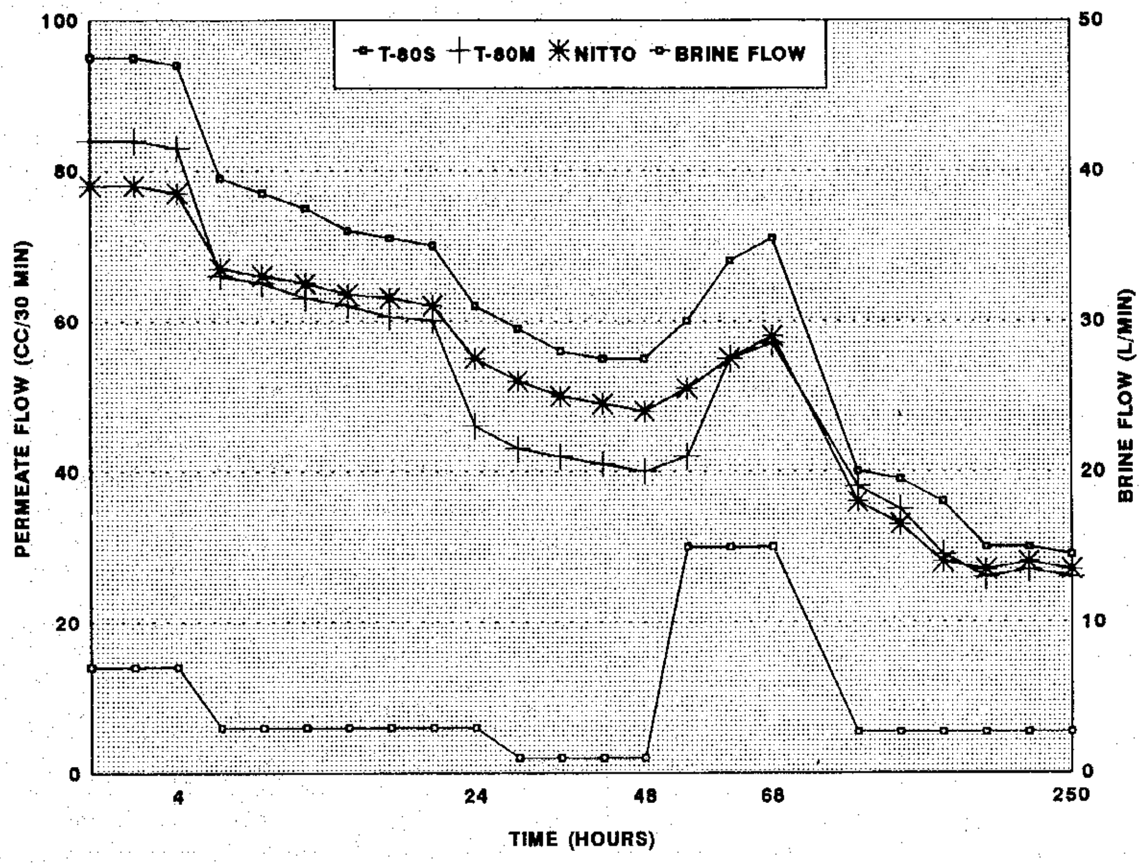


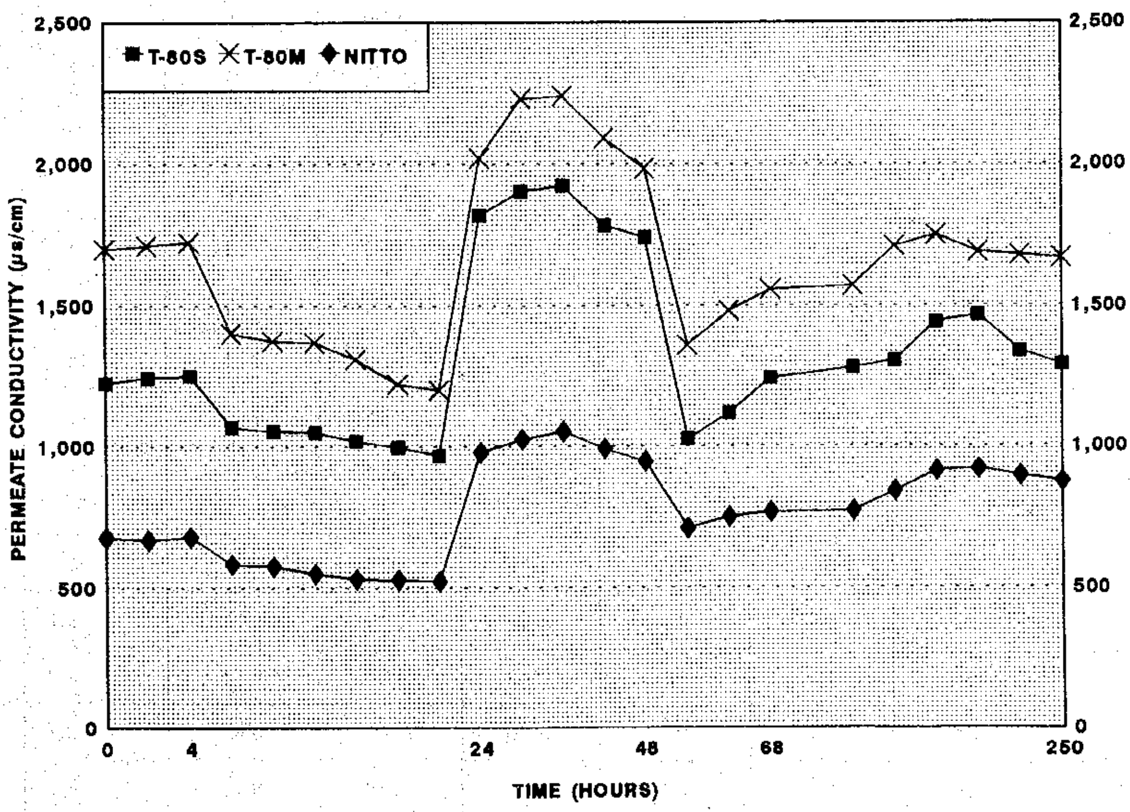


Fig. 2 Turbidity Tolerance of Various SWRO Membrnes

(Toray UTC 80S,Toray UTC 80M & Nitti Denko NTR 70SWC) vs Time

Operation Conditions:Pressure=56 Kg/cm^2,Feed SDI= 6.4, pH=8.2

Table 1 Turbidity Tolerance of Various Flat Membrane

(TORAY 80S, TORAY 80M & NITTO NTR 70 SWC) VS TIME
(FEED SDI = 6.4, pH= 8.2, TEMP.= 25°C, PRESSURE= 56 KG/CM2)

	PERMEATE FLOW CC/30 MIN			PERMEATE CONDUCTIVITY µs/cm			
TIME HOURS	T-80S	T-80M	NITTO	T-80S	T-80M	NITTO	BRINE L/MIN
	95	84	78	1224	1700	678	7
	95	84	78	1245	1712	670	7
4	94	83	77	1250	1723	680	7
	79	66	67	1068	1402	584	3
	77	65	66	1054	1375	577	3
	75	63	65	1050	1370	551	3
	72	62	63.5	1019	1310	531	3
	71	60.5	63	997	1222	529	3
	70	60	62	968	1200	523	3
24	62	46	55	1819	2020	979	3
	59	43	52	1905	2230	1025	1
	56	42	50	1923	2240	1053	1
	55	41	49	1784	2090	991	1
48	55	40	48	1742	1984	946	1
	60	42	51	1025	1360	711	15
	68	55	55	1116	1481	750	15
68	71	57	58	1241	1557	767	15
	40	38	36	1279	1571	771	2.7
	39	35	33	1302	1210	840	2.7
	36	29	28	1442	1750	912	2.7
	30	26	27	1466	1690	919	2.7
250	30	27	28	1338	1678	895	2.7

7.1.5 Tolerance Tests of Turbidity with Mini-Modules

7.1.5.A. Analysis of Seawater Turbid Materials Accumulated on MF Filter

Contents

List of Tables

List of Figures

The durability of desalination RO membrane is affected by the suspended matters contained in the raw seawater feed. To investigate the durability, components of the suspended matters in the raw seawater, collected from the Gulf were measured, and the stability of the components were confirmed by passing seawater, pretreated by the traditional pretreatment equipment, through the RO modules. In addition, the feed seawater, permeate water and concentrate water were also analyzed.

1. Objectives

The main purpose of analyzing turbid materials accumulated on Millipore filter is to identify the composition of suspended solids causing turbidity in raw seawater. In the preparative experiment research work, seawater turbid materials accumulated on the 0.45 micron Millipore filter was analyzed, using SEM,EDX and FT-IR. However,it was clear from the analytical result that different soluble ions such as Na^{+}, Ca^{++}, Mg^{++}, Cl^{-}, Al^{+++} etc. are the dominant species present, along with the deposits, which influenced the analysis of the minute particles. Objectives of this present experiment is to detect minute suspended silt particles present in seawater more accurately in absence of the effect of soluble ions adhere on with deposition on the filter papers.

2. Experimental Methods

(1) Preparation of seawater turbid materials samples deposited on the SDI measuring filter paper

SDI measuring cylinder(10L) was filled with seawater and 0.45 micron filter paper was inserted in the measuring cell with effective surface upward. A fixed pressure of 30 PSI was maintained in the cylinder and SDI was measured on 15 minutes bases for pretreated seawater and 10 minutes basis for raw seawater. After completion of SDI measuring time, the cylinder was filled with permeate water and pressurized to 30 PSI. Soluble ions remained with residue were washed away with one liter of permeate flow through the millipore filter paper. After washing the soluble ions the filter paper was collected for analysis.

General properties of seawater

Location	:	Al Jubail, Arabian Gulf
Date	:	August, 1994
Volume of seawater filtered	:	10 L

Composition of seawater : Table 4.1

Table 1 Composition of seawater of Jubail on 31st July, 1994

		mg/L	mg/L as CaCO3
Cation	Na+	12900	28043
	K+	490	627
	Ca++	508	1270
	Mg++	1644.138	6766
	Total Cation	**15542.14**	**36706**
Anion	M-alk		129
	Cl-	23500	33145
	SO4--	3030	3156
	Total Anion	**26530**	**36431**

Sample-1

Sampling point : after DMF(Dual Media Filter)
Date of sampling : 7 August, 1994
Volume of seawater filtered : 10 L
SDI : 2.7

Sample-2

Sampling point : after DMF
Date of sampling : 8 August, 1994
Volume of seawater filtered : 10 L
SDI : 1.7

Sample-3

Sampling point : seawater before DMF
Date of sampling : 9 August, 1994
Volume of seawater filtered : 10 L
SDI : 6.05

Sample-4

Sampling point : seawater before DMF

Date of sampling	:	10 August, 1994
Volume of seawater filtered	:	10 L
SDI	:	6.00

3. Analysis of sample

Analysis of prepared samples by SEM and EDX has already been done in R&D Center. Same analysis was conducted in Japan.

4. Results and Discussion

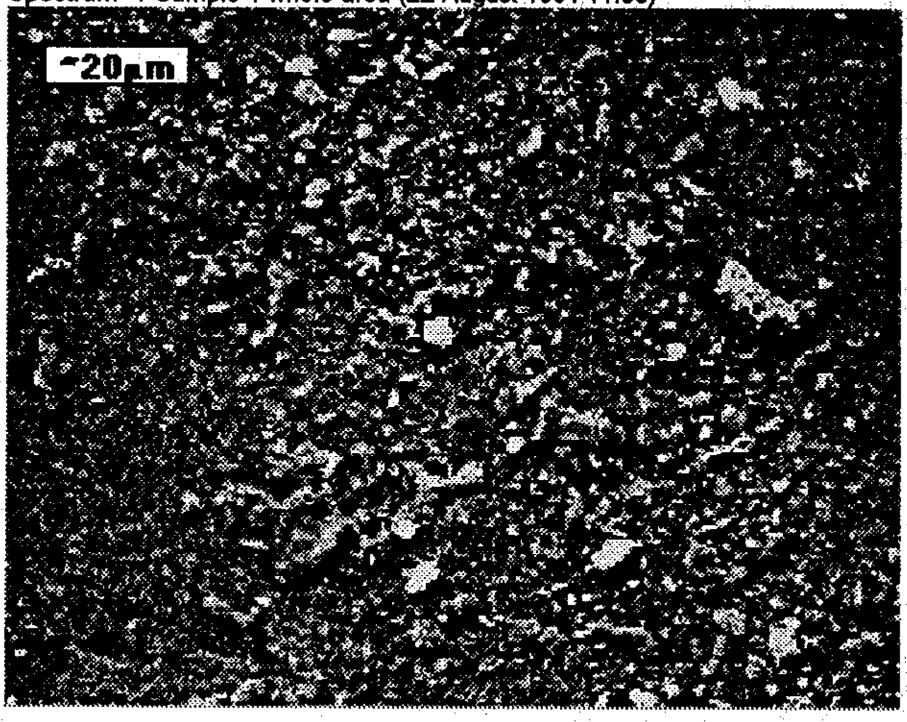
The analysis results both for pretreated and raw seawater turbid materials collected on the surface of 0.45 micron Milipore filter paper are given in Fig. 1 to Fig.9. Fig. 1 and Fig. 3 shows the SEM spectrum of pretreated seawater turbid material, while Fig. 2 and Fig. 4 shows EDX spot spectrum of the same, respectively. Both the sample showed approximately same composition of deposits expect Ca content in the 1st sample is slightly higher than the 2nd one (Fig. 2 and Fig. 4).
Fig. 5 and Fig. 8 are the SEM spectrum of samples collected using raw seawater as the source of turbid material deposits. Fig. 6, Fig. 7 and Fig. 9 contain EDX of the same, respectively. Fig. 7 is the EDX particle spectrum of sample No.3.
Almost in all cases the peak of Ca is the most intense followed by that of Si Al and Mg and the Fe peak is the least intense.

Untreated raw seawater from the Gulf was found to have a higher turbidity(SDI value) than the seawater collected in the Red Sea. It is estimated that the suspended oil contains inorganic components including large amount of Ca, Si and Al, and silty materials.
Operational results utilizing higher turbidity feed seawater was shown in Section 7.2.3. Flow diagram and photographs of the test plant were shown in Fig. 10 and Fig. 11.

Although the operation time was short and the seawater has a higher turbidity than the seawater in the Red Sea, it shows that steady operation with SWRO membranes (Toray and Nitto Denko)is possible by feeding pretreated seawater using the same method of pretreatment as before.

It is necessary to continue the operation of the test plant to verify the suitability of the pretreatment and behavior of membrane at long run operation.

