



Development of reverse osmosis membranes cast directly on various support materials
by Juin-yih Lai

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
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Abstract:

The reverse osmosis process is characterized by the use of pressure in excess of osmotic pressure to force fresh water at ambient temperature through a selective membrane capable of rejecting dissolved salts. It is a technically feasible process, with good thermodynamic efficiency, flexibility and simplicity.

The purpose of this work was to develop cellulose acetate membranes cast directly on various support materials and optimize the conditions.

Most variables that affect salt rejection and water flux of membranes have been considered in 239 runs. Sixteen different kinds of supports, several types of cellulose acetate, cellulose acetate contents, different ratios of acetone to formamide, heat treatment temperatures, evaporating times, and pressures were tested.

The polyvinyl chloride support is the most promising for cellulose acetate membranes. The type E398-10 cellulose acetate was the best for PVC supports. The best results always came when a casting solution with 21.9% cellulose acetate content was used.

The acetone to formamide ratios were found not to be important.

By adjusting some other variables, such as evaporating time and heat treatment temperature, one can get the same results although the acetone-formamide ratios were different.

Most membranes are very sensitive to heat treatment. Decreasing the heat treatment temperature always increased the water flux and decreased the salt rejection for short evaporating time. It seems the shorter the evaporating time the better the results for cellulose acetate membranes. Membranes with PVC supports are less compressible under high pressure than other membranes.

A set of casting conditions for optimal membranes was found: casting environment: 70°F, 50% humidity; solvent evaporating time: 5 sec.; gelation: 0°C, 1 hour; heat treatment: 84°C, 4 min.; supports: PVC, ES, 2.0 microns, Millipore Corp.; solution: E398-10 cellulose acetate (21.9%)-formamide-acetone ternary solution.

The average water flux and salt rejection, based on 124 hour runs, was 23.5 GSFD and 95.7% respectively.

134
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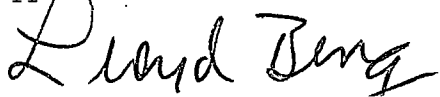
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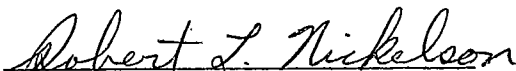
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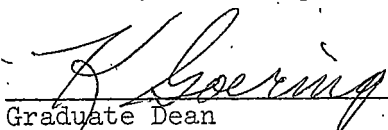
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ABSTRACT

The reverse osmosis process is characterized by the use of pressure in excess of osmotic pressure to force fresh water at ambient temperature through a selective membrane capable of rejecting dissolved salts. It is a technically feasible process, with good thermodynamic efficiency, flexibility and simplicity.

The purpose of this work was to develop cellulose acetate membranes cast directly on various support materials and optimize the conditions.

Most variables that affect salt rejection and water flux of membranes have been considered in 239 runs. Sixteen different kinds of supports, several types of cellulose acetate, cellulose acetate contents, different ratios of acetone to formamide, heat treatment temperatures, evaporating times, and pressures were tested.

The polyvinyl chloride support is the most promising for cellulose acetate membranes. The type E398-10 cellulose acetate was the best for PVC supports. The best results always came when a casting solution with 21.9% cellulose acetate content was used.

The acetone to formamide ratios were found not to be important. By adjusting some other variables, such as evaporating time and heat treatment temperature, one can get the same results although the acetone-formamide ratios were different.

Most membranes are very sensitive to heat treatment. Decreasing the heat treatment temperature always increased the water flux and decreased the salt rejection for short evaporating time. It seems the shorter the evaporating time the better the results for cellulose acetate membranes. Membranes with PVC supports are less compressible under high pressure than other membranes.

A set of casting conditions for optimal membranes was found: casting environment: 70°F, 50% humidity; solvent evaporating time: 5 sec.; gelation: 0°C, 1 hour; heat treatment: 84°C, 4 min.; supports: PVC, BS, 2.0 microns, Millipore Corp.; solution: E398-10 cellulose acetate (21.9%)-formamide-acetone ternary solution.

The average water flux and salt rejection, based on 124 hour runs, was 23.5 GSFD and 95.7% respectively.

I. INTRODUCTION

The water problem - the problem of how to have water in adequate quantity and of adequate quality, available at a reasonable cost, when and where needed - is one of world-wide importance.

A new conventional source of water may be developed today for a cost of 13 cents to 70 cents per thousand gallons. It is estimated that by 1980 this cost will have risen to 20 cents to 90 cents per thousand gallons ⁽¹⁾. In terms of improvements in technology and/or equipment, there is little potential for savings in this respect. Clearly, desalination will be a part of the solution of the total water problem.

Many processes have been tried for desalination. Some of them have been used in actual large desalination plants in many countries. Those are: multistage flash distillation, longtube vertical distillation, electrodialysis (brackish water only), vapor compression distillation, direct freezing, and reverse osmosis.

Saline water conversion is still in its infancy, since the cost of desalination is still relatively high. But, in some areas desalination is even now competitive with other means of obtaining usable water.

It was reported that cost of fresh water obtained by small desalination plant (multi-stage flash evaporation) was about \$.80 to \$1.10 per thousand gallons, and for a large plant 20-40 cents per thousand gallons (50 million gallons per day products or more) with present technology ⁽¹⁾.

Recently, reverse osmosis is one of the most interesting processes. Possibly the most important reason is the recent development of membranes which combine good salt rejection with moderately high water flux. Second, is the appealing conceptual simplicity of the method, which essentially consists of removal of salt by filtering it away from water under pressure.

Third, this process tends to avoid scaling problems and to minimize corrosion since it always operates at ambient temperature. Fourth, the energy requirements for the process are low. The theoretical minimum of work for desalting sea water at 25°C is 2.65 Kilowatt-hours per thousand gallons. The energy consumption of multistage flash distillation and long-tube vertical distillation, for example, is six times that of the reverse osmosis process⁽³⁾.

The reverse osmosis process is characterized by the use of pressure in excess of osmotic pressure to force fresh water at ambient temperature through a selective membrane capable of rejecting dissolved salts. The process name is derived from the phenomenon whereby water under an applied pressure driving force flows in a reverse direction to the flow in an osmotic experiment where the driving force is the concentration gradient.

The most important part of reverse osmosis equipment is the membrane. The important membrane properties are water flux, salt rejection and membrane life. Flux is usually given in gallons/ft.²-day (GSFD) and salt rejection is usually given as % salt rejection or salt reduction factor. = 100/(100-percent rejection). Many kinds of membranes have been

tried for reverse osmosis, some of them with high rejection but very low flux, such as ethyl cellulose-poly-acrylic acid membranes, and some of them with high flux but low rejection, such as poly-acrylonitrile membranes.

Cellulose acetate is the most promising membrane which provides high rejection and moderately high flux. The first recognition that salt rejection by membranes might be useful in desalination seems to have been by Reid at the University of Florida⁽³⁾. Reid and Breton obtained a maximum water flux of .945 GSFD and salt reduction factor of 25 (96% salt rejection) from their cellulose acetate membranes.

Since then cellulose acetate membranes have been improved quite rapidly. Total cost for products by the reverse osmosis process, using cellulose acetate membranes, is still high. It is mainly caused by the low flux and short membrane life.

General Atomic Division of General Dynamics has proposed a design for a 1 million gallon per day reverse osmosis pilot plant. The minimum cost of fresh water produced by this pilot plant was estimated to be 75.5 cents per thousand gallons from sea water⁽⁶⁾.

The water flux of their membranes is about 10 GSFD under 1440 psi. pressure. If the flux can be increased to 20 GSFD and keep the other conditions the same, for example, the cost of fresh water obtained from this pilot plant could be reduced to about 50 cents per thousand gallons⁽³⁾.

In this pilot plant the cost of membrane replacement is about one third of the total cost. It is reported that the labor cost of membrane replacement would be much higher than the cost of the membrane itself. It is believed that the membranes cast directly onto porous supports could reduce the high labor cost of membrane replacement, as a shorter time and more simple procedure would be required to replace the membrane.

Donald Wang⁽⁵⁾ has successfully investigated a membrane by using direct casting on porous supports. His membrane, cast from cellulose acetate (E-400 -25, 21.9%) formamide (31.2%) acetone (46.9%) ternary solution on rigid porous epoxy filled fiberglass supports (Gelman Versapor .9 micron), can provide an average water flux of 21 GSFD and 95% salt rejection.

The purpose of this work is to develop cellulose acetate membranes cast directly on other support materials and optimize the conditions.

Most variables that affect salt rejection and water flux of membranes have been considered in 239 runs. Different kinds of membrane support, casting solution composition, heat treatment temperature, solvent evaporating time and operating pressure are all important. Sixteen different kinds of supports, five types of cellulose acetate, six different cellulose acetate contents, five different ratios of formamide to acetone and several evaporating times have been tested in fabricating membranes. Several different heat treatment temperatures were used before the membranes were tested at three pressures.

In all processes for water desalination, the water and the salt to be separated must ultimately diffuse apart by molecular diffusion. Thus, at the phase boundary where the separation is effected there will be a salt-concentration boundary layer, the salt concentration at the phase boundary exceeding that in the bulk brine. This salt-concentration polarization is important in desalination by reverse osmosis. For simplicity, the film-theory was used for the turbulent flow. The boundary layer is idealized as a thin, liquid film in which eddy motion is assumed to be negligible and therefore mass transport takes place by molecular diffusion alone.

