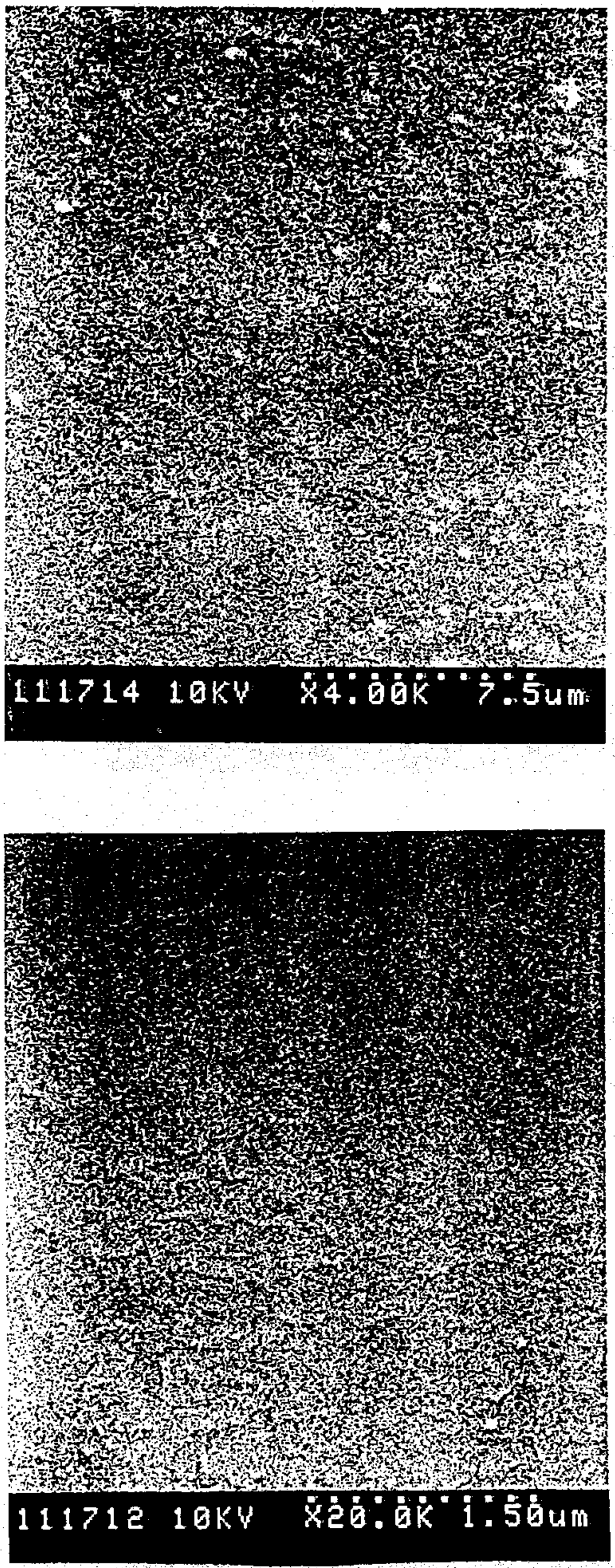


Fig. 3(1) **Low accelerated voltage SEM observation with Membrane Surface of Sample No.1**

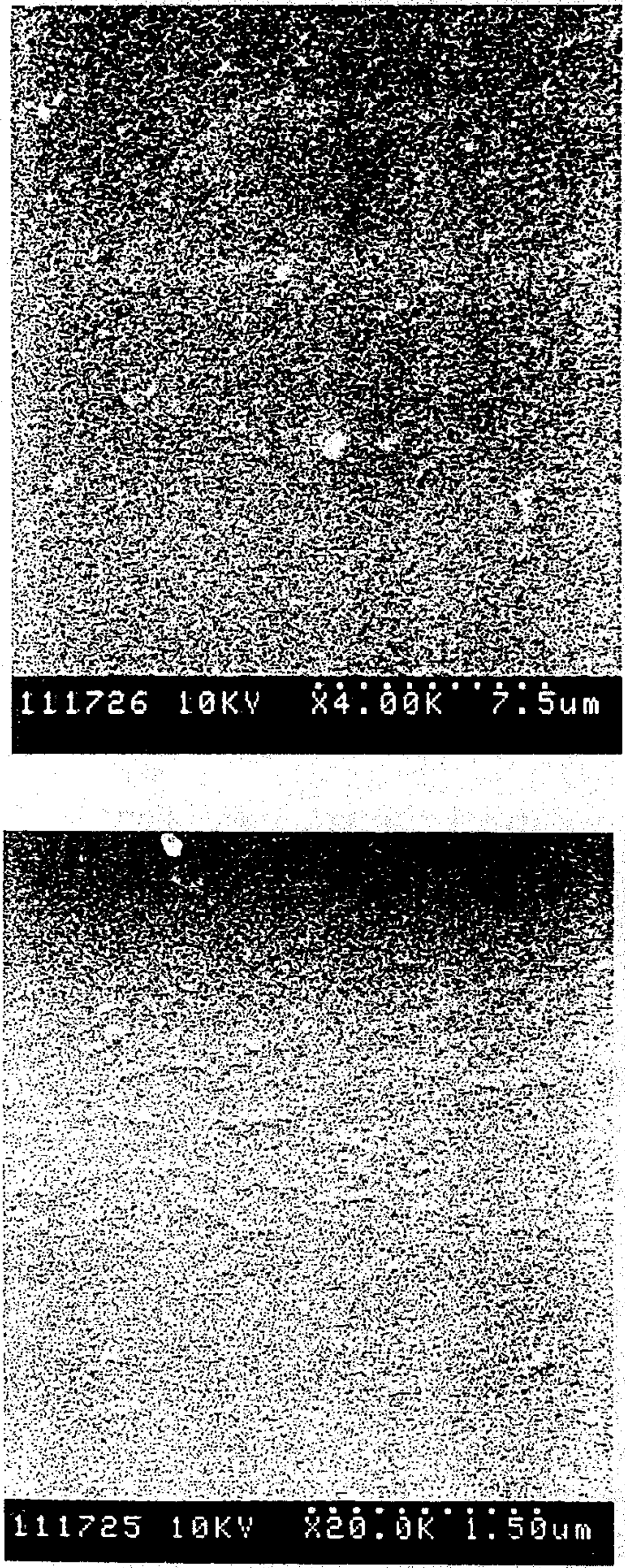


Fig. 3(2) Low accelerated voltage SEM observation with Membrane Surface of Sample No.2

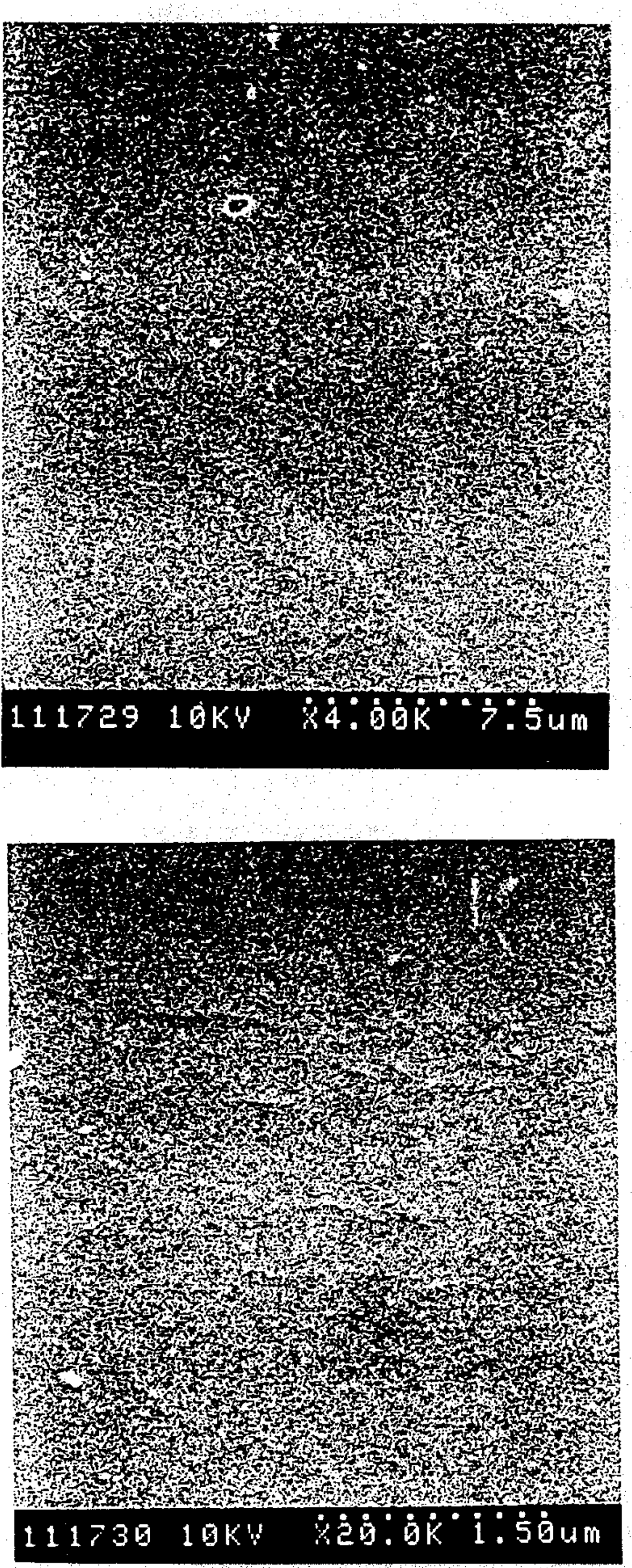


Fig. 3(3) Low accelerated voltage SEM observation with Membrane Surface of Sample No.3

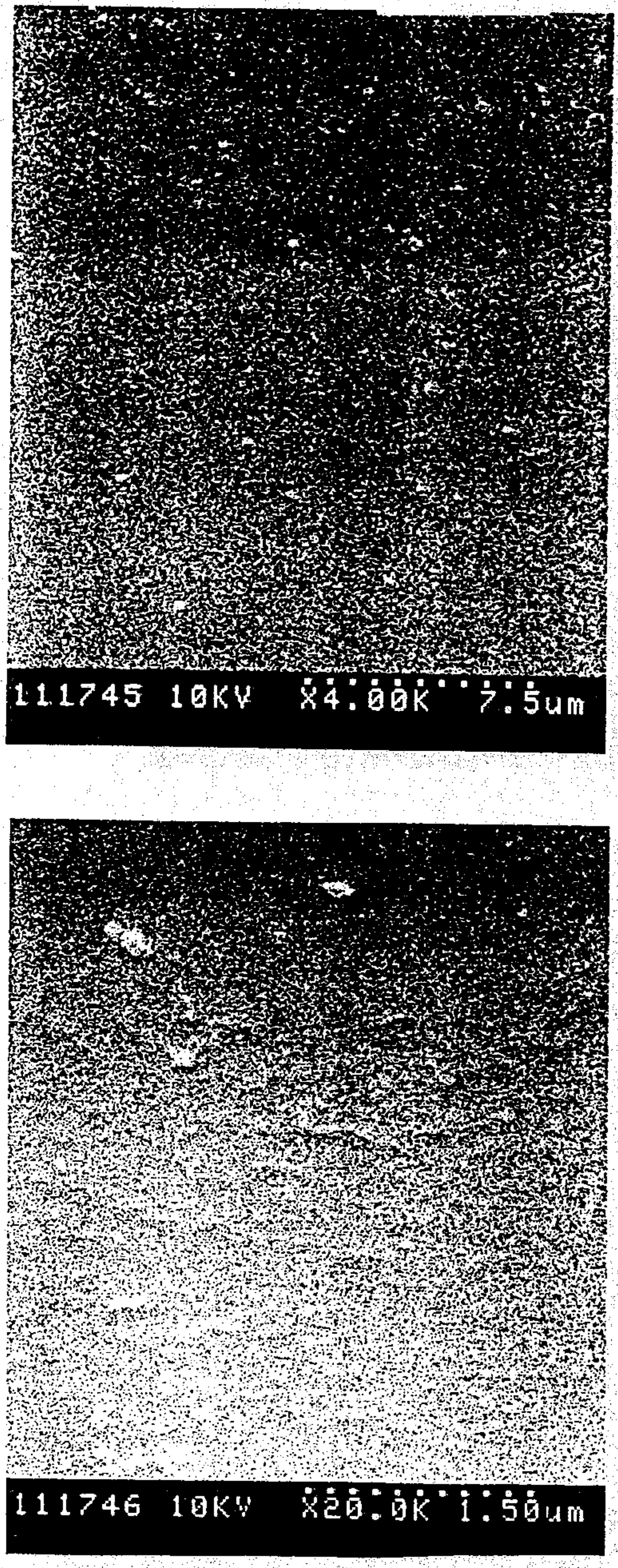


Fig. 3(4) Low accelerated voltage SEM observation with Membrane Surface of Sample No.4