Operator : John G O'Hara
Client : Abdul Rahman Abanmy
Job : Job number 56 SDI filter papers (0.45 micron)
Spectrum 1 Sample 1 whole area (22 August 1994 11:00)



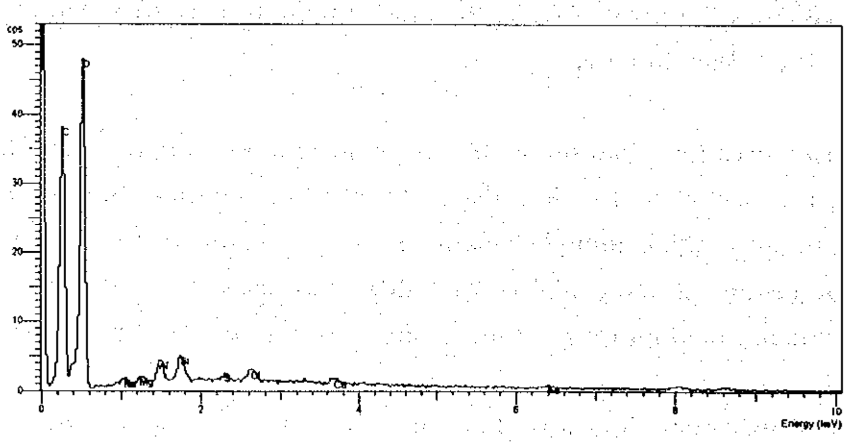
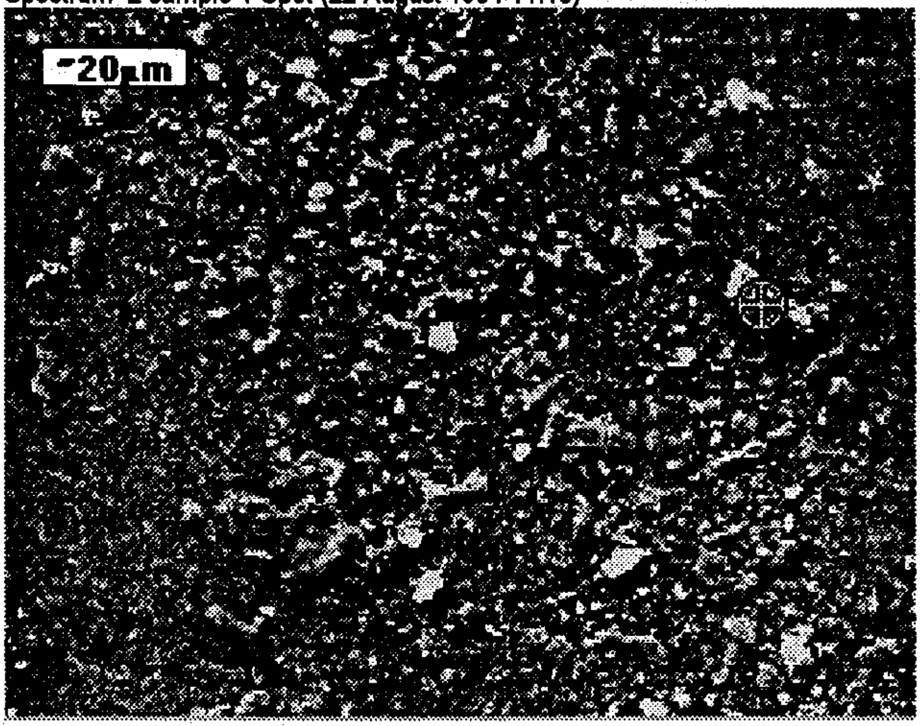


Fig. 1 Spectrum 1 Sample 1 whole area(22 August 1994 11:00)

Operator : John G O'Hara
Client : Abdul Rahman Abanmy
Job : Job number 56 SDI filter papers (0.45 micron)
Spectrum 2 sample 1 Spot (22 August 1994 11:13)



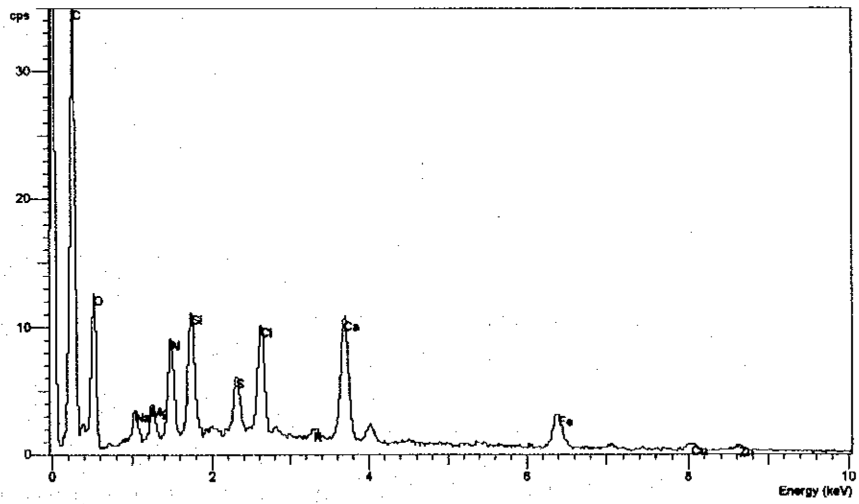
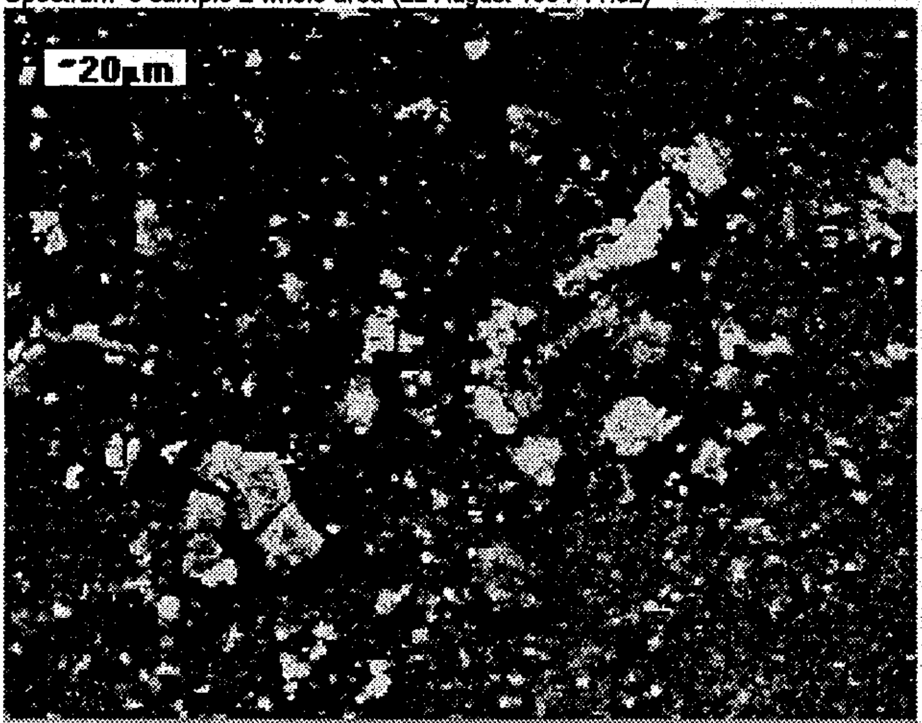


Fig. 2 Spectrum 2 Sample 1 Spot (22 August 1994 11:13)

Operator : John G O'Hara
Client : Abdul Rahman Abanmy
Job : Job number 56 SDI filter papers (0.45 micron)
Spectrum 3 sample 2 whole area (22 August 1994 11:32)



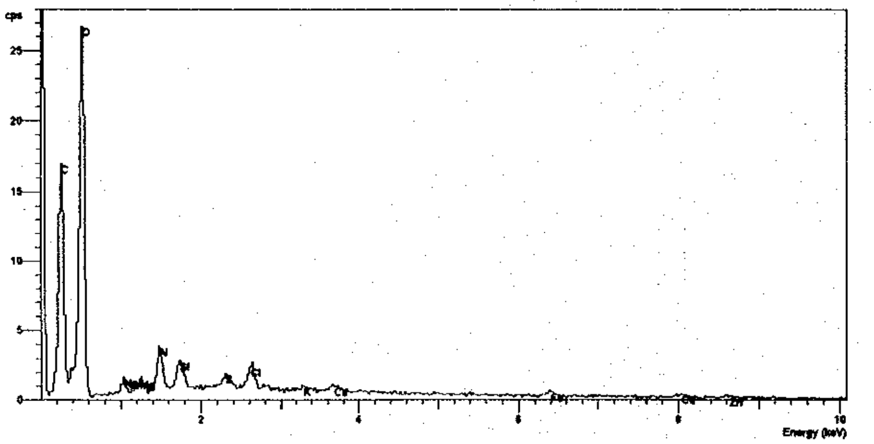
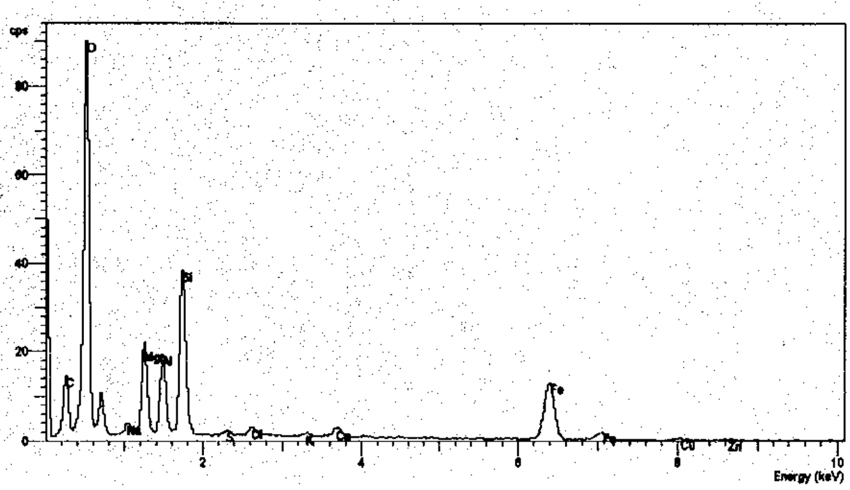


Fig. 3 Spectrum 3 Sample 2 whole area(22August 1994 11:32)

Operator : John G O'Hara
Client : Abdul Rahman Abanmy
Job : Job number 56 SDI filter papers (0.45 micron)
Spectrum 4 sample 2 Spot (22 August 1994 11:49)



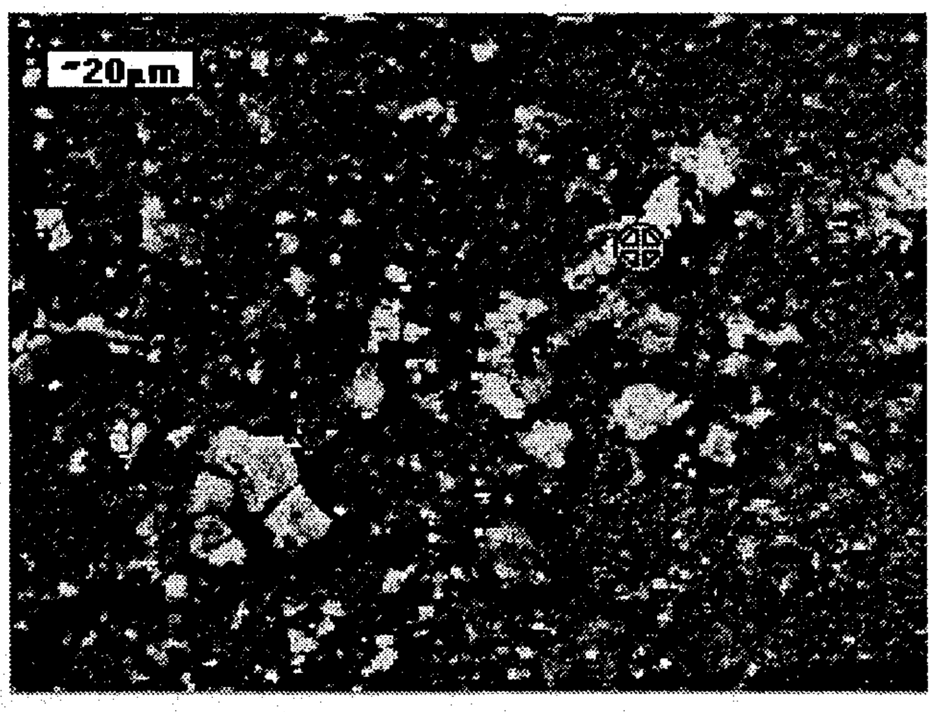
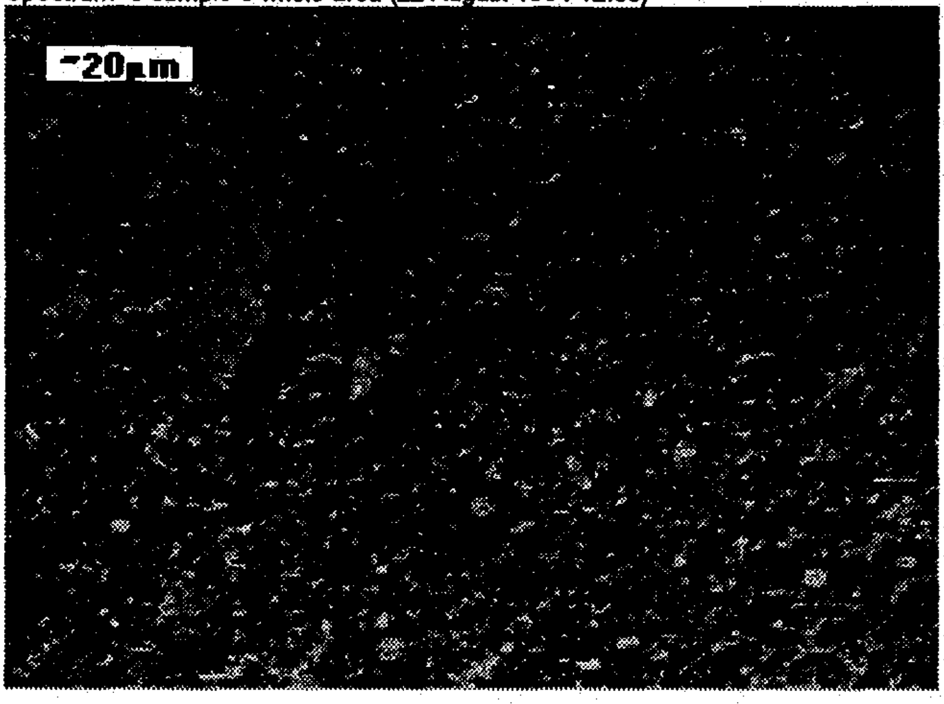


Fig. 4 Spectrum 4 Sample 2 Spot (22 August 1994 11:49)

Operator : John G O'Hara
Client : Abdul Rahman Abanmy
Job : Job number 56 SDI filter papers (0.45 micron)
Spectrum 5 sample 3 whole area (22 August 1994 12:53)



