7.1.1 Investigation on Commercial RO Modules for Hybrid System

Contents

7.1.1.A. Collecting Information and Evaluation

Contents

List of Tables

In case of seawater desalination by reverse osmosis (RO) process, membrane modules of high salt rejection are used and the potable water which is produced by seawater RO usually has a total dissolved solids (TDS) content of 500 mg/l or less. In general, since membrane modules of high salt rejection tend to have low permeability, attempts to produce potable water with low TDS levels result in low production and attempts to raise production result in a product with a relatively high TDS level which is unsuitable for drinking.

On the other hand, product water obtained by the evaporation (MSF) of seawater is extremely pure, with a salt content which is so low that it cannot be used for drinking without adding hardness components. Consequently, if product water from MSF is blended with permeate water from low rejection RO, drinking water with a suitable salt content can be obtained economically. This sort of blending of MSF and RO waters for making drinking water from seawater is proposed as a hybrid system (MSF–RO).

The aims of this study are to select RO membrane modules suitable for the Hybrid System (MSF–RO), using the most practical of the commercially available membranes with suitable salt rejection and high permeability, and to confirm its feasibility for use in the hybrid system.

1. Objectives

To build an MSF/RO hybrid system that can fully utilized the combined advantages of the two methods, it is necessary to select an RO membrane which is suitable for this purpose. Such a membrane must have respectively good salt rejection, but high flux characteristics, and is available as a standard product in the market.

2. Investigation Method

Information on various off–the shelf membrane products from Japanese as well as overseas markets was examined through a survey of the related literature and a membrane performance comparison based on publications obtained from manufacturers of seawater desalination reverse osmosis membrane such as NITTO–DENKO, TOYOBO, TORAY, DUPONT, FILMTEC, FLUID SYSTEM and HYDRANAUTICS.

3. Investigation Results

The investigation results are summarized below.

(1) Investigation Summary of Various RO Elements
The latest catalogs and standard design and operation information of suitable commercial RO modules for hybrid system(MSF–RO) were collected. Information collected was summarized as technical specifications of commercial RO membranes in Table 1, Table 2, Table 3 and Table 4.

(2) Commercial RO Module Samples for the Test Plant
Commercial RO module samples were provided by TOYOBO, TORAY and NITTO DENKO. Operation of the RO test plant will be performed using following newly provided elements as shown in Table 5.

Table 1 Technical Specifications of SWRO Membranes of (Toyobo, Toray and Nitto Denko)

MAKER			TOYOBO				TORAY		NITTO DENKO	
MODEL		Unit	Original Design HR8355F	Base HM8255F	New Design HR8355FI	Base HM8255FI	Original Des SP-120	New Design SU820	Original Design Base	New Design NTR-70SWC-S8
Module										
Number of elements			1	2	1	2	1	1		1
Size, Diameter		mm	OD 305	OD 305	OD 305	OD 298	OD 201	OD 201		OD 201
Length		mm	L 2640	L 2640	L 1330	L 2640	L 1016	L 1016		L 1016
Weight		Kg			125	205		20		21
Material			Cellulose Triacetate	Cellulose Triacetate	Cellulose Triacetate	Cellulose Triacetate	Composite Polyether	Aromatic Polyamide		Composite Polyamide
Product Flow Rate	Nominal	m^3/D	>25.0	>25.0	12	27.5	9.0	16.0		16.4
	Minimum	m^3/D			10	25	7.6	14.0		16.4
Salt Rejection	Nominal	%	99.2	99.2	99.4	99.4	99.7	99.4		99.4
	Minimum	%			99.2	99.2	99.5			99.2
Test Conditions										
Feed Water, NaCl Solution		ppm	35,000	35,000	35,000	35,000	35,000	35,000		35,000
Pressure		Kg/cm^2	55	55	55	55	56	56		56
Temperature		℃	25	25	25	25	25	25		25
		%	30	30	30	30				
Concentrate Flow Rate		L/min					40	80		80
Feed water pH							6 - 7	6.5		6.5
Operation Range										
Operationg Pressure (Min.)		Kg/cm^2	-	—						
(Normal)		Kg/cm^2	55	55			50 - 65	65		
Maximum Pressure		Kg/cm^2	60	65	60	65	70	70		70
Temperature(Min, Std, Max)		℃	5, 25, 40	5, 25, 40	5 ~ 40	5 ~ 40	-, 25, 35			, , 40
Concentration Flow Rate Range		m^3/D			15 ~ 150	35 ~ 120	34.6 ~ 57.6	115		
Feed Water Qualities			<4.0	<4.0	<4.0	<4.0	<5	<4.0		<4.0
pH (Min, Std, Max)			3, 6, 8	3, 6, 8	6.0 ~6.5	6.0 ~6.5	5.0 ~ 8.5	3 ~ 9		2, -, 10
pH(Cleaning)								2 ~ 10		
Residual Chlorine(short time)		ppm	<1	0.2~1.0	0.1~0.2	0.1~0.2	0	0		< 0.1 (1.0)
Fe + Mn		ppm			< 0.1	< 0.1				
Max Feed Flow Rate		L/min					140	200		200
Std. Feed Flow Rate		L/min					40 ~ 60			
Min Brine Flow Rate		L/min	10.4	24.3				>40		45, ($2.7m^3/h$)
Std. Brine Flow Rate		L/min					24 ~ 40			
Max Brine Flow Rate				83.3						
Pressure Drop		Kg/cm^2						<1		0.84/Element

Table 2 Technical Specification of SWRO Membranes of Fluid System

TECHNICAL SPECIFICATIONS OF COMMERCIAL SEA WATER RO MEMBRANES						
Membrane Maker		Fluid System				
Type		SW	SW	SW	SW	SW
Model	Unit	TFC 1501	TFC 2021 HP	TFC 2031 HF	TFCL 1821 HP	TFCL 2822
Module						
Number of Elements	No.	1	1	1	1	1
Membrane Material		PA	PA	PA	PA	PA
Membrane Area	m2					27.87
Size, Diameter	mm	152.4	203.2	203.2	101.6	203.2
Length	mm	1016	1016	1524	1016	1016
Weight	Kg	9.1	18.1	26.4	4.5	18.1
Product Flow Rate						
Nominal	m3/d	8	22.7	34.8	4.5	19
Minimum	m3/d					
Salt Rejection,						
Nominal	%	99.3	99	99	99.4	99.4
Minimum	%	99	98.6	98.6	99.2	99.2
Test Conditions						
Feed water , NaCl Solution	ppm	32800	32800	32800	32800	32800
Pressure	Kg/cm2	56.3	56.3	56.3	56.3	56.3
Temperature	deg.C	25	25	25	25	25
Recovery	%	7	7	11	7	7
Concentrate Flow Rate	m3/d					
Feedwater pH		5.7	5.7	5.7	7.5	7.5
Operation Range						
Operating Pressure						
Minimum	Kg/cm2					
Normal	Kg/cm2	56.3	56.3	56.3	56.3	56.3
Maximum	Kg/cm2	70.3	70.3	70.3	70.3	70.3
Operating Temp. Range	deg. C	1.0 - 45	1.0 - 45	1.0 - 45	1.0 - 45	1.0 - 45
Concentrate Flow Rate	m3/d					
Feed Water Qualities						
pH Range		4.0 - 11	4.0 - 11	4.0 - 11	4.0 - 11	4.0 - 11
pH Range (Cleaning)		2.5- 12	3.5 - 12	3.5 - 12	2.5 - 11	2.5 - 11
Residual Chlorine	ppm	0	0	0	0	0
Max. SDI (15 min)					5	5
Allowable Turrbidity(NTU)		1	1	1	1	1
Rec. Turrbidity (NTU)			0.2	0.2	0.2	0.2
Max. Feed Flow Rate	m3/d					
Std. Feed Flow Rate	m3/d					
Min. Brine Flow Rate	m3/d					
Std. Brine Flow Rate	m3/d					
Max Brine Flow Rate	m3/d					
Pressure Drop	Kg/cm2	0.7	0.7	1.05	0.7	0.7

Table 3 Technical Specification of SWRO Membranes of of DuPont

TECHNICAL SPECIFICATIONS OF COMMERCIAL SEA WATER RO MEMBRANES								
Membrane Maker		Dupont						
Type	Unit	HF	HF	HF	HF	HF	HF	HF
Model		B-10 / 6410	B-10 / 6440	B-10 / 6440 T	B-10 / 6840	B-10 / 6840 T	B-10 / 6840 TA	B-10 / 6880 T TWIN
Module								
Number of Elements	No.	1	1	1	1	1	1	2
Membrane Material		PA	PA	PA	PA	PA	PA	PA
Membrane Area	m2							
Size, Diameter	mm	143	143	152	264	277	264	297
Length	mm	493	1190	1260	1499	1499	1499	2051
Weight	Kg	10	22.7	31.8	102	122	102	286
Product Flow Rate								
Nominal	m3/d	0.946	6.06	5.3	23.85	18.9	18.93	52.3
Minimum	m3/d							
Salt Rejection,								
Nominal	%	> 98.5	> 98.5	99	> 98.5	99	99	99.2
Minimum	%			98.5		98.5	98.5	98.7
Test Conditions								
Feed water , NaCl Solution	ppm	30000	30000	30000	30000	30000	30000	35000
Pressure	Kg/cm2	56.25	56.25	56.25	56.25	56.25	56.25	70.31
Temperature	deg.C	25	25	25	25	25	25	25
Recovery	%	30	30	30	30	30	30	35
Concentrate Flow Rate	m3/d	2.21	14.14	12.37	55.65	44.1	44.17	97.13
Feedwater pH								
Operation Range								
Operating Pressure								
Minimum	Kg/cm2							
Normal	Kg/cm2	56.25	56.25	56.25	56.25	56.25	56.25	56.25
Maximum	Kg/cm2	70.31	70.31	84.37	70.31	84.37	70.31	84.37
Operating Temp. Range	deg. C	0 - 35	0 - 35	0 - 40	0 - 35	0 - 40	0 - 40	0 - 40
Concentrate Flow Rate	m3/d							
Feed Water Qualities								
pH Range		4.0 - 9	4.0 - 9	4.0 - 9	4.0 - 9	4.0 - 9	4.0 - 9	4.0 - 9
pH Range (Cleaning)		2.3 - 11.0	2.3 - 11.0	2.3 - 11.0	2.3 - 11.0	2.3 - 11.0	2.3 - 11.0	2.3 - 11.0
Residual Chlorine	ppm	0	0	0	0	0	0	0
Max. SDI (15 min)		3	3	3	3	3	3	3
Allowable Turrbidity (NTU)								
Rec. Turrbidity (NTU)								
Max. Feed Flow Rate	m3/d							
Std. Feed Flow Rate	m3/d	3.15	20.2	17.67	79.5	63	63.1	149.43
Min. Brine Flow Rate	m3/d	1.55	7.57	7.57	22.71	22.7	22.71	45.79
Std. Brine Flow Rate	m3/d	2.21	14.14	14.14	55.65	44.1	44.17	97.13
Max Brine Flow Rate	m3/d	9.08	56.78	56.78	151.4	151.4	151.4	76.32
Pressure Drop	Kg/cm2	0.42	0.42	0.42	0.42	0.42	0.42	0.63