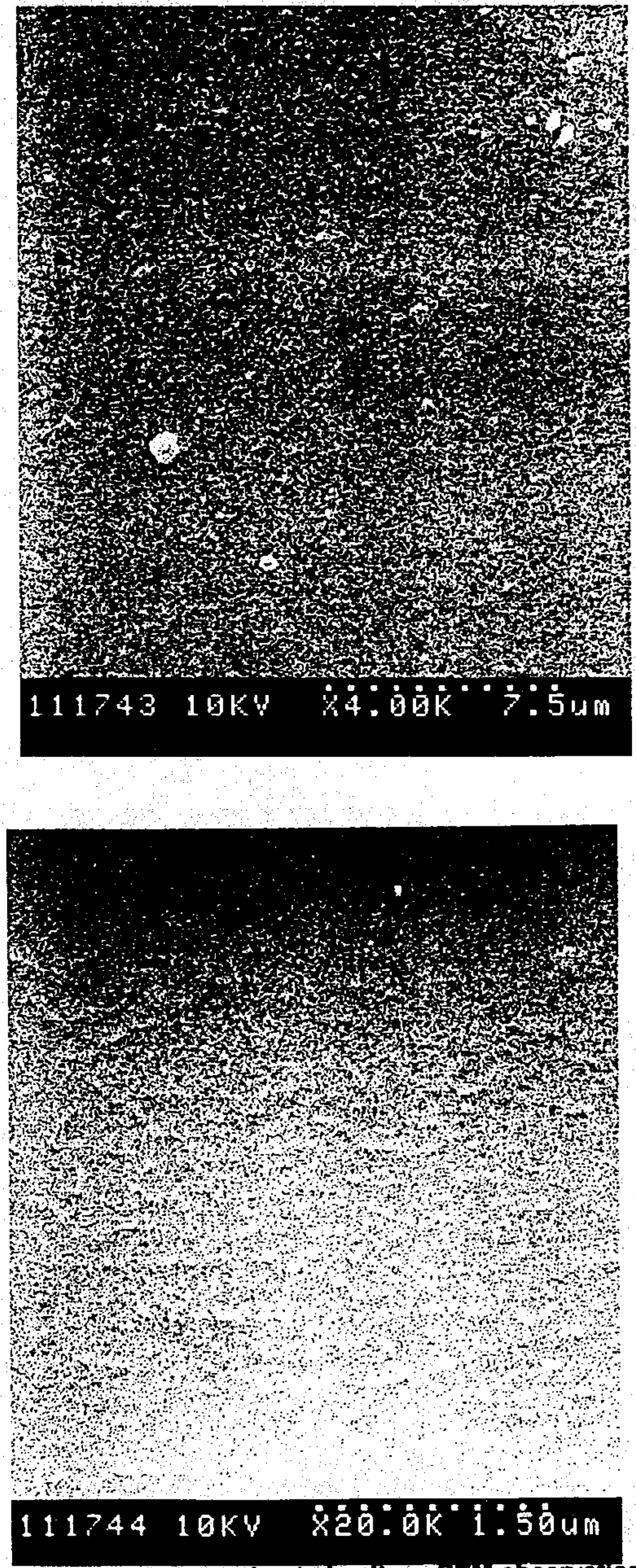


Fig. 3(5) Low accelerated voltage SEM observation with Membrane Surface of Sample No.5

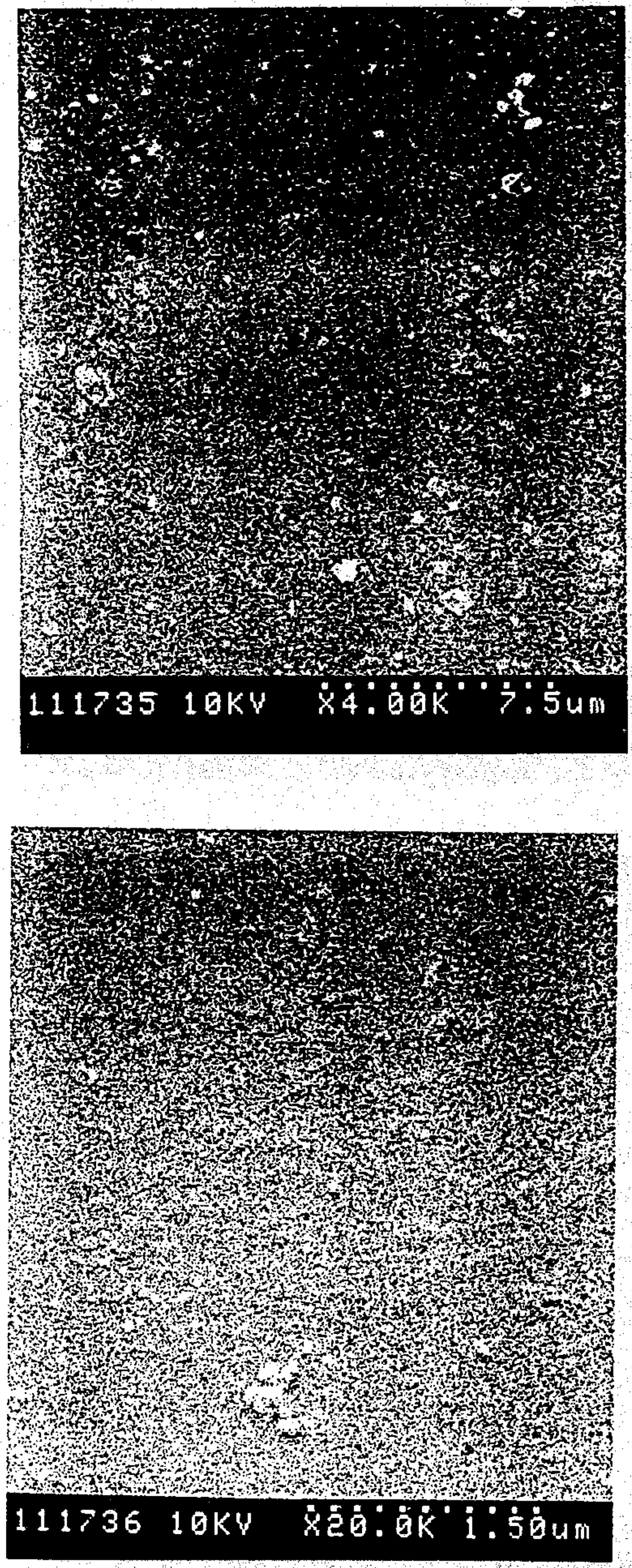


Fig. 3(6) Low accelerated voltage SEM observation with Membrane Surface of Sample No.6

