and replacing the cap.

(4) Supply a source of clean water to feed inlet.

(5) Slowly begin pumping water through the purifier to drive the porous plug through the tubular membranes. An average pumping rate of 30 to 60 strokes/minute is recommended.

(6) The plug will be expelled through the concentrate effluent line after approximately three minutes of pumping at a rate of 60 strokes/minute.

(7) Before returning the purifier to operation, reinstall the orifice and reattach the concentrate effluent line.

5.6 STORAGE REQUIREMENTS

The membrane modules of the purification unit must be protected from dryness and biological or chemical attack during storage periods. The membrane modules in the purifier must be kept moist at all times to avoid permanent damage. For short-term storage (several days to approximately a week in duration) in field application, a solution of approximately 10 percent vinegar can be pumped into the unit. This will provide moisture and protect the membranes from attack by hydrolysis. Over longer storage periods, a 0.5 percent formaldehyde solution in available clean tap water is recommended for protection from biological attack. This solution should be periodically (weekly-monthly) pumped through the module to provide adequate protection.

To assure optimum membrane performance and lifetime, the purifier units should always be flush cleaned immediately prior to storage (See Section 5.5.1).

An alternate method of long-term storage has been suggested, but has not been proven in long term tests. A thin film of the 0.5 percent formaldehyde solution is deposited on the membrane walls by the passage of a porous plug through the modules (by the action of pneumatic pressure). This mode of storage has the following advantages: (1) essentially no maintenance requirements, and (2) purifier units are in their minimum weight conditions.

5.7 TRANSPORT REQUIREMENTS

The purification unit should be transported only in the folded orientation, with a rubber strap installed around its circumference. In the interest of light weight and maximum impact resistance during transport, it is recommended that the internal passages of the membrane modules be pumped or drained free of water. Over the short periods required for transport, sufficient moisture will be retained by the membrane pressure support structure to protect the membrane from dryness, provided that <u>all inlet and outlet ports are tightly capped</u>.

5.8 MAINTENANCE REQUIREMENTS

The purifier assembly has a few areas which require some attention periodically. They are as follows:

(1) The membrane cleaning procedures are described in Section 5.5.

(2) Orifice plugging may occur with inadequate prefiltration. This will cause overpressurization at low pumping rates and poor salt rejection. Performance can be restored by cleaning the orifice to assure free passage of concentrate. The orifice plate is located inside the nylon B-nut section of elbow fitting on the concentrate effluent line.

(3) Overpressurization can cause irreversible damage to the RO membranes. A pressure relief diaphragm is installed inside the nylon B-nut at the end of the elbow fitting installed into the pressure gauge manifold (opposite the orifice elbow fitting). Should diaphragm failure occur, the system will be depressurized, and a new diaphragm must be installed. In replacing the diaphragm, the cap must be retightened by 1-1/4 turns after finger tightness is achieved.

(4) Air leakage in the feed suction line and fittings between the prefilter and the pump is detrimental to system performance. The entrained air will cause irregular pump operation, require high pumping rates to maintain 600 psig pressure, and reduce flow capacity. The filter outlet fitting and the pump inlet male connector fitting should be checked (particularly around the threads) if air leakage is suspected.

(5) At intervals of approximately 100 hours, or when the pressure fluctuation at 600 psig exceeds ±20 psig, the charge pressure of the accumulator should be checked, The charge pressure should be maintained at 300 ±10 psig.

5.9 SPARE PARTS

A spare parts package has been provided with each of the brackish purifier units 006 through 015 and the seawater purifier unit. Components essential to system operation which can be readily replaced are provided. In addition a spare pre-filter is included in the event the original pre-filter becomes fouled and fails to deliver the required flow rates. The total listing of spare parts is as follows:

LIST OF SPARE PARTS

Quantity*	Item	Part Number	Manufacturer
1	Pressure Gauge	P563-1/8-CBM	U. S. Gauge
1	Filter (5 micron)	MBY 2001 CC	Pall Trinity Micro Corp.
1	Orifice	0600 490021-3	Philco-Ford Corp. Liquid Process Products
1	Relief Diaphragm	0600 490023	Philco-Ford Corp. Liquid Process Products
1	Plug Assembly-Relief Diaphragm	0600 490024	Philco-Ford Corp. Liquid Process Products
4	Piston Seal - PolyPak	12500750	Parker Seal Co.
4	Check Valve	C2949B-4Q	Circle Seal Corp.
2	Male Connector	ZY400-1-2	Swagelok
2	Elbow	ZY400-2-2	Swagelok
1	Male Run Tee	ZY400-3-TMT	Swagelok
1	Plug	ZY400-P	Swagelok

*Quantity shown is the quantity in each purifier assembly.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The feasibility of a lightweight hand-operated brackish water purifier incorporating tubular reverse osmosis membranes has been demonstrated. Size, weight, output quantity, output purity, energy consumption and lifetime goals have been achieved.