(7.1.1.A)

Table 4 Technical Specification of SWRO Membranes of Hydranautics and Filmtec

TECHNICAL SPECIFICATIONS OF COMMERCIAL SEA WATER RO MEMBRANES						
Membrane Maker		Hydranautics			FILMTEC	
Type	Unit	SW	SW	SW	SW	SW
Model		4040 HSY-SWC1	6040-HSY-SWC1	8040-HSY-SWC1	30 HR- 8040	30 - 8040
Module						
Number of Elements	No.	1	1	1	1	1
Membrane Material		Composite PA	Composite PA	Composite PA	PA	PA
Membrane Area	m2	6.5	14.4	29.27		
Size, Diameter	mm	100.3	151.1	201.9	203.2	203.2
Length	mm	1016	1016	1016	1016	1016
Weight	Kg	8.2	13.6	18.1		
Product Flow Rate						
Nominal	m3/d	5.1	9.1	18.9	15	22.7
Minimum	m3/d					
Salt Rejection,						
Nominal	%	99.5	99.5	99.5	99.5	99.5
Minimum	%	99.2	99.2	99.2		
Test Conditions						
Feed water , NaCl Solution	ppm	32800 *	32800 *	32800 *	32000	32000
Pressure	Kg/cm2	56.25	56.25	56.25	56.25	56.25
Temperature	deg.C	25	25	25	25	25
Recovery	%	10	10	10	8	
Concentrate Flow Rate	m3/d	45.9	81.9	170.1		
Feedwater pH		6.0 - 7.0	6.0 - 7.0	6.0 - 7.0		
Operation Range						
Operating Pressure						
Minimum	Kg/cm2					
Normal	Kg/cm2	56.25	56.25	56.25	56.25	56.25
Maximum	Kg/cm2	70.31	70.31	70.31	70.31	70.31
Operating Temp. Range	deg. C	Max. 45	Max. 45	Max. 45	Max. 45	Max.45
Concentrate Flow Rate	m3/d					
Feed Water Qualities						
pH Range		3.0 - 10.0	3.0 - 10.0	3.0 - 10.0	2.0 - 11.1	2.0 - 11.0
pH Range (Cleaning)					2.0 - 12	2.0 - 12
Residual Chlorine	ppm	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Max. SDI (15 min)		4	4	4	5	5
Allowable Turrbidity(NTU)		1	1	1		
Rec. Turrbidity (NTU)						
Max. Feed Flow Rate	m3/d	86.4	163.2	408		
Std. Feed Flow Rate	m3/d	51	91	189	187.5	
Min. Brine Flow Rate	m3/d		81.9			
Std. Brine Flow Rate	m3/d	45.9		170.1		
Max Brine Flow Rate	m3/d					
Pressure Drop	Kg/cm2				0.7	

* ASTM Standard Synthetic Seawater

Table 5 RO Elements Provided for the Operation of the RO Test Plant

Manufactures	Model No.	Quantity provided
TOYOBO	HR8355FI	2
TOYOBO	HM8255FI	4
TORAY	SU820	2
NITTO DENKO	NTR-70SWC-S8	2

(3) Information on TOYOBO RO Modules (HM8255FI + HR8355FI)
Information obtained from TOYOBO(dated 2nd July 1994) are as follows:

(3.1) Expected Performance of the Test Plant Operation

(1) Comments

Comments based on information of the seawater composition at Al-Jubail plant site(Table 6.4.2-1, page 6-44 Interim Report, March 1994) are as follows:

1) TDS 44000mg/L is little less than the total amount of ions.
2) Total amount of the cation equivalent is 1.11 times higher than the total amount of anion. The Na+ value may be a little high.
3) Salinity value of 35.1 is too low

Expected performance for the RO test plant was calculated based on the above mentioned seawater composition. However, more accurate seawater analysis was performed by SWCC. Calculation of the expected performance for the Test Plant is to be obtained using latest seawater composition data.

(2) Expected Performance for the RO Test Plant

1) Case 1.(original design)

HM8255FI(two elements) + HR8355FI(one element)

Operation conditions were:

Feed water Pressure	:	60 – 65 Kg/cm^2
Feed Flow Rate	:	66.7 m^3/day
Temperature	:	25 – 35 deg. C
Recovery	:	37 %

Product Flow Rate : 24.7 m^3/day

(See Attached Material–1 for further details).

2) HM8255FI(two elements)

Operation Conditions were:

Feed water Pressure	: 60 – 65 Kg/cm^2
Feed Flow Rate	: 66.7 m^3/day
Temperature	: 25 – 35 deg. C
Recovery	: 30 %
Product Flow Rate	: 20.0 m^3/day

(See Attached Material–2 for further details).

3) Recommendations

A. HM8255FI(two elements) operation bypassing the HR8355FI is recommended as shown in item 2 above.

B. An orifice plate is inserted in upstream of the product flow valve. Removal of this orifice or enlargement of its hole is recommended (if required flow rate and pressure are difficult to control).

C. As composition of the seawater may change seasonally, operating condition needs to change accordingly.

(3.2) Storage of used elements for TOYOBO Membranes (HM8255FI & HR8355FI)

For chemicals, concentration, pH, Temperature, etc.,

(See Attached Material–3 ,Stand–by Requirement for "HOLLOWSEP" Modules).

Additional information is as follows:

1)	Less than three days	: in the pressure vessels as it is
2)	More than three days	: operate 1 to 2 hours every three days
3)	Long term storage	: soak in 0.5% formaline solution. SBS is so easily oxidized that SBS is not recommended

(3.3) Quality of RO feed water for TOYOBO Membranes (HM8255FI & HR8355FI)

Residual chlorine	: 0.1 – 0.2
Fe^{+++} + Mn^{++}	: less than 0.1ppm
pH	: 6.0 – 6.5
SDI	: Less than 4.

(4) **Information for NITTO DENKO Modules (NTR−70SWC−S8)**

Information obtained from NITTO DENKO(dated, 30th May,1994) was summarized as follows:

(4.1) Summary

Expected performance for the RO test plant was calculated. The results of calculation are summarized in Table 6. Designed product flow rate of 20m^3/day may be obtained using two NITTO DENKO elements NTR−70SWC−S8

(4.2) Design and operation condition of the Test Plant

(1)	Design capacity of the Test Plant	:	20 m^3/day
(2)	Performance of the high pressure pump	:	
	Flow rate	:	2.0−3.5m^3/Hr,48−84.0m^3/day
	Pressure	:	50 − 70 Kg/cm^2 x 15 kW
(3)	Module provided	:	NTR−70SWC−S8, two elements
(4)	Minimum brine flow rate	:	2.7m^3/Hr, 64.8 m^3/day
(5)	Product flow rate	:	(2)−(4)=84.0−64.8=19.2m^3/day

(4.3) Expected performance and operating conditions of the two NITTO DENKO elements(NTR−70SWC−S8) using the Test Plant :

No. of elements	:	Two,(NTR−70SWC−S8)
Composition of feed seawater	:	AL−JUBAIL POWER PLANT on 20/02/1993
pH(adjusted with H_2SO_4)	:	7.0
Temperature	:	30 degree C
Product water flow rate*	:	19 m^3/day
Feed water flow rate	:	84 m^3/day
Brine flow rate	:	64.8 m^3/day
Recovery	:	22.8 m^3/day
Quality of permeate(TDS)	:	224 ppm

*** Because of limitation of capacity of high pressure pump the product capacity is limited to 19 m3/day.**

List of Attached Materials

(5) **Temperature Correction Factors**

Information of temperature correction factors of permeate flow rate for RO membranes were collected as follows:

(5.1) "Standardization method of water permeate flow performance data of reverse osmosis membrane element and module"

JIS(Japanese Industrial Standard) Testing Methods for Solutes Rejection and Water Flux of Reverse Osmosis Membrane Element and Module using Aqueous Solution of Various Solutes, JIS K 3805-1990, Translated and Published by Japanese Standards Association
(Attached Material-4)

(5.2) Standard Practice for Standardizing Reverse osmosis Performance Data
ASTM D 4516-85(Reapproved 1989)
(Attached Material-5)

(5.3) Temperature correction factors for NITTO DENKO RO flat sheet membrane
(Attached Material-6)

(5.4) Temperature correction factors for TOYOBO hollow fiber type module HM8255FI
(Attached Material-7)

(5.5) Temperature correction factors for NITTO DENKO spiral-wound type module
(Attached Material-8)

(6) Instruction manual for NITTO DENKO RO/UF Test Cell C70-F
(Attached Material-9)

4. Conclusion

(1) From a literature survey on performance of seawater desalination reverse osmosis membranes (SWRO) from seven manufacturers, Toyobo, Toray, Nitto Denko, Fluid Systems, DuPont, Hydranautics and FilmTec, it was found that most of the standard RO membranes on the market are made to give high salt rejection. Obtaining, and testing low rejection, high flux membranes suitable for an MSF/RO hybrid systems is

not available in the market. (Ready-made products would be required)

(2) All of the SWRO membranes examined had their specified feed salinity levels in the range of 30,000 - 35,000 ppm, and their performance with seawater with salinity levels of 43,00 - 46,000 ppm, as in the case of seawater off the Saudi Arabia coast, is not given. Therefore, it is necessary to establish the physical, chemical and biological durability for the latter case through actual tests.

(3) By conducting performances tests on membrane products which are actually available, useful information can be obtained regarding the manufacturing of SWRO membranes suitable for a Hybrid System(MSF/RO).

(4) Through this investigation, it was possible to collect large amount of useful information and data regarding ways of utilizing SWRO membranes, and the future dirction of the study.