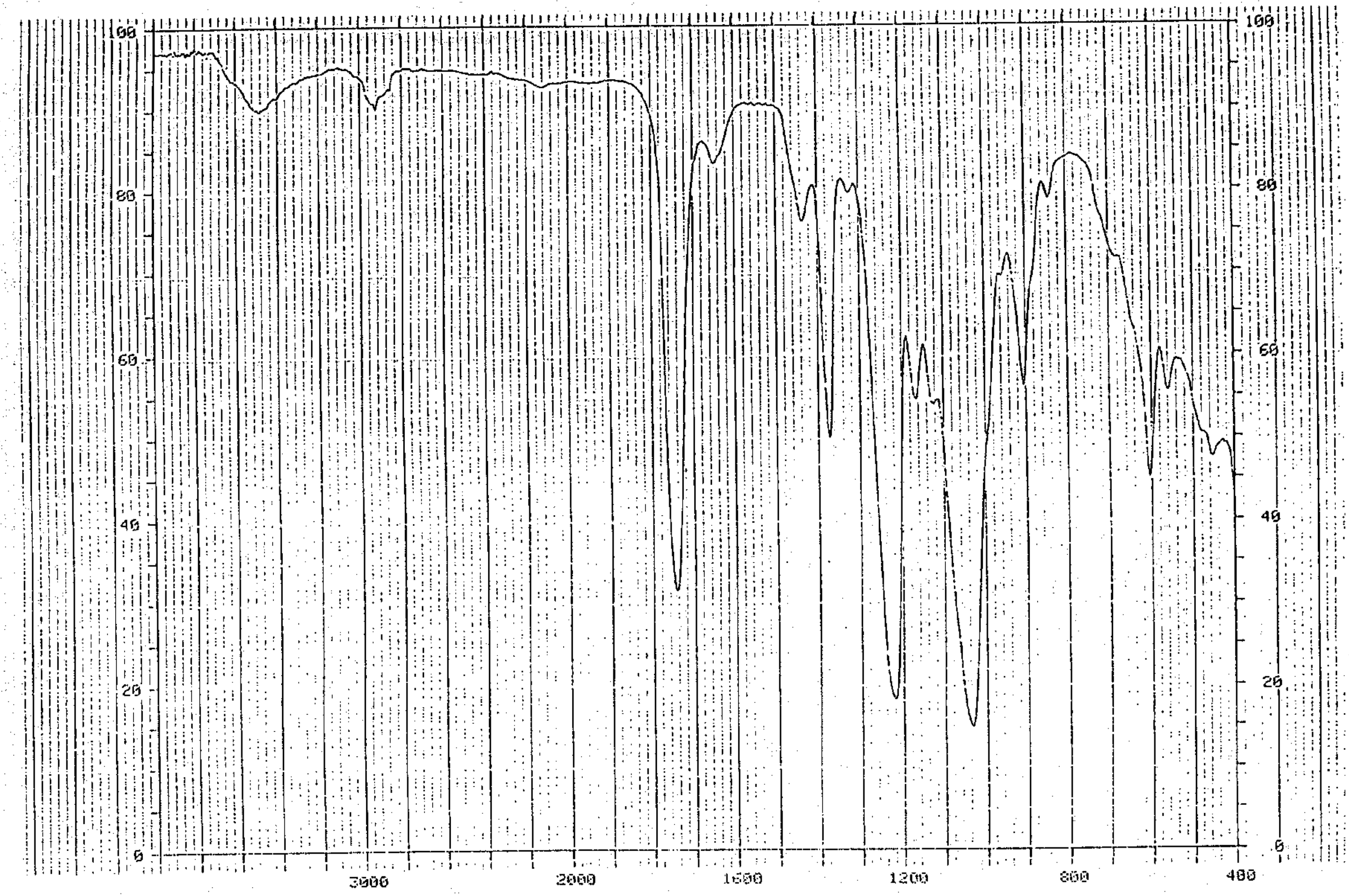


Fig. 4(1) IR chart with Membrane Surface of Sample No.1

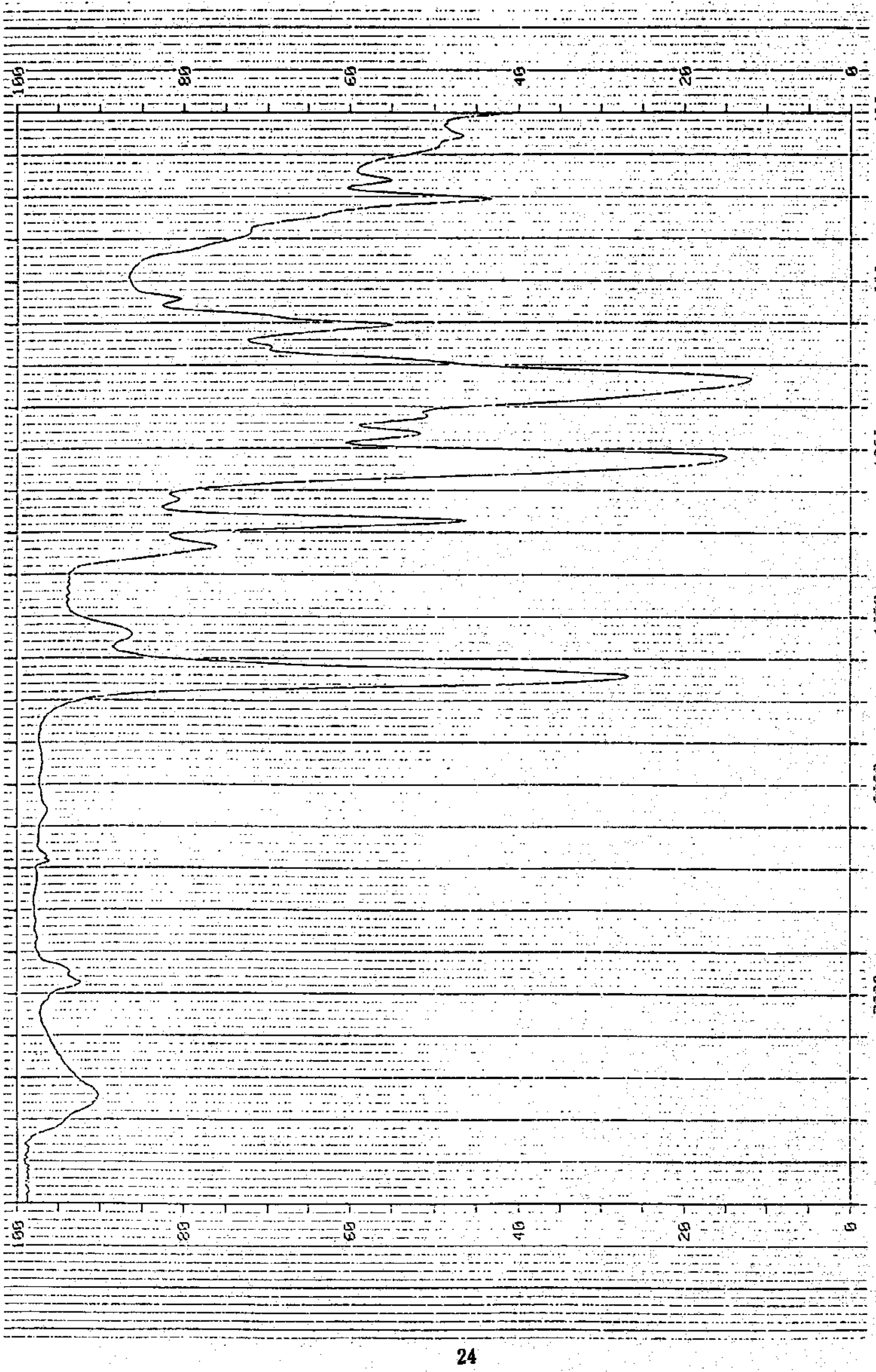


Fig. 4(2) IR chart with Membrane Surface of Sample No.2

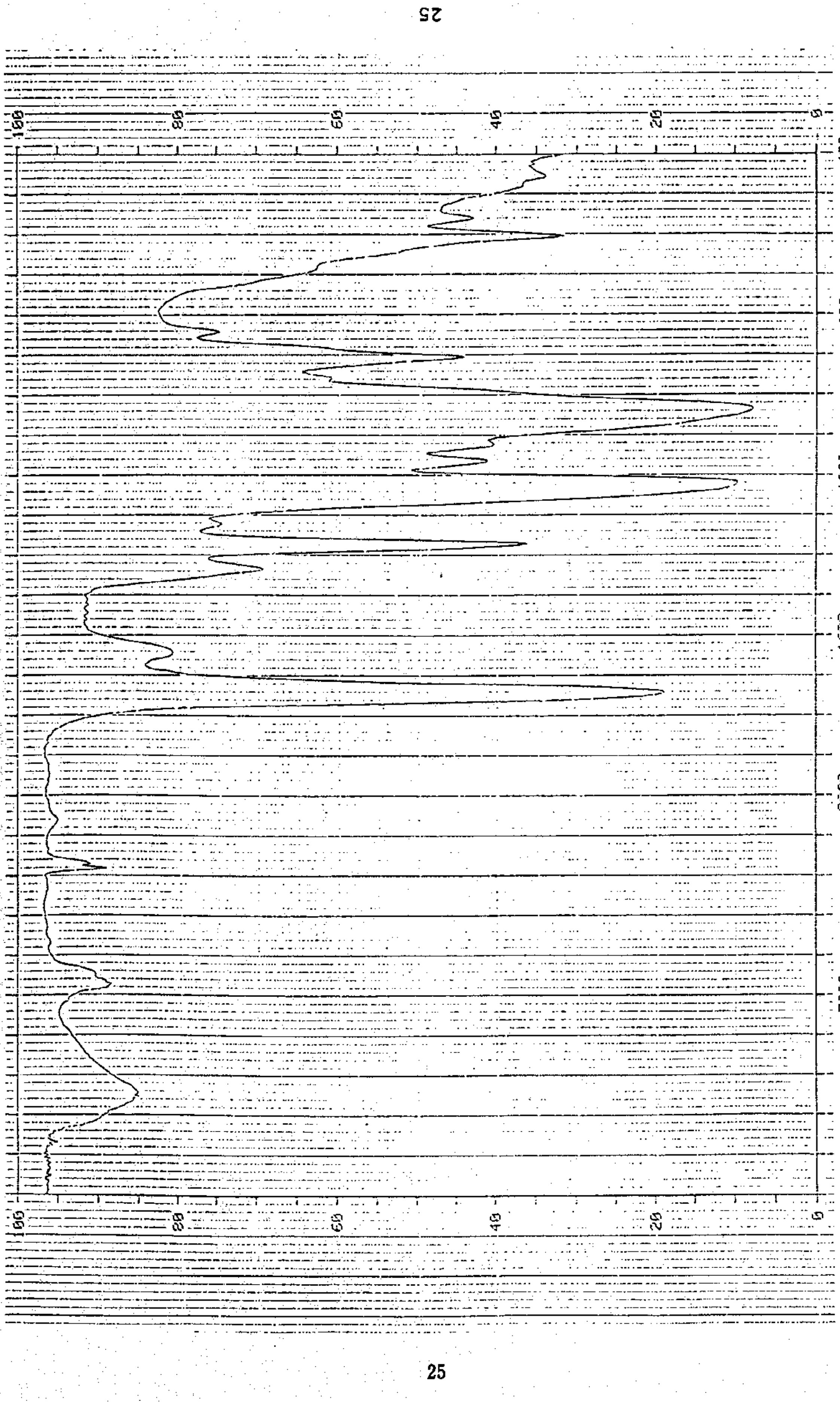


Fig. 4(3) IR chart with Membrane Surface of Sample No.3

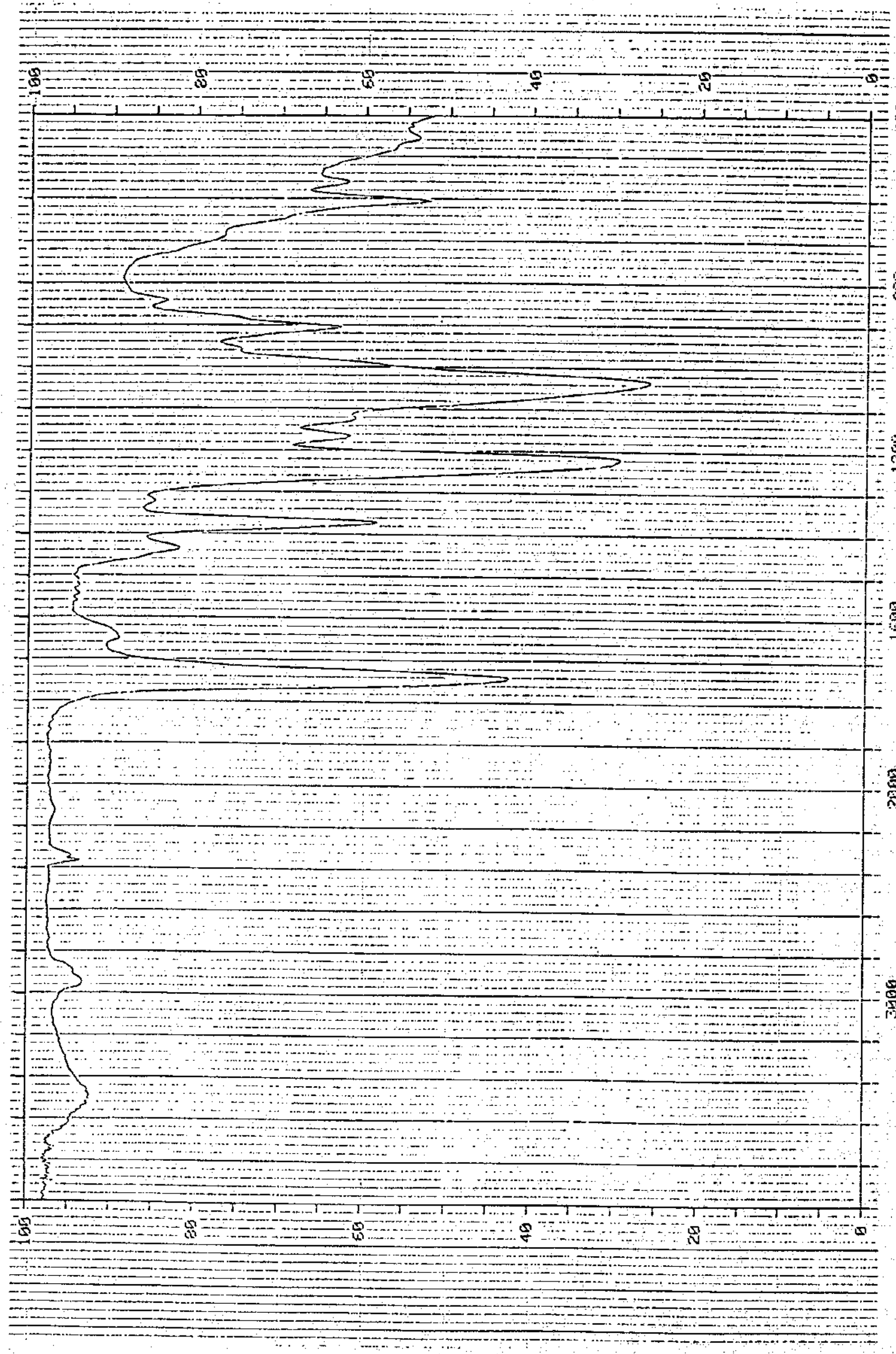


Fig. 4(4) IR chart with Membrane Surface of Sample No.4

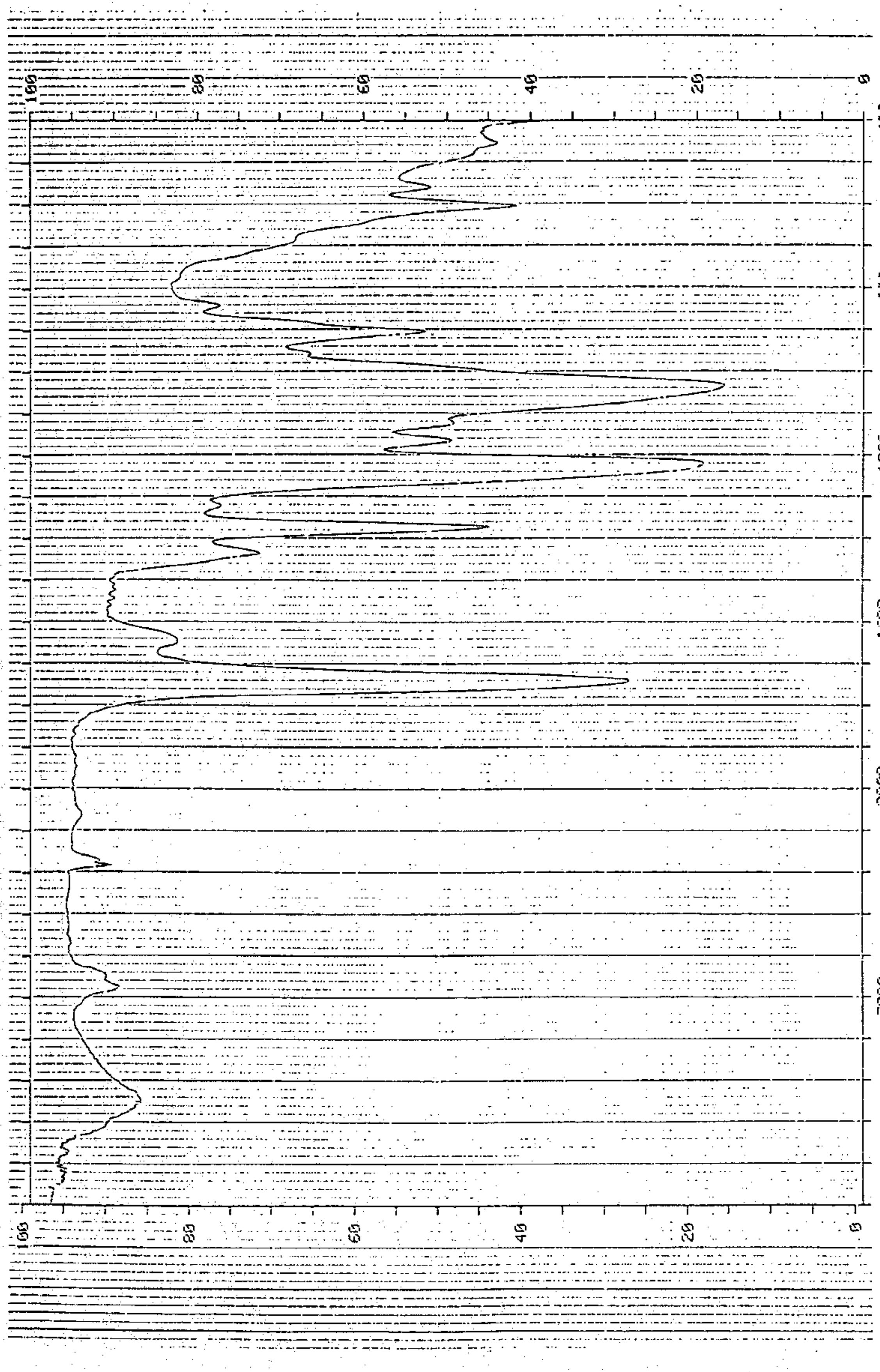


Fig. 4(5) IR chart with Membrane Surface of Sample No.5

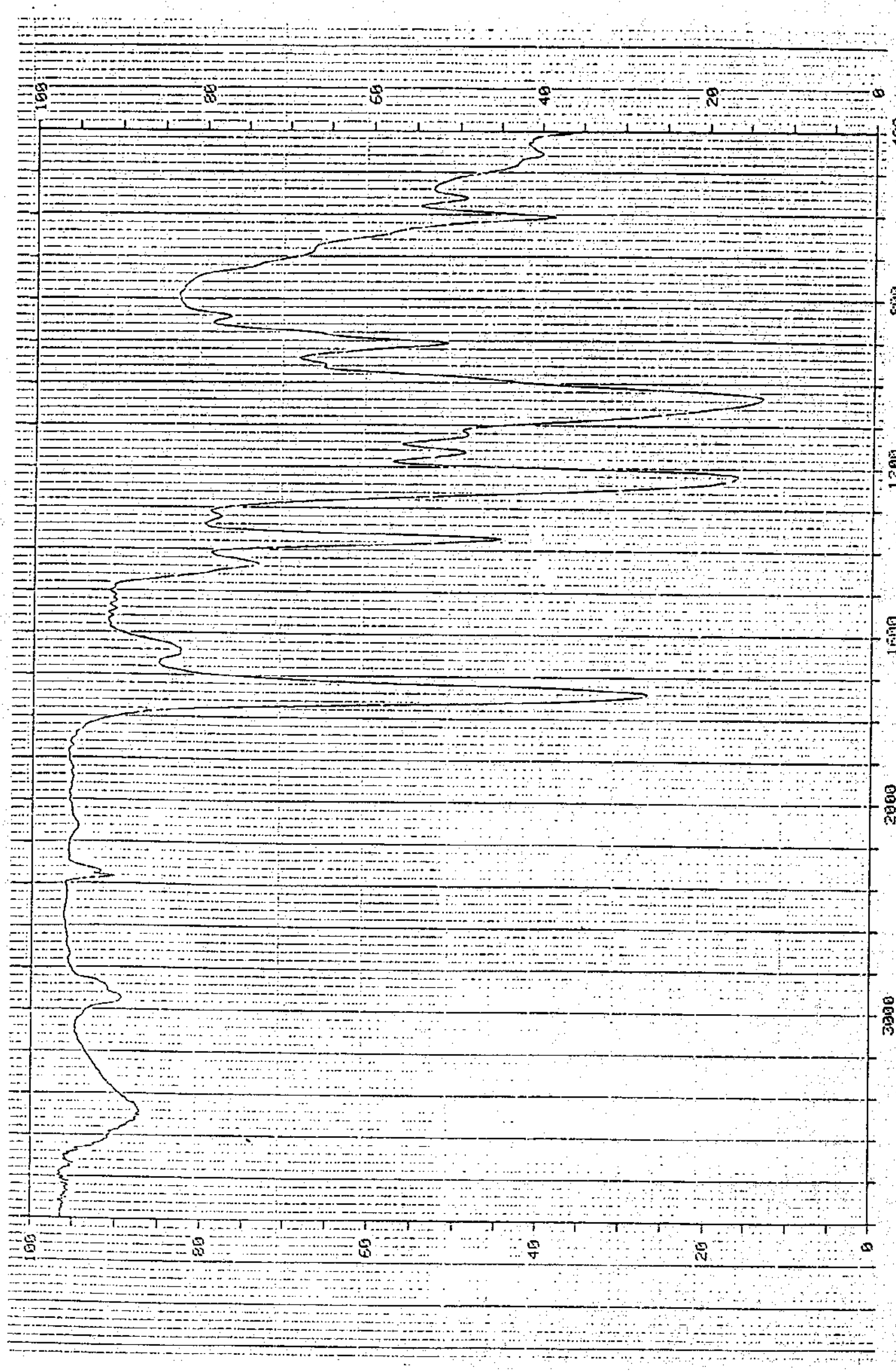
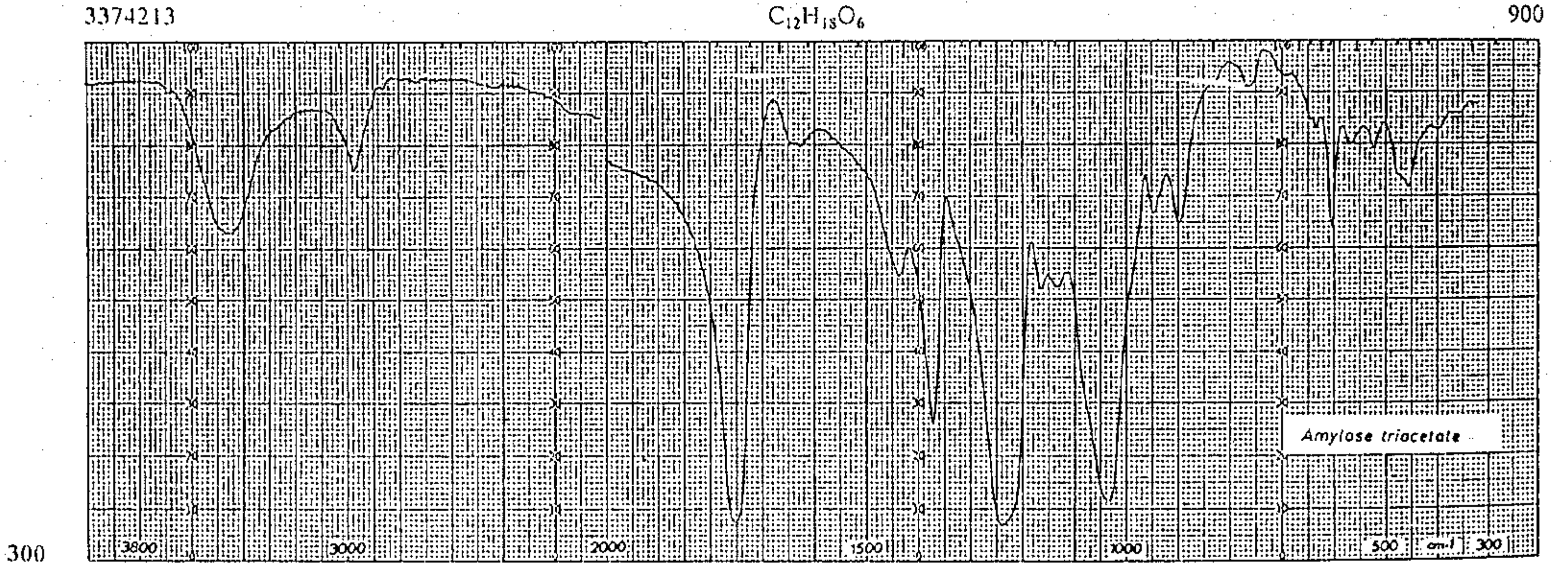