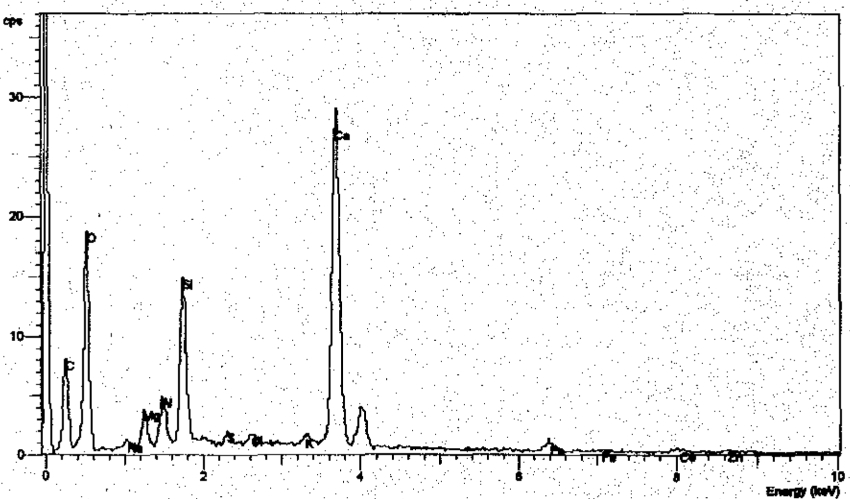
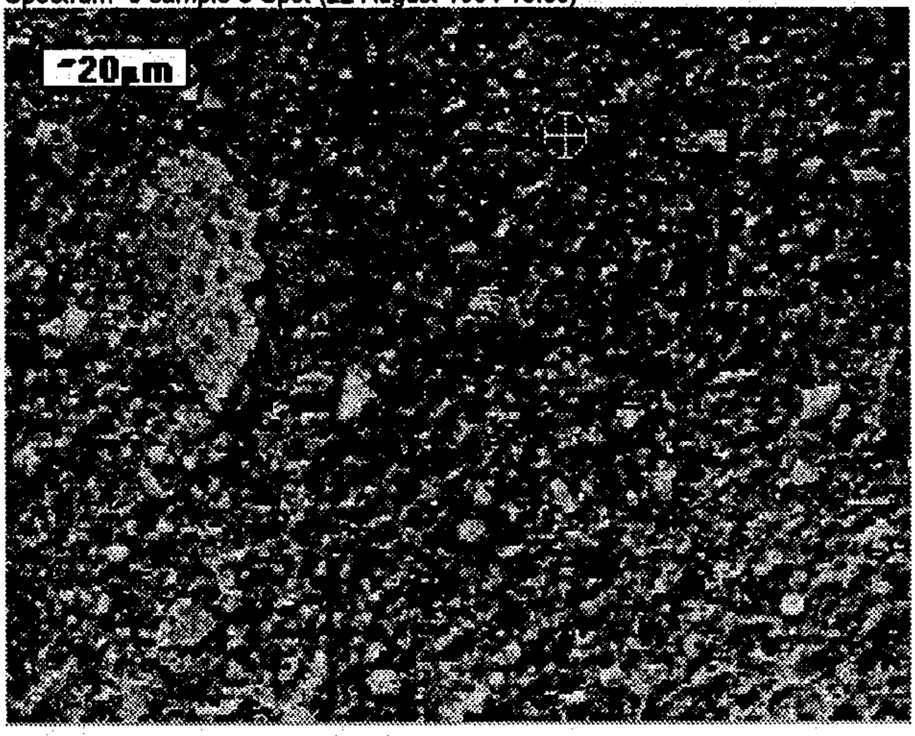


Fig. 5 Spectrum 5 Sample 3 whole area(22 August 1994 12:53)

Operator : John G O'Hara
Client : Abdul Rahman Abanmy
Job : Job number 56 SDI filter papers (0.45 micron)
Spectrum 6 sample 3 Spot (22 August 1994 13:03)



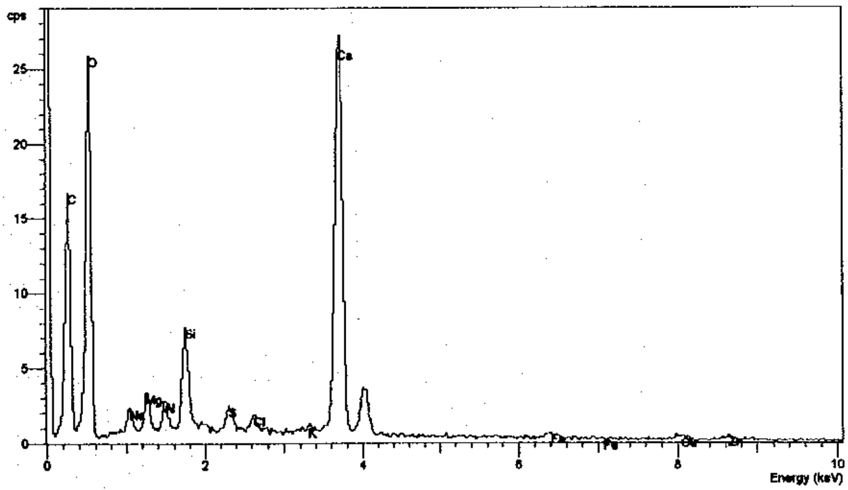
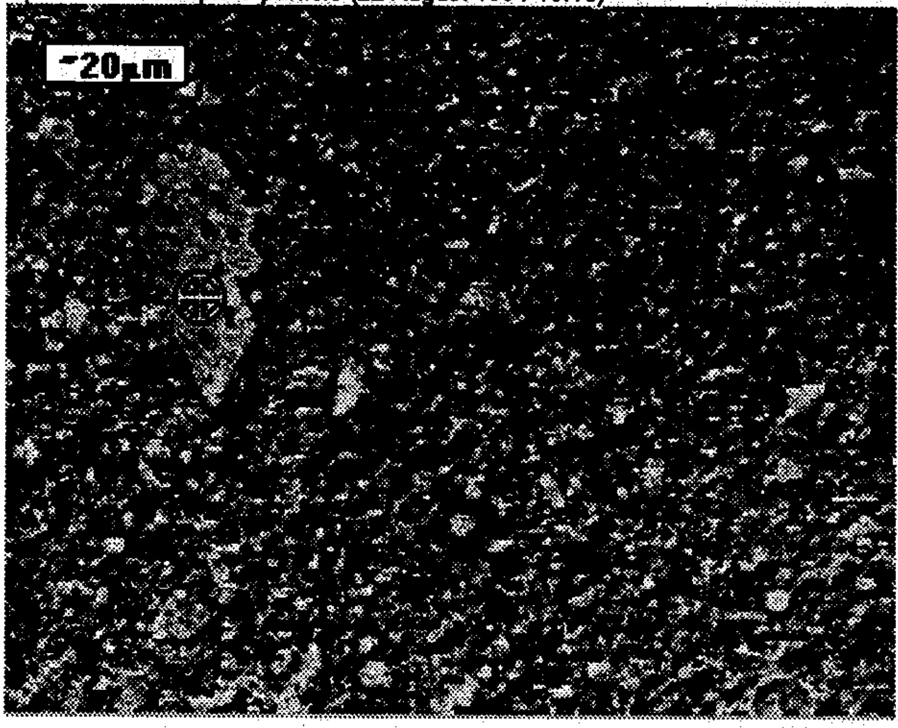


Fig. 6 Spectrum 6 Sample 3 Spot (22 August 1994 13:03)

Operator : John G O'Hara
Client : Abdul Rahman Abanmy
Job : Job number 56 SDI filter papers (0.45 micron)
Spectrum 7 sample 3 particle (22 August 1994 13:15)



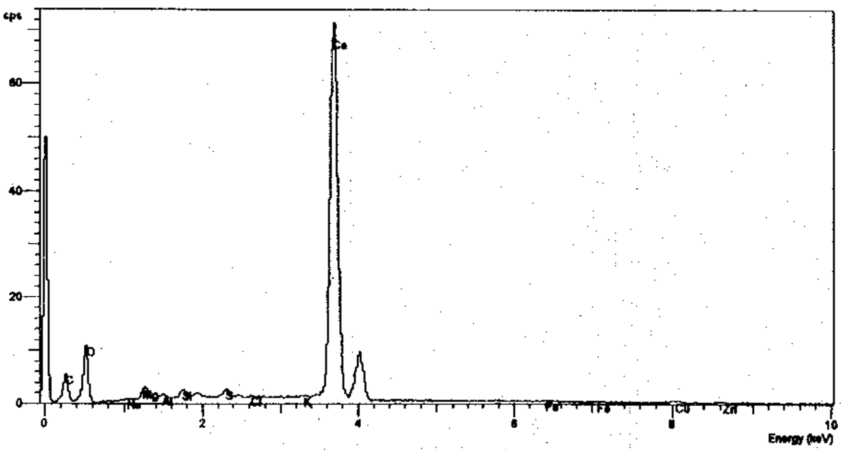
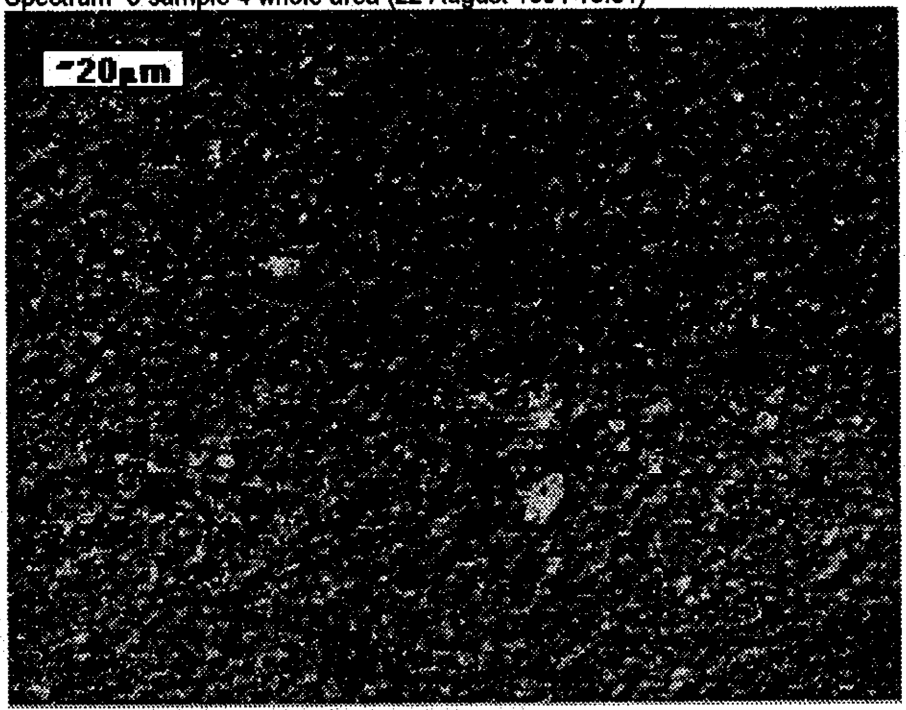


Fig. 7 Spectrum 7 Sample 3 Particle (22 August 1994 11:00)

Operator : John G O'Hara
Client : Abdul Rahman Abanmy
Job : Job number 56 SDI filter papers (0.45 micron)
Spectrum 8 sample 4 whole area (22 August 1994 13:31)



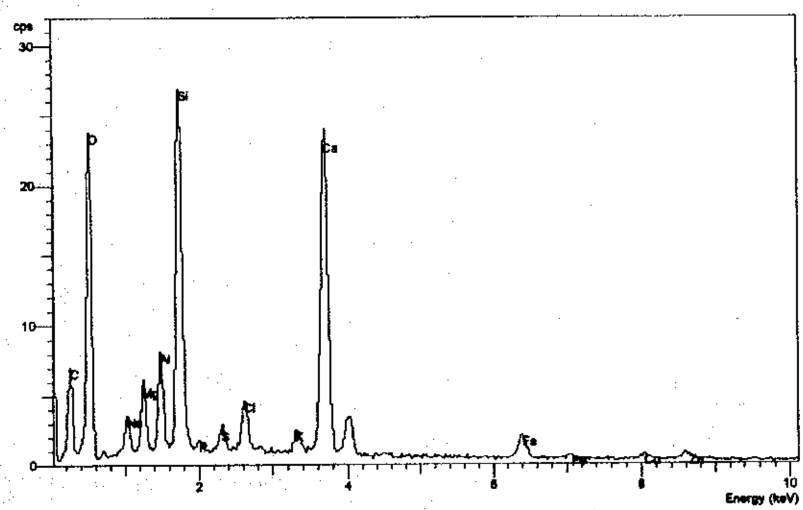
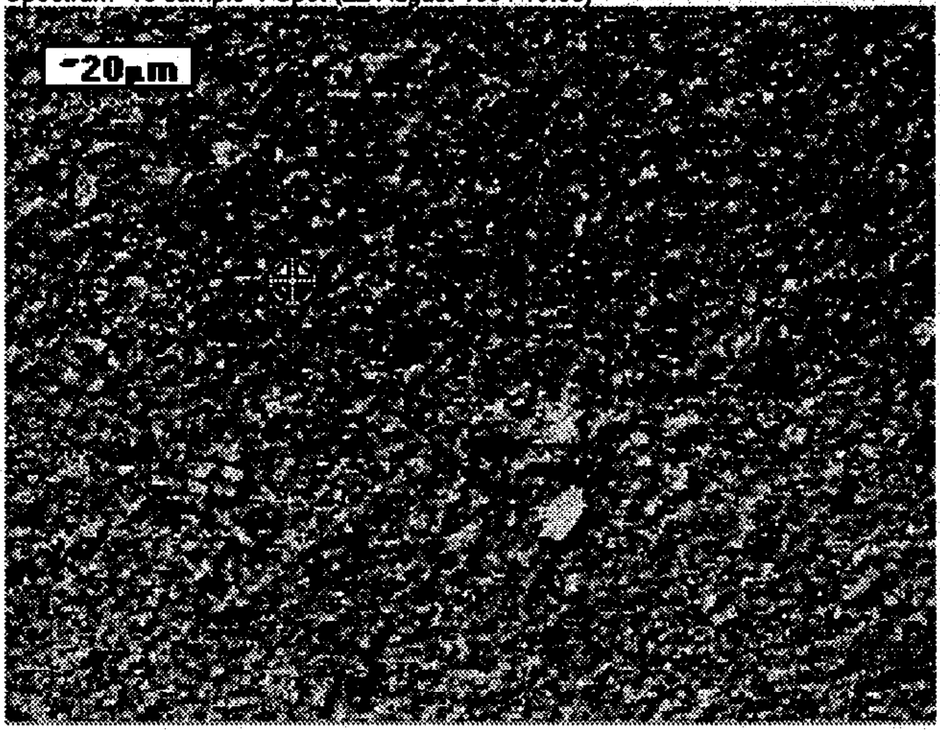


Fig. 8 Spectrum 8 Sample 4 whole area(22 August 1994 13:31)

Operator : John G O'Hara
Client : Abdul Rahman Abanmy
Job : Job number 56 SDI filter papers (0.45 micron)
Spectrum 10 sample 4 Spot (22 August 1994 13:53)