The following equation⁽⁴⁾ expresses the film theory prediction for the salt concentration build-up at the membrane surface in terms of the permeation flux, the fluid mechanical parameters, and Schmidt number, N_{sc} , for salt diffusion. For a high salt rejection membrane, approaches unity.

$$\frac{C_2'}{C_2^b} = \frac{\exp[(v'/j_D \bar{U}) N_{sc}^{2/3}]}{r + (1-r) \exp[(v'/j_D \bar{U}) N_{sc}^{2/3}]}$$

where

C_2' = salt concentration at membrane interface,
g/cm³

C_2^b = salt concentration in bulk solution
g/cm³

v' = product water flow velocity through the membrane, cm/sec.

j_D = Chilton-Colburn mass transfer j-factor

N_{sc} = Schmidt number for salt diffusion

$\bar{U}$ = average velocity over the cell, cm/sec.

r = salt rejection

II. EQUIPMENT AND PROCEDURE

A. MEMBRANE FABRICATION EQUIPMENT

A constant temperature and humidity chamber was used for membrane casting of all runs. The chamber was constructed with a fiber glass body, a safety glass window (10 1/2" x 32") in front of the chamber, and two 6" diameter rubber plate covered working holes on the front chamber door (40" x 10"). The chamber contains lights, a heater, cooler, fan, two salt solution containers and a thermoprobe connected to an electronic temperature controller. The temperature was kept at $24.5 \pm 0.2^{\circ}\text{C}$ and humidity was kept at 50% by using saturated $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ salt solution. A level aluminum surface with the dimensions of 8 inches by 5 inches was used for membrane casting in order to produce even membrane thicknesses.

B. TEST CELL

The test cells shown in Figure 4 were made of stainless steel 304 blank flanges with 4.5" outside diameter and a 2" diameter test area. The membrane was supported by a 1/8 inch porous stainless steel plate (Grade H, pore size 5 microns, Pall Corp.) which was mounted between the two halves of the cell. The salt water under pressure was circulated through the upper half.

C. MEMBRANE TEST SYSTEM AND FLOW DIAGRAM

The flow diagram is shown in Figure 5. The test system consisted of four test cells, a filter, two parallel test lines, and a plastic feed tank with stirrer and cooler. System pressure was controlled with

backpressure regulators. A nitrogen cylinder was used to load the regulators.

The pressure used for all runs was 800 psi. except Runs 185, 186, 187, and 188. The temperature of the feed solution (1% NaCl) was kept at 25°C. Control of the cooling water rate can control the temperature of the feed solution. A maximum feed flow rate of 11.4 ml./sec. was used. The average volume of the test cells was 8.3 ml., so that the feed in the cell was replaced every 0.73 sec. and the average feed flow velocity across the cell was 7.9 cm./sec.

D. TEST PROCEDURE

The following is the membrane fabrication procedure used for this study. The support was fixed on the aluminum plate with masking tape which was about .005" thick. A glass rod was used to spread the solution smoothly onto the support, with the tape as a thickness guide, in a constant temperature and humidity chamber. The cast solution was evaporated as long as needed. The aluminum plate was immersed with the membrane in 0°C ice water for one hour. Then the membrane was heat treated with the aluminum plate in hot water which had been heated to the required temperature. The heat treatment time used was four minutes. The membrane was immersed in cold water until it was tested. It was cut to the dimension to fit the test cell when it was tested.

The membranes were firmly mounted in the test cells with the cellulose acetate film facing the high pressure side. The pump was started

and the pressure gradually increased until 800 psi was reached. Cold water to the cooler was adjusted to keep the temperature of the feed solution at 25°C. The feed concentration was checked when every sample was taken. The sample was taken once every hour or two and most membranes were tested four to eight hours.

A conductivity bridge (Industrial Instruments Model RC-16 B-2) was used in conjunction with a conductivity cell to analyse the concentration of salt water and product water. The relationship between concentration and resistance can be approximately expressed as:

$$C_t = \frac{6.4 - (t-25) \times .1}{(R_t) 1.0496}$$

where

C_t = salt water concentration, moles/liter

t = temperature of conductivity measurement, °C

R_t = resistance at temperature t , ohms

This equation was used to calculate concentration from different temperature and resistance to make a plot of concentration versus resistance at different temperatures. This plot, Figure 6, was used to convert the resistance of every sample to concentration. Periodically this curve was checked against standard NaCl solutions.

III. RESULTS

Two hundred and thirty-nine membranes have been made to optimize conditions among the variables which affect the salt rejection and water flux of membranes. The results of all of these tests are tabulated in Table XI.

A. SUPPORTS

The membrane support has an important effect upon the properties of the membrane. Possible membranes that were considered are shown in Table I.

Nine kinds of filter materials were studied: mixed esters of cellulose, nylon, Millipore proprietary, teflon, polyvinyl chloride, polyvinylidene fluoride, Gelman Versapor, cellulose triacetate and α -cellulose.

The range of pore size of the supports which were tested varied from .05 to 5.0 microns.

The first casting solution contained 21.9% E398-10 cellulose acetate, 31.2% formamide, and 46.9% acetone. In the evaluation of the supports, the following factors were kept constant: casting environment - 70°F, 50% relative humidity; solvent evaporating time - 5 seconds; gelation - 0°C, 1 hour; heat treatment - 86°C, 4 minutes.

Table II shows that polyvinyl chloride is the most promising material. Two different pore sizes of this material are promising. BD (.6 micron) gives the highest water flux (31.5 GSFD) and moderately high

salt rejection (93%). BS (2.0 microns) gives the best salt rejection (97.3%) and a high water flux (21.3 GSFD).

Teflon gives very high water flux, 30.4 GSFD, but low salt rejection 76.5%.

For the same material, pore size near .6 micron seems to always give higher water flux than other pore sizes for the solution using E398-10 type cellulose acetate. It is true for polyvinyl chloride, as previously shown, and also true for Versapor, mixed esters of cellulose and Millipore proprietary filters.

Use of E400-25 type of cellulose acetate instead of E398-10 cast on different kinds of materials shows quite different results. These tests were made keeping solution composition and other variables the same. The results are shown in Table III. By using E400-25 cellulose acetate, Versapor can get best results, especially in the .9 micron size..

B. CELLULOSE ACETATE TYPE

Five different grades of cellulose acetate (E398-3, E398-10, E394-45, E394-60, E400-25) were studied. The acetyl contents of E398, E394, and E400 are 39.8, 39.4 and 39.9 percent respectively. The viscosities of E398-3, E398-10, E394-45, E394-60, and E400-25 are 1.8 to 3.9; 8.0 to 13.0; 39 to 52; 53 to 75 and 17 to 35 seconds, respectively. The melting point range of these cellulose acetates is from 230 to 260°C.

E400-25 cellulose acetate can give better results for Versapor

support than E398-10, E394-3, E394-60, and E400-45. Versapor was the only support studied by Wang⁽⁴⁾ when he considered the effect of type of cellulose acetate.

The author has studied the effect of type of cellulose acetate on other different supports, BD (PVC, .6 micron), BS (PVC, 2.0 micron) and VF6 (polyvinylidene fluoride, .45 micron).

Table IV shows how different cellulose acetates affect the water flux and salt rejection for BD supports with all variables except heat treatment temperature kept constant.

E398-10 gives highest water flux and rather high salt rejection, and E398-3 gives the highest salt rejection and a rather high water flux. It is obvious that E398 is the best type for BD (PVC, .6 micron) supports. When BS (PVC, 2.0 microns) was studied, only E398-10 and E398-3 were considered. The best results of 21.3 GSFD average water flux and 97.3% average salt rejection can be obtained by using E398-10 cellulose acetate.

Table V shows that E400-25 is the best cellulose acetate type for polyvinylidene fluoride supports among E398-10, E398-3, E394-60, and E400-45.

C. COMPOSITION OF SOLUTION

1. Ratio of Acetone and Formamide

With the cellulose acetate content at 20%, four different ratios of acetone to formamide, 1, 1.25, 1.75, and 2 have been studied.

The usual ratio used in most runs is 1.5. The purpose of this study is to see if there is any other ratio of acetone to formamide that can give better results than that of 1.5.

Table VI lists those different acetone-formamide ratios with different evaporating time. Three different evaporating times, 10, 20, and 30 seconds have been tested for ratio of 2 with the best results at 20 sec. and the best result at a ratio of 1.75 is when 10 seconds (among three different evaporating times 5, 10, and 20 seconds) evaporating time is used.

When evaporating time is kept the same, increase of the ratio always decreases the salt rejection. It was shown in salt rejection versus acetone-formamide ratio on Figure 1. Five seconds, 10 seconds, and 20 seconds of evaporating time have been plotted. Though ratios around 1.25 to 1.75 could give a little higher water flux, yet they still could not affect flux much. It is shown in water flux versus acetone-formamide ratio on Figure 2. When the evaporating time is kept the same, the flux only shows little differences though the ratios are different. It also shows that short evaporating time always gives higher water flux.