Fig. 4(6) IR chart with Membrane Surface of Sample No.6



(1) amylose triacetate
(2) white fibrous material
(3) C.T. Greenwood, Department of Chemistry, University of Edinburgh
(5) linear amylose from potatoe starch, fractionated from dimethylsulfoxide by addition of butanol, acetylation according to W. Banks, C.T. Greenwood, D.J. Hourston, Trans. Farad. Soc. *64* (1968) 363
(6) W. Banks, C.T. Greenwood, Europ. Polym. J. *4* (1968) 457. . . 64
(7) KBr (4/1000)

Fig. 5 Reference IR chart of amylose triacetate

7.1.3 Comparison Test of Flat Membrane Recirculation Test with Clear Water

(7.1.3)

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1. OBJECTIVES:

Objectives of the test is to establish a comparison for the performance of various flat sheet SWRO membranes to select a suitable one for MSF-RO Hybrid desalination system.

Comparison of flat membrane performance were conducted utilizing four flat sheet SWRO membranes: Toray 80S, Toray 80M, Nitto Denko 70SWC and Fluid System TFCL S7721. As a first screening test, the comparison was conducted in a closed system by circulating both the brine and the permeate to the feed tank. The temperature was maintained at 25℃, pressure at 56 Kg/cm^2 and brine flow at 7 l/m. Flux was calculated on effective surface area of the membrane.

2. EXPERIMENTAL

The main testing equipment used in the experiment is the Mini Module Tester(2) having model RUW-5(Fig.1-6) which consists of four testing cells having model No. C-70F, membrane diameter 75 mm, with an effective area of 32 cm^2. The four cells are connected in series and membrane samples 7.5 cm in diameter were cut evenly taking care not to contaminate or destroy the active membrane surface, and were loaded into the cell. The product from each cell is collected, measured and analyzed separately. Conductivity, temperature and pH of the feed and product were monitored and measured every 30 minutes using standard equipment.

3. RESULTS AND DISCUSSION:

Table (1) shows the specification and test results of different membranes. Flux was calculated on the effective surface area of the membrane (deducting the area covered by the "O" ring from the total surface).

At pressure of 56.6 Kg/cm^2, both Toray membranes, UTC 80S and 80M have salt rejection in excess of 99.4% as compared to 98.62% for Nitto NTR 70 SWC and 98.89% for Fluid System membranes, respectively. At the same pressure, the highest flux, however was obtained from Fluid System membrane followed by Toray 80S, while Nitto Denko membrane has the least flux. Noticeable increase in flux resulted upon increasing applied pressure only with Fluid System and Toray 80M membrane. Contrary to the known concept of increasing membrane flux with pressure, the remaining Toray and Nitto Denko membranes

showed no increase in flux with an increase in the applied pressure.

4. CONCLUSION:

From the test result it is observed that in general membranes with high rejection tend to have low flux and vice versa.

(7.1.3)

Table 1

Test Results of Different Commercial SWRO Flat Sheet Membranes Tested at RDC Test Plant (Mini(2)-RUW-5)

Operating conditions: **Concentrate flow : 7 L/min**
Temperature : 25℃± 0.1℃
pH : -7
Seawater EC : -59750 μS/cm

Membrane	Test Pressure kg/cm^2	Flux M^3/M^{2}D	% Rejection	Flux on Effective area M^3/M^{2}D
Toray UTC805	56.6	0.72849	99.43	0.855
	60.3	0.62198	99.51	0.720
Toray 80 M	56.6	0.4856630	99.62	0.570
	60.3	0.51548	99.66	0.600
Nitto NTR 70 SWC	56.6	0.60068	98.62	0.705
	60.3	0.58157	98.50	0.675
Fluid System TFCL S7721	56.6	0.92020	98.89	0.9825
	60.3	1.08209	99.04	1.245

*** Temperature of the tests controlled at 25℃**

*** Tests done at two different pressuresi.e. = 56.6kg/cm^2 & 60.3kg/cm^2**

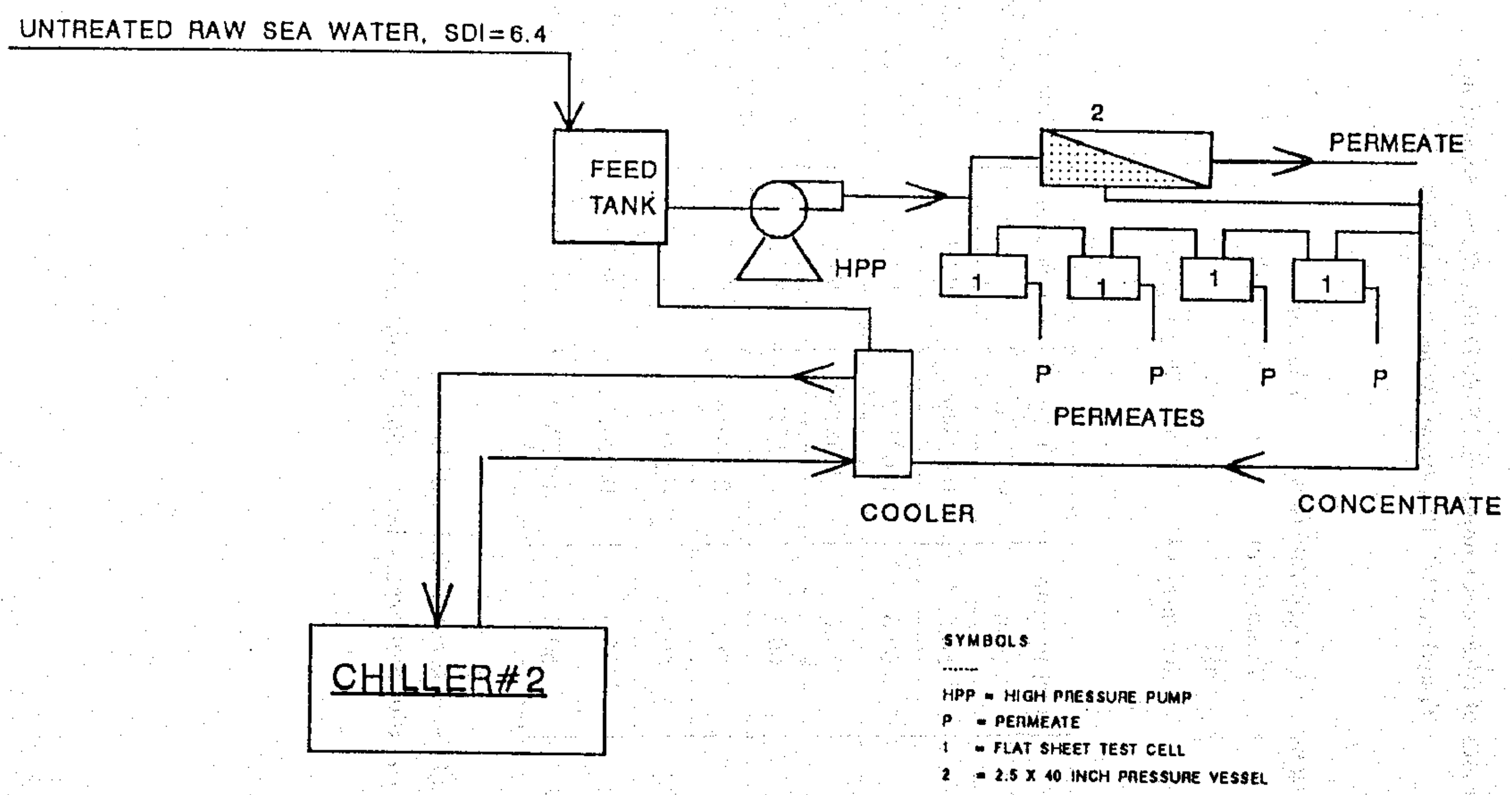


Fig. 1 Schematic Flow Diagram of Mini Module Tester-2(RUW-5)

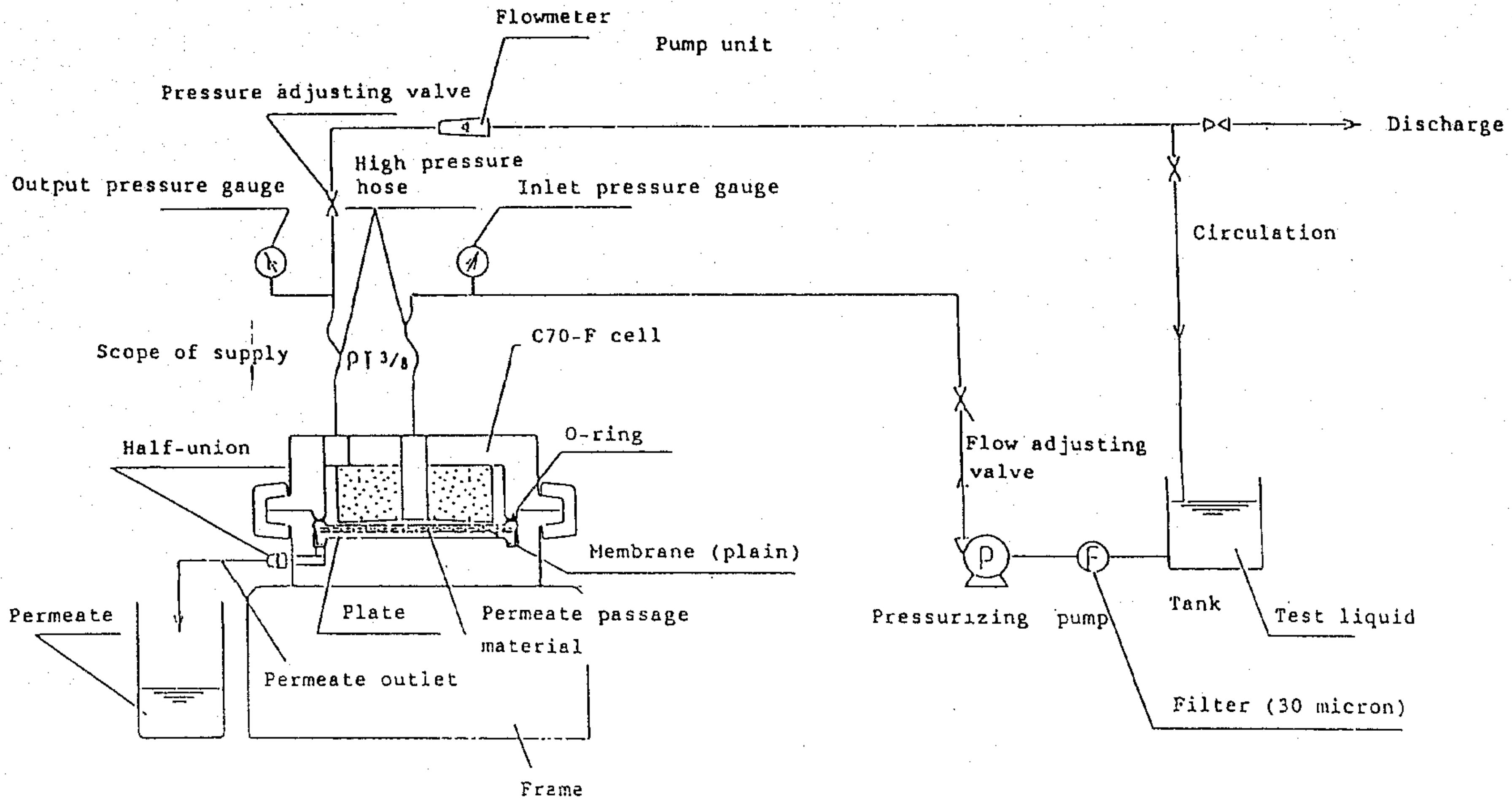


Fig. 2 Piping Diagram of Mini-Module Test Cell-2(RUW-5)