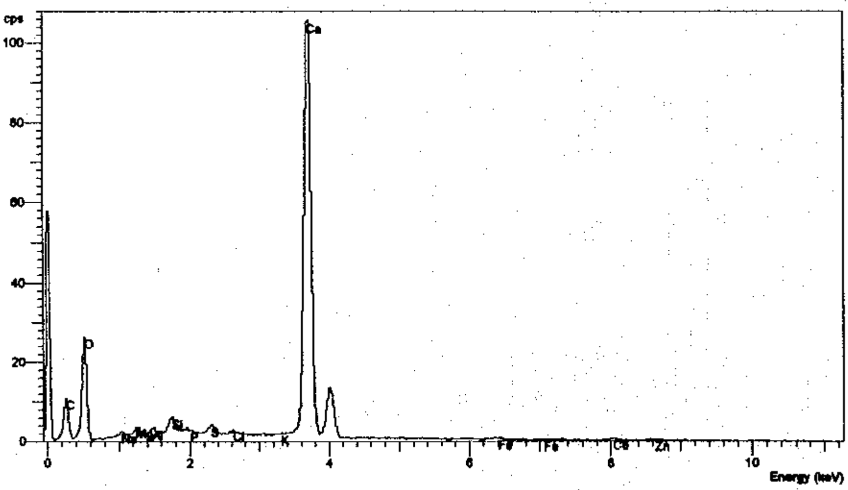


Fig. 9 Spectrum 10 Sample 4 Spot (22 August 1994 13:53)

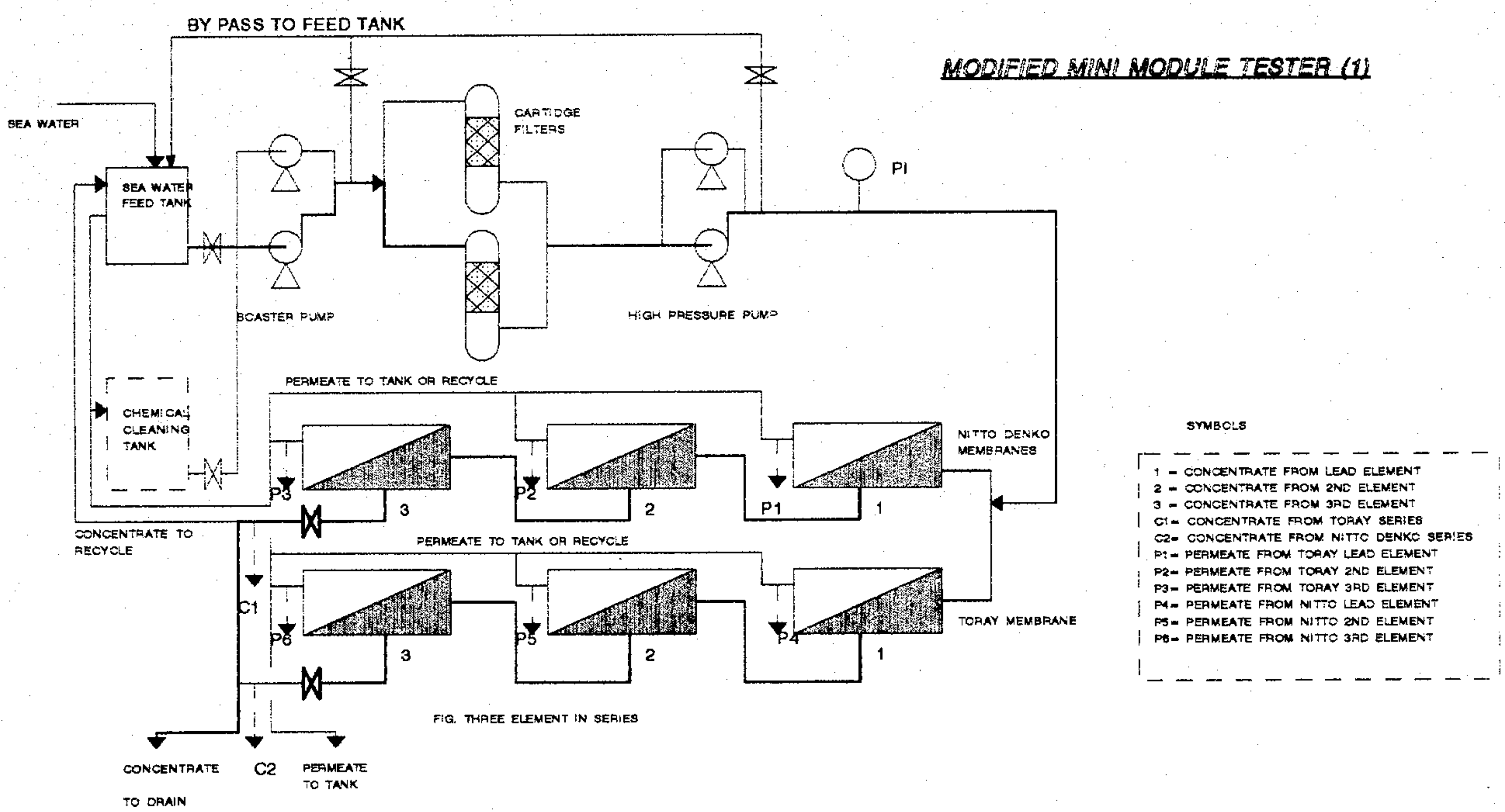


Fig. 10 Flow Diagram of Mini-Module Tester(1)

7.1.5.B. Analysis of Raw Seawater, RO Feed Water, Permeate and Concentrate

Contents

List of Tables

1. Objectives

It is necessary to analyze chemical elements dissolved in feed and concentrate for evaluation of membrane performance.

2. Analytical equipment and method

Analytical equipment:

1–Atomic absorption model varian – AA – 972
2–Ion Chromatography model shimazu – HIC – 6A
3–Auto–titrator model – model FISHER 465

Analytical Methods:

Anion:	Cl^-	:	analyzed by titration with (0.0137N) AgNO3
	$SO4^{2-}$	:	analyzed by Ion Chromatography after dilution
	m–alkalinity	:	analyzed by titration with 0.1N HCL
Cation:	Na^+, K^+	:	analyzed by Atomic absorption after dilution
	Ca^{2+}, Mg^{2+}	:	analyzed by titration with (0.01N)EDTA
T.D.S.		:	analyzed by Evaporation method
Salinity		:	analyzed by applying factor (1.805) x CL (concentration)

3. Constituents of sea water

Constituent of seawater analyzed in July, 1994 is shown in Table 1.

4. Results and Discussion

It was pointed out that cation and anion balance of Raw seawater analysis data in 1993 was not so good balanced as shown in Table 2, however the analysis date obtained lately in July, 1994 show good balance as shown in Table 1. This fact shows that analytical method and analysis data obtained for Raw Sea Water lately is accurate and reliable.

The results of analysis done on 14/8/94 at Al–Jubail Research Center for pretreated seawater

and permeate from Toray lead, 2nd and 3rd elements are summarized in table (3 to 6) while permeate from Nitto Denko lead, 2nd and 3rd elements and also concentrate from Toray and Nitto Denko are summarized in table 6 to 11, respectively, which are self explanatory.

In addition, latest data of water analysis are attached with Appendix 7.1.5–2.

Table 1 Constituents of Seawater (1)

		mg/l	mg/l as $CaCO_3$
Cation	Na^+	12688	27583
	K^+	494	632
	Ca^{++}	505	1263
	Mg^{++}	1545	6358
	Total Cation		35835
Anion	M-alk		129
	Cl^-	23000	32440
	Br^-	80	50
	SO_4^{--}	3030	3156
	Total Anion		35775

T.D.S = 46843 mg/l
Salinity = 41.54 gm/kg

Table 2 Constituents of Seawater (2)

		mg/l	mg/l as $CaCO_3$
Cation	Na^+	15000	32609
	K^+	580	742
	Ca^{++}	500	1263
	Mg^{++}	1555	6399
	Total Cation		41000
Anion	M-alk		129
	Cl^-	23500	33145
	SO_4^{--}	3400	3542
	Total Anion		36816

T.D.S = 44000 mg/l
Salinity = 35.1 gm/kg

Table 3 Analysis of Feed Water and Permeate Water Mini Module Tester Exp. Analysis of Feed Water

		mg/l	mg/l as $CaCO_3$
Cation	Na^+	12290	26717.4
	K^+	485	620.2
	Ca^{++}	480	1200.0
	Mg^{++}	1553.499	6393.0
	Total Cation	14808.5	34930.6
Anion	M-alk		113.0
	Cl^-	22400	31593.8
	SO_4^{--}	2878	2997.9
	Total Anion	25278	34704.7

Table 4 Analysis of Feed Water and Permeate Water Mini Module Tester Exp. T-1-Permeate

		mg/l	mg/l as $CaCO_3$
Cation	Na^+	139	302.2
	K^+	4.4	5.6
	Ca^{++}	0.4	1.0
	Mg^{++}	0.243	1.0
	Total Cation	144.043	309.8
Anion	M-alk		18.4
	Cl^-	200	282.1
	SO_4^{--}	1	1.0
	Total Anion	201	301.5

Table 5 Analysis of Feed Water and Permeate Water Mini Module Tester Exp. T-2-Permeate

		mg/l	mg/l as $CaCO_3$
Cation	Na^+	122	265.2
	K^+	3.8	4.9
	Ca^{++}	0.4	1.0
	Mg^{++}	0.486	2.0
	Total Cation	126.686	273.1
Anion	M-alk		17.0
	Cl^-	160	225.7
	SO_4^{--}	1	1.0
	Total Anion	161	243.7

Table 6 Analysis of Feed Water and Permeate Water Mini Module Tester Exp. T-3-Permeate

		mg/l	mg/l as $CaCO_3$
Cation	Na^+	175	380.4
	K^+	5.7	7.3
	Ca^{++}	0.4	1.0
	Mg^{++}	0.729	3.0
	Total Cation	181.829	391.7
Anion	M-alk		20.5
	Cl^-	262	369.5
	SO_4^{--}	1	1.0
	Total Anion	263	391.1

Table 7 Analysis of Feed Water and Permeate Water Mini Module Tester Exp. N-1-Permeate

		mg/l	mg/l as $CaCO_3$
Cation	Na^+	65	141.3
	K^+	2	2.6
	Ca^{++}	0.8	2.0
	Mg^{++}	1.458	6.0
	Total Cation	69.258	151.9
Anion	M-alk		17.3
	Cl^-	87.5	123.4
	SO_4^{--}	1	1.0
	Total Anion	89	141.8

Table 8 Analysis of Feed Water and Permeate Water Mini Module Tester Exp. N-2-Permeate

		mg/l	mg/l as $CaCO_3$
Cation	Na^+	72	156.5
	K^+	2	2.6
	Ca^{++}	0	0.0
	Mg^{++}	0.243	1.0
	Total Cation	74.243	160.1
Anion	M-alk		18.4
	Cl^-	103	145.3
	SO_4^{--}	1	1.0
	Total Anion	104	164.7

Table 9 Analysis of Feed Water and Permeate Water Mini Module Tester Exp. N-3-Permeate

		mg/l	mg/l as $CaCO_3$
Cation	Na^+	77	167.33
	K^+	2.6	3.3
	Ca^{++}	0.2	0.5
	Mg^{++}	0.243	1.0
	Total Cation	80.043	172.2
Anion	M-alk		18.9
	Cl^-	105	148.1
	SO_4^{--}	1	1.0
	Total Anion	106	168.0

Table 10 Analysis of Feed Water and Permeate Water Mini Module Tester Exp. Brine-T-1-3

		mg/l	mg/l as $CaCO_3$
Cation	Na^+	16900	36739.1
	K^+	567	725.1
	Ca^{++}	600	1500.0
	Mg^{++}	1973.16	8120.0
	Total Cation	20040.16	47084.2
Anion	M-alk		132.0
	Cl^-	30200	42595.2
	SO_4^{--}	3674	3827.1
	Total Anion	33874	46554.3

Table 11 Analysis of Feed Water and Permeate Water Mini Module Tester Exp. Brine-N-1-3

		mg/l	mg/l as $CaCO_3$
Cation	Na^+	14400	31304.3
	K^+	500	639.4
	Ca^{++}	528	1320.0
	Mg^{++}	1744.74	7180.0
	Total Cation	17172.74	40443.7
Anion	M-alk		112.0
	Cl^-	25497	35961.9
	SO_4^{--}	3317	43455.2
	Total Anion	28814	39529.1

7.2 Experiment with RO Mini–Module (1)

7.2.1 Installation of RO Mini-Module Tester

Contents

List of Figures

1. Objective

After assessing the performance of various flat sheet membrane with the flat membrane test equipment, their performance, as assembled in the form of commecialized Mini-module (2.5" dia), need to be assessed. For this reason installation of a Mini-module Tester was essential.

2. Summary of experimental equipment-Installation

2.1 Installation of experimental equipment-(Mini Module Tester 1 and 2)

June 8	:	Checking RO pilot plant parts moved from the west coast
20	:	Flat membrane tester (owned by SWCC) installed in RO test building
28	:	Preparing for tests with Flat Membrane Tester (owned by SWCC)
July 6	:	Tests with Flat Membrane Tester (owned by SWCC)
21	:	Equipment sent by JICA (RO-1 test unit, RO-2 test unit, chiller unit, cooling tower) arrived at SWCC R&D Center
24	:	Checked list of materials 27/28: Transfer materials to installation site
28	:	Test operation of Mini-module Tester (1) and Chiller
August 2	:	Connecting utilities to each unit (water supply and drainage, power supply, foundations for some units, seawater supply and drainage)
14	:	Test operation of Mini-module Tester (1) and Chiller
17	:	Experiments with Mini-module Tester(1)
September 1	:	Prepare for experiments with Mini-module Tester (2)
7	:	Experiments with Mini-module Tester(2)

2.2 Experimental equipment-Utilities Installation

A) Chiller installation

The chiller was installed to adjust the water temperature. Chiller Unit #2 is connected to the Flat Membrane Tester (owned by SWCC) and the Mini-module Tester No. 2. Chiller Unit #1 is connected to the concentrated water pipe of Mini-module Tester No. 1.

B) Connection with pretreatment section: Both Mini-module Tester 1 and 2 was connected with SWCC pretreatment unit.

3. Short discription of individual units:

a. Pre-treatment equipment:

The sand filters owned by SWCC consist of two towers. About 5 mg/l of flocculant (as Fe) is added for the first two hours of operation. This is then reduced to about 1 mg/l. No. 2 Filter is used as a polishing filter.