Two pass seawater desalination is possible with a lightweight hand-operated purifier operated at a peak pressure of 600 psig. However, considerable total energy consumption is required in two pass operation.

For optimum performance and maximum life of the brackish water purifier, attention should be given to the following precautions:

(1) Do not exceed an operating pressure of 650 psig.

(2) Do not operate without a ten micron or finer particulate prefilter.

(3) Flush and fill the purifier with potable water for storage (permeate water is preferred).

(4) Certain feed water conditions and compositions should be avoided, particularly extremes in pH and temperature. Waters high in organics and biological activity may reduce performance. The presence of oxidizing agents will reduce membrane life. Quantitative feed water restrictions are listed in Section 5.

The particular combination of pump body materials, cylinder surface finish and ring seals will lead to long term pump service because corrosion is eliminated and wear is minimal.

The corrosion resistant pressure gauge mounted on top of the unit is an effective guide for maintaining pressure control during operation. Long term pressure control with a pressure relief valve was found to be unsatisfactory.

6.2 RECOMMENDATIONS

The accumulator should be incorporated into the pump housing itself. This would allow for a reduction in cost and the substitution of a plastic material for the present 316 stainless steel.

The design of the rest pads and stabilizing arms into a single package would allow for slipping of the membrane assembly into this package.

A redesign of the outer shell, the inner tube assembly and the base and top plates could allow for a bolt-on outer shell rather than a bonded into place shell. This would permit the removal and replacement of the individual RO membrane modules.

The elimination of the membrane module spools could be achieved by designing the inner tube assembly and the base and top plates as a unit and wrapping the membrane around the inner tube itself. This would eliminate the cost of the spools and six end fittings and make a smaller package. Development of methods for production of long lengths of membrane is required for this modification.

The material of the orifice/relief valve housing should be changed to PVC from 316 stainless steel. For a molded top plate, the outlets could be designed into the top plate itself.

Another area for further investigation is the quick disconnect push button fastener for attaching the rest pads to the stabilizing arms. The fastener assembly used in the assembly of the units was chosen because of its availability. A more compact, simple, twist or snap-in connector should be considered for future units.

NOMENCLATURE

A = product water permeation coefficient [(gpd)/ft^2 psi] or [cm/sec atm]

B = salt permeation coefficient [(gpd/ft^2] or [cm/sec]

C = salt concentration (ppm)

C_B = salt concentration in brine solution (ppm)

C_{B_o} = salt concentration of brine solution at module inlet (ppm)

C_P = salt concentration in permeate solution (ppm)

C_W = salt concentration at the membrane-feed solution interface (ppm)

D = tube diameter (inch)

F = fractional recovery = Q_P/Q_{B_o}

J = production permeation velocity or flux through the membrane (relative to a stationary observer) [(gal/day ft^2)] or [cm/sec]

JTU = Jackson Turbidity Units

L = flow section length, ft

N = pumping rate, strokes per minute

N_{RE} = Reynolds number = $\frac{U_B D}{\nu}$

NOMENCLATURE (Continued)

P = pressure (psig)

P_o = pressure at system inlet (psig)

Q = volumetric flow rate (gpm)

Q_B = volumetric bulk brine flow rate (gpm)

Q_{B_o} = bulk brine volumetric flow rate at module system inlet (gpm)

Q_p = volumetric product flow rate (gpm)

R = salt rejection = $(C_B - C_P)/C_B$

U_B = brine velocity (ft/sec)

U_{B_o} = brine velocity at module or test cell inlet (ft/sec)

GREEK

δ = membrane thickness

ν = kinematic viscosity = μ/ρ (cm^2/sec)

π = osmotic pressure (psi)

ρ = total mass density of fluid (gm/cm^3)

μ = absolute viscosity (gm/cm sec or poise)

SUBSCRIPTS

B = brine (bulk average)

o = initial or inlet

P = permeate

ABBREVIATIONS

gpd = gallons per day

gpm = gallons per minute

hp = horsepower

ppm = parts per million

psig = gage pressure, pounds per square inch

ACKNOWLEDGEMENTS

We gratefully acknowledge the assistance of Mr. W. H. Bachle, Mr. L. E. Hawkins, and Mr. T. D. Stantial in the initial design of the brackish water purifier.