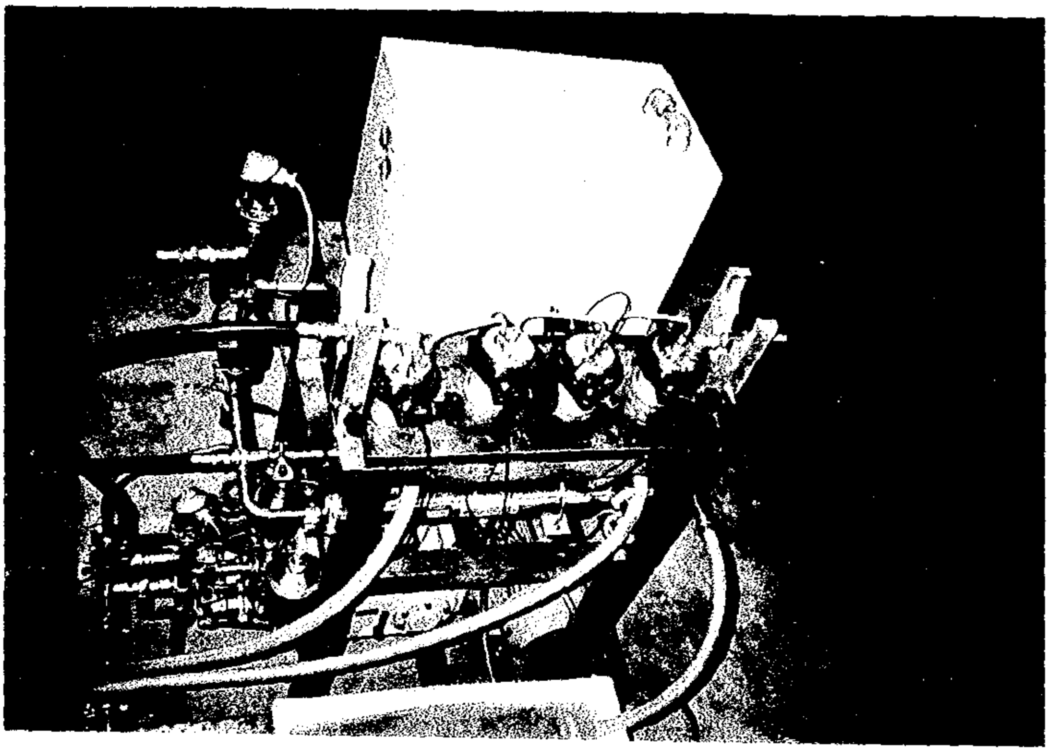


Fig. 3 Mini-Module tester-2(RUW-5)

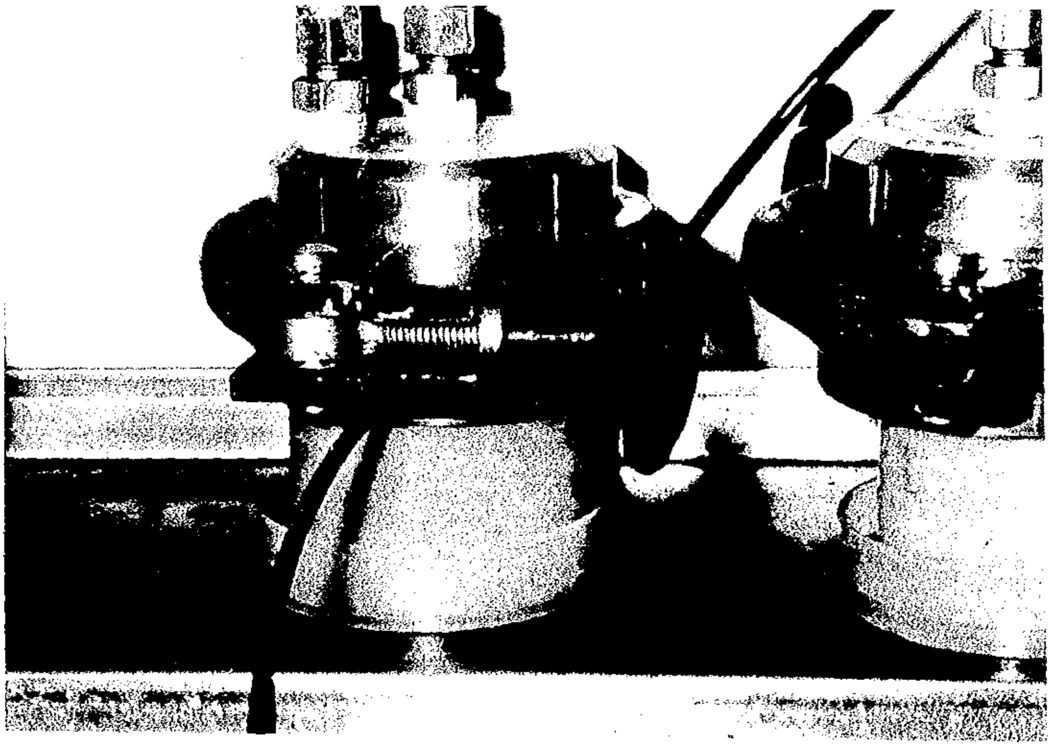


Fig. 4 Flat membrane cell Model No.(-70F)

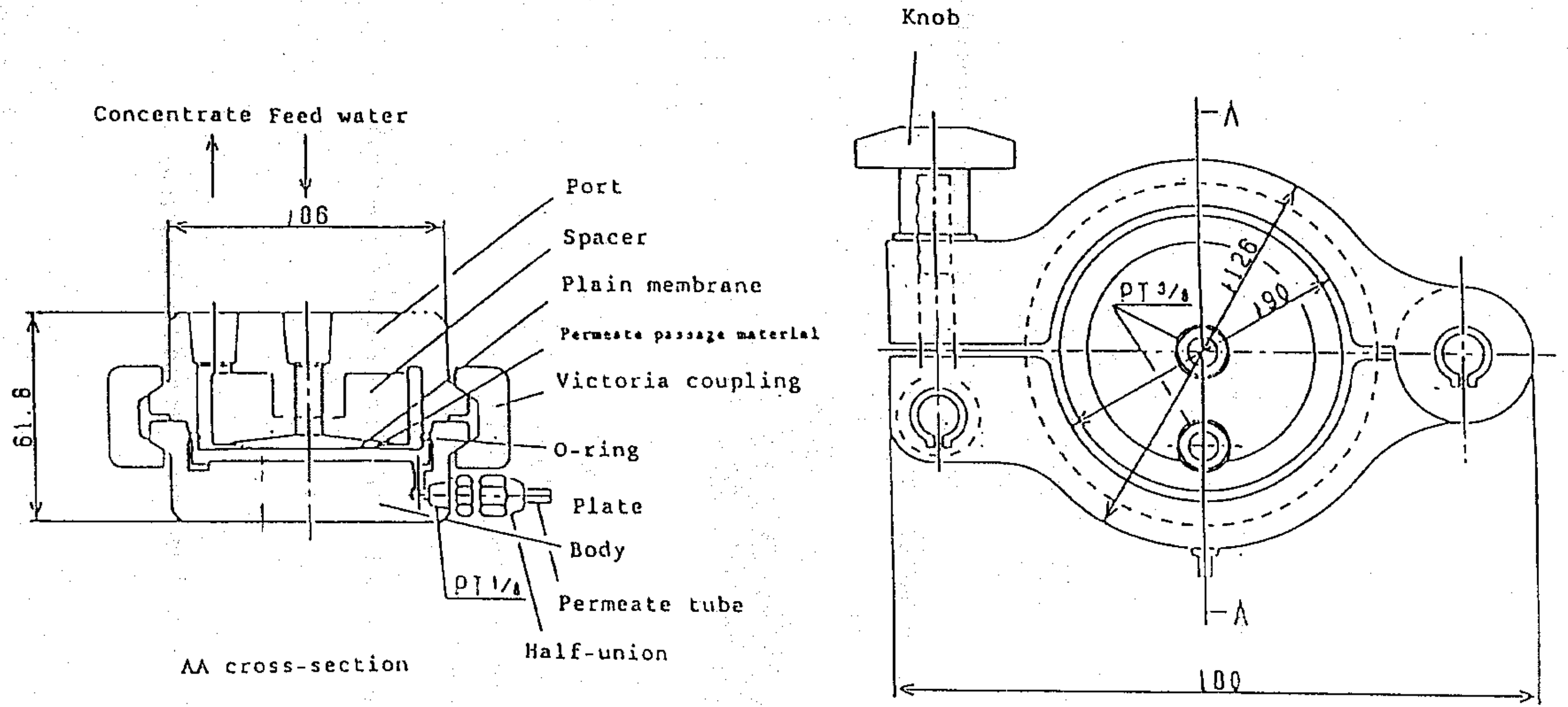
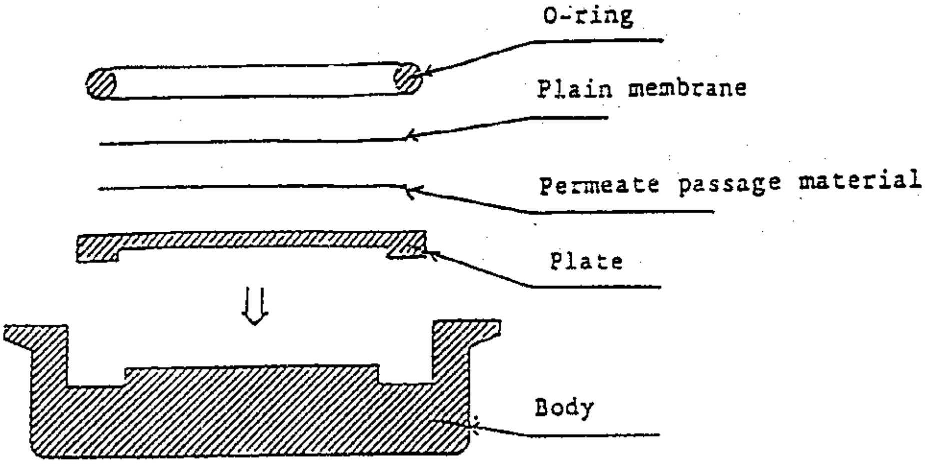


Fig. 5 Piping Connection of Flat Membrane Cell

(7.1.3)



Model:	C70F
Dimension:	180 mm x 62 mm
Max operating pressure:	**70 Kgcm^2**
Max flow rate:	15 l/min
Weight:	4 Kg
Membrane to be used:	OD=75 cm, Effective area–32 cm^2

Fig. 6 Flat Membrane Cell and Flat Membrane

7.1.4 Tolerance Test of Chlorine and Turbidity with Flat Membrane Tester

7.1.4.A. Chlorine Tolerance Test

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(7.1.4.A)

1. OBJECTIVES:

Salt rejection and permeate flow value (flux) are the two most importent basic properties of the membrane used in a Hybrid desalination system. Chlorine and Turbidity tolerance are also importent membrane properties that influence membrane flux and salt rejection and consequently the membrane performance. The main objective of this work is to establish an experimental procedure for the selection of chlorine tolerance membrane for use in Hybrid system. For this purpose only some preliminary experiments were carried out. The SWCC flat membrane tester was operated to measure membrane salt rejection and flux when the feed contains about .3ppm to 10ppm of chlorine. Three different types of membrane samples were tested.

2. SUMMARY:

Membrane chlorine tolerance test was investigated for three flat sheet membranes: Toray 80S, Toray 80M and Nitto Denko, utilizing SWCC Flat Sheet test unit. Chlorine concentration in the feed was varied : 10 ppm, 5 ppm, 1 ppm & 0.3 ppm, and presently the experiment is continuing at about 0.1 ppm. The pretreated feed with SDI of 2.5 ± 0.5 was taken from the SWCC pilot plant. Feed temperature and pH were maintained at 25℃and 6.7 ± 0.2, respectively. All membranes tested exhibited a decrease in salt rejection (i.e increase of permeate conductivity) which depends on the chlorine concentration & the membrane type. Within 5 hours of operation at 10 ppm of chlorine in the fiid the membrane salt rejection of about 95% without chlorine decreased to 57.37%, 87.73% and 78.17% for Toray 80s, Toray 80M and Nitto Denko membrane, respectively. Further decrease was observed when the experiment was extended to 200 hours. Similar decrease but at a lower rate was observed when chlorine content in the feed was reduced to 5 ppm and 1 ppm. At about 0.3 ppm of residual chlorine in the feed membrane salt rejection decreased gradually but at a far lower rate than in the three previous cases.

In general, the rate of membrane degradation increases as the chlorine concentration in the feed is increased. Both Toray 80M & Nitto Denko membranes have similar tolerance to chlorine, while Toray 80S tends to be more chlorine sensitive. Presence of chlorine in the feed also effects the permeate flow with Toray 80S membrane showing more flow than the remaining membranes at the same chlorine concentration in the feed.

3. EXPERIMENTAL:

Fig (1) shows a schematic flow diagram of SWCC flat sheet membrane tester which consists of a booster pump, a high pressure pump, a cartridge filter, an ultrafilter, and 12 identical test cells arranged in parallel, with a common fiid header. Each cell has its own individual pressure and flow indicator. The unit is equipped with a cooler connected to the chiller #2 to cool the recycle brine. It has an automatic trip device for abnormal pressure. PVC and SS316 piping are used in the low and high pressure sections, respectively. Fig. (2) shows the photographic picture of SWCC flat membrane tester while Fig. (3) shows the detail drawing of the flat membrane cell.

Chlorine concentration was maintained at the desired level by adding Sodium hypochloride solution in the feed tank. Flow & conductivity, of both permeate and feed as well as feed temperature, residual chlorine content, pressure, etc, were measured every four hours.

4. RESULTS AND DISCUSSIONS:

The performance data of the three membranes (Toray - UTC 80S, Toray UTC 80M, and Nitto Denko) investigated in presence of 10 ppm of Cl_2 in feed are given in Table (1). Plots of permeate flow vstime and permeate conductivity vstime are given in Fig. 4. All membranes tested exhibited a decrease in their salt rejection (increase in permeate conductivity) which occurred mainly during the first few hours of testing followed by a gradual decrease thereafter during the rest of the 200 hours test period. Within the first five hours of passing 10 ppm of chlorinated feed, the membrane salt rejection of about 99% with non-chlorinated feed dropped to 59.37%, 81.73 and 78.17% for Toray UTC 80S, Toray UTC 80M and Nitto Denko, respectively. After 200 hours the membrane salt rejection was reduced down to 32.71%, 48.37% and 42.02% for Toray 80S, Toray 80M and Nitto Denko membranes, respectively.

By contrast to the reduction in membrane salt rejection the permeate flow for Toray UTC 80S increased at the start from 57 CC/30 min for non-chlorinated feed to 80 CC/30 min for feed containing 10 ppm Cl_2 and decreased gradually to about 56 CC/30 min after 200 hours. Similar behavior but at lower rate was also observed for Toray 80M. Permeate flow decreased reaching a value of 58 CC/30 min after 200 hours test. This however, was not the case with Nitto Denko membrane, which showed a decline of permeate flow from 40 CC/min for non-chlorinated feed to 31 CC/30 min and remained nearly constant for the rest of the

200 hours test period.