By adjusting the evaporating time and heat treatment temperature, almost the same results could be gotten, though the acetone and formamide ratios are different. For example, Runs 129 and 130, acetone and formamide ratio 2.0, evaporating time 20 seconds, heat treatment 84°C, gave almost the same results as Runs 94 and 95, ratios 1 and 5 seconds

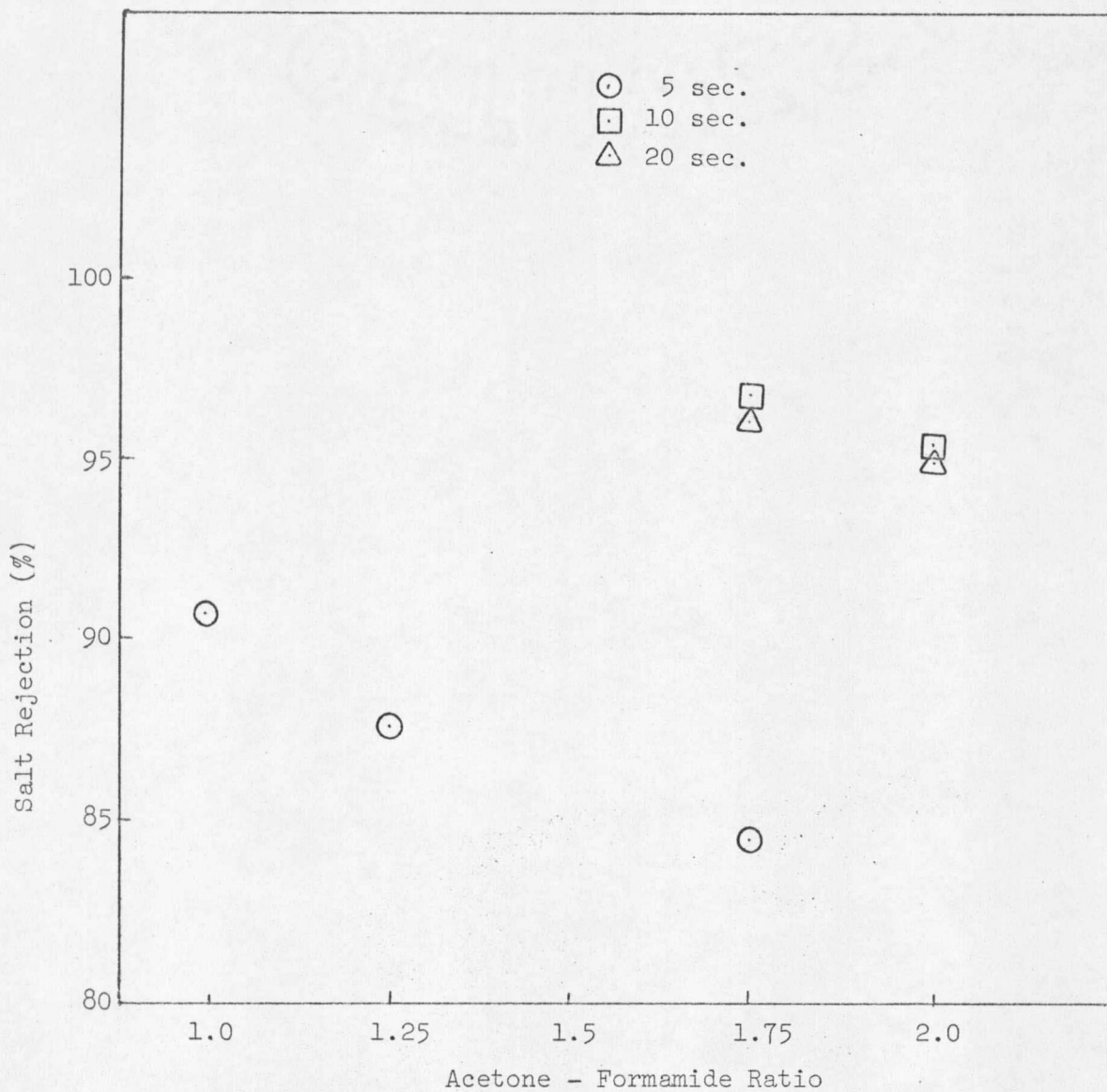


Figure 1. Effect of Acetone-Formamide Ratio and Evaporating Time on Salt Rejection.

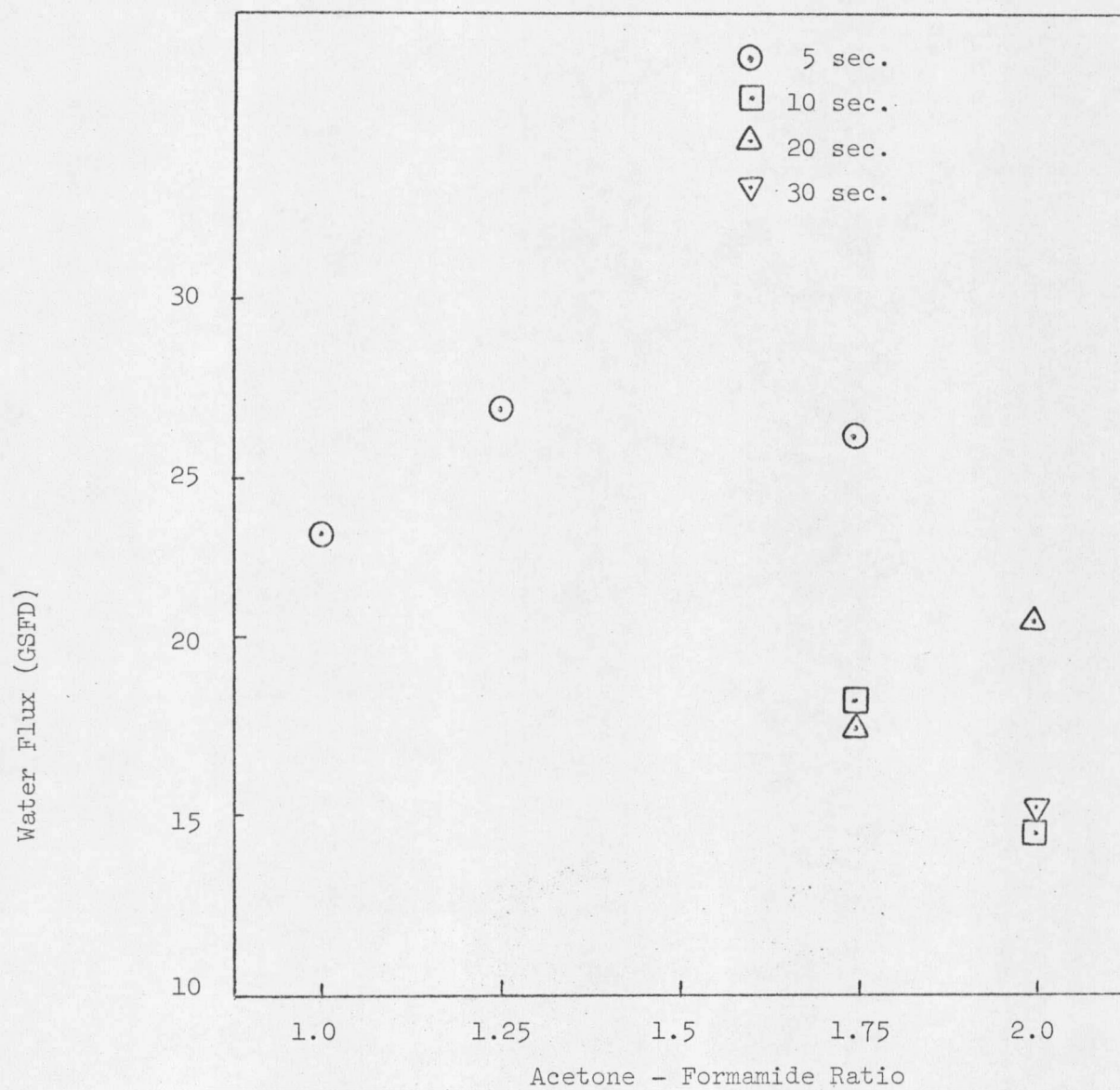


Figure 2. Effect of Acetone-Formamide Ratio and Evaporating Time on Water Flux.

evaporating time, 86°C heat treatment temperature. From this fact, the ratio of acetone and formamide of most of the other runs has been 1.5.

2. Cellulose Acetate Content

Four different percentages of cellulose acetate, 25, 21.9, 20 and 15 have been studied for membranes using E398-10. The results are shown on Table VII. The membranes cast on BD (polyvinyl chloride, .6 micron) supports were considered first. The best water flux of 31.5 GSFD with 93.0% salt rejection was obtained with 21.9%. The best salt rejection with moderately high water flux (18.1 GSFD of flux, 97.1% salt rejection) was obtained with 20%.

When cellulose acetate content of 20% was tried on BS (polyvinyl chloride, 2.0 microns) supports, the average water flux was 3.7 GSFD, and average salt rejection was 96.9%. Changing the cellulose acetate content to 21.9% changed both water flux and salt rejection to average values of 21.3 GSFD and 97.3%, respectively.

When E398-3 was used instead of E398-10, membranes that were cast on BD supports showed that membranes containing 21.9% cellulose acetate gave a little better results than those membranes which contained 20%.

Five different percentages of E400-25 cellulose acetate: 10, 12.5, 15, 20 and 21.9, have been tested on Versapor supports. These showed that 21.9% cellulose acetate content gave the best results.

D. HEAT TREATMENT

Wang's study showed that more than four minutes of heat treatment time could not give better results than four minutes did. So, four minutes of heat treatment time has been used for all runs.

Table VIII shows the effect of six different heat treatment temperatures on the results of membranes cast from E398-3 cellulose acetate solution on BD supports (polyvinyl chloride, .6 micron). These data are shown on Figure 3. Five seconds of evaporating time has been used for all runs listed. This shows that decreasing the heat treatment temperature always increases the water flux. This fact is just as true for the case of short evaporating time. For longer evaporating times decreasing the heat treatment temperature may decrease the water flux.

For example, evaporating time and heat treatment temperature of Runs 96 and 97 were 30 seconds and 84°C, respectively, and that of Runs 121 and 122 were 30 seconds and 82°C, respectively. The former gave higher water flux than the latter. There were some more examples which can be seen in Table IX.