SWCC pretreatment unit is capable of supplying pretreated seawater (SDI<3) continuously to Mini-module Tester 1 and 2.

b. Flat Membrane Tester (owned by SWCC):

This Tester is used for testing flat membranes. The unit has an ultra filtration so that it can be used even when the SDI of the water supply to the RO membrane is high. This unit was connected with Chiller #2 to control feed temperature.

c. Mini-module Tester (1): Mini-module tester (1) has a set of six RO modules and the number of modules used can be reduced to suit the experimental conditions. Chiller #1 is connected to the concentrated water outlet and the water temperature can be controlled while both permeate and reject are circulated back to feed.

d. Modified form of Mini-module Tester-1

Mini-module Tester-1 has been modified from its original arrangement of pressure vessel: Six pressure vessels in one series to Six pressure vessels in two series.

Each series consist of three pressure vessel also in series. Separate Reject Flow meter and pressure gauge were installed to record both flow and pressure separately for individual series.

Six RO modules were employed. The brine blow pipe was installed at down-flow point of the brine flow meter.

Mini-module Tester (2) Model RUW-5 :

Mini-module Tester (2) can be used either for performance evaluation of a 2.5" diameter SWRO membrane module or for evaluation of four types of flat sheet membranes or to evaluate a simple ultrafiltration membrane as it has three options of operation chiller #2 is connected with their unit to control the feed temperature. Fig.1-5 shows the individual picture of different units, while Fig. 6 shows

interconnection of individual units.

Inter Connection with SWCC Units:
Fig. 1 shows the details of interconnections.

4. Conclusion

Utilizing facilities of Mini–module Tester 1 and 2, various types of commercial SWRO membranes were investigated, both in flat sheet and mini modular (2.5" dia) form, with a view to develop a comparative analysis of their performance in order to make a tentative selection of suitable one for MSF–RO hybrid system.

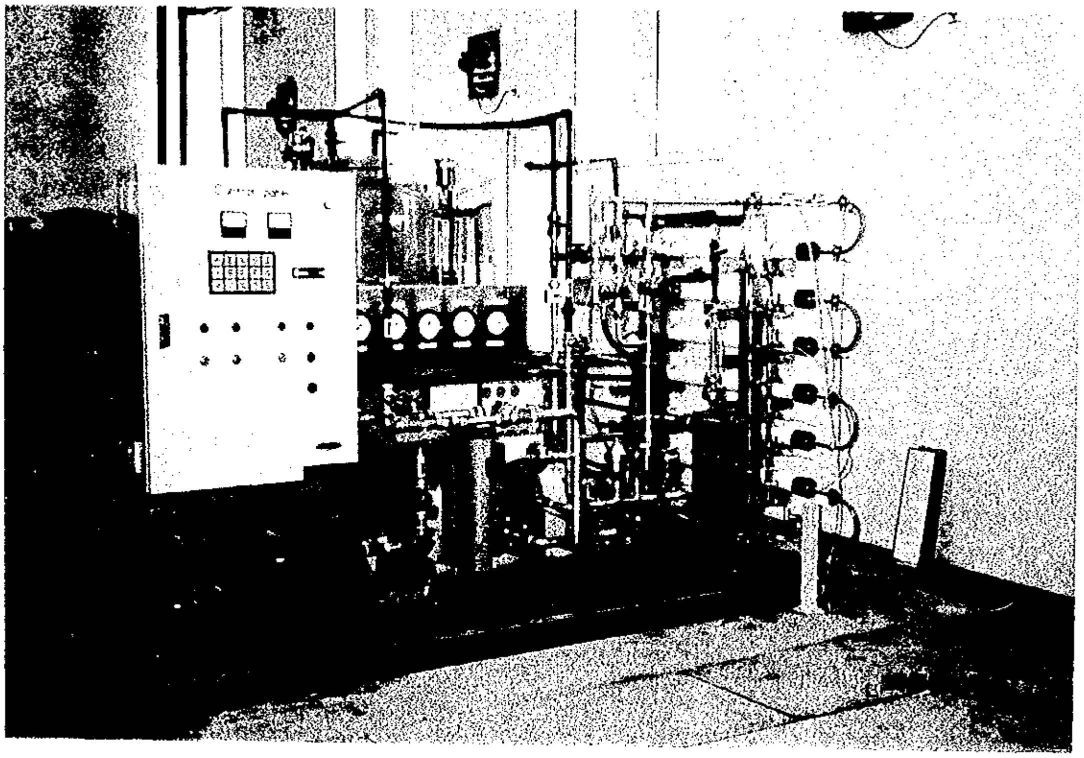


Fig. 1 Mini-Module Tester(1)

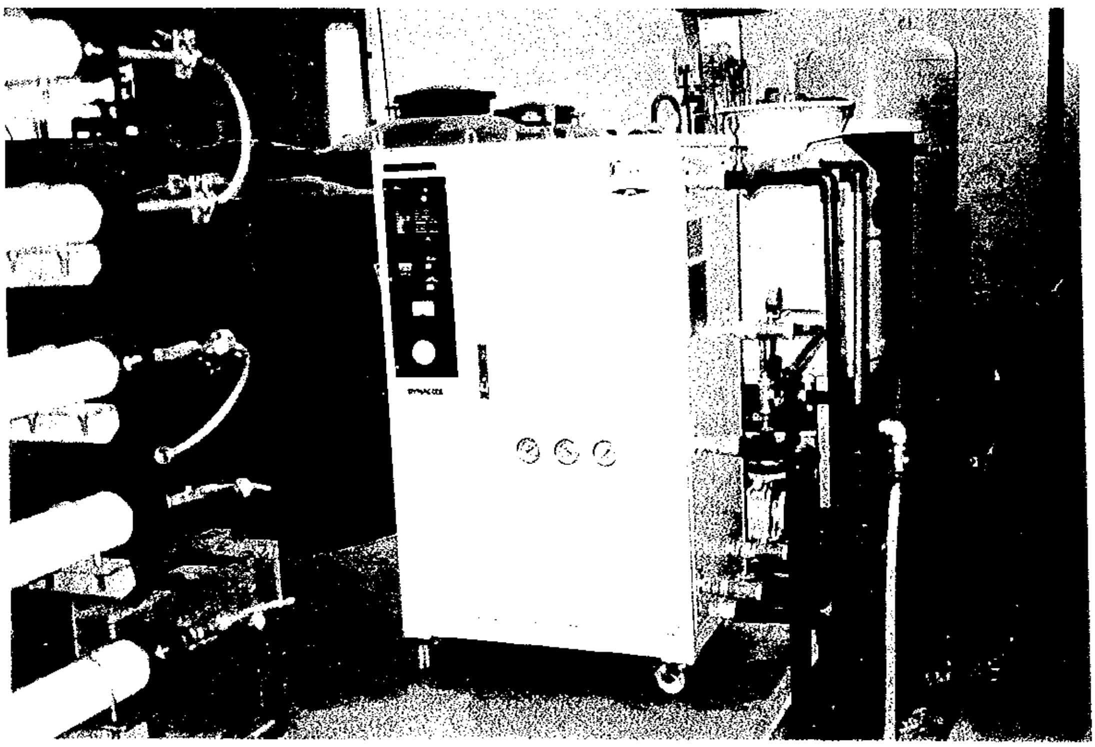


Fig. 2 Chiller Unit for Mini-Module Tester(1)

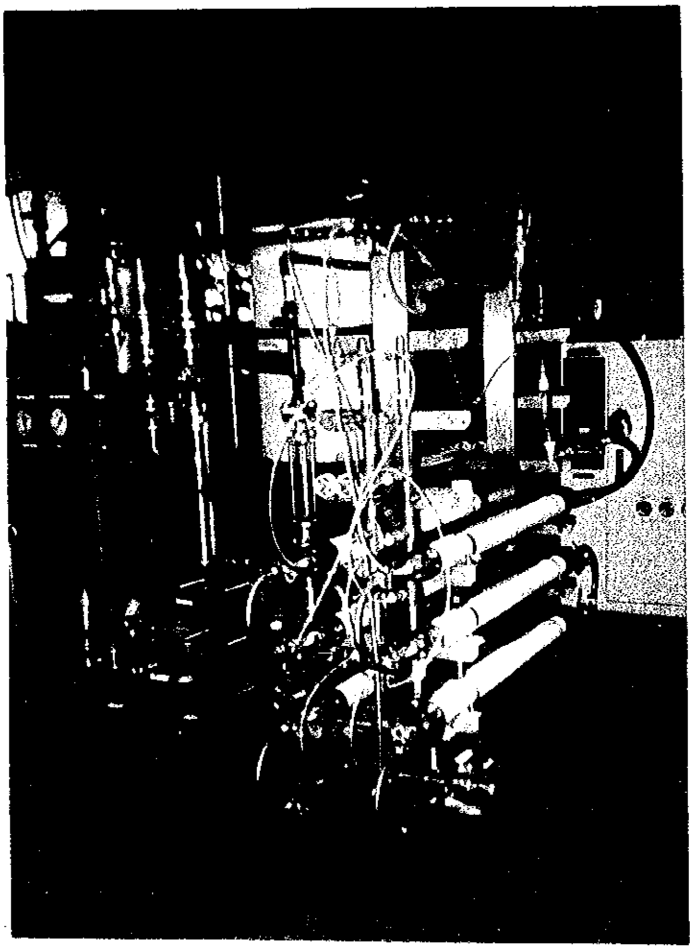


Fig. 3 Modified Mini-Module Tester(1)

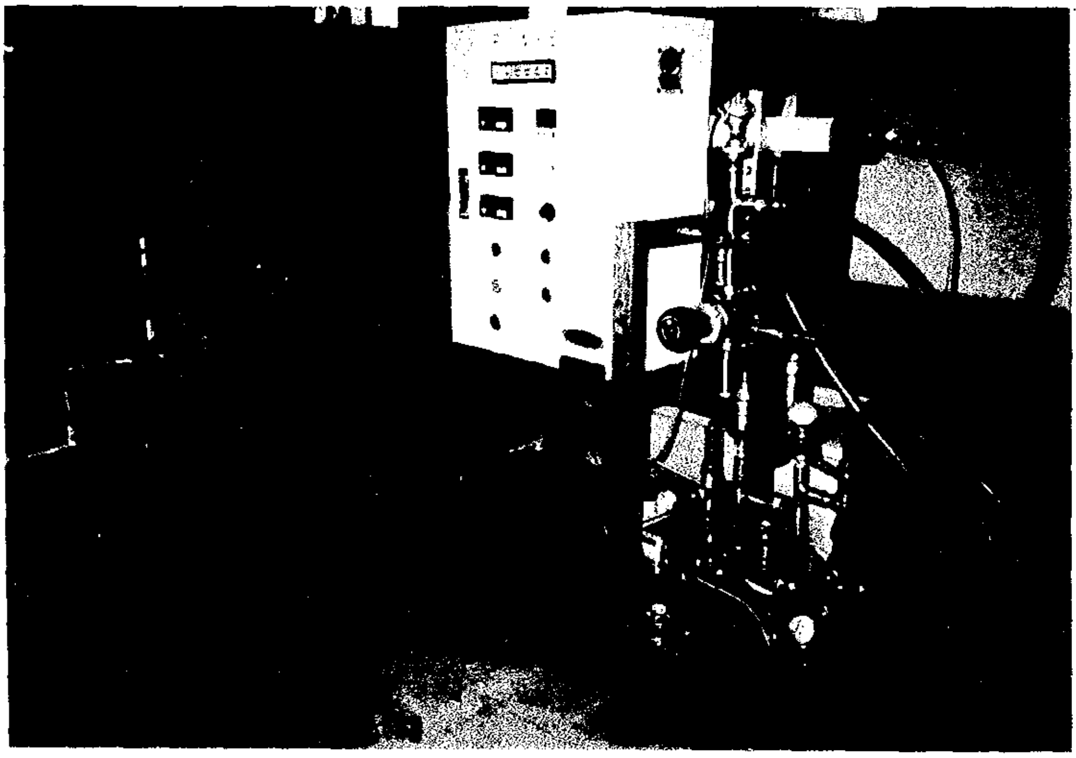


Fig. 4 Mini-Module Tester(2)

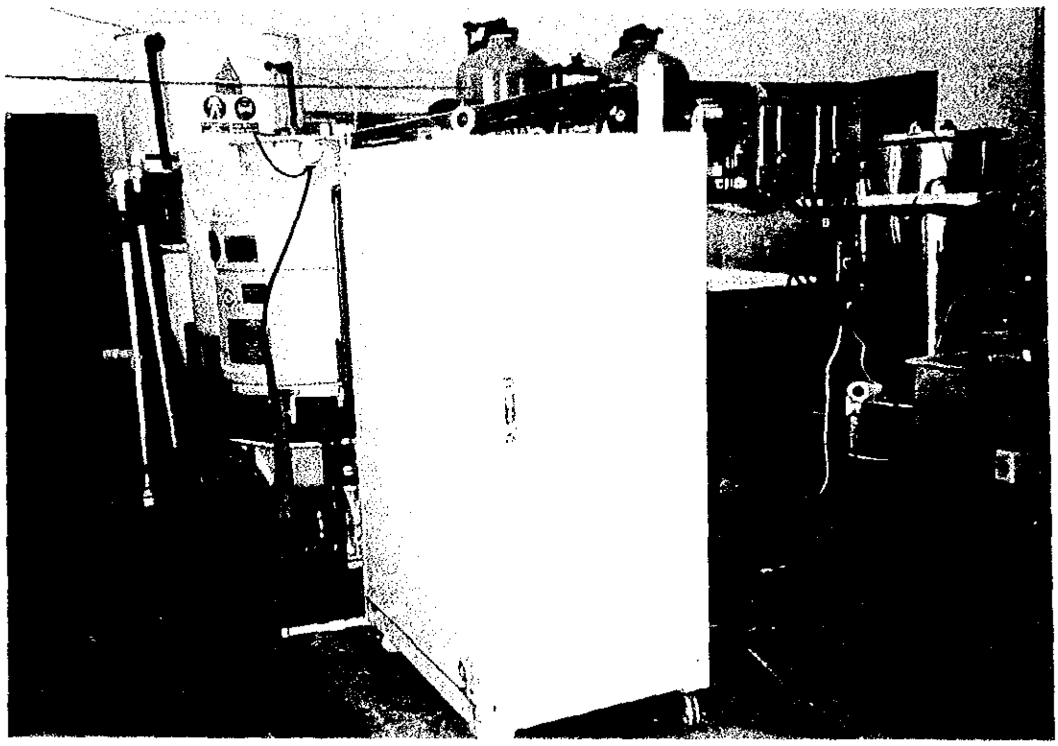


Fig. 5 Chiller Unit for Mini-Module Tester(2)