Table (2) and Fig. (5) show the performance of the above three membrane when maintaining 5 ppm of residual chlorine in the feed. From the table it can be concluded that a gradual decrease of membranes salt rejection (i.e increase in permeate conductivity) occurred in all three cases. Toray 80S decreased from 95.35% to 65.78%, Toray 80M from 96.16% to 83%, Nitto from 91.19% to 76.60% within 300 hours of operation. But the decline is less than in the case of 10 ppm Cl_2 in feed. As expected Permeate flow in all the three cases increased gradually from 30 CC/30 min to 67 CC/30 min, from 22 CC/30 min to 46 CC/30 min, and from 16 CC/30 min to 23 CC/30 min for Toray 80S, Toray 80M and Nitto Denko membranes, respectively, but at a lesser rate than that in the case of 10 pm of residual chlorine in the feed.

The permeate flow and conductivity at 1 pm of residual chlorine in the feed are plotted vs operatin time in Fig.(6). In all three cases there is a noticeable rise in both permeate flow and conductivity but with much steeper rise in those values for permeate from the Toray UTC–80S membranes. The two membranes: Toray 80M and Nitto Denko NTR 70SWC have similar tolerance to chlorine. At this level of residual chlorine in the feed, membrane degradation is occurring but at a much slower rate than that observed earlier at residual chlorine concentration of 10 ppm and 5 ppm in feed.

After 1850 hours of operation with an average of 0.3 ppm of residual chlorine in the feed, there is no noticeable change of permeate flow in case of Nitto Denko membrane, but a gradual slight increase in permeate flow in the case of Toray 80S and Toray 80M (Fig. 7). The permeate conductivity for Toray 80M increased slightly, at initial stage of chlorine addition, but remained almost steady during the rest of the test period of (1850 hours). The permeate conductivity for both Toray 80S and Nitto Denko membranes increased gradually but at lesser rate than in the previous cases of 10, 5 and 1 ppm.

5. CONCLUSION:

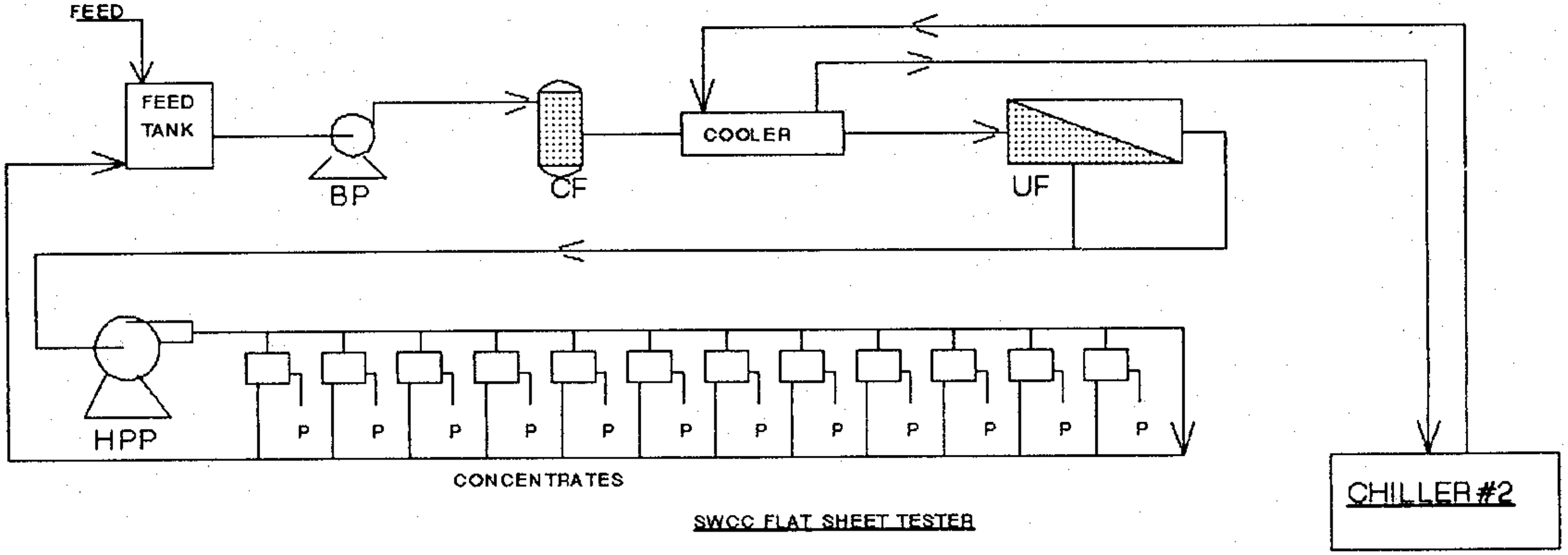
The rate of degradation of membrane by chlorine in the feed is dependent on the chlorine concentration. The higher the concentration of chlorine in the feed the higher the rate of degradation. At high concentration of 10 ppm residual chlorine in the feed a drastic membrane degradation takes place, while in case of 0.3 ppm of residual chlorine in the feed slow membrane degradation is noticed at a very low rate.

(7.1.4.A)

Both Toray 80M and Nitto membranes have identical tolerance to chlorine, while Toray 80S has lesser tolerance to chlorine and is more effected than the other two membranes by the presence of residual chlorine in the feed.

(7.1.4.A)

FIGURE : SCHEMATIC FLOW DIAGRAM OF SWCC FLAT SHEET TESTER



SUMBOLS

UF = ULTRAFILTATION FILTER
CF = CARTIDGE FILTER
P = PERMEATE
BP = BOOSTER PUMP
HPP = HIGH PRESSURE PUMP

Fig. 1 Schematic Flow Diagram of SWCC Flat Sheet Membrane Tester

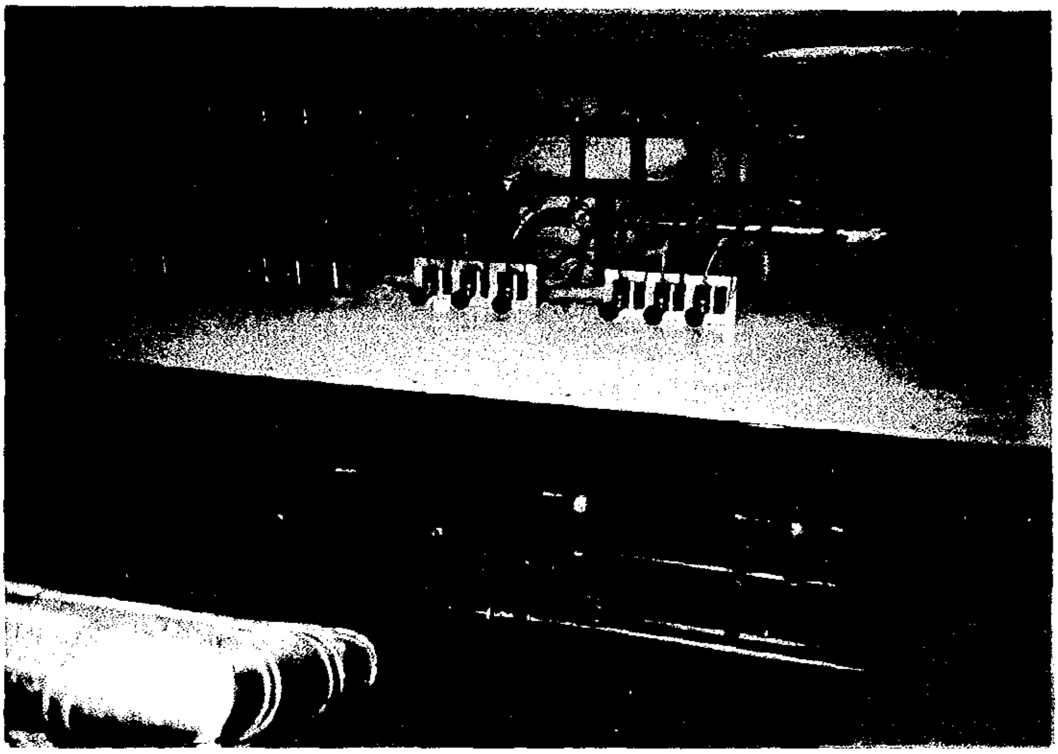
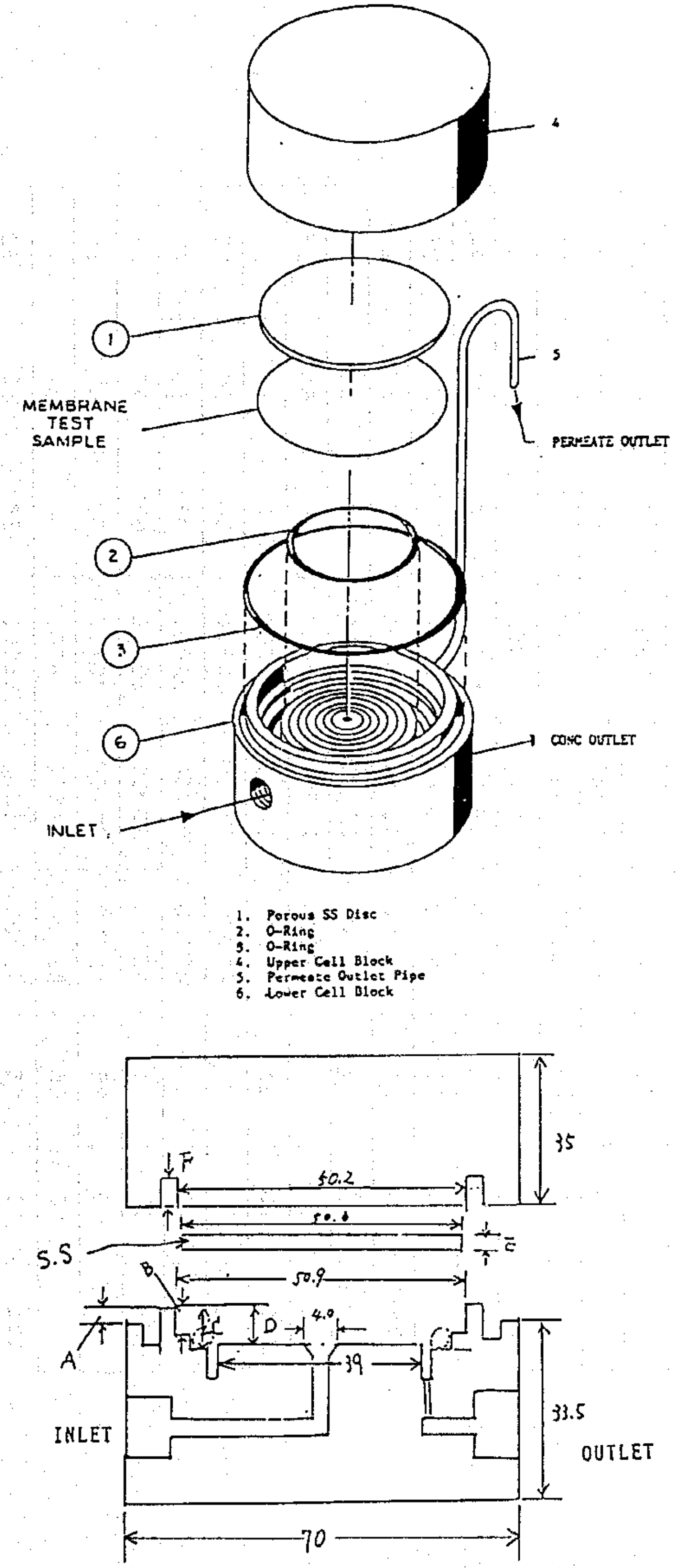


Fig. 2 Flat Sheet Membrane Tester of SWCC



1. Porous SS Disc
2. O-Ring
3. O-Ring
4. Upper Cell Block
5. Permeate Outlet Pipe
6. Lower Cell Block

Fig. 3 Detailed Drawing of the SWCC Flat Sheet Membrane Cell

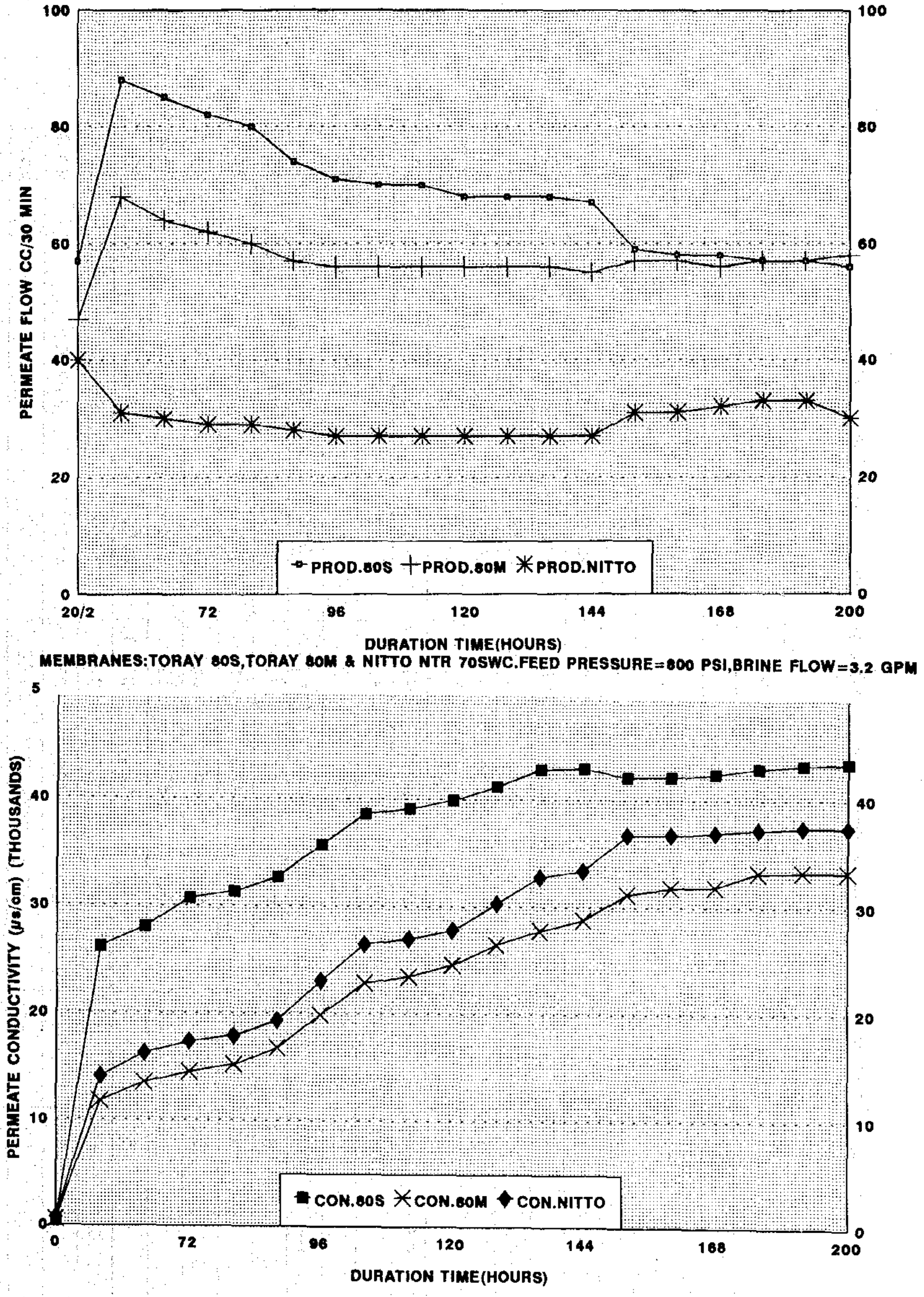
(7.1.4.A)

Table 1 Flat Seet Membrane Tolerance Test for Chlorine

Chlorine 10 ppm

(MEMBRANE: TORAY UTC 80S, 80M, & NITTO NTR 70 SWC
FEED SDI <3, PRESSURE=800 PSI, BRINE FLOW=3.2GPM, CL2=10PPM.)