Table VIII shows that salt rejection for those membranes did not change much around 86, 84 and 82°C of heat treatment temperature and changed considerably when the temperature was decreased down to 81, 80 and 78°C. When cellulose acetate type of E400-25 was used instead of E398-3, it still showed that decreasing the heat treatment always decreased the salt rejection. This can be seen in Table IX. It is also true for other

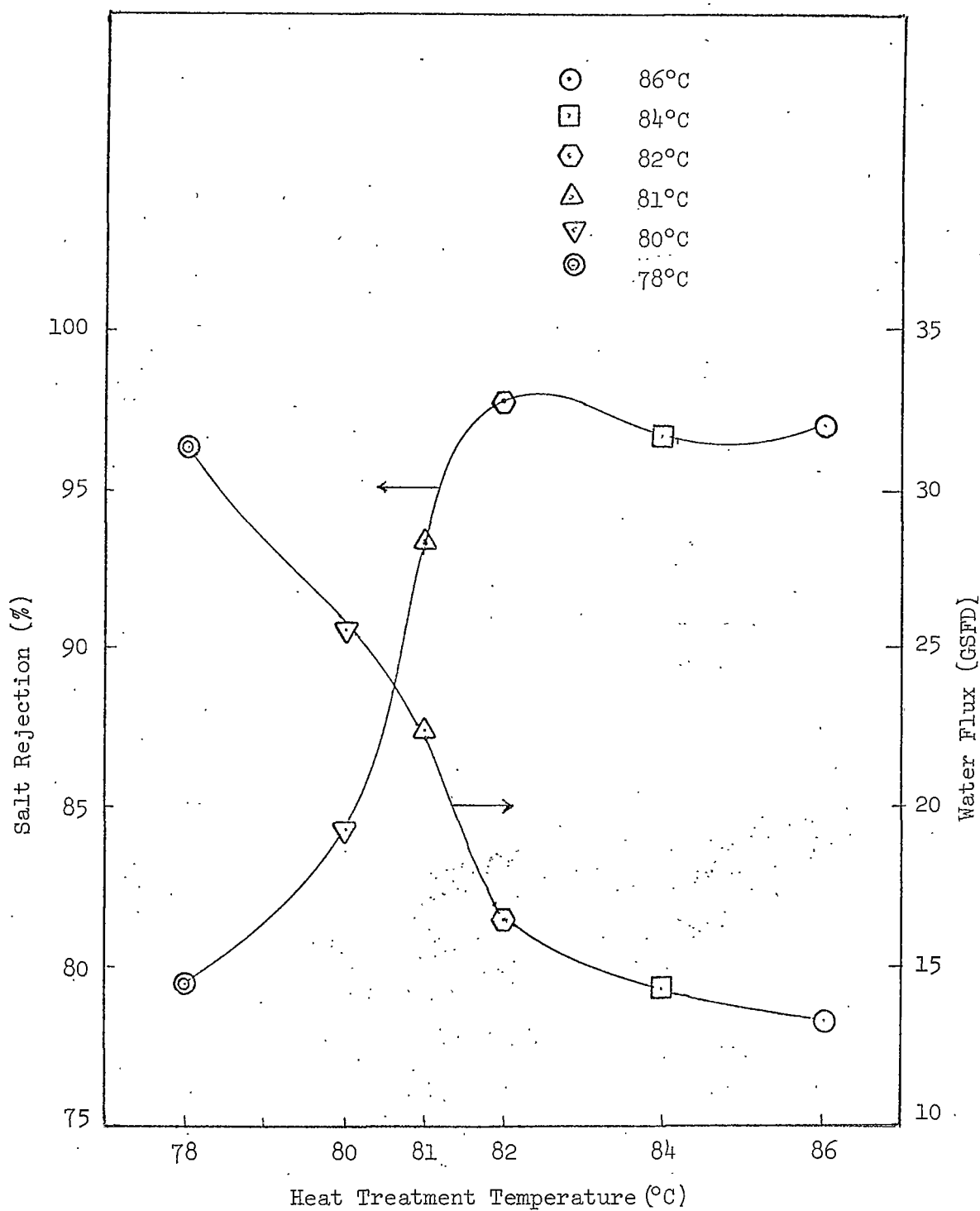


Figure 3. Effect of Heat Treatment (BD, E398-10-21.9%)

membranes with different types of cellulose acetate. The effect of heat treatment on both salt rejection and water flux can be clearly seen in Figure 3.

E. EVAPORATING TIME

Short evaporating time always gives higher water flux and slightly lower salt rejection than longer evaporating time. Many illustrations can be found in Table XI. Considering both water flux and salt rejection, it seems the shorter the evaporating time the better the results for cellulose acetate membranes.

F. MEMBRANE LIFE

Several 124 hours long runs were studied for membrane life. The membranes of Runs 22, 27, 28 and 53 were reused after one and a half months as Runs 185, 186, 187 and 188 respectively. Those four membranes were BD supports, 21.9 cellulose acetate content, 86°C heat treatment temperature. The average water flux and salt rejection in first four hours were 31.5 GSFD and 93.0%, respectively, and that of the 124 hours period, 28.3 GSFD and 92.0%, respectively. At the end of 124 hours, flux and salt rejection decreased 16.5 and 1.9% in average, respectively from the start.

The membranes of Runs 225 and 228 which were made of BS supports, 21.9% cellulose acetate content, 84°C heat treatment temperature were reused in 124 hours long Runs 237 and 238 after 18 days. The water flux and salt rejection at the end of 124 hours were decreased 9.2 and .73% from the start, respectively. This fact showed that the membranes

immersed in water for shorter periods appear to be better. The average water flux and salt rejection were 23.5 GSFD and 95.7, respectively, based on 124 hours period.

G. PRESSURE

After the 124 hour long run the same four membranes (22, 27, 28, and 53) were tested under changing pressure. Taking the water flux at 800 psi as a basis, the average water flux at 1200 psi was 1.385 times that at 800 psi and that at 1500 was 1.82 times. These results are given in Table X.

In theory water flux is proportional to driving force ($P - \pi$) where π is osmotic pressure (for 1 weight % sodium chloride solution $\pi = 115$ psi). Then water flux at 1200 psi should be 1.59 times that at 800 psi, and at 1500 psi should be 2.03 times that at 800 psi.

Let the actual water flux value divided by the theoretical value be the efficiency. Then the average efficiency at 1200 psi is 87.3% and that at 1500 psi is 89.7%. On the same basis, Wang's membranes gave efficiencies at 1200 psi and 1500 psi of 79.9% and 69.9%, respectively.

It showed that the newly developed membrane is less compressible under higher pressure than Wang's membrane. The usually optimum pressure used in reverse osmosis desalination plants is around 1500 psi.

To increase the pressure increases the salt rejection slightly for this type of membrane.

H. DIFFERENT BATCH OF CELLULOSE ACETATE

The author found that different batches of cellulose acetate affected the water flux and salt rejection of membranes. The membranes of Runs 22, 27, 28, and 53 as well as Runs 191, 192 and 193 were made by the same procedure and same conditions except the cellulose acetate was from a different batch made by Eastman Corp. The average water flux and salt rejection of Runs 22, 27, 28, and 53 were 31.5 GSFD and 93.0%, respectively. And the average flux and salt rejection of Runs 191, 192, and 193 were 11.5 GSFD and 97.7%, respectively. It appears that any attempt to make optimal membranes from this new lot of cellulose acetate would require a new set of casting conditions.

IV. CONCLUSION

The polyvinyl chloride support, polyvic BS, Millipore (2.0 microns) was the most promising among those commercially available porous supports that were tested. It is strong, flexible, easy to cast, shrinks less during the heat treatment, and can stand high pressure.

The author found the optimum conditions for membranes by direct casting on polyvinyl chloride porous support (Millipore, BS, 2.0 microns) to be as follows when cast at 70°F and 50% humidity:

Casting solution: cellulose acetate E398-10 (acetyl content 39.8%, viscosity 10 sec., lot no. LS1440 Eastman Chemical Company) 21.9%, formamide 31.2%, acetone 26.9% by weight.

Casting solution layer thickness: $.005 \pm .001$ inches.

Solvent evaporating time: 5 seconds.

Gelation: 0°C, 1 hour in water.

Heat treatment: 84°C, 4 min. in water.

The average water flux and salt rejection based on 124 hours long run were 23.5 GSFD and 95.7%, respectively.