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1. Williams, R. H., *et al*., "Final Report, Lightweight Reverse Osmosis Membrane Module", U. S. Army Land Warfare Laboratory Contract DAAD05-70-C-0256, Aeronutronic Publication No. U-4877, Newport Beach, California: Physics and Chemistry Laboratory, Advanced Development Operation, Aeronutronic Division, Philco-Ford Corporation (November 1970). Also published as U. S. Army Technical Report LWL-CR-17B69.

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APPENDIX A

DETERMINATION OF PERCENT PLUGGING AND FOULING INDEX

APPENDIX A

DETERMINATION OF PERCENT PLUGGING AND FOULING INDEX

The fouling index is an indicator of the suspended solids content of a feed solution. It is based upon the percent plugging of a 47 mm diameter, 0.45 micron millipore filter given a standard upstream pressure of 30 psig. The percent plugging is calculated by recording times to collect 100 ml and 500 ml samples of filtrate at prescribed continuous run intervals, ($\Delta\theta$). Typical run intervals are 5, 10 and 15 minutes. The percent plugging is computed and defined as follows:

$$\% \text{ plugging} \equiv (1 - t_i/t_f)\ 100 \qquad (1)$$

where

t_i = times to collect 100 ml and 500 ml samples at initiation of run interval

t_f = times to collect 100 ml and 500 ml samples at completion of run interval

The percent plugging, equation (1), is computed for both 100 ml and 500 ml sample sizes. Close agreement is expected; thus the two sample sizes provide mutual checks upon validity of the test data.

A test system schematic, Figure A-1, shows the essential components and instrumentation required for percent plugging determinations. A pressure regulator is required in order to maintain the standard upstream filter pressure of 30 psig.

The fouling index is defined as percent plugging at 30 psig divided by the total run time interval.

$$\text{Fouling Index } (\text{min}^{-1}) \equiv \frac{\% \text{ plugging}}{\Delta\theta} \qquad (2)$$

The following test apparatus, test instructions and sample calculations can serve as a guide in percent plugging and fouling index determinations.

<u>Test Apparatus</u> (Figure A-1)

(1) Millipore low pressure filter cell for 47 mm filters, Model XX4304700, glass-filled polypropylene housing.

(2) Millipore standard filters, 0.45 micron, Number HAWP04700, Type HA, 47 mm diameter, white.