			PERMEATE CONDUCTIVITY µs/cm			PERMEATE FLOW CC/30 MIN		
TIME HRS	Cl2 PPM	TEMP °C	T80S	80M	NITTO	T80S	T80M	NITTO
0	0	28	407	590	753	57	47	40
	10	25	26200	11780	14080	88	68	31
	10	25	28000	13490	16230	85	64	30
72	10	24	30700	14500	17350	82	62	29
	10	23	31300	15200	17880	80	60	29
	10	23	32700	16760	19340	74	57	28
96	10	21	35700	19900	23100	71	56	27
	10	22	38600	22900	26500	70	56	27
	10	21	39100	23500	27000	70	56	27
120	10	21	39900	24600	27800	68	56	27
	10	21	41200	26500	30300	68	56	27
	10	21	42800	27800	32800	68	56	27
144	10	21	42900	28800	33400	67	55	27
	10	25	42100	31200	36700	59	57	31
	10	25	42100	31800	36700	58	57	31
168	10	25	42400	31900	36900	58	56	32
	10	25	42900	33200	37200	57	57	33
	10	25	43200	33300	37400	57	57	33
200		25	43400	33300	37400	56	58	30



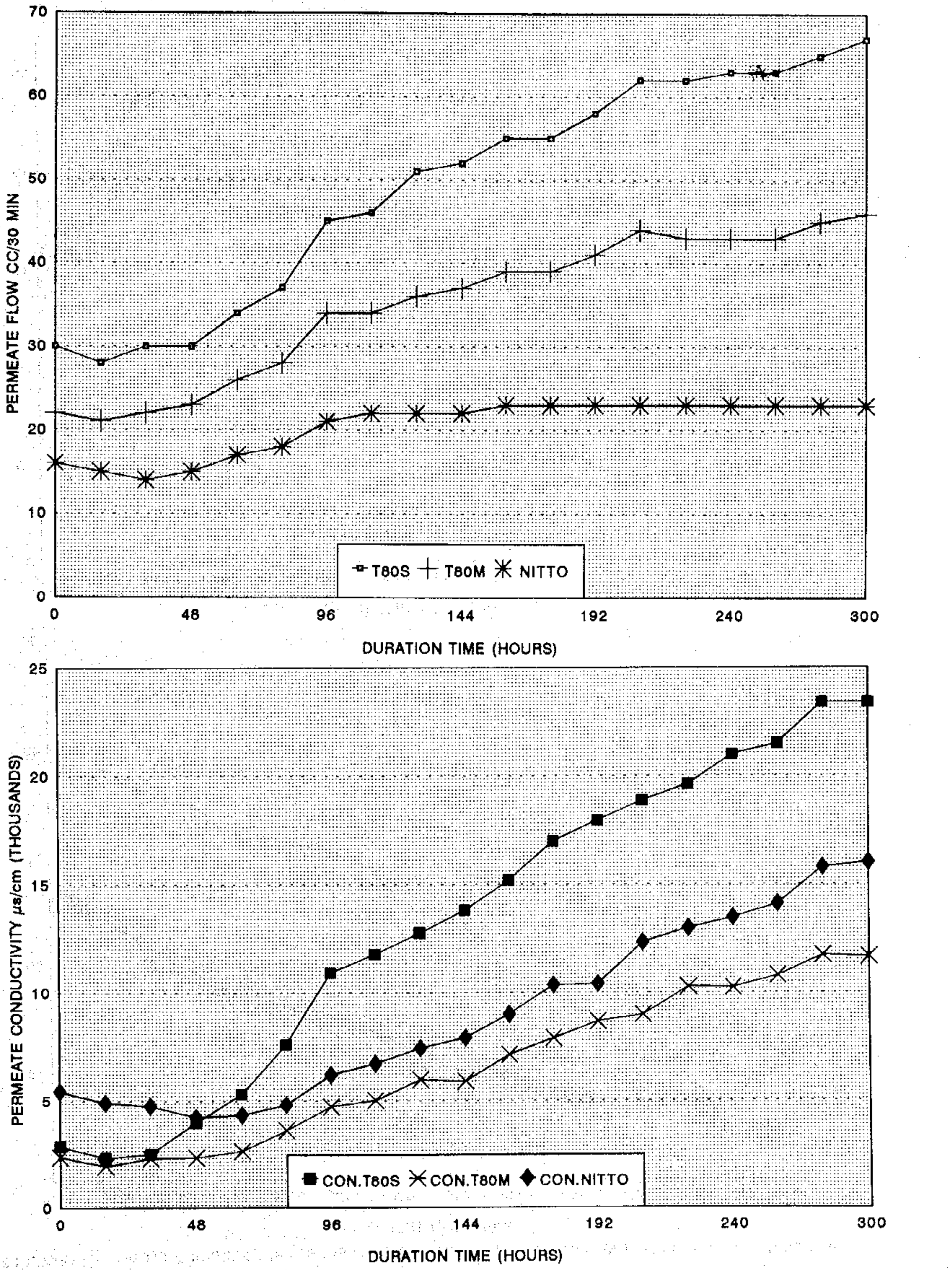
MEMBRANES:TORAY 80S,TORAY 80M & NITTO NTR 70SWC.FEED PRESSURE=800 PSI,BRINE FLOW=3.2 GPM

Fig. 4 **Flat Sheet Membrane Tolerance Test for Chlorine**
Cl_2 = 10 ppm

Table 2 Flat Seet Membrane Tolerance Test for Chlorine Chlorine 5 ppm

(MEMBRANE:TORAY UTC 80S, 80M & NITTO NTR 70SWC,FLAT SHEET,
FEED SDI<3, PRESSURE=800PSI,BRINE FLOW=3.2GPM, CL2=5PPM.)

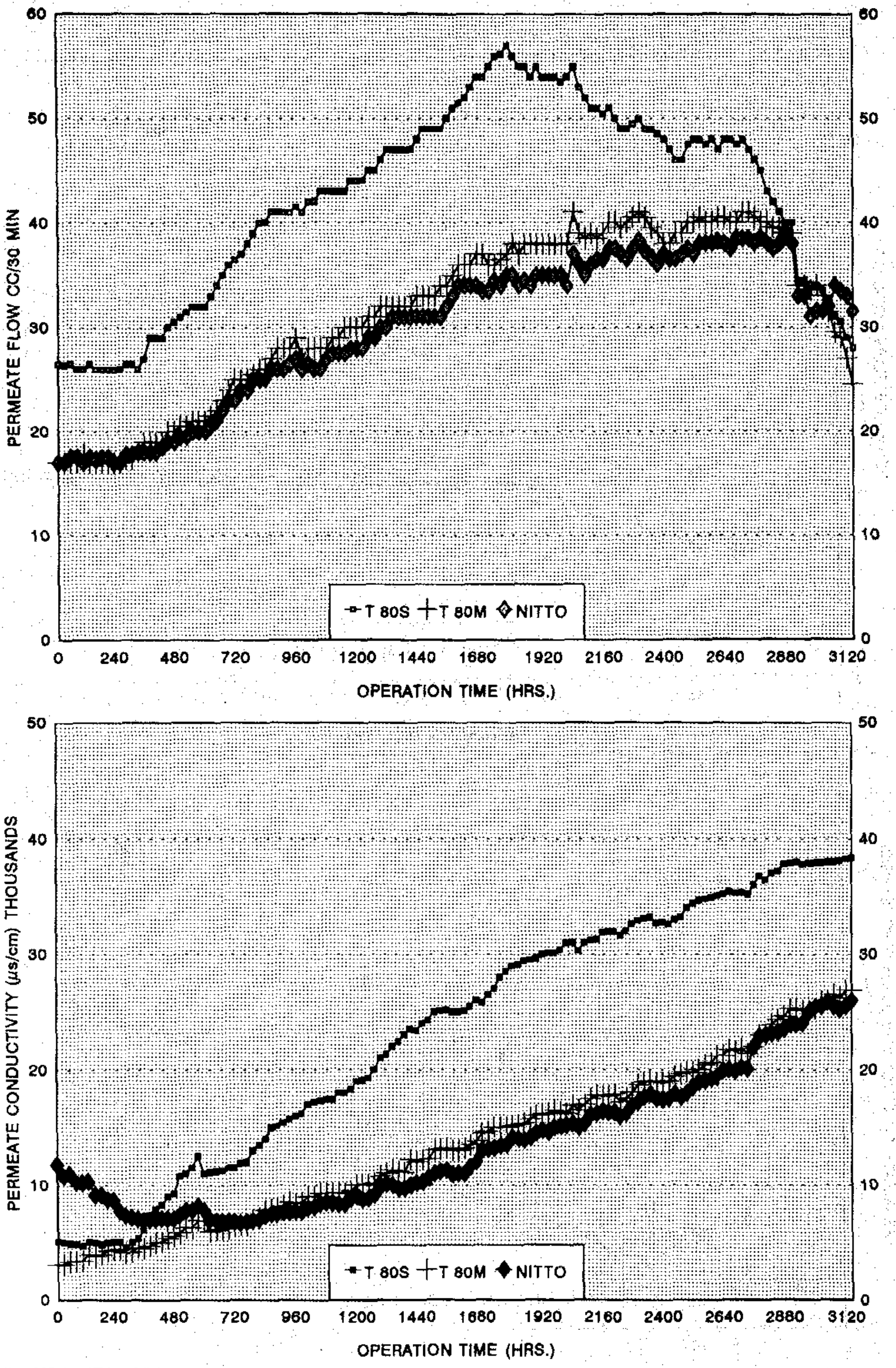
	PERMEATE FLOW CC/30 MIN			PERMEATE CONDUCTIVITY μs/cm					
TIME HOURS	T80S	T80M	NITTO	T 80S	T 80M	NITTO	FEED.CON. μs/cm	CL2 PPM	TEMP
0	30	22	16	2870	2370	5440	61800	0	25
	28	21	15	2330	1950	4910	62200	0	24.5
	30	22	14	2510	2310	4750	61800	4	25
48	30	23	15	3990	2340	4230	63300	5	25.2
	34	26	17	5300	2640	4330	63300	5.1	25
	37	28	18	7600	3600	4800	63800	5.9	25
96	45	34	21	10920	4720	6210	64200	6	25.1
	46	34	22	11770	5010	6720	64700	6.5	25.2
	51	36	22	12760	5970	7430	63600	6.8	25
144	52	37	22	13800	5900	7910	63700	4.8	24
	55	39	23	15190	7120	9000	64500	6.9	25
	55	39	23	16980	7890	10350	65100		24.8
192	58	41	23	17950	8660	10400	66200		25
	62	44	23	18870	8970	12320	66000	6.8	24.9
	62	43	23	19620	10260	12980	67000	7.9	25
240	63	43	23	21000	10231	13460	66900	4.3	25
	63	43	23	21500	10780	14100	67200		24.9
	65	45	23	23400	11720	15780	68200	4	25.1
300	67	46	23	23400	11650	16000	68400		24.9



(MEMBRANES:TORAY 80S, TORAY 80M & NITTO NTR 70SWC.FEED PRESSURE=800 PSI,BRINE FLOW=3.2 GPM

Fig. 5 **Flat Sheet Membrane Tolerance Test for Chlorine**
Cl_2 = 5 ppm

(7.1.4.A)