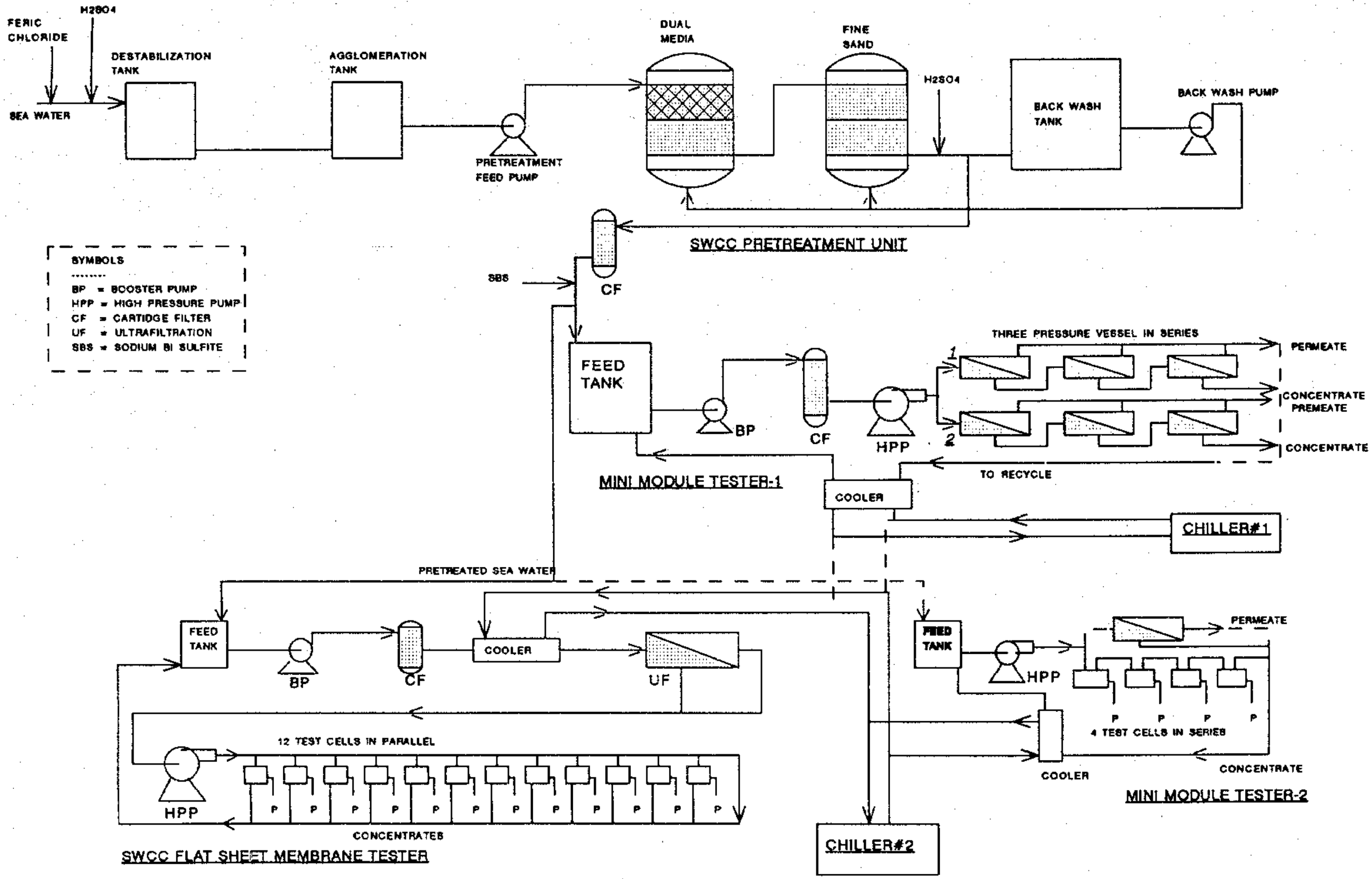


FIGURE 6: SCHEMATI FLOW DIAGRAM OF SWCC PRETREATMENT & MEMBRANE SELECTION TEST UNITS

7.2.2 RO Module Selection Test

Contents

List of Tables

List of Figures

1. OBJECTIVES:

Objectives of the tests are to perform a comparative study on the performance of various SWRO membrane elements (2.5 inch dia.) based on the performance information of flat sheet SWRO membranes, already evaluated, to select the one suitable for Hybrid desalination system.

2. SUMMARY:

In hybrid desalination system normally both thermal desalination plant such as MSF plant and SWRO plant exist side by side. The low salinity product from MSF plant, TDS of 50 ppm (Max), is blended with product of SWRO plant, TDS, normally less than 1000 ppm, to produce final product of less than 500 ppm TDS. To optimize a hybrid desalination plant it is required to use SWRO membranes with highest possible flux and reasonable good salt rejection rather than a membrane with high salt rejection and low flux. To establish a SWRO membrane that meets the above criteria, various types of SWRO membranes were investigated through a series of experiments using flat sheet and minimodules (2.5x40'inch) SWRO units. Tested MINIMODULES are :Toray SU – 806 (Type 1), Toray SU – 806 (TYPE – 2), Nitto Denko NTR 70 SWC, Hydranautic HSA 2540 CAB2, Filmtec SW 30 HR 2540 (A), Filmtec SW 30 2540 (F) and Fluid system TFCL S2721.

Above mentioned SWRO membrane elements, diameter 2.5 inch, which were received from various membrane manufacturers were investigated using SWCC/JICA minimodule tester #1 and #2. This was done after completion of flat membrane comparison test utilizing SWCC flat sheet tester and SWCC/JICA minimodule tester (2). Pretreated seawater from SWCC pretreatment unit was used as feed in mini module tester #1, and 3.5% NaCl solution was used as feed in all tests conducted by the minimodule tester #2. Membranes were investigated at different pressures, temperature and brine flow rates. After completion of evaluation tests which was done for a short period for all the available membranes, only two membranes: Toray SU–806 and Nitto Denko NTR 70 SWC were selected to evaluate on continuous operation. The test is continuing utilizing mini module tester #1, arranging the membrane in two parallel lines. First line contains three elements of Toray arranged in series, while the second line has three elements of Nitto Denko, also arranged in series.

3. EXPERIMENTAL:

Figures 1 shows schematic flow diagrams of the Mini Module tester #1 which consists of a feed tank, a permeate tank, two booster pumps, two cartridge filters and two high pressure pumps. PVC and SS316 piping are used in the low and high pressure sections, respectively. The high pressure pump supplies feed to the SWRO unit which consist of two parallel lines and each of them can contain up to three 2.5x40inch SWRO membrane modules arranged in series. The tester is equipped with a cleaning system and a control panel.

The pretreated seawater feed is supplied to the feed tank from SWCC pretreatment unit. The feed SDI and pH were maintained at 2.5 ± 0.5 and 6.9, respectively. The unit is equipped with automatic devices to shut off the unit automatically at an emergency. All short duration tests were conducted by circulating both the permeate and the reject to the feed tank. Feed temperature was maintained to 25 ± 3 ^{O}C by the water cooler. During long term continuous operation, both the permeate and the reject were sent to drain.

Description of tester #2 was given earlier. To allow the tests a 2.5"x40" membrane holding pressure vessel was connected to the system replacing the 4 flat sheet membrane test cells. Feed was prepared by dissolving 3.5 kg of NaCl in 96.5 liters potable water for all tests done by tester #2.

4. RESULTS AND DISCUSSION:

Table (1) shows a list of the various SWRO membranes tested by both minimodule tester #1 and #2. Performance evaluated at various operation conditions are plotted in Figures 2 to 16. Permeate flow rate and permeate conductivity of Toray SU-806 (Type - 1) vs feed pressures are plotted in Fig.2(A), while those at different brine flow rate are plotted in Fig.2(B). Fig.3(A) shows the permeate flow and conductivity at different temperatures, while Fig.3(B) shows the temperature correction coefficient curve at different temperatures. In the Fig.2(A) a steep rise in permeate flow is observed when pressure is raised from 46 to 61 kg/cm^2. Decrease of permeate conductivity is also observed when the pressure is increased. In Gifure 2(B) a raise in permeate flow and a decease in permeate conductivity was observed with increase in brine flow. In Figure 3(A) a rise in permeate flow and permeate conductivity was observed with in a rise in feed temperature. A steep rise in permeate flow was observed when tempereture increased from 33℃ to 39℃.

Fig.4(A) and (B) is a plot of Toray SU–806 (Type –2) performance at different pressures and brine flow rates, respectively. In Figure 12 (B) it appears that permeate conductivity decreases as brine flow increases, but permeate flow shows a steeper rise when brine flow is increased from 4 L/min to 7 L/min. In Figure 12 (A) it appears that the permeate flow increases as pressure is increased, while permeate conductivity decreases as the feed pressure is increased.

Fig.5(A) and (B) shows the performance of Hydranautics 2540 HSA swc1 membrane at different pressures and brine flow rates. A gradual increase of permeate flow was observed when pressure increased to 61 kg/cm^2 but unexpectedly permeate flow decreased when pressure increased above 61kg/cm^2. The conductivity of permeate initially increased up to 6500 $\mu s/cm^2$ with increasing brine flow up to 7 L/m which is not normally expected. However, permeate conductivity decreased gradually when brine flow rate was increased above 7 L/m up to 12 L/m, Fig.5(B).

Fig.6(A) and (B) is a plot of permeate conductivity and permeate flow vs pressure, permeate conductivity and permeate flow vs brine flow of Fluid system TFCL S7721 membrane, respectively while Fig.7(A) and (B) is a plot of membrane permeate flow and conductivity vs temperature, and the tempereture correction coefficient vs temperature, respectively. Comparison of performances using two different feeds: pretreated seawater and 3.5% NaCl solution at different pressures and brine flow rates are plotted in Fig.8(A) and (B) respectively. It was observed that both permeate flow and salt rejection were higher in the case of 3.5% NaCl solution than in the case of sea water feed, Fig.8(A) and (B).

For Filmtec SW30 2540 membrane, permeate conductivity and permeate flow vs tempereture are ploted in Figure 9(A), tempereture correction co efficient vs temperetures are ploted in Figure 9(B), permeate conductivity and permeate flow vs pressures are plotted in Fig.10(A), while permeate conductivity and flow vs brine flow rate are plotted in Fig.10(B), respectively. Fig.11(A) and (B) shows a comparison of this membrane performance using two different feeds: pretreated seawater and 3.5% NaCl solution. From the Figure it is clear that membrane performance using 3.5% NaCl as feed is better than that using seawater feed.

Fig.12(A) and (B) shows the performance of Filmtec SW 30 HR 2540 membrane at different pressures and different brine flow rates. From Fig.19(A), it appears that permeate flow increases as feed pressure increases and permeate conductivity decreases as feed pressure is

increased. A steep rise in permeate flow was observed when pressure was increased from 51 kg/cm^2 to 56 kg/cm^2. Unexpectedly, permeate flow decreases when brine flow is increased from 4 to 12 l/m Fig.19(B). However, permeate conductivity decreases as brine flow is increased.

Table (2) summarises the evaluation results for all membranes at pressure of 56 kg/cm^2, brine flow 7 l/m, and temperature (25±3)℃. Seawater was used as feed. Modules were arranged in series during the tests with two elements per line. Table (3) summarises the evaluation results of four types of membranes tested using 3.5% NaCl solutin as feed. From Table(2) it appears that Fluid System membrane has the highest permeate flow followed by Filmtec SW 30HR, Toray, Hydranautics and Nitto Denko. The lowest permeate flow from Nitto Denko membrane is probably due to low surface area of this membrane elements Table (1). However, the permeate conductivity shows higher value for Fluid system followed by Hydranautics, Filmtec SW 30 2540, Toray su 806 (type-1), Nitto Denko NTR 70 swc, Toray 806 (type-2) and Filmtec sw 30 HR 2540. when two modules were arranged in series.

In case of results obtained from tests of single membrane element, highst permeate flow was observed from Fluid system TFCL S7721 followed by Filmtec SW 30 HR 2540, Toray su 806 (type-1), Filmtec SW 30 2540, Toray SU 806 (type-2), Hydranautics HSA 2540 SWC1 and Nitto Denko NTR 70 SWC. However, the permeate conductivity shows higher value for Hydranautics HSA 2540 SWC1 followed by Filmtec SW 30 2540, Nitto Denko NTR 70 SWC, Filmtec SW 30 HR 2540, Toray SU 806(type-2), Fluid system TFCL S7721 and Toray SU 806 (type-1).

When the evaluation was done with 3.5% NaCl as feed: the highest permeate flow was observed when using Fluid System membrane, followed by Filmtec and Toray membranes. The permeate conductivity for Toray, Filmtec SW 30 2540 and Fluid System was found nearly identical, but Bilmtec, SW 30 HR 2540 has higher permeate conductivity.

5. CONCLUSION:

Almost all the membranes except hydranautics membrane, gave results in agreement with the supplier specification.

6. RECOMMENDATIONS:

Flux (m3/m2.D) calculation based on surface area of membrane elements need to be done after receiving surface area for 2.5 inch. dia. membranes from manufacturers. Evaluation of commercial sized (8 inch. dia.) membrane elements is to be done.

Table 1

List of Various SWRO Membrane Elements
Tested by Minimodule Testers

Manufactures/Suppliers	Membrane type	Membrane area in M^2	Element No.
DOW (FILMTEC)	SW30HR - 2540 - A	N/A	A1707515 A1706541
DOW (FILMTEC)	SW30 - 2540 - F	N/A	A1997531 A1997162
FLUID SYSTEM	FLUID SYSTEM TFCL S7721	N/A	299706 299708
TORAY	SU - 806 (TYPE - 1)	2.6	30820288 30820289 30820290 30820293 30820294 30820295
TORAY	SU -806 - (TYPE -2)	2.6	30820517 30820518
HYDRANAUTICS	2540-HSA-SWC1	1.7	00605045 00605051 00605056 00605057 00605061 00605062
NITTO DENKO	NTR - 70 SWC - S2	1.7	3110031 3110032 3110034 3110035 3110039 3110040

Table 2 Summary of Performance Evaluation of SWRO Elements(2.5 inch dia.) Using Pre-treated Seawater Feed

Membrane	Membrane Area	Results of Two Elements in Series		Results of Single Elements	
	m^2 /Element	Permeate Conductivity μs/cm	Permeate Flow L/min	Permeate Conductivity μs/cm	Permeate Flow L/min
Nitto Denko NTR-70SWC	1.7	460	0.81	419	0.46
Hydranautics 2540-HSA-C320	Unknown	1,060	0.88	756	0.47
Fluid system TFCL S7721	Unknown	1,588	1.56	322	1.12
Toray SU-806(Type-1)	2.6	431	1.2	260	0.87
Toray SU-806(Type-2)	2.6	524	1.05	331	0.7
Filmtec SW 30-2540	Unknown	559	1.46	454	0.86
Filmtec SW 30HR 2540	Unknown	365	1.55	355	0.97

Operation conditions:

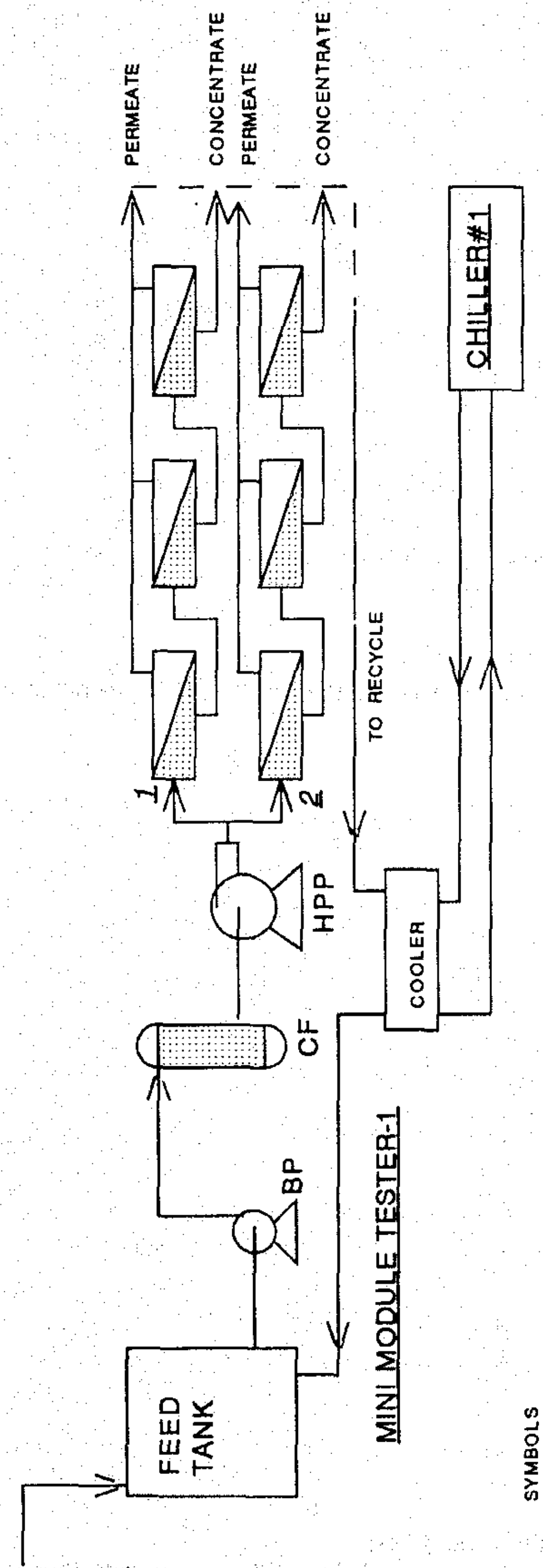
Test duration	=	1 hr
Pressure	=	56 kg/cm^2
Temperature	=	25°C
Brine flow	=	7 l/m
Membrane arrangement	=	Two element in series and single element.
Feed	=	Pretreated seawater
SDI	$<$	3
pH	$\simeq$	7

Table 3

Membranes test results: Tested in RDC Test Plant
using 3.5% NaCl Solution as feed

(Operation conditions: Pressure= 56 kg/cm2, brine flow= 7 l/m, tempereture = 25 ° c, duration time = 1 hr/reading)

Membrane	Permeate conductivity µs/cm	permeate flow l/m
Toray SU - 806 (Type - 1)	307	0.78
Filmtec SW 30 2540	393	0.96
Filmtec SW 30 HR 2540	411	1.08
Fluid system TFCL S7721	322	1.12



SYMBOLS
....
BP = BOOSTER PUMP
HPP = HIGH PRESSURE PUMP
CF = CARTIDGE FILTER
1 = THREE TORAY SU-808 MEMBRANES
2 = THREE NITTO NTR70 SWC EMBRANES

Fig. 1 **Schematic Flow Diagram of Mini-Module Tester(1)**

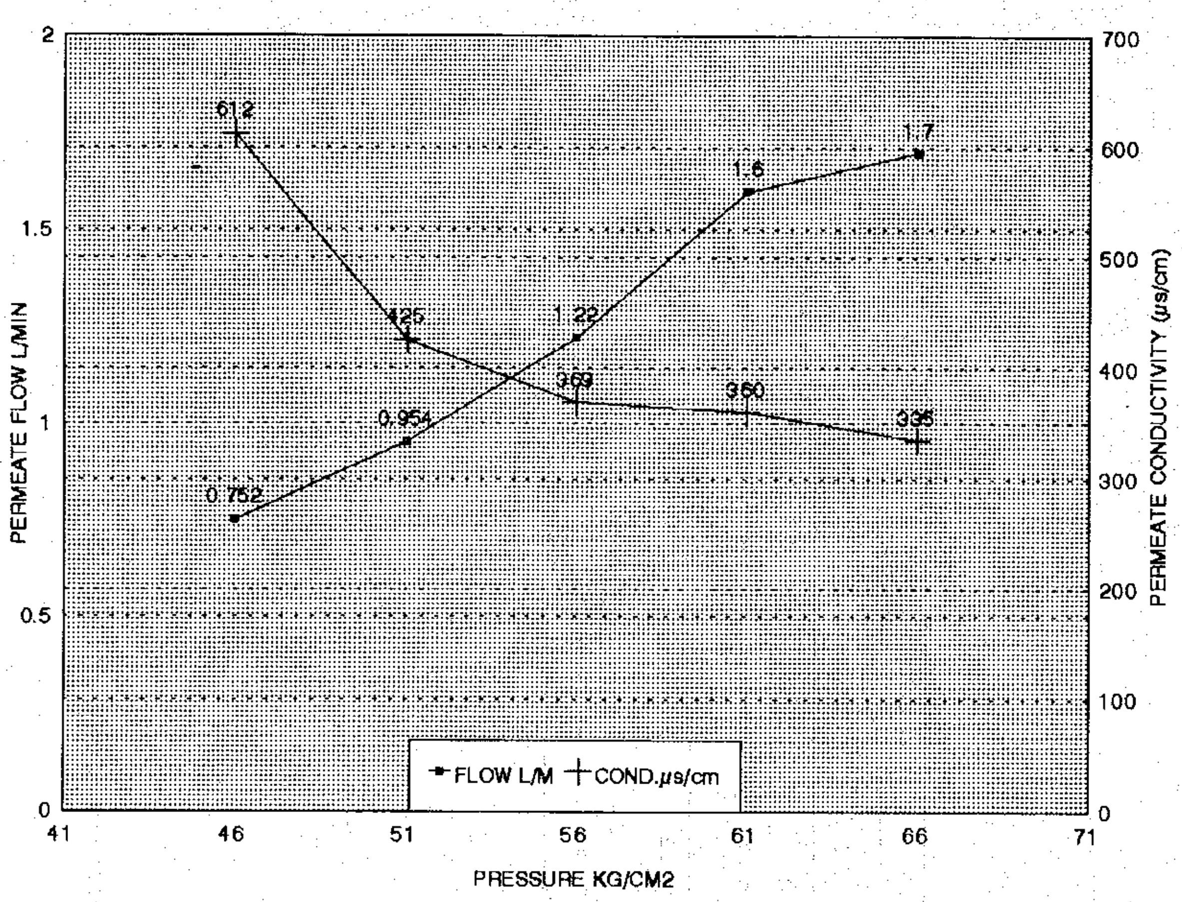


Fig. 2-A Performance of Toray SU-806(Type-1) SWRO Membrane

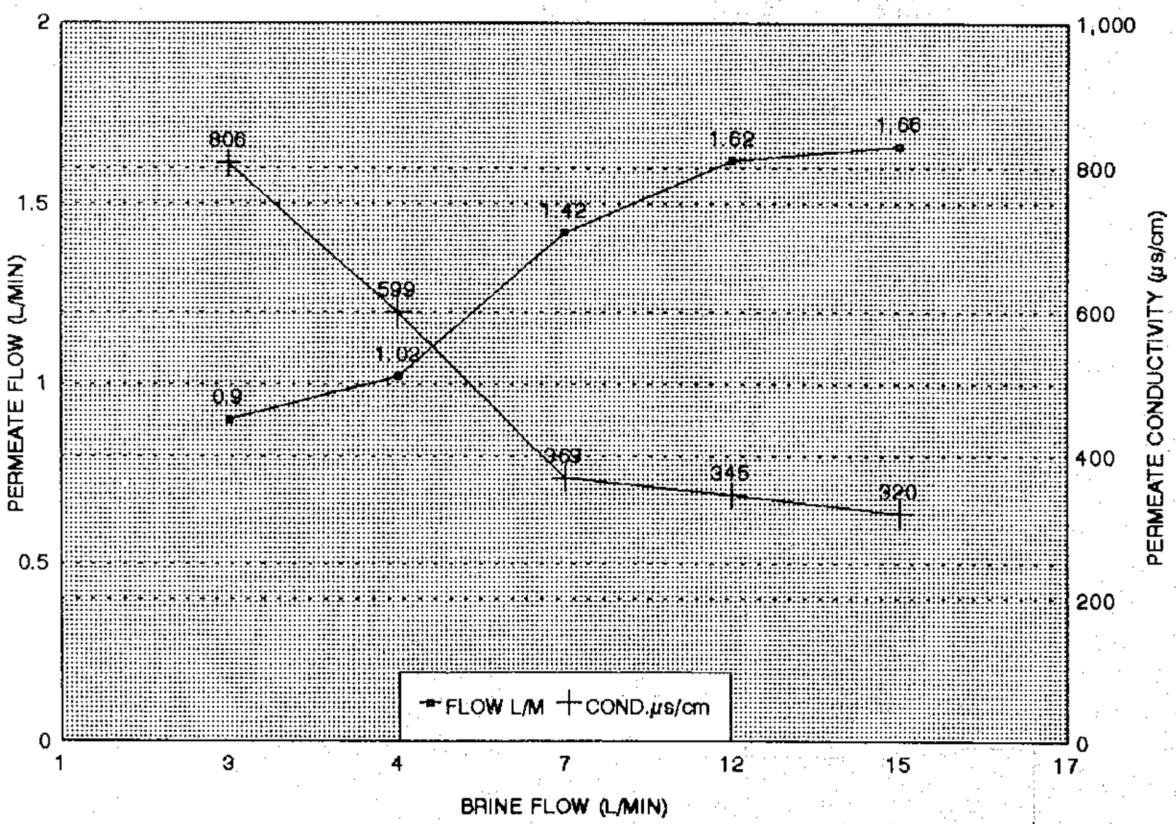


Fig. 2-B Performance of Toray SU-806(Type-1) SWRO Membrane

(OPERATION CONDITIONS: FEED SDI = 2.5 ± 0.2, pH=6.8±0.2, TEMP. = 25±2 °C, TWO ELEMENTS IN SERIES)

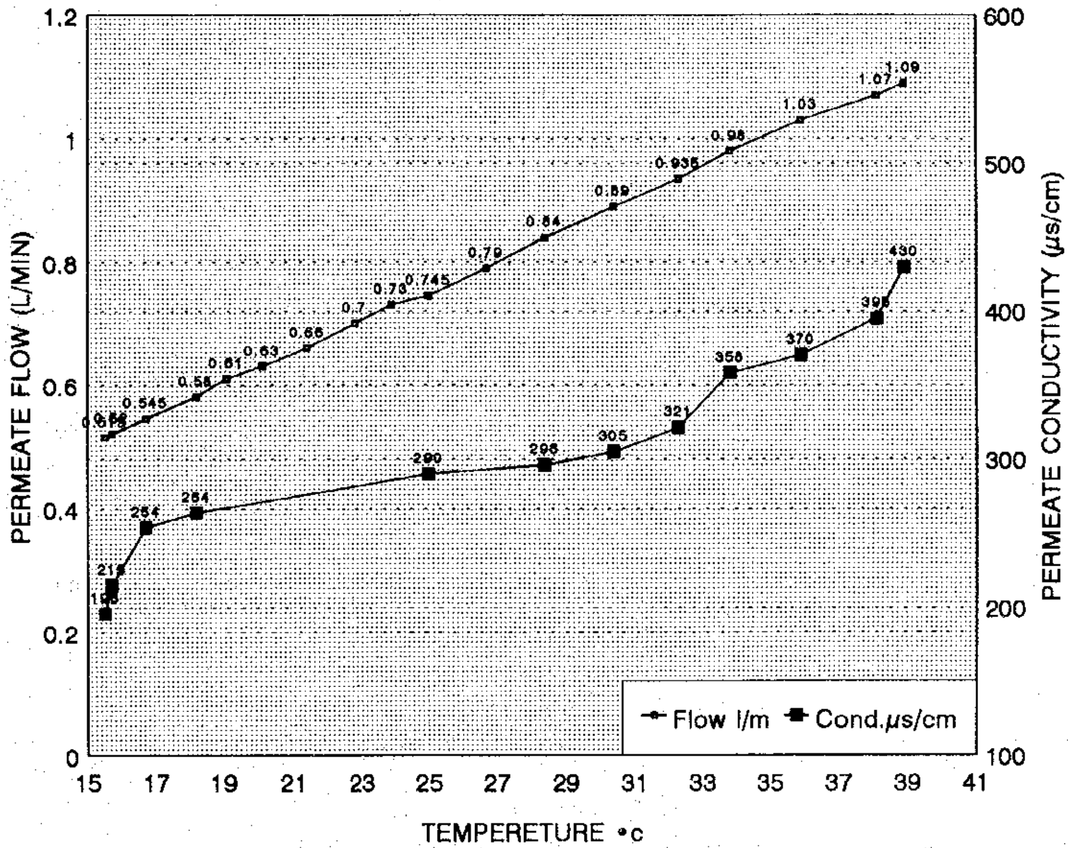


Fig. 3-A Performance of Toray SU-806(Type-1) SWRO Membrane vs Temperature

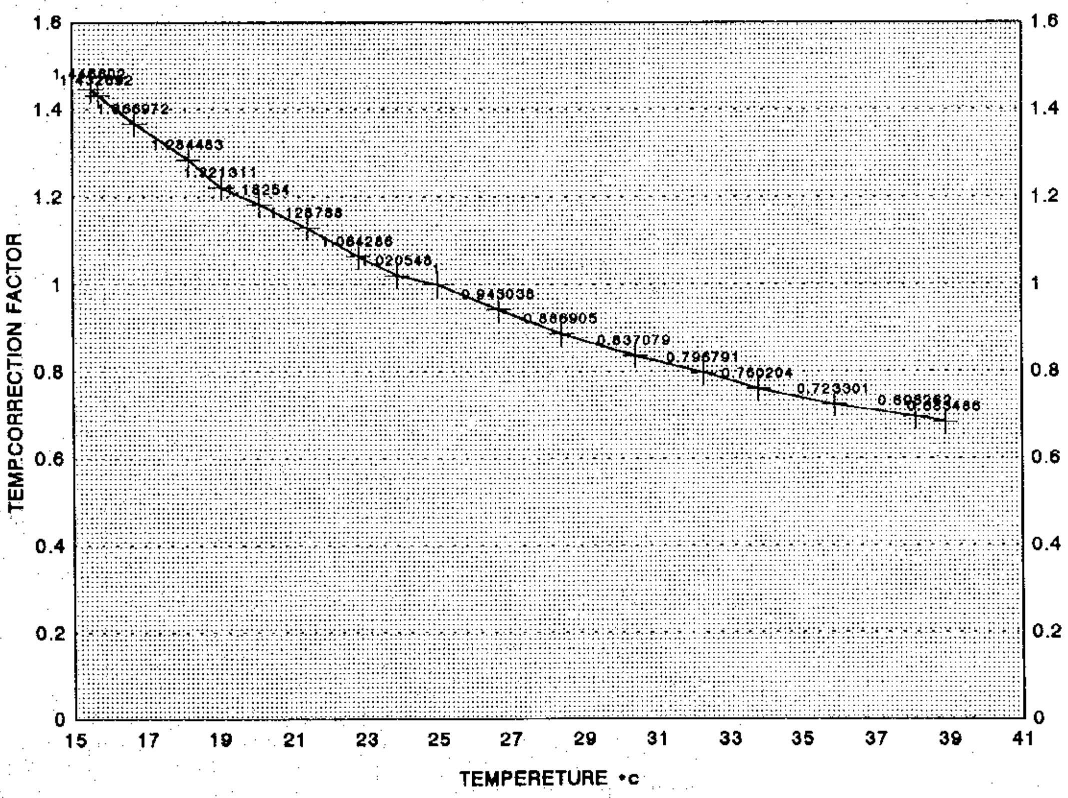


Fig. 3-B Performance of Toray SU-806(Type-1) SWRO Membrane vs Temperature

(OPERATION CONDITIONS:PRESSURE=56 KG/CM2,FEED SDI=2.5±0.3,pH= 6.8±0.2, PRESSURE VESSEL 2.5 X 40 INC)