Table 6 Expected RO Module Performance for the Operation of the RO Test Plant

Elements:NITTO DENKO NTR-70SWC-S8
No. of elements:Tow and four
Feed seawater :at AL-JUBAIL POWER PLANT on 20/02/1993
Feed TDS :47,660 ppm
Feed pH :adjusted with H_2SO_4

No. of Elements	Product Flow Rate		Temperature	Recovary	Feed Flow Rate	Brine Flow Rate	Inlet Pressure	Outlet Pressure	Permeate	Remarks
	m^3/day	m^3/Hr	°C	%	m^3/Hr	m^3/Hr	Kgf/cm^2	Kgf/cm^2	ppm	
2	19	0.792	25	22.8	3.5	2.7	66.7	66.6	193	
2	19	0.792	30	22.8	3.5	2.7	64.4	64.3	224	
2	19	0.792	35	22.8	3.5	2.7	62.4	62.3	259	
2	16	0.666	25	19.0	3.5	2.8	61.5	61.3	223	
2	16	0.666	30	19.0	3.5	2.8	59.5	59.4	259	
2	16	0.666	35	19.0	3.5	2.8	58.4	58.3	300	
2	20	0.833	25	23.0	3.633 *	2.8	68.8	68.7	184	* Feed flow rate exceeds the Maximum flow rate of the high pressure pump
2	20	0.833	30	23.0	3.6 *	2.8	66.4	66.2	214	
2	20	0.833	35	23.0	3.6 *	2.8	64.3	64.2	248	
4	20	0.833	25	23.0	3.633 *	2.8	56.1	55.8	371	
4	20	0.833	30	23.0	3.6 *	2.8	56.0	55.7	434	
4	20	0.833	35	23.0	3.6 *	2.8	54.8	54.5	501	

7.1.1.B. RO Module Plant Design Simulation for Hybrid System

Contents

List of Tables

List of Figures

1. Introduction

This report describes computer projection of a 10,000 m^3/d SWRO plant to be used as part of hybrid MSF–RO plant which is part of joint SWRO desalination research under the Japan–Saudi Arabia desalination technical cooperation. This report discusses the result of a computer simulation of the performance of a SWRO plant under different operating conditions and also the performance of as applicable to spiral wound RO membrane element.

2. Design Factors

Various prerequisite for the RO plant are shown below:

(1) RO Elements

Numerical values as available from standard 8" Hydranautics were used as input parameter as well as from a hypothetical RO element.

Type: 8"x40" Spiral wound type, Composite RO Membrane

Specifications for basic performance:

*Specifications of Standard type 8040–HSY–SWC1
Salt Rejection = 99.5%
Water Flux = approx. 5000 gpd (about 19 m^3/d)

*Specifications similar to the above, with various hypothetical salt rejection rates but constant flux types of 8" elements.
Salt Rejection = 99.0% to 99.75%
Water Flux = approx. 5000 gpd (about 18.9 m^3/d)

Standard testing conditions :

Feed water	32,000 ppm NaCl
Applied Pressure	56 kgf/cm^{2*}
Water Recovery rate	7%
pH	6 to 7

(2) RO Modules

An RO module consists of minimum six of the above RO elements installed in series in a pressure vessel. The RO plant consists of an appropriate numbers of modules to give a water production capacity of 10,000 m^3/d.

(3) RO System Feed Water Conditions

Feed water	:	Standard seawater from the Saudi Arabian eastern coast, TDS about 4.2%, as determined by seawater analysis.
Water temperature	:	25℃ to 45℃
SDI	:	4.0 or less
Water Recovery rate	:	30 to 45%

3. Projected RO Module Design Performance

(1) Software

The software packages used for RO systems's design calculations were Hydranautics RODES Version 4.50 (1993) and RODES Version 4.05 (1990).

(2) RO Plant Performance Simulation

Based on pre-requisites seawater from Saudi Arabian eastern coast requisites of seawater, and a RO plant with a capacity of 10,000 m^3/d, the following operating parameters were changed to obtain simulation data of the RO performance.

(2-1) Feed water temperature : 25 to 45℃

(2-2) Average specific flux rate (Design flux load) : 0.225 to 0.549 m^3/m^2/d (5.5 to 13.5 gpd).

The number of RO elements used in the RO plant were varied between 624 and 1524 to set the prescribed design flux rates of production per unit of membrane surface area, provided that one element has 29m^2?(315 ft^2)of active membrane area.

(2-3) Water recovery rate : 35 to 45%

4. Simulation Results

Simulation values of operating pressures and quality of the permeate (TDS and Cl^-) which are indicative of RO performance during the initial operation, are shown in Table 1.

(1) Relation of feed water temperature to pressure and product TDS concentration

As the result of output data No.1 to 19, Fig. 3–1 shows the relationship between feed water temperature and the operating pressure at the module inlet port and the TDS concentration of the water which is produced at a recovery rate of 40% and design flux rates of 0.225, 0.281, 0.352 and 0.439 $m^3/m^2/d$.

(2) Relation of design flux to pressure and TDS concentration in the product at a feed water temperature of 30℃

As the results of output data of No. 4 to 8, Fig. 2 shows the relationship between the operating pressure at the module inlet and the TDS concentration of the water which is produced at a feed water temperature of 30℃, a recovery rate of 40% and design flux rates of 0.225 to 0.439 $m^3/m^2/d$.

(3) Relation of design flux to pressure and TDS concentration in the product at a feed water temperature of 35℃

As the results of output data of No. 9 to 12, Fig. 3 shows the relationship between the operating pressure at the module inlet and the TDS concentration of the water which is produced at a feed water temperature of 35℃, a recovery rate of 40% and design flux rates of 0.225 to 0.439 $m^3/m^2/d$.

(4) Relation of design flux to pressure and TDS concentration on the product at a feed water temperature of 40℃

As the results of the operation of No. 13 to 16, Fig. 4 shows the relationship between the operating pressure at the module inlet and the TDS concentration of the water which is produced at a feed water temperature of 40℃, a recovery rate of 40% and design flux rates of 0.225 to 0.439 $m^3/m^2/d$.

(5) Relation of recovery rate to pressure and solute concentration in the product at a feed water temperature of 35℃ and a design flux rate of 0.281 $m^3/m^2/d$

As the results of output data No. 20 to 22, Fig. 5 shows the relationship between the operating pressure at the module inlet and the TDS and Cl^- concentration of the water which is produced at a feed water temperature of 35℃ and a design flux rate of 0.281 $m^3/m^2/d$.

(6) Relation of various element rejection rates to solute concentration of the product at a feed water temperature of 35℃, a design flux of 0.281 $m^3/m^2/d$ and a recovery rate of 40%.

As the results of output data No.23 to 32, Fig. 6 shows the relationship between various element salt rejection rates and the TDS and Cl^- concentration of the water which is produced under operating conditions of a feed water temperature of 35℃, a design flux rate of 0.281 $m^3/m^2/d$ and a recovery rate of 40%.

(7) Table 2 shows the simulated performance of SWRO plant where the simu–contains were:

Feed water temperature of 35 degree C, design flux of 0.281 $m^2/m^2/d$ and a recovery rate of 40%.

The standard conditions were:

constant salt rejection of 99.5% and flux of 4000 – 65000 gallons per day(15 to 25 m^3/d)

Relations between the performance flux and the concentration of solute(TDS and Cl^-) in the product water is shown in Fig. 7.

Table 1 Values Obtained as a Result of the Simulation Carried out for the Performance Design of the Seawater Desalination RO System in Saudi Arabia

Material NO.	Performance of the RO membrane	RO designed flux for the unit area of the membrane ($m^3/m^2/day$)	Recovery rate (%)	Feed water temp. (°C)	Operating Pressure (kgf/cm^2) Inlet	Operating Pressure (kgf/cm^2) Outlet	Quality of the permeate as TDS (mg/L)	Quality of the permeate as CL^- (mg/L)
1	Rej=99.50%	0.352	40	25	67.4	66.6	499	290
2	ditto	0.281	40	25	62.3	61.7	624	363
3	ditto	0.225	40	25	60.0	59.6	798	465
4	ditto	0.549	40	30	76.2	74.7	369	215
5	ditto	0.439	40	30	69.8	68.6	462	269
6	ditto	0.352	40	30	65.5	64.7	581	339
7	ditto	0.281	40	30	61.9	61.3	736	429
8	ditto	0.225	40	30	59.9	59.5	942	548
9	ditto	0.439	40	35	68.9	67.8	542	316
10	ditto	0.352	40	35	63.8	63.0	674	393
11	ditto	0.281	40	35	61.7	61.1	864	503
12	ditto	0.225	40	35	58.9	58.5	1091	635
13	ditto	0.439	40	40	65.9	64.8	618	360
14	ditto	0.352	40	40	63.6	62.8	788	459
15	ditto	0.281	40	40	60.5	60.0	996	580
16	ditto	0.225	40	40	59.1	58.7	1276	743
17	ditto	0.439	40	45	65.6	64.5	719	418
18	ditto	0.352	40	45	63.6	62.8	916	533
19	ditto	0.281	40	45	60.7	60.2	1159	675
20	ditto	0.281	30	35	55.4	54.4	764	445
21	ditto	0.281	35	35	58.3	57.6	805	469
22	ditto	0.281	40	35	65.6	65.1	928	540
23	Rej=99.75%	0.281	40	35	62.8	62.3	442	257
24	Rej=99.60%	0.281	40	35	62.8	62.3	706	411
25	Rej=99.50%	0.281	40	35	62.8	62.3	882	514
26	Rej=99.45%	0.281	40	35	62.8	62.3	970	565
27	Rej=99.40%	0.281	40	35	62.8	62.3	1058	616
28	Rej=99.35%	0.281	40	35	62.8	62.3	1146	667
29	Rej=99.30%	0.281	40	35	62.8	62.3	1234	718
30	Rej=99.25%	0.281	40	35	62.8	62.3	1321	769
31	Rej=99.20%	0.281	40	35	62.8	62.3	1409	820
32	Rej=99.00%	0.281	40	35	62.8	62.3	1759	1024