V. APPENDIX

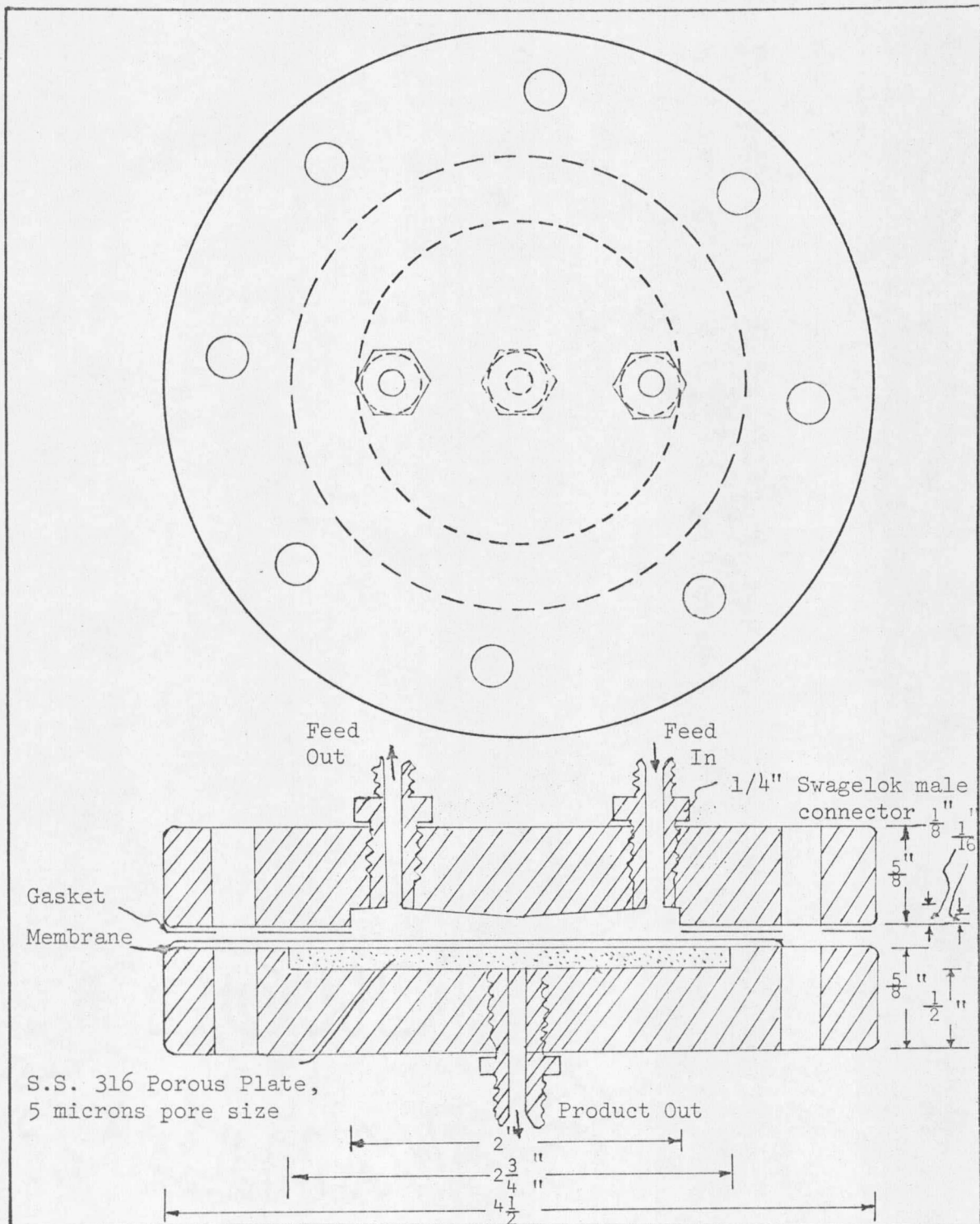


Figure 4. Test Cell

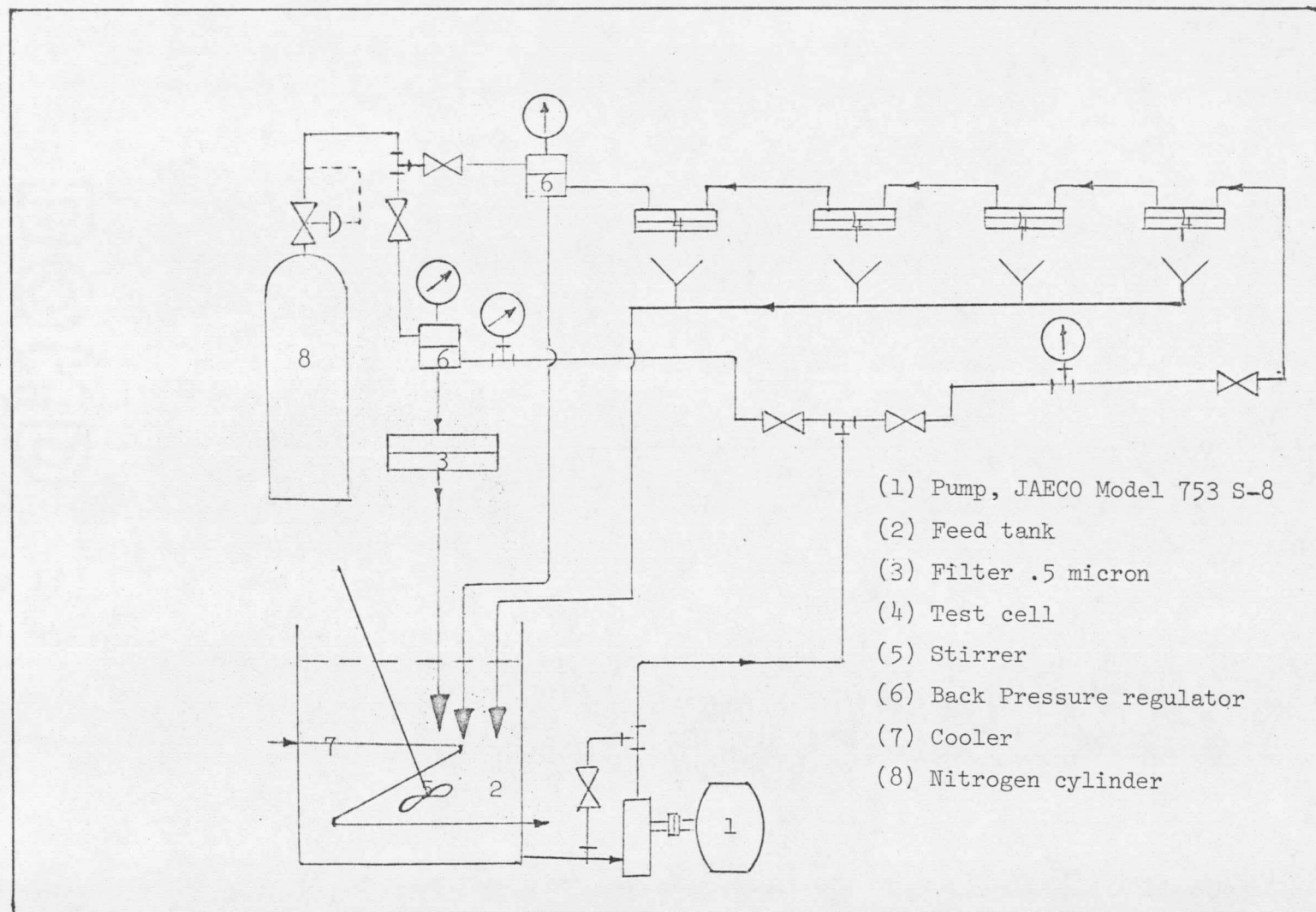


Figure 5. Test System and Flow Diagram

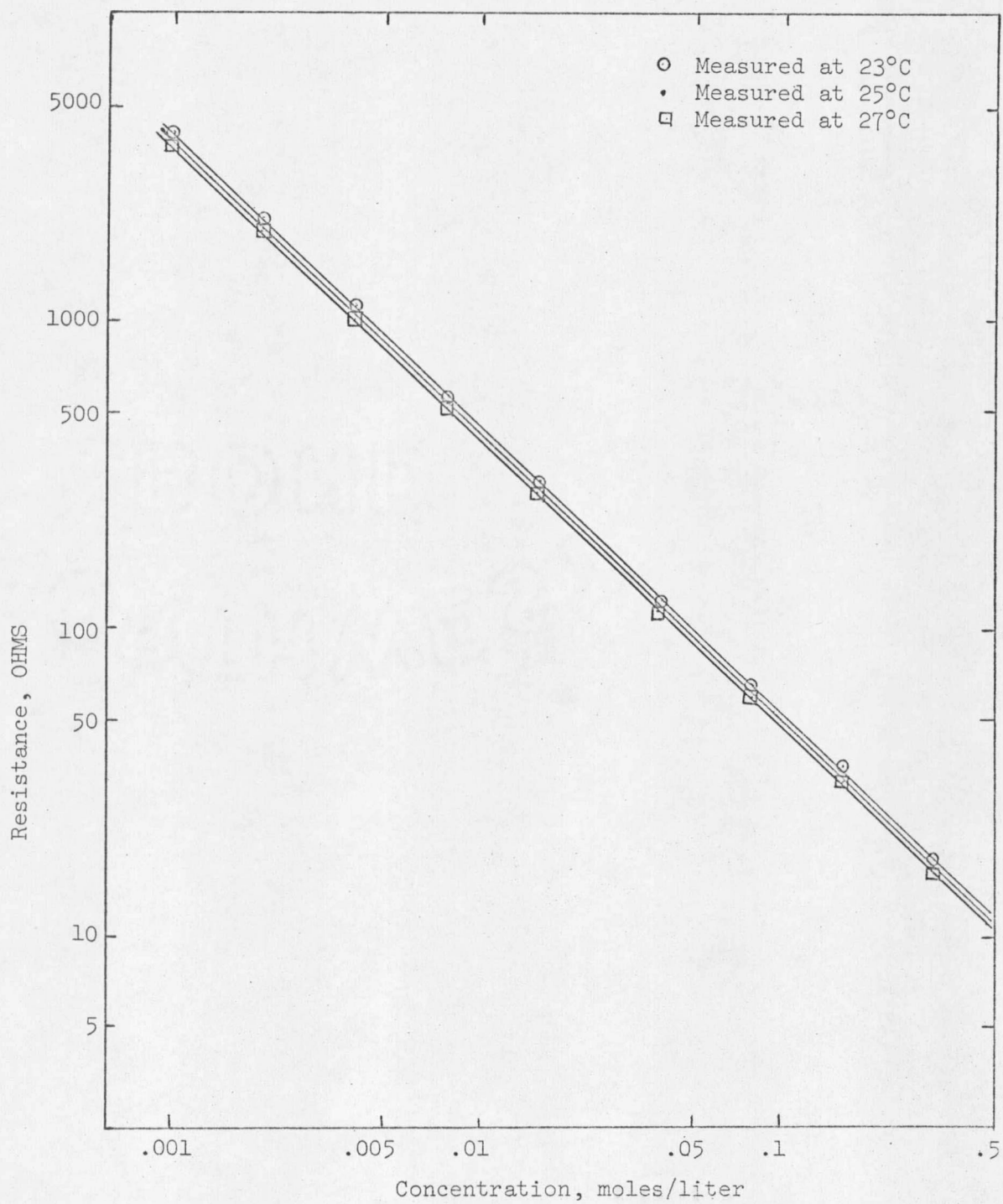


Figure 6. Calibration of Conductivity Cell

TABLE I. Characteristics of Supports

Material	Commercial name	Pore size (micron)	Acetone resistance ***	Remark
*Mixed esters of cellulose	MF-Millipore, VC AA GS	0.1 0.8 0.22	III	bad membrane formation, hard to cast GS, completely dissolved
*Nylon	Duralon NR	1.0	II	strong, flexible fair membrane formation
*Proprietary	Solvinert UH UG	0.5 0.25	II	good membrane formation
*Teflon	Mitex LS	5.0	I	stable at temperatures in excess of 500°F good membrane formation
*Polyvinyl chloride	Polyvic BD BS	0.6 2.0	III	strong, flexible easy to cast excellent membrane formation
**Polyvinylidene fluoride	VF-6	0.45	III	low strength, hard to cast fair membrane formation
**Triacetate	GA-8 GA-6 GA-10	0.2 0.45 0.05	II	hard to cast
**Versapor	Versapor 6424 6429	5.0 0.9	I	easy to cast
**Cellulose	Alpha-8	0.2	I	hard to cast

* Millipore Corporation

** Gelman Corporation

*** I No chemical effect on filter.

II Slight swelling or distortion, but satisfactory for fluid cleaning and sterilizing.