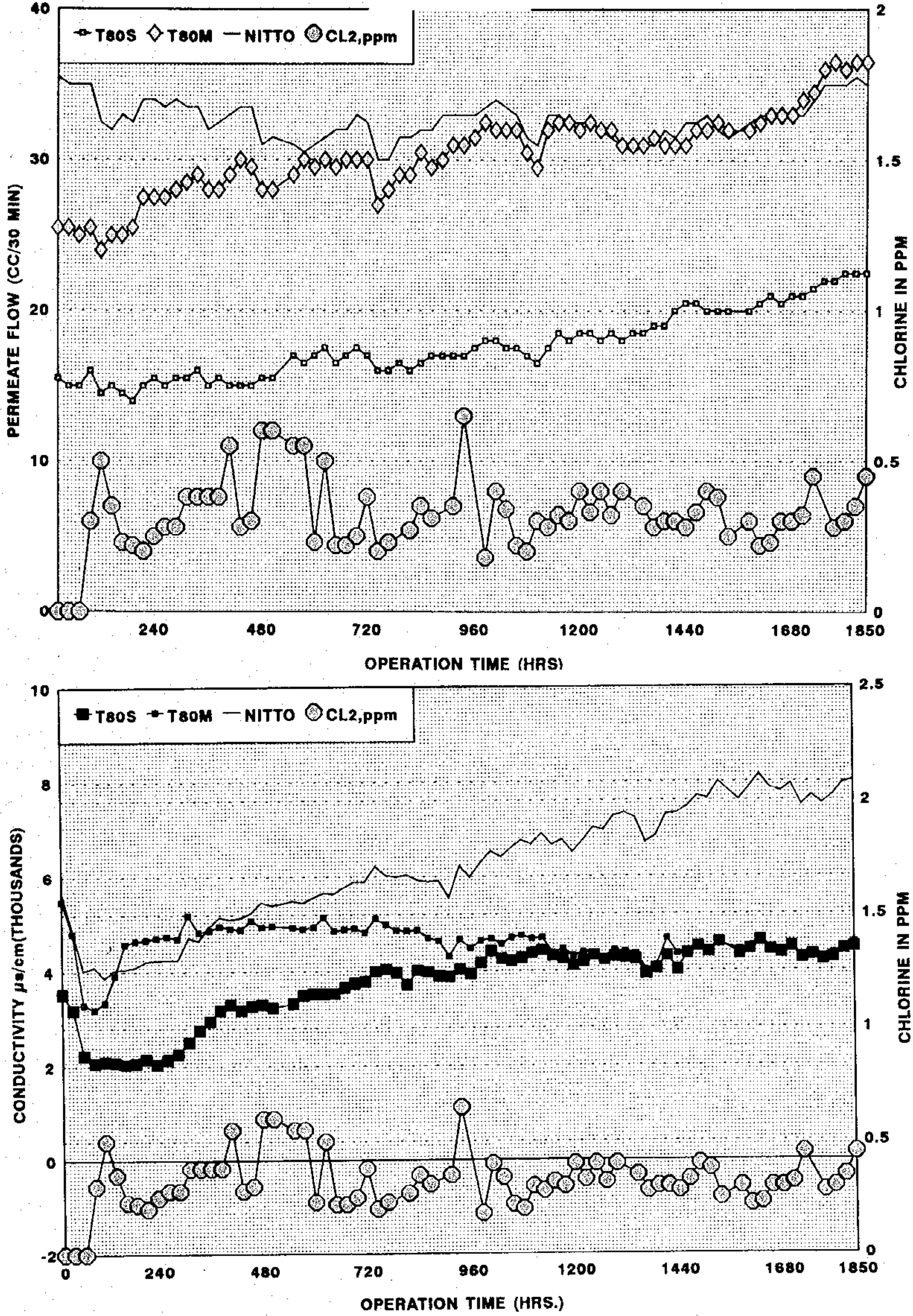


(MEMBRANES:TORAY 80S,TORAY 80M & NITTO NTR 70SWC,FEED PRESS=800 PSI,BRINE FLOW= 3.2 GPM, CL2= 1 PPM)

Fig. 6 **Flat Sheet Membrane Tolerance Test for Chlorine**

Cl_2 = 1 ppm

(7.1.4.A)



(OPERATION CONDITIONS: PRESSURE=800 PSI & BRINE FLOW= 3.2 GPM)

CHLORINE TOLERANCE OF VARIOUS SWRO FLAT MEMBRANES
(TORAY UTC80S,TORAY UTC80M & NITTO NTR70SWC)VS TIME

Fig. 7 Flat Sheet Membrane Tolerance Test for Chlorine

Cl_2 = 0.3 ppm

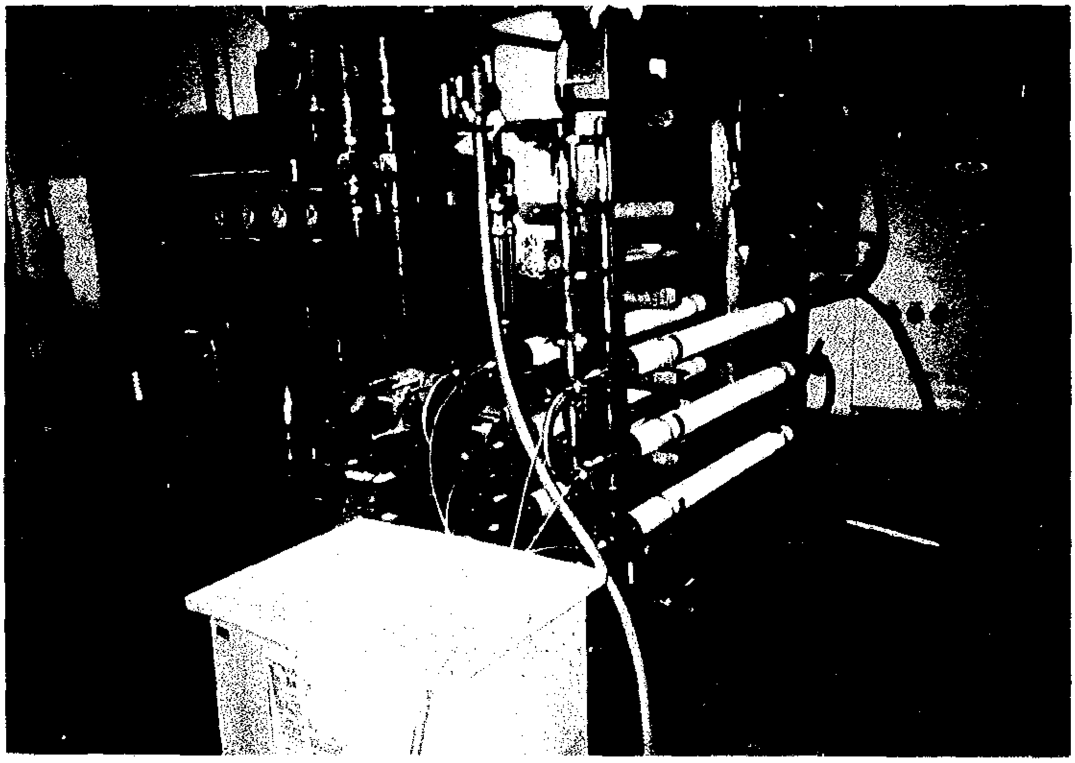


Fig. 11 Photograph of Mini–Module Tester (1)

7.1.4.B. Turbidity Tolerance Test

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1. OBJECTIVES:

The main objective of this experiment is to establish a procedure to select a membrane, having comparatively more tolerance to turbide materials in feed water, for use in Hybrid desalination system. Turbide metarials increases membrane resistance to passage of permeate and cause a sharp decline in permeate flow. To measure this effect, relation between feed flow rate and accumulation of turbide materials upon the surface of membrane was observed at different feed flow rates. The feed consists of raw untreated seawater having SDI 6.4. Three types of flat membranes were evaluated: Tora UTC 80S, Toray UTC 80M and Nitto NTR 70 SWC.

During normal operation of a SWRO plant, the membranes are subject to fouling by suspended or sparingly soluble materials present in the sea water. The nature and frequency of the fouling depends on quality of feed water, proper design and operation of the SWRO plant, membrane composition and configuration. The rapidity of fouling, and the membrane regeneration efficiency by cleaning may not be similar for all membranes. Membrane tolerance to turbidity reflects its resistance to physical, chemical or biological fouling factors. To find a specific durable membrane that will ensure good reliable performance in hybrid system good tolerance to turbidity is required to optimize production and lower the operation cost.

2. EXPERIMENTAL SETUP:

Fig. 1: shows a schematic flow diagram of minimodule tester #2, the main test unit used in this experiment, describe earlier, which can be arranged to allow for the connection and testing of a one 2.5"x40" membrane instead of the four flat membrane test cells. With the help of a computerized control panel, the RPM of the high pressure pump can be controlled to the desired level to adjust the feed pressure. Feed temperature of the experiment was controlled to a fixed value 25℃ with the help of an automatic temperature control computerized device.

The four cells having model No. C–70F, membrane diameter 75 mm, with an effective are of 32 cm^2, arranged in series, were utilized in the experiment. Temperature of the feed was maintained to 25℃ by cooling the recycled reject by the cooler connected to chiller #2.

Common foulants originated from turbidity materials are scale made of calcium carbonate, calcium sulfate, and metal oxides as well as silica, organic and biological matter, etc. Fouling results in decline of permeate flow. To investigate this action, Raw Seawater SDI = 6.4, pH = 8.3, conductivity = 60000 μS/cm, TDS ≃ 43000 ppm was used as foulant source in the experiment. Seawater incoming pipeline was connected to the feed tank for continuous supply of the feed water.

3. FEED AND OPERATING CONDITIONS:

Operation conditions were maintained at Pressure 56 kg/cm^2, temperature 25 ± 0.2℃. Brine flow was varied from 1, 3, 7 and raised up to 15 L/m, while test duration time was 24, 20, 4 and 20 hours, respectively. After 68 hours of operation the unit was run with 2.7 L/m of brine flow for another 180 hours under the same conditions.

4. RESULTS AND DISCUSSION:

Fig. (2) shows the performance of the various membranes tested under different brine flow conditions vs operation time while the same data are listed in Table (1). The test results show that the permeate flow decreases as the brine flow decreases. However, when the brine flow is increased significantly to 15 l/m the permeate flow also increases. In general a gradual decline of permeate flow is observed at a fixed brine flow rate of 3 l/m. During the first 24 hours of operation at 3 l/m brine flow the permeate flow decreased from 79 CC/30 min to 70 CC/30 min for Toray 80S, 66 CC/30 min to 60 CC/30 min for Toray 80M and 67 CC/30 min to 62 CC/30 min for Nitto membrances, respectively. During the last 180 hours of operation with approximately the same brine flow rate this value decreased from 40 to 30 CC/30 min for the Toray 80S, from 38 to 27 CC/30 min for Toray 80M and from 36 to 28 CC/30 min for Nitto Denko membranes. It appears that flux decline due to turbidity is less in the case of Nitto Denko followed by Toray 80M and Toray 80S.

At a very low brine flow of 1 L/m, within 24 hours it was observed that the permeate conductivity increased from 968 to 1923 μS/cm for Toray 80S, 1200 to 2240 μS/cm for Toray 80M and 523 to 1053 μS/cm for Nitto denko membranes. For the first 24 hours of operation the permeate conductivity gradually decreased in all the cases when the brine flow rate was kept at 3 l/m. But it gradually increases during the last 180 hours of operation: from 1241 μS/cm to 1338 μS/cm for Toray 80S, from 1557 to 1678 μS/cm for Toray 80M and from 767 to 895 μS/cm for Nitto Denko membrane.

After 24 hours of operation permeate conductivity increased gradually, in all three cases. At a very low flow of brine the change of permeate conductivity was significant, presumably due to high brine concentration at the surface of membrane at low flow of brine.

5. CONCLUSION:

Unlike membrane salt rejection which is not highly changed by a change in brine flow, the permeate flow is dependent on brine flow and tends to decrease as brine flow is decreased. Flux decline due to turbidity is less in the case of Nitto Denko followed by Toray 80M and Toray 80S.

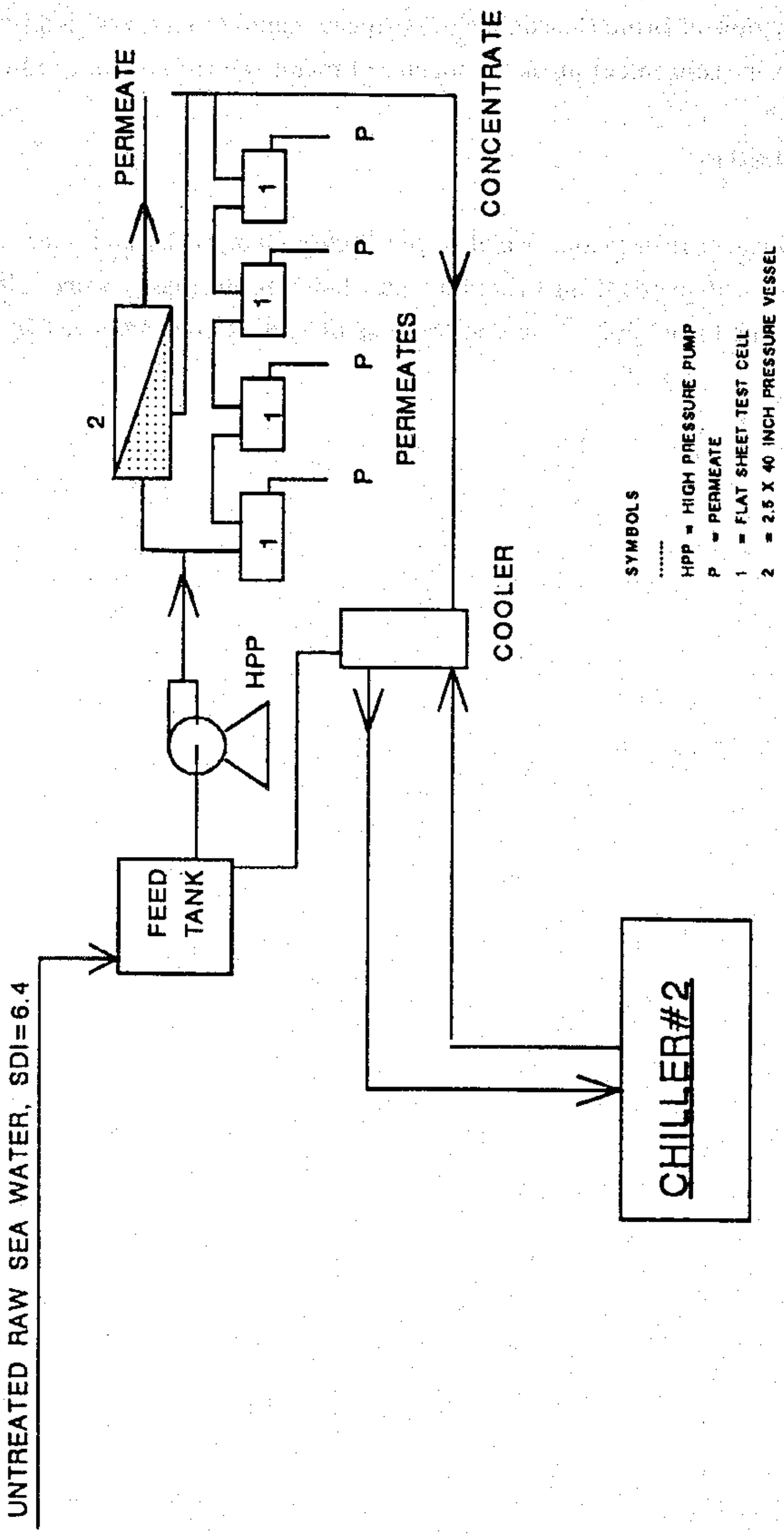

Fig. 1 Schematic Flow Diagram of Mini Module Tester-2(RUW-5)