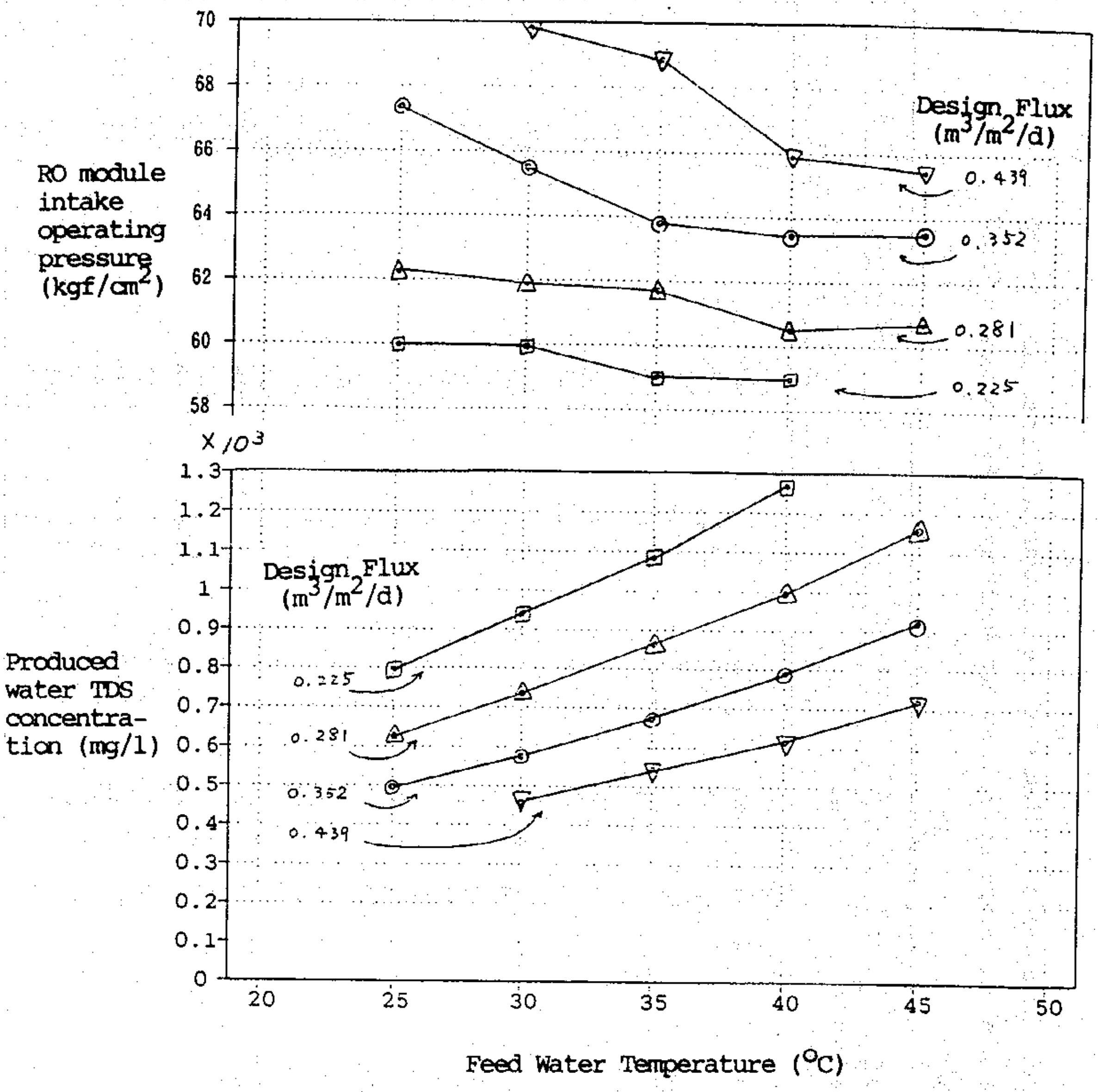


Fig.1 Simulation of Correlation of Feed water Temperature with Product TDS and Module Intake Pressure for Various Design Flux Values

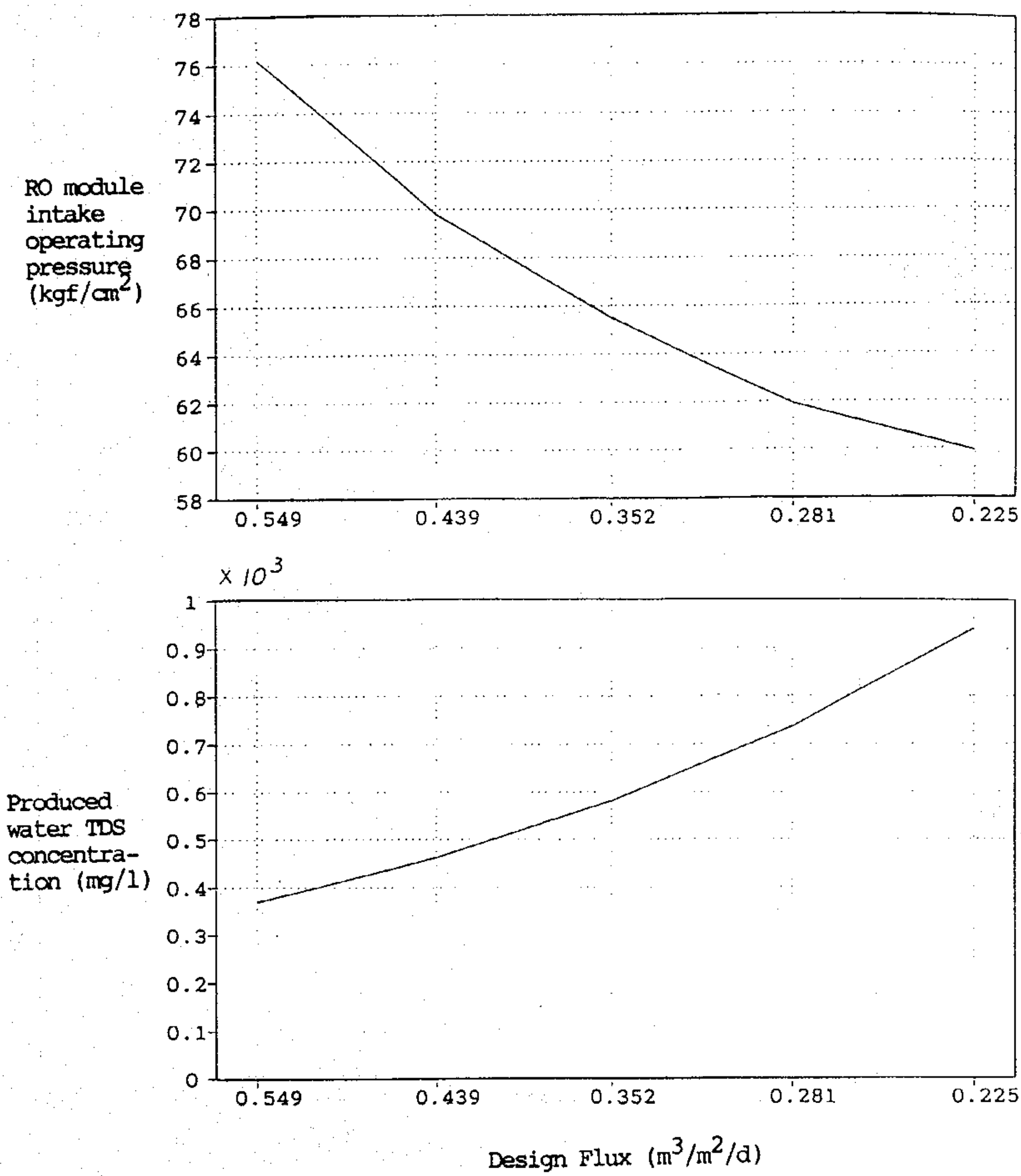


Fig.2 Simulation of Correlation of Design Flux with Product TDS and Module Intake Pressure for Operation at Seawater Temperature of 30 degree C

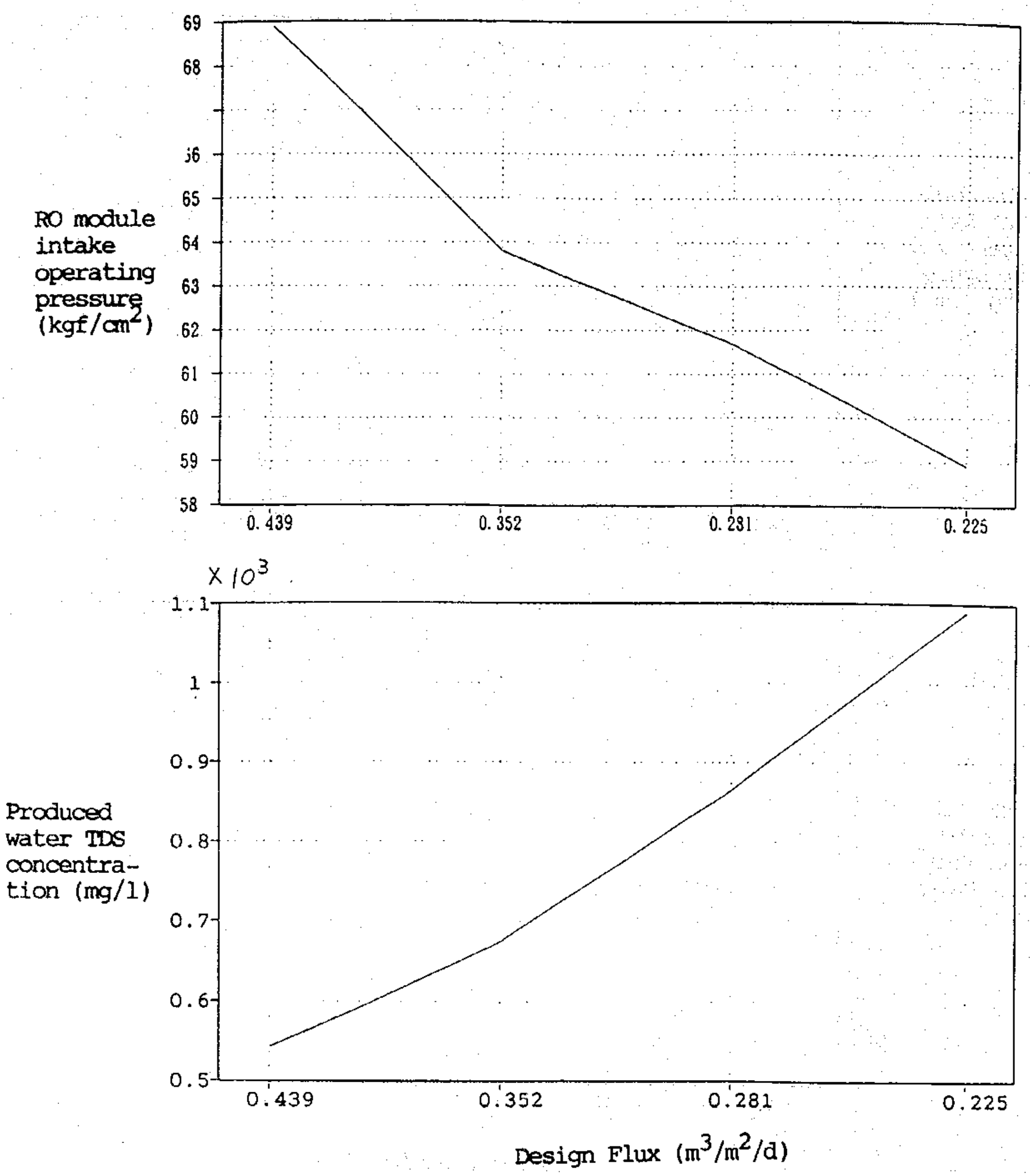


Fig.3 Simulation of Correlation of Design Flux with Product TDS and Module Intake Pressure for Operation at Seawater Temperature of 35 degree C