III Filter dissolves or disintegrates.

TABLE II. Effect of Type of Support (I) (E398-10)

Material	Commercial name	Pore size (micron)	Av. W.F. (GSFD)	Av. S.R.(%)
Mixed esters of cellulose	VC	.1	No flux	
	AA	.8	2.9	91.3
Nylon	NR	1.0	7.2	66.3
Mill. proprietary	UH	.5	22.5	87.5
	UG	.25	18.5	77.1
Teflon	LS	5.0	30.4	76.5
Polyvinyl chloride	BD	.6	31.5	93.0
	BS	2.0	21.3	97.3
Polyvinylidene fluoride	VF6	.45	14.0	85.6
Triacetate	GA8	.2	3.7	88.2
	GA6	.45	2.6	92.5
	GA10	.05	No flux	
Versapor		5.0	11.6	90.5
		.9	21.7	88.5
Cellulose	ALPHA-8	.2	2.3	95.4

Solution: Cellulose acetate (E398-10) 21.9%, formamide 31.2%, acetone 46.9%

Casting environment: 70°F, 50% humidity

Solvent evaporating time: 5 sec.

Gelation: Temp., 0°C; Time, 1 hr.

Heat treatment: Temp., 86°C; time, 4 min.

TABLE III. Effect of Type of Supports (II) (E400-25)

Material	Commercial name	Pore size (micron)	Av. W.F. (GSFD)	Av. S.R.(%)
Mixed esters of cellulose	AA	.8	12.2	81.7
Nylon	NR	1.0	4.7	94.8
Mill. proprietary	UH	.5	10.2	91.4
	UG	.25	5.9	85.8
Teflon	LS	5.0	5.8	96.0
Polyvinyl chloride	BD	.6	12.5	96.0
	BS	2.0	10.0	93.8
Polyvinylidene fluoride	VF6	.45	12.8	97.2
Versapor		5.0	24.5	85.5
		.9	21.0*	95.0*

Solution: Cellulose acetate (E400-25) 21.9%, formamide 31.2%, acetone 46.9%

Casting environment: 70°F, 5 sec.

Gelation: Temp., °C; time, 1 hr.

Heat treatment: Temp., 86°C; time, 4 min.

* Wang's best membranes

TABLE IV. Effect of Type of Cellulose Acetate (I) (BD Supports)

Type of Cellulose Acetate	Temperature	Run No.	W.F. (GSFD)	S.R. (%)	Av. W.F. (GSFD)	Av. S.R. (%)
398-10	86°C	R-22	34.0	94.0		
	"	R-27	29.2	94.5		
	"	R-28	38.5	90.0		
	"	R-53	24.5	93.4	31.5	93.0
400-25	86°C	R-31	15.8	98.0		
	"	R-32	12.2	98.0		
	"	R-43	11.8	91.0		
	"	R-44	9.3	87.0	12.5	96.0
	84°C	R-47	29.1	73.5		
	"	R-48	25.6	86.5	27.4	80.0
	84°C	R-51	11.6	84.5		
	"	R-52	11.0	77.5	11.3	81.0
394-60	84°C	R-49	Almost No Flux			
	"	R-50	Almost No Flux			
398-3	82°C	R-210	16.7	97.5		
	"	R-211	16.3	98.0	16.5	97.8

Support: BDWP 14200 (PVC, Millipore)

Solution Composition: Cellulose Acetate 21.9%, Formamide 31.2%, Acetone 46.9%.

Casting Environment: 70°F, 50% humidity.

Solvent Evaporating Time: 5 sec.

Gelation: Temp., °C; Time 1 hr.

Heat Treatment: 4 min.

TABLE V. Effect of Type of Cellulose Acetate (II) (VF6 Supports)

Type of Cellulose Acetate	Temperature	Run No.	W.F. (GSFD)	S.R. (%)	Av. W.F. (GSFD)	Av. S.R. (%)
398-10	86°C	R-3	22.2	96.5		
	"	R-5	10.5	98.0		
	"	R-20	12.2	58.5		
	"	R-24	15.0	76.5		
	"	R-66	10.0	98.4	14.0	85.2
	84°C	R-67	14.0	84.5		
	"	R-68	10.0	92.5	12.0	88.5
398-3	86°C	R-71	35.0	62.0		
	"	R-72	44.5	41.3		
	"	R-73	10.5	86.5		
	"	R-74	11.5	94.0	25.4	70.9
394-60	86°C	R-69	13.5	76.5		
	"	R-70	19.0	73.5	16.3	75.0
400-25	84°C	R-56	31.4	90.6		
	"	R-57	27.9	90.0	29.7	90.3
	86°C	R-29	2.3	96.4		
	"	R-37	16.3	97.5		
	"	R-41	14.5	97.0		
	"	R-42	10.0	97.5		
	"	R-46	21.0	97.5	12.8	97.2

Support: Polyvinylidene fluoride, VF6, .45 micron, Gelman.

Solution Composition: Cellulose Acetate 21.9%, Formamide 31.2%, Acetone 46.9%.

TABLE VI. Effect of Ratio of Formamide and Acetone

Run No.	Ratio	Evaporating Time (Sec.)	W.F. (GSFD)	S.R. (%)	Av. W.F. (GSFD)	Av. S.R. (%)
R96	1:2	30	12.8	97.5		
R97	"	"	17.5	98.0	15.2	97.8
R88	"	20	17.5	94.5		
R89	"	"	23.4	95.4	20.5	95.0
R129*	"	"	17.5	92.2		
R130*	"	"	29.0	88.2	23.3	90.2
R109	"	10	15.2	95.5		
R110	"	"	14.0	95.0	14.6	95.3
R90	1:1.75	20	17.5	95.7		
R91	"	"	17.5	96.5	17.5	96.1
R98	"	10	21.0	97.0		
R99	"	"	14.5	96.5	17.8	96.8
R100	"	5	23.4	86.5		
R101	"	"	28.0	77.5	25.7	84.5
R92	1:1.25	5	21.0	87.6		
R93	"	"	31.6	87.6	26.3	87.6
R94	1:1	5	22.2	90.0		
R95	"	"	23.4	91.5	22.8	90.7

Cellulose acetate content: 20% (E400-25)

Support: Versapor, .9 micron

Heat Treatment; Temp., 86°C; time, 4 min.

*Heat treatment temperature: 84°C

TABLE VII. Effect of Cellulose Acetate Content (E398-10 on BD Support)

Run No.	C. A. Content (WT.%)	Heat Treatment Temp. (°C)	W.F. (GSFD)	S.R. (%)
R145	25.0	86	2.6	95.7
R146	"	"	1.9	95.4
			Av. 2.3	95.6
	21.9*	"	Av. 31.5	93.0
R151	20.0	88	5.7	98.2
R152	"	"	6.0	98.7
R153	"	"	7.0	98.4
R154	"	"	10.5	98.0
R155	"	"	7.0	98.6
R156	"	"	13.0	98.0
			Av. 8.2	98.3
R149	"	86	20.0	96.5
R150	"	"	19.0	98.0
R159	"	"	16.3	96.3
R160	"	"	17.0	97.5
			Av. 18.1	97.1
R137	"	84	12.3	96.5
R138	"	"	15.8	95.4
R157	"	"	20.4	94.1
R158	"	"	24.8	90.8
			Av. 18.3	94.2
R147	15.0**	86	Almost no flux	
R148	"	"	"	

* Data have been shown in Table II

** Evaporating time 60 sec., the other runs are 5 sec.

TABLE VIII. Effect of Heat Treatment (I) (E398-3-21.9%)

Run No.	Heat Treatment Temp. (°C)	Water Flux (GSFD)	Salt Rejection (%)
R62	86	10.5	97.0
R200	"	14.6	97.0
R201	"	12.3	98.4
R204	"	12.8	97.0
R205	"	<u>16.3</u>	<u>95.7</u>
		Av. 13.3	97.0
R202	84	16.5	96.2
R203	84	<u>12.2</u>	<u>97.0</u>
		Av. 14.4	96.6
R210	82	16.7	97.5
R211	"	<u>16.3</u>	<u>98.0</u>
		Av. 16.5	97.8
R217	81	23.0	93.4
R218	"	26.0	93.4
R219	"	20.7	93.6
R220	"	<u>20.3</u>	<u>93.7</u>
		Av. 22.5	93.5
R212	80	25.6	96.3
R213	"	20.4	85.5
R216	"	<u>30.4</u>	<u>70.5</u>
		Av. 25.5	84.3
R214	78	31.5	88.6
R215	"	<u>31.5</u>	<u>70.5</u>
		Av. 31.5	79.6

Support: PVC, BD;

Solvent Evaporating time: 5 sec.

TABLE IX. Effect of Heat Treatment (II) (E400-25, 20%)

Run No.	F./A.	Evaporating Time (sec.)	Heat Treatment Temp. (°C)	W.F. (GSFD)	S.R. (%)
R41	1:1.5	5	86	15.2	97.0
R42	"	"	"	10.5	97.5
				Av. 12.9	97.3
R56	1:1.5	5	84	31.4	90.6
R57	"	"	"	27.9	90.0
				Av. 29.4	90.3
R96	1:2	30	84	12.8	97.5
R97	"	"	"	17.5	98.0
				Av. 15.2	97.8
R121	"	30	82	11.9	95.7
R122	"	"	"	7.0	95.2
				Av. 9.5	95.5
R88	"	20	86	17.5	94.5
R85	"	"	"	23.4	95.4
				Av. 20.5	95.0
R107	"	20	84	17.5	94.0
R108	"	"	"	15.2	93.5
				Av. 16.4	93.8
R90	1:1.75	20	86	17.5	95.7
R91	"	"	"	17.5	96.5
				Av. 17.5	96.1
R131	"	"	84	16.5	94.4
R132	"	"	"	15.2	96.3
				Av. 15.9	95.4

Support: Versapor .9 micron.