PERCENT PLUGGING/FOULING INDEX TEST FLOW DIAGRAM

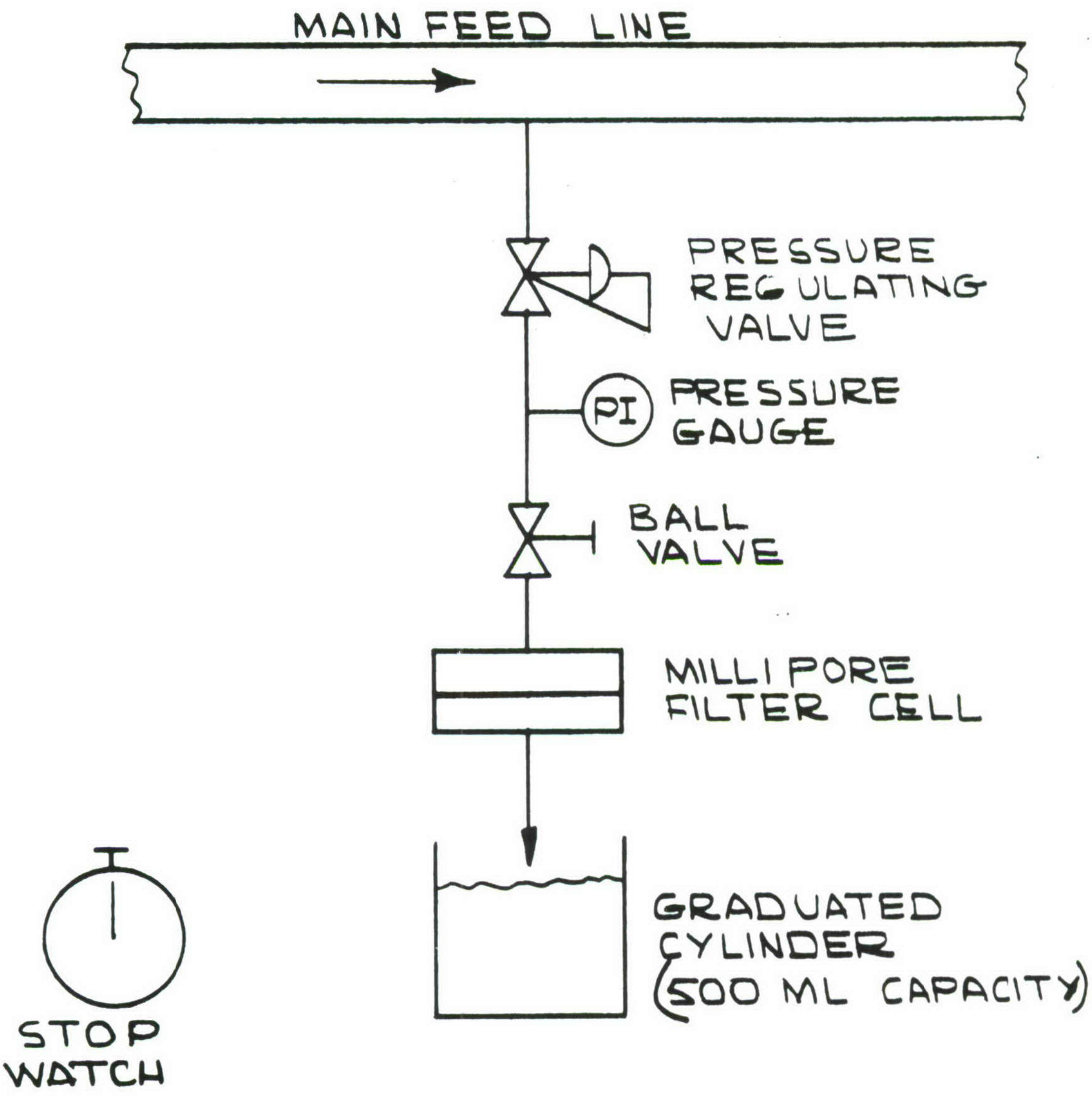

FIGURE A-1. PERCENT PLUGGING/FOULING INDEX TEST FLOW DIAGRAM

(3) Pressure regulating valve for maintenance of 30 psig upstream filter pressure. (corrosion resistant)

(4) Pressure gauge, 0-30 psig. (corrosion resistant)

(5) Ball valve or equivalent to isolate the filter cell when replacing filter elements.

(6) Fittings and connecting lines, polyethylene, polypropylene or PVC.

(7) Graduated cylinder, 500 ml capacity.

(8) Stop watch.

Procedures

(1) Orient the filter holder in a downflow position shown in Figure A-1.

(2) Unbolt the filter holder and install a 0.45 micron filter element upon the backup plate. Reassemble the filter holder.

(3) Open the ball valve.

(4) Trapped air may be bled from the filter holder by momentarily loosening the filter holder bolts. Retighten the bolts and prepare to collect samples.

(5) Measure the time required to collect 100 ml and 500 ml of filtrate immediately after air is bled from the system and flow is established.

(6) Repeat step 5 after 5, 10, and 15 minutes of continuous elapsed flow time, maintaining 30 psig upstream pressure at all times.

Sample Calculations

(1) Given the following basic test data:

$t_{i_{100}}$ = 20 seconds (time to collect 100 ml at initiation of run)

$t_{i_{500}}$ = 95 seconds (time to collect 500 ml at initiation of run)

$t_{f_{100}}$ = 49 seconds (time to collect 100 ml at 15 minutes total elapsed flow time)

$t_{f_{500}}$ = 235 seconds (time to collect 500 ml at 15 minutes total elapsed flow time)

(2) Compute "% plugging" for 100 ml and 500 ml sample sizes (Equation (1)):

$$\% \text{ plugging} = 1 - \frac{20}{95} = \underline{\underline{0.790}} \text{ (100 ml samples)}$$

$$\% \text{ plugging} = 1 - \frac{49}{235} = \underline{\underline{0.792}} \text{ (500 ml samples)}$$

There is good correlation between each sample size, a required result.