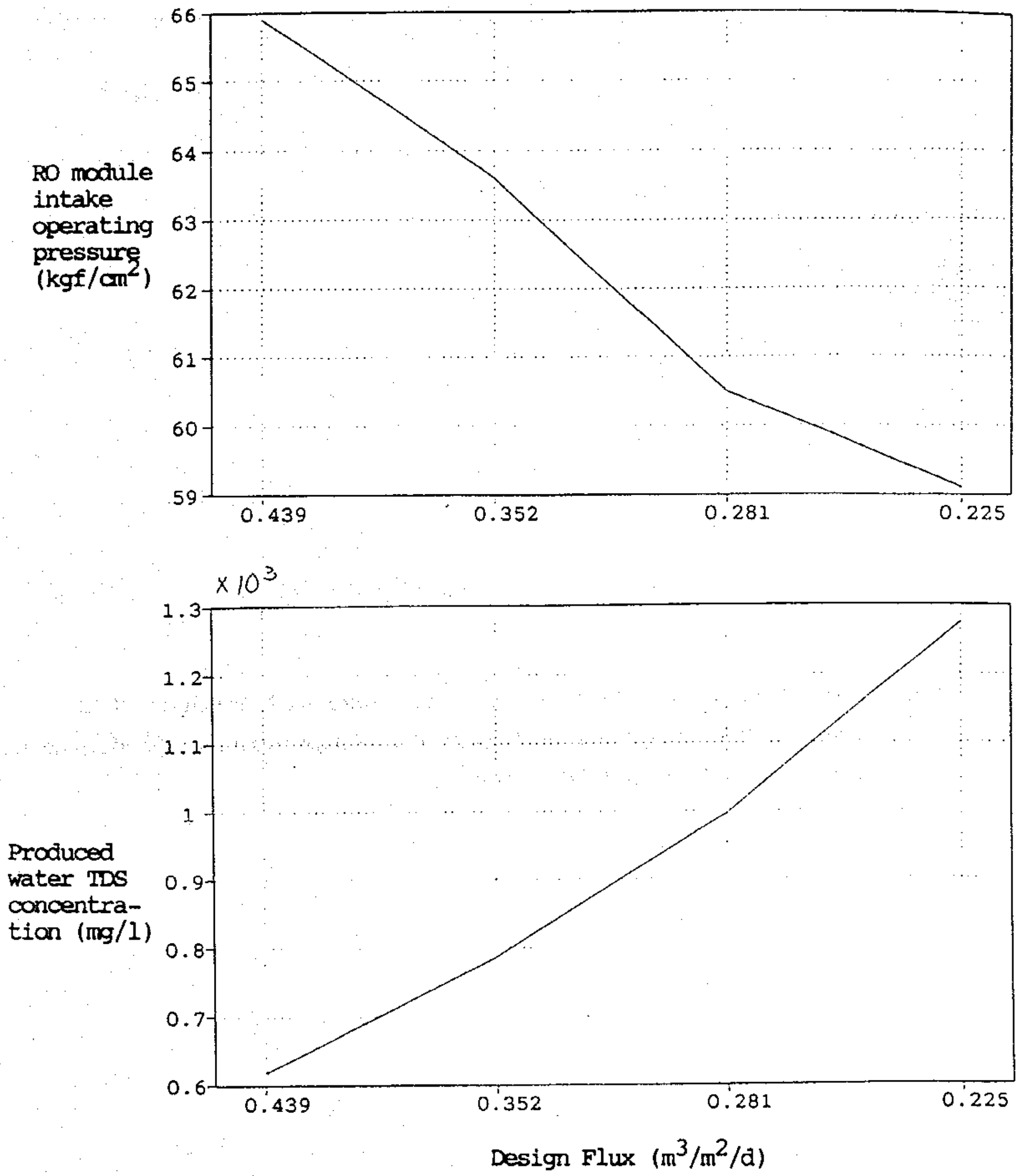


Fig.4 Simulation of Correlation of Design Flux with Product TDS and Module Intake Pressure for Operation at Seawater Temperature of 40 degree C

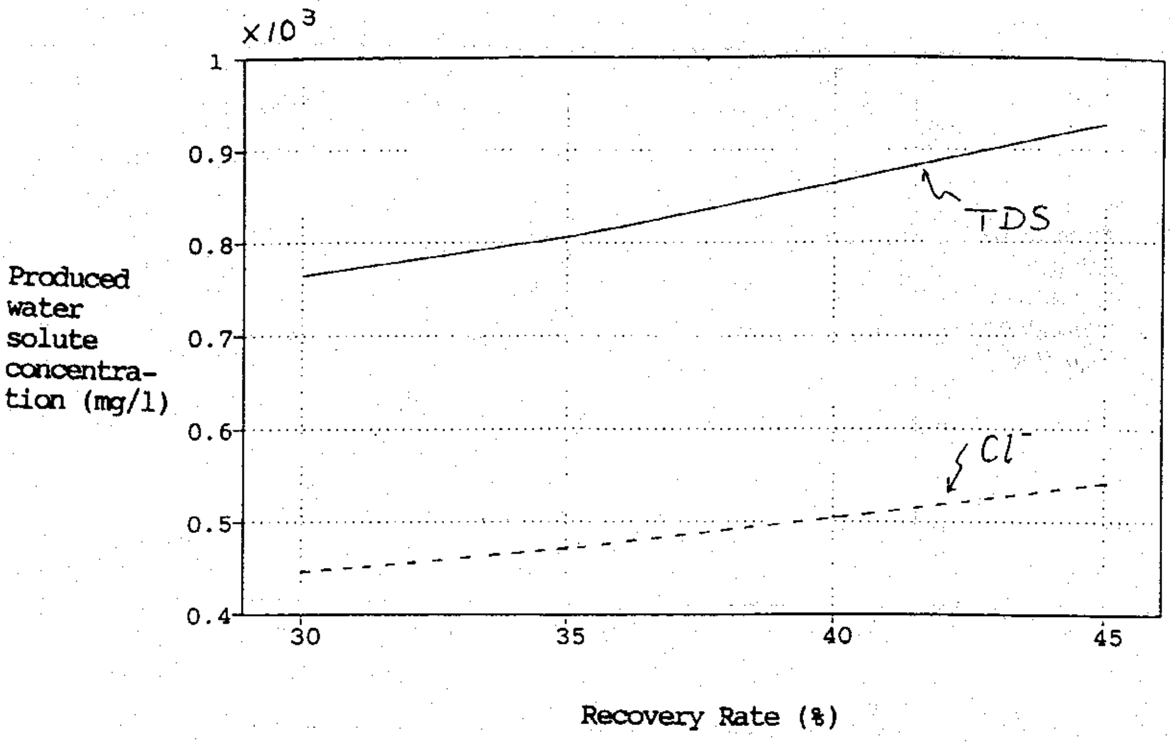


Fig.5 Simulation of Correlation of Recovery Rate with Product TDS and Cl- Concentrations with Seawater Temperature of 35 degree C and Design Flux of 0.281 m^3/m^2

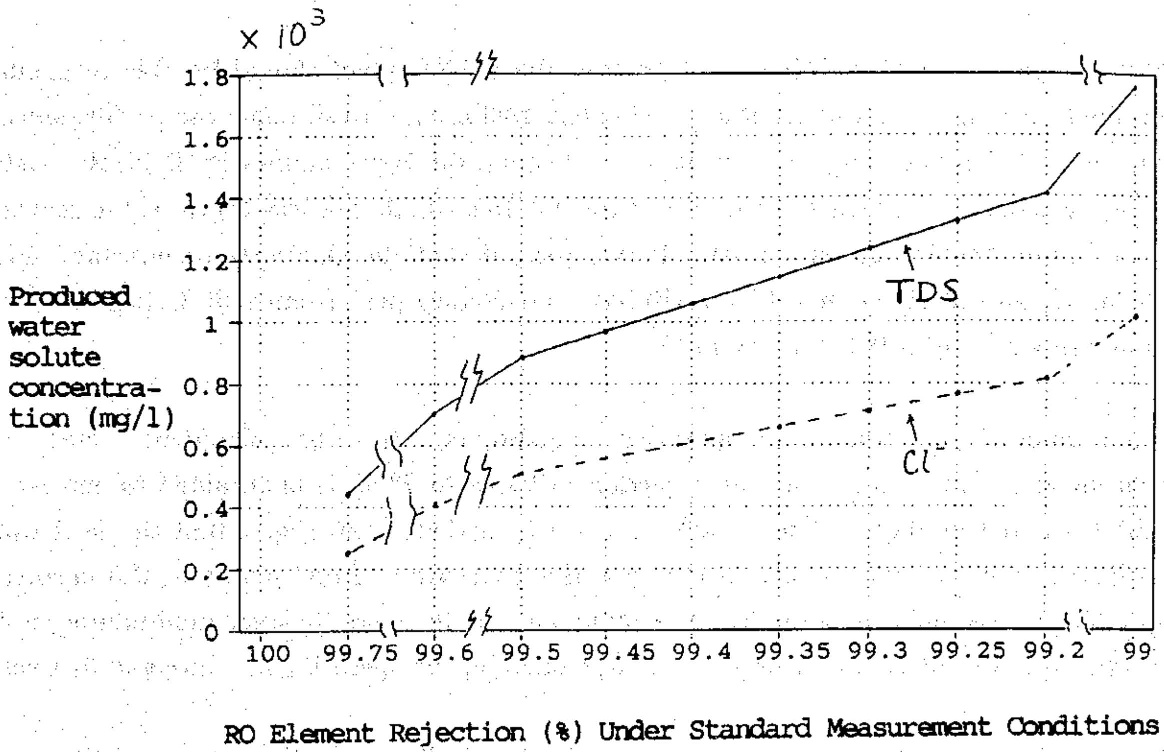


Fig.6 Simulation of Correlation of RO Element Rejection Performance with Product TDS and Cl^- Concentrations with Seawater Temperature of 35 degree C, Design Flux of 0.281 m^3/m^2 and Recovery Rate of 40%.

5. Discussion

For a hypothetical MSF=RO hybrid process, the SWRO plant should be able to produce product water at a stable TDS of approximately 1000ppm. To simulate the performance of such a SWRO plant using spiral wound membranes, the Hydranautics RODES, RO system design calculation was used. The feed water for this simulation was taken as the seawater from Saudi Arabian eastern coast. It was proved that the currently membranes (Flux: $18.9m^3/d$ and salt rejection: 99.5%) will have satisfactory performance at 35 degree C with design flux rates of 0.28 to 0.23 $m^3/m^2/d$

Furthermore, at standard operating conditions, (pressure:56Kgf/cm^2 and salt concentration:3.2% NaCl) the salt rejection of 99.55 to 99.32 is maintained to achieve an initial product quality of 200 - 1000 ppm. It is obvious from Fig. 1 that the feed water temperature has a major effect on the operating pressure and the quality of RO permeate, specially in case of a hypothetical RO plant located in Saudi Arabia, maintaining stable product quality will require complicated adjustment of the operating pressure and flux rate.

In general, a rise in temperature is accompanied by a fall in operation pressure and the salt concentration of RO permeate seems to increase. As a countermeasure, the operation of a part of RO plant can be suspended to increase the operating pressure and maintain the same salt concentration of the RO permeate.