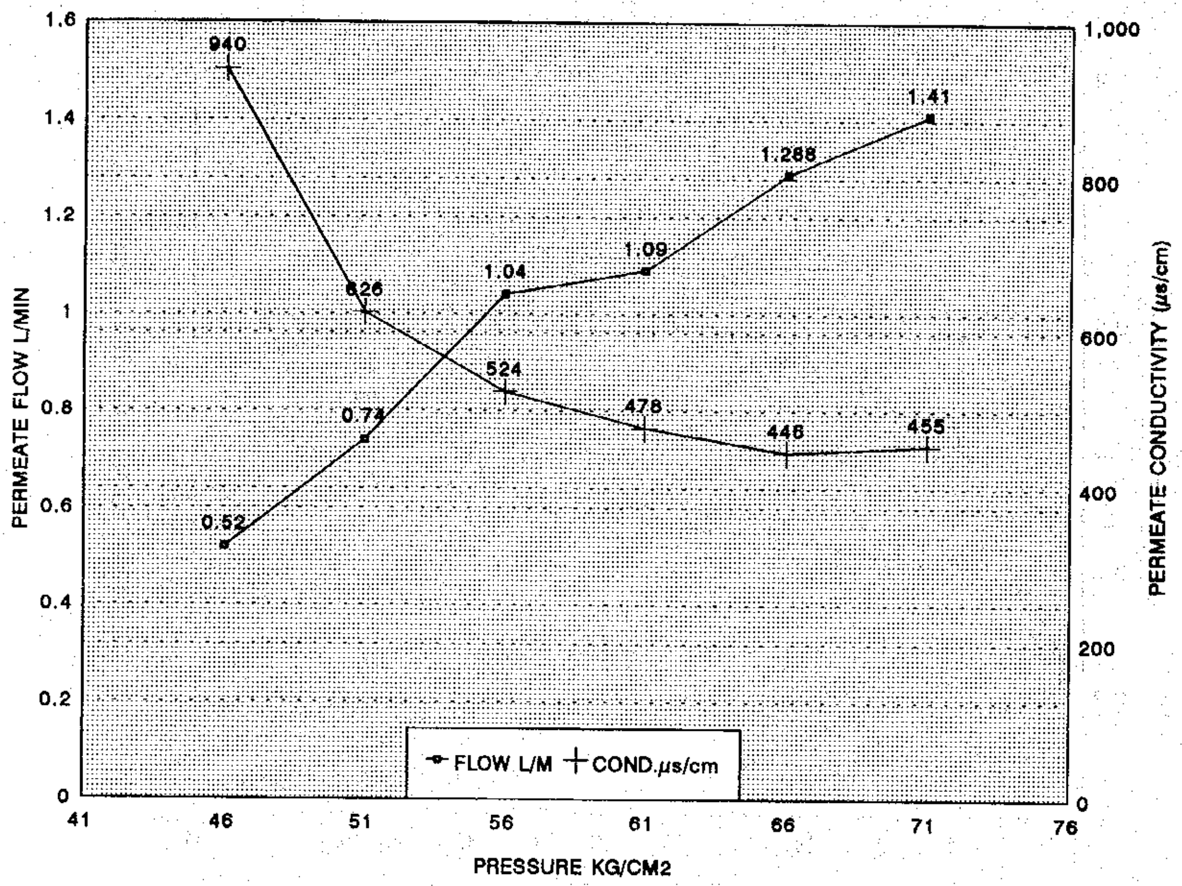


Fig. 4-A Performance of Toray SU-(2) SWRO Membrane

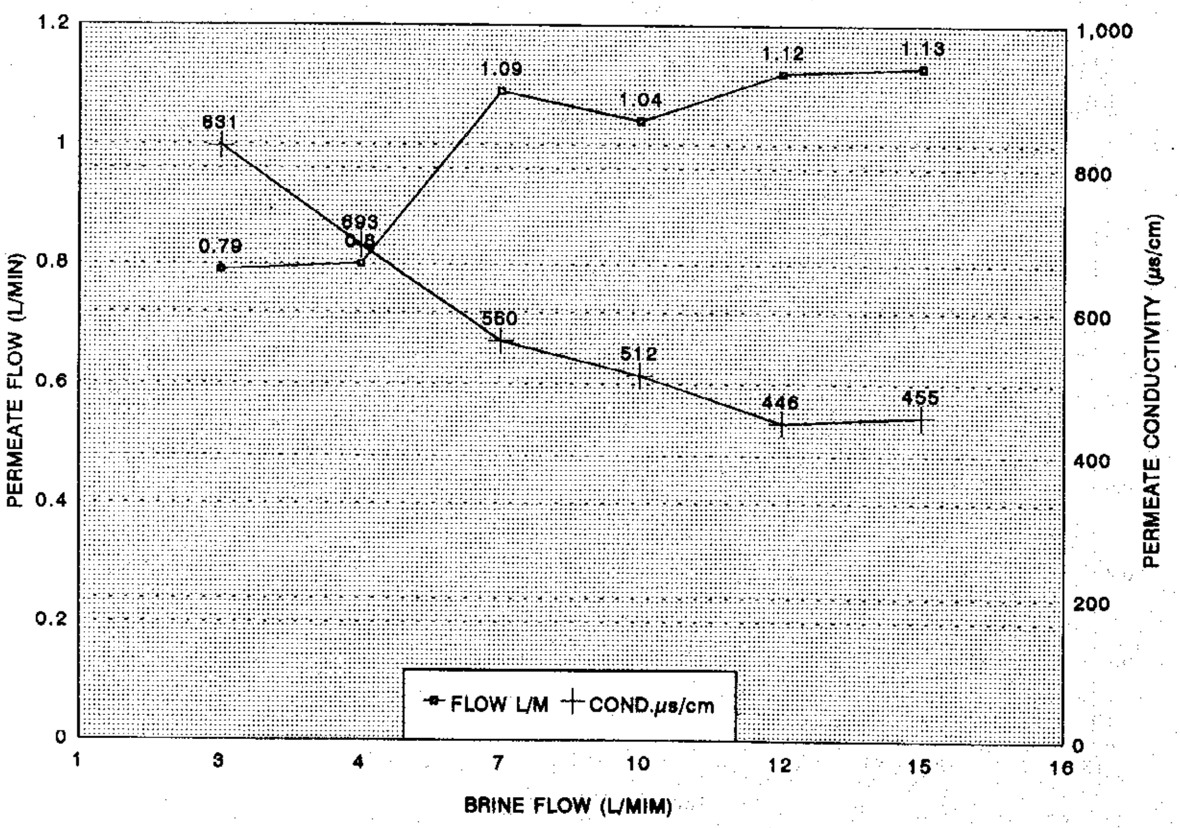


Fig. 4-B Performance of Toray SU-(2) SWRO Membrane

(OPERATION CONDITIONS:FEED SDI=2.5±0.3, pH=6.7±0.3, TEMP.=25±2°C,TWO ELEMENTS IN SERIES)

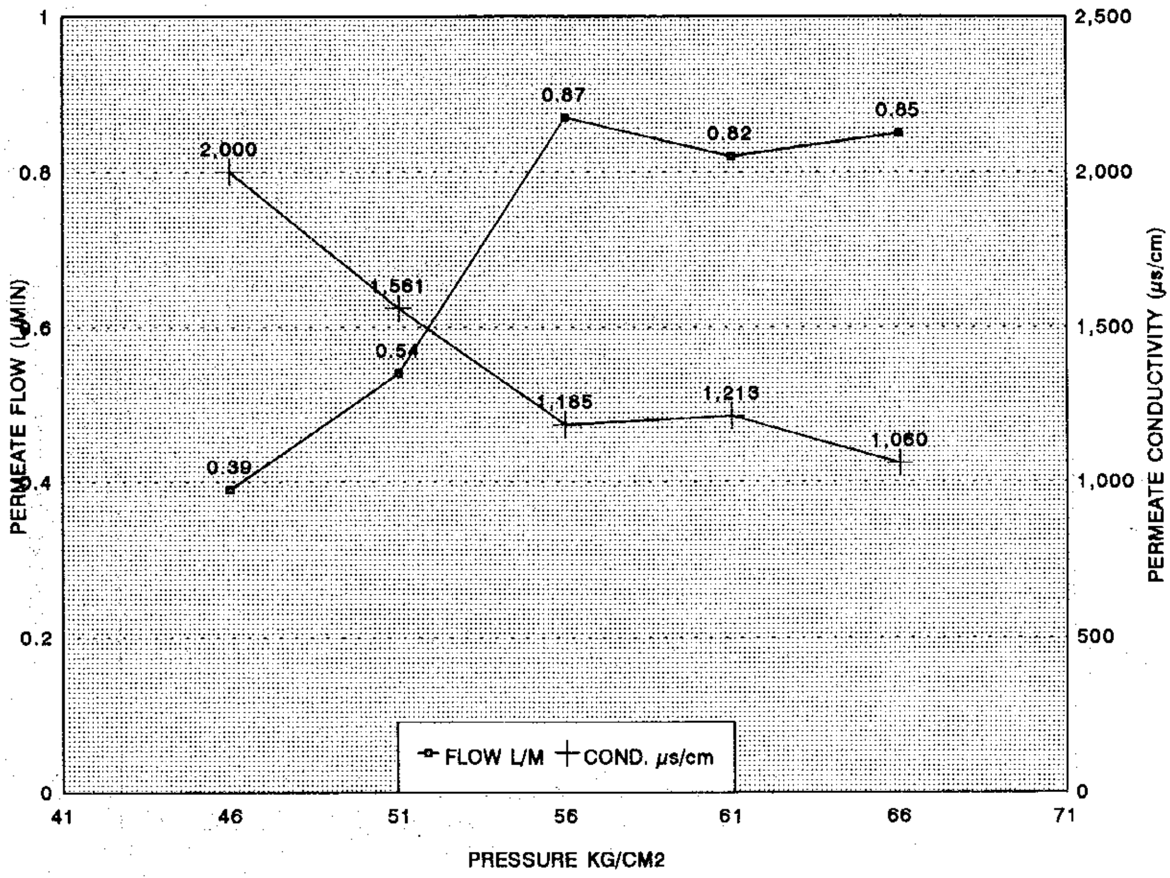


Fig. 5-A Performance of Hydranautics 2540 HSA SWC1 SWRO Membrane

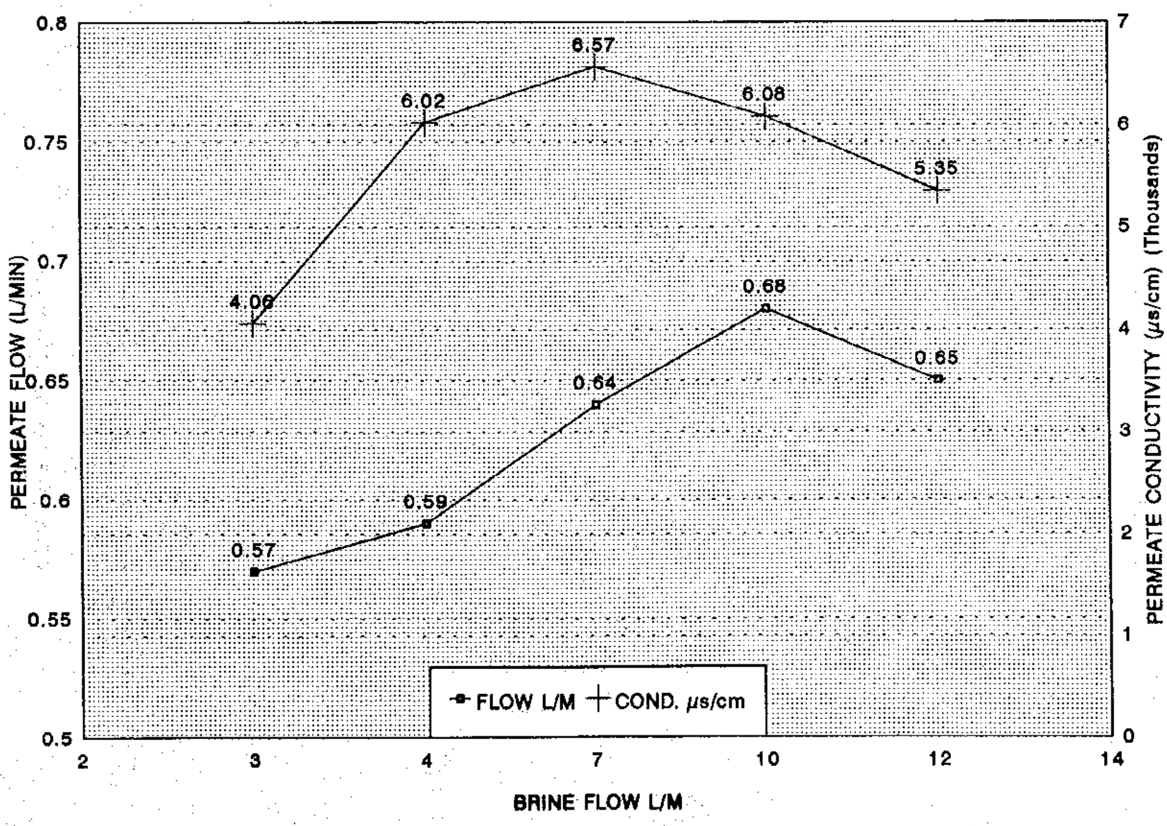


Fig. 5-B Performance of Hydranautics 2540 HSA SWC1 SWRO Membrane

(OPERATION CONDITIONS:FEED SDI= 2.5±0.5,pH=6.8±0.2, TEMP=25±2°C,PRESSURE=56 KG/CM2)