(3) Compute "Fouling Index" (Equation (2)):

$$\text{Fouling Index} = \frac{79}{15} = \underline{\underline{5.3}} \text{ min}^{-1}$$

APPENDIX B

SPECIFICATIONS SHEET

SPECIFICATIONS -

LIGHTWEIGHT HAND OPERATED

R.O. WATER PURIFIER

I. SIZE AND WEIGHT

1. Dimensions: 12 inches high, 6 to 7 inches in diameter
2. Overall Purifier Volume: 0.30 ft^3
3. Weight (dry): 10.3 lb (excluding filter)

II. MEMBRANE MODULE CHARACTERISTICS

1. Configuration: Tubular assembly wrapped in 5 layers and 7 rows on each of 4 spools.
2. Total Length: 166 feet
3. Tube Outside Diameter: 0.24 inches
4. Tube Inside Diameter: 0.166 inches
5. Tube Inside Surface Area: 7.0 ft^2

III. PERFORMANCE AND OPERATION

1. Operating Pressure: 600 psig
2. Membrane-Support Sleeve Burst Pressure: 1500 psig
3. Output: 1.0 pint per two minutes (250 ml/min)
4. Salt Rejection: Average of 0.90 with feed of 5000 ppm NaCl
5. Nominal feed flow rate: 0.152 gpm

IV. PRESSURIZATION COMPONENTS

1. Pump: (Two piston plastic Philco-Ford No. 0600 490001)
2. Accumulator: (5 cu in. Greer No. A70544-200)
3. Pressure Relief Diaphragm: (Philco-Ford No. 0600 490023)
4. Orifice: (Philco-Ford No. 0600 490021-3)

V. ADDITIONAL FEATURES

1. Provision for periodic membrane cleaning, by water flush, porous plug, and/or chemical cleaning.

APPENDIX C

PARTS LISTS AND DATA LISTS

PARTS LIST

R.O. PURIFIER ASSEMBLY 0600 490000

Item No.	Qty. Req'd	Drawing or Part No.	Nomenclature	Specification
1	1	0600 49001	Pump Assy.	
2	1	0600 490008	Tube Assy.	
3	1	0600 49009	Base Plate Assy.	
4	1	0600 490010	Shell, Outer	
5	1	0600 490011	End Cap	
6	3	0600 490012	Tube End Fitting	
7	2	0600 490013	Pad, Rest	
8	2	0600 490014	Arm, Stabilizing Pad	
9	2	0600 490015	Block-Rest Pad	
10	2	0600 490016-1	Support-Arm	
11	2	0600 490016-2	Support-Arm	
12	1	0600 490017-1	Housing Assy.	
13	1	0600 490018	Clamp-Hsg. Assy.	
14	4	0600 490019	Block - Quick Disc. Assy.	
15	4	0600 490020	Spacer - Pad Attach	
16	1	0600 490021-3	Orifice	
17	2	0600 490022	Clip-Spool/End Fitting	
18	1	0600 490023	Relief Diaphragm	
19	1	0600 490024	Plug Assy - Mod.	
20	1	P563-1/8 CBM	Gauge-Pressure	U.S. Gauge 0-100 psig
21	4	15S1-3-1AF	Stud Assy.	Camloc
22	4	15S11-ZAE	Retaining Washer	Camloc
23	4	15R1-1AE	Receptacle	Camloc
24	4	15R10-1AD	Retaining Nut	Camloc
25	2	ZY-400-2-2	Elbow	1/4 T x 1/2 MPT Nylon Swagelok
26	1	ZY-400-3TMT	Male Run Tee	1/4 T x 1/4 T x 1/8 MPT Nylon Swagelok
27	1	ZY-400-P	Plug	1/4 T Nylon Swagelok Nylon
28	1	MS25281-4	Clamp	Nylon
29	7		Screw-Soc. Hd. Cap	#10-24 UNC x .38 Lg. Cres
30	2		Screw-Soc. Hd. Cap	#10-24 UNC x 1.50 Lg. Cres
31	4		Screw-Soc. Hd. Cap	#10-32 UNF x .38 Lg. Cres
32	3	AN960C3	Washer	
33	8	2-008	Seal O-Ring	Parker Compound 674-70
34	1	MBY 2001-CC	Filter Assy.	Pall Trinity Micro Corp
35	1		Tube - High Press.	1/4 OD x .062 Wall x 4.5 Lg. Nylon
36	1		Tube - Conc.	1/4 OD x .062 Wall x 6.0 Lg. Tygon
37	1		Tube - Feed	1/4 OD x .062 Wall x 72.0 Lg. Tygon
38	1		Tube - Filter	3/8 OD x .062 Wall x 6.0 Lg. Tygon
39	1		Tube - Permeate	5/10 OD x .062 Wall x 36.0 Lg. Tygon
49	AR	Grade A	Sealing Comp.	Loctite
41	AR		Tape - Thd. Seal	Teflon
42	AR	Epon 828	Resin	Shell Chem.
43	AR	Versamid	Hardener	Shell Chem.