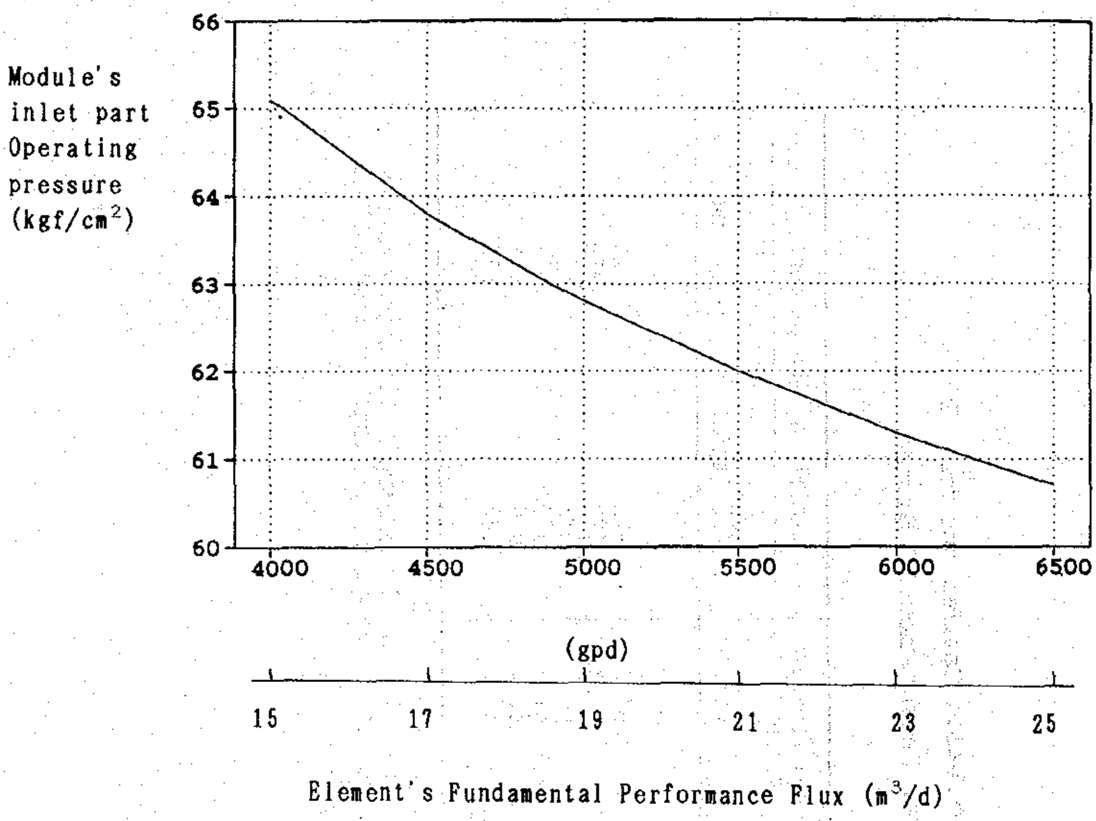
However extreme increase in the design flux load (average specific flux rate) is not desirable as it accelerates contamination of the membrane surface and consequently necessitate frequent cleaning.

In conclusion, the disadvantage of RO system (variation of salt passage with temperature and membrane contamination), can be supplemented by incorporating MSF and RO. The cost reduction may be studied and appraisal of joining MSF and RO process.

Table 2 Values Obtained as a Result of the Simulation Carried out for the Performance Design of the Seawater Desalination RO System in Saudi Arabia 13

Material NO.	Performance of the RO membrane	RO designed flux for the unit area of the membrane ($m^3/m^2/day$)	Recovery rate (%)	Feed water temp. (°C)	Operating Pressure (kgf/cm^2)		Quality of the permeate	
					Inlet	Outlet	as TDS (mg/L)	as CL^- (mg/L)
	Rej=99.50%							
33	Flux 4000	0.281	40	35	65.1	64.5	695	405
34	Flux 4500	0.281	40	35	63.8	63.3	788	459
(25)	Flux 5000	0.281	40	35	62.8	62.3	882	514
35	Flux 5500	0.281	40	35	62.0	61.4	976	568
36	Flux 6000	0.281	40	35	61.3	60.7	1070	623
37	Flux 6500	0.281	40	35	60.7	60.1	1165	678

(Note) Instead of the feed seawater near Saudi Arabia, a typical composition of TDS=43129mg/L, Cl^- concentration = 23500mg/L was tentatively used, and the simulation was carried out on the assumption that the feed's pH is adjusted to 7 with H_2SO_4 to prevent scaling.



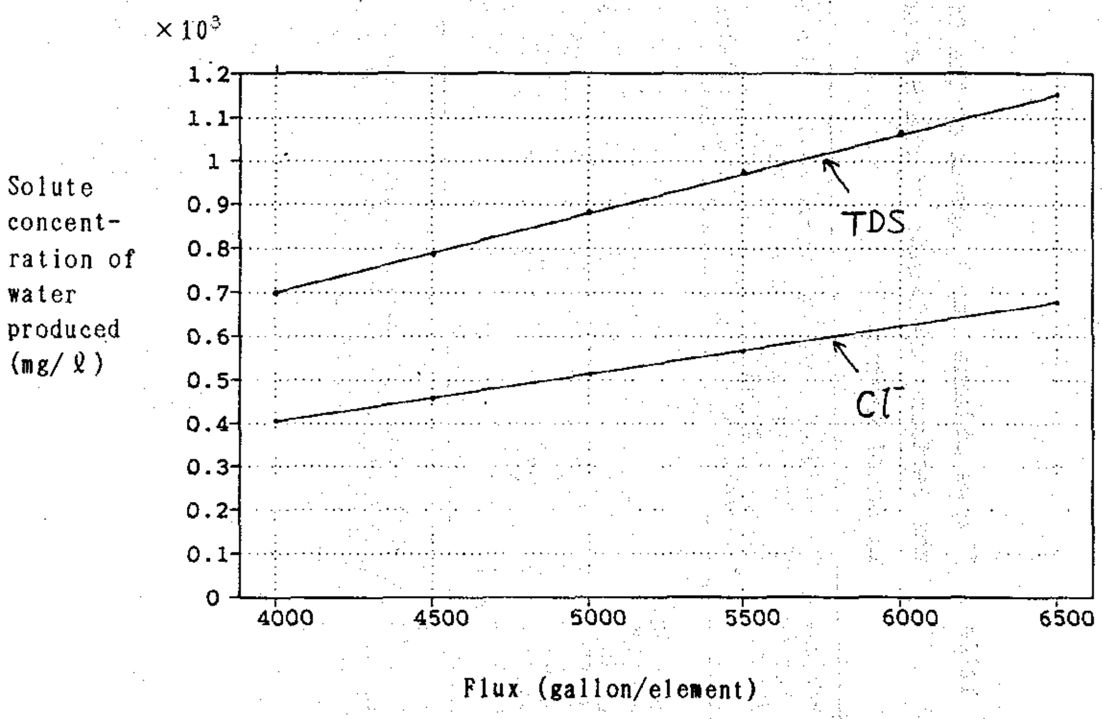


Fig.7 RO Elements' Fundamental Performance:

Depends on the Flux when the Rejection is fixed at 99.5%

Influence on the RO Plant's Performance:

Seawater Temperature:35 degree C

Designed Flux:0.281m^3/m^2/d

6. Concerning the usefulness of a hybrid MSF–RO System

(1) Limits of the MSF–RO Hybrid

1) If the TDS of RO product water is 500 ppm or below a certain standard water quality, there is no need of dilution with MSF product water and this method can not be applied.

2) If the TDS of RO product water exceed 500 ppm, a dilution factor is established depending on the TDS of RO product water.

3) In reality, the MSF product water blend ratio(the amount of product water produced by MSF, divided by total product water) is restricted by the amount of product water supplied by MSF and RO.

The TDS of MSF product water is approximately of the order of 20 ppm. The table below shows the relationship between dilution factor and MSF water blend ratio for a final product quality of 500 ppm.

Quality of water passed RO	Dilution factor	Blend ratio (RO:MSF)	MSF water blend ratio (%)
500 ppm	x 1	1 : 0	0
600 ppm	x 1.2	1 : 0.2	16. 6
750 ppm	x 1.5	1 : 0.5	33. 3
1000 ppm	x 2	1 : 1	50
1250 ppm	x 2.5	1 : 1.5	60. 0
1500 ppm	x 3.0	1 : 2	66. 7
2000 ppm	x 4	1 : 3	75. 0
2500 ppm	x 5	1 : 4	80
42000 ppm	x 84	1 : 83	98. 8

*From the RO plant simulation using seawater of Saudi Arabia eastern coast, under conditions: 35℃ temperature, 40% recovery rate, 60 kgf/cm^2 operating pressure and design flux rates from 0.28 to 0.23 $m^3/m^2/d$, the resulting RO water TDS obtained varies from 860 to 1100 ppm. Based on these data and setting an upper limit of 1250 ppm for RO product water quality, we see that a blend ratio of

RO:MSF=1:1.5, or MSF water blend ratio of 60% would be a conservative upper limit. Based on specific restrictions on blending operations and engineering considerations, actual runs can be applied in the future.

(2) Significance of the Hybrid MSF-RO Method

As the performance of SWRO plant fluctuates, the Hybrid System may be disadvantage for a single SWRO plant train as it follows:

1) As the TDS of RO product water increases with temperature, the blending of this water with MSF product water evens out the effect of high TDS.

2) Because a lower quality of RO product water is acceptable, the RO operation is simplified.

3) Electric power from the MSF generators can be used for the RO plant.

4) The MSF plant is difficult to stop and start frequently, variations in the water demand can be met by more flexible RO process.

5) The water supply capacity can be increased by installing a new RO plant with a comparatively low cost investment and a short load time.

6) Waste heat from MSF plant can be utilized to maintain a stable high feed temperature(35 degree C) throughout the year and similarly the normal operating pressure can be set at 60 Kg/cm^2 to reduce power consumption.

7) Comparing with conventional SWRO conditions, the effective life of the RO membrane can be enhanced.

8) As the TDS of RO product water in creases with time (aging compaction of membranewater), the blend of the water with MSF distillate lessens this effect.

7.1.2 Performance Evaluation of Fouled Membrane

7.1.2.A. Visit and Survey of SWCC SWRO Plants

Contents

List of Tables

1. Objective

For the purpose of the analysis of contaminated RO membranes, SWCC/JICA team visited four RO plants to make an on-site survey, to see whether or not some fouled membranes can be obtained from a SWCC SWRO plant and also to see whether or not a RO tests could be established at the SWRO plant, to be used for research by the SWCC's RDTC (Memorandum attached).

2. SWRO Plants Visited

A team made of the four visitors shown in next page visited the four plants shown in Table 1 and investigated their mode of operation.

3. Results

On the whole, the operating records were faultless, the working ratios were high and the SDI of the pretreated seawater was a good 1 to 3. (See Table 1)

All of the plants indicated that they could provide contaminated and worn membranes and that on-site testing would be possible. The SWCC/JICA team must now select the most suitable site.

The team had friendly technical discussions everywhere they went and there were keen interchanges of questions and answers. There were also questions and answers at the lecture given by the JICA Team at the SWCC RDTC (Jubail), which was well attended (see Table 2).