TABLE X. Effect of Pressure on Flux

Run No.	Operating Pressure				
	800 Psi GSFD	1200 Psi GSFD	Efficiency (%)	1500 Psi GSFD	Efficiency (%)
R-185B	31.0	43.1	88.0	57.7	92.0
R-186B	21.2	29.2	87.5	37.7	88.5
R-187B	26.4	36.4	87.0	48.0	89.6
R-188B	21.9	29.2	87.0	38.7	89.6
TS*163	22.6	28.4	79.4	31.8	69.7
TS*166	22.6	28.7	80.4	32.0	70.0

Solution: E398-10, 21.9%

Support: PVC, BD, Millipore

Heat Treatment: 86°C, 4 min.

* Wang's membranes, E400-25, 21.9%, Versapor .9 micron, Gelman Co.

TABLE XI. Results of All Runs (1)

Run No.	Support	C.A.		A./F.	S.E.T. (Sec.)	H.T.T. (°F)	W.F. (GSFD)	S.R. (%)
		Type	Cont.(%)					
1	G-.9	398-10	21.9	1.5	5	86	16.4	87.0
2	G-.9	"	"	"	"	"	23.2	91.5
3	VF-6	"	"	"	"	"	22.2	96.5
4	G-.9	"	"	"	"	"	25.6	87.0
5	VF-6	"	"	"	"	"	10.5	98.0
6	BD	"	"	"	"	"	35.0	87.0
7	BD (Front)	"	"	"	"	"	12.8	90.0
8	G-5.0	"	"	"	"	"	9.1	91.0
9	G-5.0	"	"	"	"	"	14.0	90.0
10	UG	"	"	"	"	"	7.0	95.7
11	VF-6	400-25	"	"	"	"	8.2	96.5
12	G-5.0	"	"	"	"	"	24.5	85.5
13	NR	398-10	"	"	"	"	9.6	62.0
14	NR	"	"	"	"	"	4.7	70.5
15	UH	"	"	"	"	"	17.5	96.2
16	UH	"	"	"	"	"	5.8	95.7
17	BD	"	"	"	"	"	38.5	84.5
18	G-.9	"	"	"	"	"	No Flux	
19	LS	"	"	"	"	"	30.4	76.5
20	VF-6	"	"	"	"	"	12.2	58.5
21	UH	"	"	"	"	"	44.2	70.5
22	BD	"	"	"	"	"	34.0	94.0
23	GA-8	"	"	"	"	"	3.7	88.2
24	VF-6	"	"	"	"	"	15.0	76.5

C.A.: Cellulose Acetate; A.: Acetone; F.: Formamide

S.E.T.: Solvent Evaporating Time;

H.T.T.: Heat Treatment Temperature;

W.F.: Water Flux; S.R.: Salt Rejection

TABLE XI Cont. Results of All Runs (2)

Run No.	Support	C.A.		A./F.	S.E.T.	H.T.T.	W.F.	S.R.
		Type	Cont.(%)		(Sec.)	(°F)	(GSFD)	(%)
25	VC	398-10	21.9	1.5	5	86	No Flux	
26	UG	"	"	"	"	"	30.0	58.5
27	BD	"	"	"	"	"	29.2	94.5
28	BD	"	"	"	"	"	38.5	90.0
29	VF-6	400-25	"	"	"	"	2.3	96.4
30	GA-8	398-10	"	"	"	"	No Flux	
31	BD	400-25	"	"	"	"	15.8	98.0
32	BD	"	"	"	"	"	12.2	98.0
33	UH	"	"	"	"	"	15.2	97.0
34	UH	"	"	"	"	"	10.5	98.2
35	NR	"	"	"	"	"	4.7	95.5
36	NR	"	"	"	"	"	4.7	94.0
37	VF-6	"	"	"	"	"	16.3	97.5
38	LS	"	"	"	"	"	5.8	96.0
39	UG	"	"	"	"	"	2.5	81.7
40	UG	"	"	"	"	"	9.3	89.9
41	VF-6	"	"	"	"	"	14.5	97.0
42	VF-6	"	"	"	"	"	10.0	97.5
43	BD	"	"	"	"	"	11.8	91.0
44	BD	"	"	"	"	"	9.3	87.0
45	BD (Front)	398-10	"	"	"	"	12.6	96.7
46	VF-6	400-25	"	"	"	"	21.0	97.5
47	BD	"	"	"	"	"	29.1	73.5
48	BD	"	"	"	"	"	25.6	86.5

C.A.: Cellulose Acetate; A.: Acetone; F.: Formamide

S.E.T.: Solvent Evaporating Time;

H.T.T.: Heat Treatment Temperature;

W.F.: Water Flux; S.R.: Salt Rejection

TABLE XI Cont. Results of All Runs (3)

Run No.	Support	C.A.		A./F.	S.E.T. (Sec.)	H.T.T. (°F)	W.F. (GSFD)	S.R. (%)
		Type	Cont.(%)					
49	BD	394-60	21.9	1.5	5	84	No Flux	
50	BD	"	"	"	"	"	No Flux	
51	BD	394-45	"	"	"	"	11.6	84.5
52	BD	"	"	"	"	"	11.0	77.5
53	BD	398-10	"	"	"	86	24.5	93.4
54	BD	"	"	"	"	"	Memb. Too Small	
55	BD (Front)	"	"	"	"	"	13.2	95.5
56	VF-6	400-25	"	"	"	84	31.4	90.6
57	VF-6	"	"	"	"	"	27.9	90.6
58	UH	"	"	"	"	"	38.5	73.5
59	UH	"	"	"	"	"	42.0	76.5
60	UH	"	"	"	"	86	7.2	80.5
61	UH	"	"	"	"	"	8.0	90.0
62	BD	398-3	"	"	"	"	10.5	97.0
63	BD	"	"	"	"	"	Leaked	
64	BD	398-10	"	"	"	84	24.5	96.7
65	BD	"	"	"	"	"	17.5	96.9
66	VF-6	"	"	"	"	86	10.0	98.4
67	VF-6	"	"	"	"	84	14.0	84.5
68	VF-6	"	"	"	"	"	10.0	92.5
69	VF-6	394-60	"	"	"	"	13.5	76.5
70	VF-6	"	"	"	"	"	19.0	73.5
71	VF-6	398-3	"	"	"	"	35.0	62.0
72	VF-6	"	"	"	"	86	44.5	41.3

C.A.: Cellulose Acetate; A.: Acetone; F.: Formamide

S.E.T.: Solvent Evaporating Time;

H.T.T.: Heat Treatment Temperature;

W.F.: Water Flux; S.R.: Salt Rejection

TABLE XI Cont. Results of All Runs (4)

Run No.	Support	C.A.		A./F.	S.E.T. (Sec.)	H.T.T. (°F)	W.F. (GSFD)	S.R. (%)
		Type	Cont.(%)					
73	VF-6	398-3	21.9	1.5	5	86	10.5	86.5
74	VF-6	"	"	"	"	"	11.5	94.0
75	AA	400-25	"	"	"	"	12.2	81.7
76	AA	"	"	"	"	"	No Flux	
77	BD	"	20.0	1.75	"	"	8.2	97.8
78	BD	"	"	2.0	"	"	12.3	81.7
79	BD	"	"	"	"	"	11.0	95.4
80	VF-6	"	"	"	"	"	5.4	88.2
81	VF-6	"	"	"	"	"	6.4	90.0
82	VF-6	"	"	1.75	"	"	19.8	95.4
83	VF-6	"	"	"	"	"	4.1	77.5
84	VF-6	"	"	1.25	"	"	19.3	17.7
85	VF-6	"	"	"	"	"	17.0	60.0
86	VF-6	"	"	1.0	"	"	52.5	26.0
87	VF-6	"	"	"	"	"	76.0	41.3
88	G-.9	"	"	2.0	20	"	17.5	94.5
89	G-.9	"	"	"	"	"	23.4	95.4
90	G-.9	"	"	1.75	"	"	17.5	95.7
91	G-.9	"	"	"	"	"	17.5	96.5
92	G-.9	"	"	1.25	5	"	21.0	87.6
93	G-.9	"	"	"	"	"	31.6	87.6
94	G-.9	"	"	1.0	"	"	22.2	90.0
95	G-.9	"	"	"	"	"	23.4	91.5
96	G-.9	"	"	2.0	30	"	12.8	97.5

C.A.: Cellulose Acetate; A.: Acetone; F.: Formamide

S.E.T.: Solvent Evaporating Time;

H.T.T.: Heat Treatment Temperature;

W.F.: Water Flux; S.R.: Salt Rejection

TABLE XI Cont. Results of All Runs (5)