PARTS LIST

PUMP ASSEMBLY 0600 490001

Item No.	Qty. Req'd	Drawing or Part No.	Nomenclature	Specification
1	2	0600 490004	Piston	
2	1	0600 490002	Housing	
3	1	0600 490003	Head	
4	1	A70544-200	Accumulator	Greer-Olaer Products -316 Cres
5	1	0600 490006	Rocker Assy.	
6	2	0600 490007	Handle Assy.	
7	2	0600 490005	Support, Pump Handle	
8	2	C2949B-4Q	Check Valve	Circle Seal
9	2	ZY400-1-2	Connector, Male	Swage-Lok
10	2		Plug, Pipe	1/8-27 NPT 316 Cres
11	4	12500750	Seal, Polypak	Parker
12	4	Z-012	Seal-O-Ring	Parker
13	4	Z-112	Seal-O-Ring	Parker
14	4	AN960C416	Washer	
15	2		Pin, Cotter	.062 Dia. x .50 Lg. Cres
16	4		Screw, Cap	1/4-20 UNC Thd x .75 Lg. Cres
17	4		Screw, Cap	10-24 UNC Thd x 1.50 Lg. Cres
18	2	MS9464-27	Pin, Headed	.248 Dia. x 1.690 Grip Cres
19	4	NAS620C416L	Washer	
20	2		Set Screw-Hex Soc	4-40 UNC x .19 Lg. Cres Cup Point
21	AR	Grade A	Sealing Compound	Loctite
22	AR		Tape-Thd. Seal	Teflon

DATA LIST

R.O. PURIFIER ASSEMBLY 0600 490000

Line No.	Dwg. Size	Drawing Number	Nomenclature	Original Drawing Date
1	E	0600 490000	Lightweight Hand Operated R.O. Water Purifier Assembly	10-16-72
2	E	0600 490001	Pump Assy. - LWL	10-10-72
3	D	0600 490002	Housing - Hand Pump, LWL	9-15-72
4	D	0600 490003	Head - Hand Pump, LWL	9-14-72
5	B	0600 490004	Piston - Hand Pump, LWL	9-15-72
6	B	0600 490005	Support - Pump Handle, LWL	9-20-72
7	D	0600 490006	Rocker Assy - Hand Pump, LWL	10-4-72
8	D	0600 490007	Handle - Hand Pump, LWL	11-3-72
9	D	0600 490008	Tube Assy - Hand Pump, LWL	9-27-72
10	D	0600 490009	Base Plate - Hand Pump, LWL	9-28-72
11	D	0600 490010	Shell-Outer, Hand Pump, LWL	10-2-72
12	C	0600 490011	End Cap - Hand Pump, LWL	9-29-72
13	A	0600 490012	Tube-Interconnect, LWL	9-11-72
14	D	0600 490013	Pad - Rest	10-4-72
15	D	0600 490014	Arm - Stabilizing Pad	10-4-72
16	C	0600 490015	Block - Rest Pad	10-4-72
17	C	0600 490016	Support - Stabilizing Arm	10-5-72
18	D	0600 490017	Housing Assy - Orifice/Relief Valve	12-6-72
19	C	0600 490018	Clamp - Housing Assembly	12-6-72
20	C	0600 490019	Block - Quick Disconnect Assy	9-19-73
21	B	0600 490020	Spacer - Pad Attach Point	9-19-72
22	B	0600 490021	Orifice - LWL	9-19-73
23	B	0600 490022	Clip - Spool/End Fitting	9-19-73
24	B	0600 490023	Relief Diaphragm	12-5-73
25	B	0600 490024	Plug Assy - Modified, Rel. Dia.	12-5-73
26	B	DL-0600 490000	Data List For R.O. Purifier Assembly	1-29-74

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