3.1 Visit and Survey of SWCC Reverse Osmosis Seawater Desalination Plants (1)

Date of Visit: 1 February 1994

Site: SWCC Jeddah Plant (Jeddah-I)

Persons Interviewed: Mr. Yousef Yahya Ayyash, Operation Division Head

Eng. Mohammad A. Farhan Al-Ghamdi, Operation Manager

Visitors : Mr. Abdulraham Abanmy (RD-Center)

Mr. Ahemed Saleh Al-Amoudi (RD-Center)

Dr. Yoshio Taniguchi (JICA Team)
Mr. Masahiro Kitagawa (JICA Team)

Summary of Results of Survey

(1) **Outline Jeddah–I SWRO Plant**

Plant capacity: 15MGPD

Raw seawater feed SDI : 5 to 6.5

Pretreatment

Chlorination:NaClO is added to seawater feed to produce 0.2 ppm residual chlorine

Flocculant:In–line dosing of 1 to 2 mg/l ferric chloride in the piping

Filter: Filters consist of dual media filtration using anthracite and sand filtration media, differential pressure based back–wash each 24 to 72 hours. Filtrate SDI was 3 or less

RO elements:Toyobo hollow fiber membranes, 10–inch modules

(2) **Membrane Testing Unit**

Test equipment consisting of two series of pressure vessels containing two 10–inch Toyobo hollow fiber membrane was used to make comparative runs.

(3) **Answers to Questionnaire**

1) **Concerning the acquisition of contaminated membranes**

Contaminated membranes (Toyobo hollow fiber membranes) can be provided on request by the research team.

2) **Concerning the possibility of on–site testing of new membranes**

A. **Only Toyobo hollow fiber membranes are used at present and there is no reason to evaluate other membranes. Jeddah operation group recommended that further work to be done in future on the improvement of Toyobo membrane rather than evaluate other membranes.**

B. **A site for testing can be offered.**

Plan 1 : Using a branch to supply feed water derived from Jeddah–I SWRO Plant.

Plan 2 : The tests can be performed at the plant's laboratory SWRO test unit.

3.2 Visit and Survey of SWCC Reverse Osmosis Seawater Desalination Plants (2)

Date of Visit:2 February 1994

Survey Site:SWCC Jeddah Plant (Jeddah–I)
SWCC Jeddah Plant (Jeddah–II)
SWCC Satellite Plant Managing Office

Persons Interviewed:Mr. Yousef Yahya Ayyash, Operation Division Head
Eng. Mohammad A. Farhan Al–Ghamdi,
Operation Manager
Mr. Abdul Rahman Al–Mohamadi,
Acting Satellite Plant Manager

Visitors:Mr. Abdulraham Abanmy (RD–Center)
Mr. Ahemed Saleh Al–Amoudi (RD–Center)
Dr. Yoshio Taniguchi (JICA Team)
Mr. Masahiro Kitagawa (JICA Team)

Summary of Results of Survey

1. **Study and Observation of Jeddah–I SWRO Control Room**
2. **Study and Observation of Jeddah–II SWRO Plant**

Later, the team observed the Jeddah–II SWRO plant which is due to start up four days later. Jeddah–II SWRO is an exact copy of Jeddah–I SWRO Plant, the plant capacity, systems, membrane types and construction are all identical to those of Jeddah–I SWRO Plant.

3. **Detailed arrangements with Satellite Plant Manager regarding future plant survey visits**

The Satellite Plant Manager in Jeddah is responsible for all small scale plants such as Umm Lujj, Duba, Haql, etc. In the absence of the Satellite Plant Manager, we met with the Acting Satellite Plant Manager and explained the details of our survey visits, requesting his cooperation with our investigations and making detailed arrangements.

He agreed that we could be provided with contaminated and deteriorated membranes from each plant. It was also arranged that we would be accompanied by Mr. Lutfi Bakhiet, a desalination engineer from SWCC satellite plant division.

3.3 Visit and Survey of SWCC Reverse Osmosis Seawater Desalination Plants (3)

Date of Visit:5–6 February 1994
Survey Site:SWCC Umm Lujj Plant
Persons Interviewed:Mr. Abdallah A. Al–Hajouri,
Plant Manager
Mr. Lutfi Bakhiet,
desalination engineer (accompanied us from Jeddah)
Visitors :Mr. Abdulraham Abanmy (RD–Center)
Mr. Ahemed Saleh Al–Amoudi (RD–Center)
Dr. Yoshio Taniguchi (JICA Team)

Summary of Results of Survey

(1) Outline of Umm Lujj Plant

Production capacity: 4400 m^3/d; Commissioning date: 1986

Pretreatment: Two stage filtration with a gravity type, dual media anthracite/sand filter with no focculant added and a pressurized rapid filtration dual media anthracite/sand filter, addition of 0.5 mg/l $CuSO_4$ bactericide, treated water SDI of 3 to 4.

RO Plant : 2–stage desalination with UOP spiral elements, 6–inch first stage module and 8–inch second stage module.

(2) Answers to Questionnaire

1) Concerning the acquisition of contaminated membranes

Membranes whose performance has deteriorated are stored together with their operation records, and can be provided.

2) Concerning the possibility of on–site testing of new membranes

Test can be conducted at the test unit or module can be fed directly from the main plant feed using an available existing pressure vessels.

(3) Questions and Discussion

1) The method of probing the permeate from each of the six elements in spiral

wound vessel was discussed and certain suggestions were made by the visiting JICA team on how to improve this procedure.

2) It was explained by JICA team that ultrasonic vibrations, produced when the output pressure of the high pressure pump is excessive cause the spacers to damage the membrane surfaces of the module. This case leads to a drop in membrane performance.

3) At the Haql and Duba plants, there was a membrane storage period of five years before operations were commenced. However, there was no noticeable deterioration in membrane performance. due to this lengthy storage.

4) The plant staff said they had noticed a drop in the volume of water produced in winter compared with the summer production. The JICA Team explained that this types of behavior is expected a drop in temperature of 10℃ reduces water production by as much as 25%.

5) Ever since the plant was started up, the periods during the year when the plant is stopped have gradually been reduced and in 1993 total down-time was no more than 50 hours. The yearly work rate, i.e., plant availability, is extraordinarily high.

3.4 Visit and Survey of SWCC Reverse Osmosis Seawater Desalination Plants (4)

Date of Visit:7-8 February 1994
Survey Site:SWCC Duba Plant
Person Interviewed:Mr. Mohd K. Alkhatieb, Acting Manager
Travel Companion:Mr. Lutfi Bakheet, desalination engineer of the satellite plants
Visitors:Mr. Abdulraham Abanmy (RD-Center)
Mr. Ahemed Saleh Al-Amoudi (RD-Center)
Dr. Yoshio Taniguchi (JICA Team)
Mr. Masahiro Kitagawa (JICA Team)

Summary of Results of Survey

(1) Outline of Duba Plant

Production capacity:4400 m^3/d; Commissioning date:1989
Pretreatment: Dual media anthracite/sand rapid filter
Seawater SDI = 4, pretreated water SDI = 1.7; The turbidity of the seawater feed is low and the pretreatment produces extremely good water.

RO Plant: 2–stage desalination with Toyobo hollow fiber membranes in first stage and Enviro–Tech spiral membranes in second stage. There is a problem with the poor performance of No.1 element(lead element) in Second Stage. This problem was discussed and at the same time, the membrane with the degraded performance was dismantled and tested with dye to investigate the cause of the deterioration. The results of the testing indicated that the membrane had received mechanical damage and Dr. Taniguchi pointed to ultrasonic waves generated by the pump as a possible cause.

(2) Module performance test plants
The plant has test equipment that allows for membrane module performance tests to be carried out at the site.

(3) Answers to Questionnaire

1) Concerning the acquisition of contaminated membranes
Since membranes whose performance has deteriorated are stored together with their operation records, they can be provided for testing.
2) Concerning the possibility of on–site testing of new membranes
It would be possible to fit new membranes on site and conduct tests.

(4) Lecture
Dr. Taniguchi spoke about dismantling and analyzing contaminated membranes. Since this plant has a problem of the deteriorating performance of the No. 1 element in Second Stage, interest in this problem was high and a lively discussion followed the lecture.

3.5 Report of On–site Survey of SWCC Reverse Osmosis Seawater Desalination Plants (5)

Date of Visit:8–9 February 1994
Survey Site:SWCC Haql Plant

(7.1.2.A)

Person Interviewed:Mr. Abdulaaziz M. Algherier,
Plant Manager
Mr. Abdul Majeed S. Altwaim
Travel Companion:Mr. Lutfi Bakheet, desalination engineer of the satellite plants
Visitors:Mr. Abdulraham Abanmy (RD–Center)
Mr. Ahemed Saleh Al-Amoudi (RD–Center)
Dr. Yoshio Taniguchi (JICA Team)
Mr. Masahiro Kitagawa (JICA Team)

Summary of Results of Survey

(1) Outline of Haql Plant

The Haql Plant is an exact copy of the Duba Plant and started operations fourmonths later.

Production capacity:4400 m^3/d

Commenced operation:1989

Pretreatment : Dual media anthracite/sand rapid filter

RO Plant: 2–stage desalination with Toyobo hollow fiber membranes and Enviro–Tech spiral membranes.

There is a problem with the poor performance of No. 1 element in Second Stage which is exactly the same as the problem in its twin plant at Duba. There was great interest shown in Dr.Taniguchi's lecture in which he explained that one of the reasons for the selective deterioration of the first stage membrane may lie in ultrasonic waves produced by the severe pressure change from the throttle valve of the pump, and in the result of the dyeing experiment to determine the cause of deterioration at Duba, which gave rise to animated discussion.

(2) Module performance test plants

The plant has test equipment that allows for membrane module performance tests to be carried out at the site.

(3) Answers to Questionnaire

1) Concerning the acquisition of contaminated membranes

Since membranes whose performance has deteriorated are stored together with their operation records, they can be provided for testing.

2) **Concerning the possibility of on–site testing of new membranes**
It would be possible to fit new membranes on site and conduct tests.

(4) Lecture

Dr. Taniguchi spoke about dismantling and analyzing contaminated membranes. Since this plant has the same problem as the Duba Plant of the deteriorating performance of the No. 1 element in Second Stage, interest in this problem, and in the results of the dyeing experiment at Duba to determine the cause of deterioration, was high and a lively discussion followed the lecture.

MEMORANDUM

Re *RO-Plant Site Survey*

1. **Objectives of the RO-Plant Site Survey**

A. To obtain fouled membrane elements with their operation history and to analyze contaminants on their surface.

B. To investigate the possibility of conducting membrane evaluation test at selected SWRO plants in fiscal year, 1994.

2. **Proposed Work**

A. Fouled membrane elements brought from the plants are to be analyzed at SWCC R&D Center by SWCC Researchers in cooperation with JICA team. Complete autopsy is to be performed and results are to be communicated to both parties SWCC and JICA including the sample source.