Run No.	Support	C.A.		A./F.	S.E.T. (Sec.)	H.T.T. (°F)	W.F. (GSFD)	S.R. (%)
		Type	Cont. (%)					
97	G-.9	400-25	20.0	2.0	30	86	17.5	98.0
98	G-.9	"	"	1.75	10	"	21.0	97.0
99	G-.9	"	"	"	"	"	14.5	96.5
100	G-.9	"	"	"	5	"	23.4	86.5
101	G-.9	"	"	"	"	"	28.0	77.5
102	GA-6	398-10	21.9	1.5	"	"	2.3	92.5
103	GA-6	"	"	"	"	"	2.8	92.5
104	VC	"	"	"	"	"	No Flux	
105	α -8 (0.2 μ)	"	"	"	"	"	2.3	95.4
106	GA-10 (0.5 μ)	"	"	"	"	"	No Flux	
107	G-19	400-25	20.0	2.0	20	84	17.5	94.0
108	G-.9	"	"	"	"	"	15.2	93.5
109	G-.9	"	"	"	10	86	15.2	95.5
110	G-.9	"	"	"	"	"	14.0	95.0
111	G-.9	"	"	"	30	82	12.9	92.7
112	G-.9	"	"	1.75	20	84	11.6	91.5
113	G-.9	"	"	"	10	"	21.0	91.5
114	G-.9	"	"	"	"	"	27.0	85.0
115	G-.9	"	"	"	5	88	4.7	93.7
116	G-.9	"	"	1.25	"	"	17.5	89.0
117	UH	"	"	2.0	20	86	5.8	94.2
118	UH	"	"	"	10	"	16.6	96.5
119	UH	"	"	1.0	5	"	16.4	96.0
120	UH	:	:	1.25	5	"	15.2	96.5

C.A.: Cellulose Acetate; A.: Acetone; F.: Formamide;

S.E.T.: Solvent Evaporating Time;

H.T.T.: Heat Treatment Temperature;

W.F.: Water Flux; S.R.: Salt Rejection

TABLE XI Cont. Results of All Runs (6)

Run No.	Support	C.A. Type	Cont(%)	A./F.	S.E.T. (Sec.)	H.T.T. (°F)	W.F. (GSFD)	S.R. (%)
121	G-.9	400-25	20.0	2.0	30	82	11.9	95.7
122	G-.9	"	"	"	"	"	7.0	95.2
123	G-.9	"	15.0	"	60	86	18.7	81.7
124	G-.9	"	"	"	"	"	22.3	91.5
125	G-.9	"	10.0	"	20	"	No S.R.	
126	G-.9	"	"	"	"	"	No S.R.	
127	G-.9	"	12.5	"	30	"	70.0	52.0
128	G-.9	"	"	"	"	"	49.0	66.0
129	G-.9	"	20.0	"	20	84	17.5	92.2
130	G-.9	"	"	"	"	"	29.0	88.2
131	G-.9	"	"	1.75	"	"	16.5	94.4
132	G-.9	"	"	"	"	"	15.2	96.3
133	G-.9	"	"	2.0	"	88	2.9	97.0
134	G-.9	"	"	"	"	"	3.0	96.3
135	G-.9	"	"	"	30	"	1.2	94.5
136	G-.9	"	"	1.75	20	"	1.2	94.5
137	BD	398-10	"	"	5	84	12.3	96.5
138	BD	"	"	"	"	"	15.8	95.4
139	BS	"	"	"	"	86	2.9	97.0
140	BS	"	"	"	"	"	2.6	98.0
141	BD (Front)	"	"	"	"	84	9.3	98.0
142	BD (Front)	"	"	"	"	"	8.2	97.0
143	BS	"	"	"	"	86	5.8	97.5
144	BS	"	"	"	"	"	2.3	95.0

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TABLE XI Cont. Results of All Runs (7)

Run No.	Support	C.A.		A./F.	S.E.T. (Sec.)	H.T.T. (°F)	W.F. (GSFD)	S.R. (%)
		Type	Cont. (%)					
145	BD	398-10	25.0	1.5	5	86	2.6	95.7
146	BD	"	"	"	"	"	1.9	95.4
147	BD	"	15.0	"	60	"	No Flux	
148	BD	"	"	"	"	"	No Flux	
149	BD	"	20.0	"	5	"	20.0	96.5
150	BD	"	"	"	"	"	19.0	98.0
151	BD	"	"	"	"	88	5.7	98.2
152	BD	"	"	"	"	"	6.0	98.7
153	BD	"	"	"	"	"	7.0	98.4
154	BD	"	"	"	"	"	10.5	98.0
155	BD	"	"	"	"	"	7.0	98.6
156	BD	"	"	"	"	"	13.0	98.0
157	BD	"	"	"	"	84	20.4	94.1
158	BD	"	"	"	"	"	24.8	90.8
159	BD	"	"	"	"	86	16.3	96.3
160	BD	"	"	"	"	"	17.0	97.5
161	BD	398-3	"	"	"	84	26.9	94.4
162	BD	"	"	"	10	86	8.2	98.0
163	BD	"	"	"	"	"	8.2	97.4
164	BD	"	"	"	5	84	39.6	70.5
165	BD	"	"	"	"	"	32.6	76.5
166	BD	398-10	21.9	"	"	"	19.6	97.2
167	BD	"	"	"	"	"	20.9	97.6
168	BD	398-3	20.0	"	"	86	12.2	98.0

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TABLE XI Cont. Results of All Runs (8)

Run No.	Support	C.A.		A./F.	S.E.T. (Sec.)	H.T.T. (°F)	W.F. (GSFD)	S.R. (%)
		Type	Cont. (%)					
169	BD	398-3	20.0	1.5	5	86	9.3	97.0
170	BD	398-10	21.9	"	"	88	11.4	97.3
171	BD	"	"	"	"	"	7.0	98.7
172	BD	"	"	"	"	"	8.2	98.6
173	BD	"	"	"	"	"	10.4	97.5
174	BD	"	"	"	"	84	21.0	96.5
175	BD	"	"	"	"	"	21.2	97.0
176	BD	"	20.0	1.25	"	"	11.6	96.0
177	BD	"	"	2.0	20	86	2.3	98.2
178	BD	"	"	"	"	"	3.5	98.3
179	BD	"	"	"	10	84	14.0	98.0
180	BD	"	"	"	"	"	18.0	97.4
181	BD	398-3	"	1.5	"	"	18.2	95.7
182	BD	"	"	"	"	"	21.0	94.5
183	BD	"	"	"	5	"	19.8	95.4
184	BD	"	"	"	"	"	17.7	97.8
185A	BD	398-10	21.9	"	"	86	34.1	90.9
186A	BD	"	"	"	"	"	24.6	91.8
187A	BD	"	"	"	"	"	30.7	90.5
188A	BD	"	"	"	"	"	23.7	94.7
189	AA	"	"	"	"	"	2.3	92.7
190	AA	"	"	"	"	"	3.5	89.8
191	BD	"	"	"	"	"	12.5	97.5
192	BD	"	"	"	"	"	12.8	97.5

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TABLE XI Cont. Results of All Runs (9)

Run No.	Support	C.A.		A./F.	S.E.T. (Sec.)	H.T.T. (°F)	W.F. (GSFD)	S.R. (%)
		Type	Cont.(%)					
193	BD	398-10	21.9	1.5	5	86	9.3	98.0
194	BS	"	"	"	"	"	25.0	98.0
195	BS	"	"	"	"	"	17.5	96.5
196	BS	398-3	"	"	"	84	36.7	87.0
197	BS	"	"	"	"	"	21.6	89.2
198	BS	"	"	"	"	86	4.7	92.7
199	BS	"	"	"	"	"	7.2	94.2
200	BD	"	"	"	"	"	14.6	97.0
201	BD	"	"	"	"	"	12.3	98.4
202	BD	"	"	"	"	84	16.5	96.2
203	BD	"	"	"	"	"	12.2	97.0
204	BD	"	"	"	"	86	12.8	97.0
205	BD	"	"	"	"	"	16.3	95.7
206	BS	"	"	"	"	84	18.5	98.0
207	BS	"	"	"	"	"	16.3	98.2
208	BS	"	"	"	"	86	12.2	91.7
209	BS	"	"	"	"	"	11.6	92.4
210	BD	398-3	"	"	"	82	16.7	97.5
211	BD	"	"	"	"	"	16.3	98.0
212	BD	"	"	"	"	80	25.6	96.3
213	BD	"	"	"	"	"	20.4	85.5
214	BD	"	"	"	"	78	31.5	88.6
215	BD	"	"	"	"	"	31.5	70.5
216	BD	"	"	"	"	80	30.4	70.5

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TABLE XI Cont. Results of All Runs (10)

Run No.	Support	C.A.		A./F.	S.E.T. (Sec.)	H.T.T. (°F)	W.F. (GSFD)	S.R. (%)
		Type	Cont.(%)					
217	BD	398-3	21.9	1.5	5	81	23.0	93.4
218	BD	"	"	"	"	"	26.0	93.4
219	BD	"	"	"	"	"	20.8	93.5
220	BS	"	"	"	"	"	20.3	93.7
221	BS	398-10**	"	"	"	86	18.7	95.7
222	BS	"	"	"	"	"	24.0	94.5
223	BD	"	"	"	"	"	12.0	98.2
224	BD	"	"	"	"	"	11.7	98.0
225	BS	"	"	"	"	84	26.3	96.3
226	BS	"	"	"	"	88	10.7	96.5
227	BS	"	"	"	"	"	9.6	96.8
228	BS	"	"	"	"	84	21.5	95.6
229	BS	"	"	"	"	86	21.2	96.5
230	BS	"	"	"	"	82	29.0	93.5
231	BD	"	"	"	"	84	24.2	90.5
232	BD	"	"	"	"	"	22.7	91.2
233	BS	400-25	"	"	"	86	9.3	94.1
234	BS	"	"	"	"	"	10.6	93.5
235	BS	398-10**	"	"	"	82	36.7	91.7
236*	BS	"	"	"	"	"	27.0	91.7
237*	BS	"	"	"	"	84	24.8	96.1
238*	BS	"	"	"	"	"	22.2	95.3
239	BS	"	"	"	"	"	25.6	94.9

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S.E.T.: Solvent Evaporating Time;

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** : Lot No. LS 1440, Eastment Chemical Products, Inc.

* : 124 hours long run

VI. LITERATURE CITED

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N378 Lai, Juin-yih
L14 Development of reverse
cop.2 osmosis membranes cast
directly on various
support materials

NAME AND ADDRESS

Bill Sager

N378

L14

cop 2