B If membrane testing at SWCC plants is allowed, the following items requires clearance from both parties :

(a) Name of site
(b) Name of membrane to be tested
(c) Who will operate the test unit and collect data?
(d) Budget required to purchase the test equipment, to install plant, etc.
(e) Test duration

At the conclusion of the visit, both teams will submit a report summarizing theirs views on the plant survey and regarding the above objectives.

SWCC TEAM

Abdulrahman Abanmy
Mr. Ahmed Al-Amodi

JICA TEAM

Dr. Yoshio Taniguchi
Mr. Masahiro Kitagawa

Table 1 Outline of the Technical Visit to SWCC RO Plants in February 1994

Date	Plant	Capacity m^3/D	Commissioning Date	Builder	Membrane System	COAGULANT PRETREATED FEED SDI
FEB. 1 FEB. 2	JEDDAH I JEDDAH II	56,800 56,800	APRIL 1989 FEB. 1994	MITSUBISHI MITSUBISHI	HFF(TOYOBO) HFF(TOYOBO)	$FeCl^3.6H_2O$ 2 - 3
FEB. 5 FEB. 6	UMM LUJJ	4,400	MAY 1986	FSD/UOP	TFC/SW	NONE 3 - 4
FEB. 6 FEB. 7	DUBA	4,400	JUNE 1989	ENVIROGENC AL-KAWTHER	HFF(TOYOBO) & SW(ENRO)	$Fe_2(SO_4)_3$ 1.7
FEB. 8 FEB. 9	HAQL	4,400	OCT. 1989	ENVIROGENC AL-KAWTHER	HFF(TOYOBO) & SW(ENRO)	$Fe_2(SO_4)_3$ 1 - 2

SWCC RESEARCH CENTER
AL-JUBAIL

SUB : A PRESENTATION ON ANALYSIS OF FOULED MEMBRANES

This lecture which is given as a part of the SWCC/JICA Cooperative Program will be presented at R&D Center, Al-Jubail:

TIME : 12:30 - 2.00 DATE: February 14, 1994

PLACE: R&D Center (Lecture Room 1022)

SPEAKER: DR. Yoshio Taniguchi

The lecture will cover the following topics:

1. Membrane fouling mechanism
   (a) Feed flow pattern through membrane
   Cross flow filtration (tangential flow filtration)
   Dead end flow
   (b) Concentration polarization
   (c) Fouling materials

2. Membrane materials and membrane performance

3. Membrane module configuration

4. Sampling point of fouled membrane module
   (a) RO plant design and pressure vessel arrangement
   (b) Membrane performance in a pressure vessel at one unit
   (c) Probing device to check a membrane performance in a pressure vessel.
   (d) Disassembling a fouled membrane element to analysis

5. Inspection of fouled membrane

6. Analysis data of deteriorated membrane

7. How to analysis fouled membrane:
   (a) SEM (b) FTIR

Those who are interested are welcome to attend. Please contact Dr. Mayan Kutty, Manager, Research Center, on or before 9th February, 94 confirming your attendance on the following:

Tel: (03) 361-3577.
Fax. (03) 361-1615.

(Dr. Mayan Kutty)
Manager, Research Center

Table 2 Persons Attending the Lecture at SWCC R&D Center
SWCC R&D Center, February 14,1994

Dr ATA M. HASSAN	R&D
ENG. Abdulaziz I. Kutbi	S.W.C.C
Abdulsalam Al-Mobayed	SWCC Fax: 361-1737
Mayankutty	SWCC R&D Center
J. K. Rahul	SWCC R&D centre.
A. H. Farooque	SWCC R&D Centre
HASSAN SALMAN	SWCC- Jubail PLANT
Prof. P.K. Abdul Aziz	R&D
SUBBA RAJAN	SWCC CENTRAL LAB JUBAIL.
MANSOOR AHMAD	R.D.C. Jubail
Dr. N. Sasikumar	RDC Jubail
John O'Hara	RDTC JUBAIL
Dr Anees U Malik	RDTC Jubail
ABDULRAHMAN AL-SUWAILEM	ENG. DEP. SWCC EP
MOHAMMAD AK AL-SOFI	SWCC SWCC EP
ESSAM E. F. EL-SAYED	SW.C.C SWCC R&D
AZHAR AMIN NOMANI	SWCC SWCC, R&D
M. ANWAR AHSAN	SWCC Al-Jubail Plan
HAMAD ALABRUTAW (Mech. Eng'r.)	SWCC (Jubail) Mech. Maint
Hassan A. Munshi	R&D
A.T.M. Jamal uddin	R&D. Jubail
DR T. L. Prakash	RDC Jubail
Ron L. OLIVER	SWCC Sr. Mech. Eng.
AbdulRahman Abanmy	RDC
Kitagawa Masahiro	JICA WRPC
Shigeru Haseba	JICA WRPC
IBRAHIM ALTISAN	SWCC. RTDC Jubail
Joseph P. Chandy	RDC Jubail
T. S. Thankachan	RDC Jubail
Radwan AL Rasheed	R.D.C. =
Ahmed Ali Alzahrani	SWCC Jubail

7.1.2.B. Fouled Membrane Analysis of Umm Lujj SWRO Plant

Contents

List of Figures

B. Fouled membrane Analysis of Umm Lujj SW RO Plant

1. Objectives

This report covers that surface analysis results of the fouled sea water membrane which was used in the Umm Lujj sea water desalination plant of Saline Water Conversion Company (SWCC). The membrane was analyzed before and after chemical cleaning test in order to investigate the identity of foulants as well as the effectivity of cleaning chemicals.

2. Sample

A leaf of the flat sheet membrane taken from a spiral wound thin film composite membrane element used in the Umm Lujj sea water desalination plant. Detailed identification of the membrane is as follows;

Date removed	: February 22, 1993
Time removed	: 1:30 pm
Train number	: RO100
Tube number	: C–3
Membrane type	: Fluid Systems (UOP), model TFC1501PA
Serial number	: 149096
Operation time	: 57678 hours in total

3. Items Analyzed

The following items were analyzed before and after chemical cleaning test;

(1) Membrane performance [Salt rejection and flux at the standard test conditions]

(2) SEM and EDX(XMA)[For the observation of fouled membrane surface and the detection of inorganic foulants on the membrane surface]

(3) FT–IR [For the detection of organic foulants]

4. Results

(1) Analysis of the fouled membrane

Membrane Performance

The performance of the original fouled membrane at the standard sea water test condition s is shown in table 1. The very low rejection and very high flux indicate substantial fouling and deterioration of the membrane.

SEM and EDX

SEM and EDX analysis of the fouled membrane is shown in figure 1 – 1 and 1 – 2. Significant deposition of microorganism, Fe compounds, Si–Al compounds and some inorganic salts were observed all over the membrane surface. The microorganisms were in several micron order,d thus they are not bacteria, but some micro marine lives.

FT–IR

FT–IR analysis of the fouled membrane is shown in figure 5. Deposition of the foulants were so thick that the absorption of the membrane itself was not found. The marked peaks on the chart are peculiar to the amid and–OH groups of microorganism. The peak at 400 cm–1 is an influence of iron compounds and the color of the deposit.

In overall, dominant foulants of this particular membrane are iron compounds and marine microorganism, and their quantities are very significant.

(2) Chemical Cleaning

Sample : The flat sheet membrane was cut into round pieces with 75 mm in diameter.

Chemicals : Following 3 chemicals were tested;
NaOH (pH12)
HCI (pH2)
Oxalic acid (0.2%)

Operation : Each cut piece was immersed in the above three solution or 24 hours. After well rinsed, measurement of the membrane performance and the surface analysis of the membrane were conducted.

(3) **Performance of the cleaned membranes**

The original fouled membrane and cleaned membranes were tested with the following conditions;

Device	**:**	**Tangential flow flat sheet test cell**
Sample	**:**	**Round cut pieces with 75 mm in diameter**
Test Solution	**:**	**3.5% NaCI**
Feed pressure	**:**	**56 bar (800 psi)**
Feed flow rate	**:**	**5l/min.**

Permeate samples were taken from the cell after 30 minutes of operation.

The results are shown in table 1. Oxalic acid improved salt rejection to an extent, wile NaOH and HCI were not able to clean the membrane effectively. Although the performance of virgin membrane is unknown to us, full recovery of the original membrane performance seems to be impossible due to the deterioration of the membrane indicated by the very high flux of the cleaned membrane.

	Rejection (%)	Flux ($m^3/m^2/day$)
(Original performance)*	(98.9)	(8.3 m^3/day for 8"element)
Fouled membrane	80	0.76
NaOH	77	1.39
HCl	83	0.79
Oxalic acid	93	0.89

*Nominal performance from the data sheet of Fluid Systems' TFC 1501PA. This is not the origial factory test data of this particular membrane element.

Table 1. Membrane Performance Before and After Chemical Cleaning

(4) Surface analysis of the cleaned membrane

<u>SEM and EDX</u>

SEM pictures and EDX charts of the cleaned membranes are shown in figure 2 – 1 to 4 – 2.

1) NaOH: Deposition of the foulants are still significant. Strong Fe absorption in the EDX chart (figure 2–1 and 2–2) indicates little cleaning effect of NaOH to the iron compounds. Cr atom, which had not been found before cleaning, was detected possibly due to the removal of organic cover layer by NaOH cleaning. The detection of Fe plus Cr may indicate the introduction of corroded metal particles from stainless steel piping. Si compounds have been partly removed.

2) HCl: Significant peak of Fe remains as shown in the EDX chart. The substantial foulants as seen in SEM pictures indicate very little effect of HCl for the cleaning of biological foulants. (figure 3–1 and 3–2)

3) Oxalic acid: The peak of Fe which is one of the major foulant of the membrane has

been almost disappeared from the EDX charts, though the peak of Si compounds remains high. SEM pictures show much fewer foulants on the oxalic acid cleaned membrane surface than on the original fouled membrane. (figure 4-1 and 4-2)

The peaks of 1, K and P found in many of the EDX charts indicate the deposition of marine microorganism on the membrane surface.

'S' comes from membrane itself and 'Au" comes from sample preparation of EDX, thus they are not related to the foulants on the membrane surface.

FT-IR

The IR spectrum of the cleaned membranes are shown in figure 6 to 8.

i) NaOH: Adsorption of membrane itself, which were not found in the analysis of the fouled membrane due to the unusual thickness of the foulants, are detected on the NaOH cleaned membrane. This means organic deposition layer was removed with this chemical to a certain extent. (figure 6)

ii) HCI: The IR chart of HCI cleaned membrane was not very different from that of the original fouled membrane. Thus, HCI is not effective for the cleaning of this particular fouled membrane. (figure 7)

iii) Oxalic acid: Adsorptions of the membrane are found, though the foulants with biological origin remains. Significant absorption of Si compounds also observed, which well coincides with the SEM and EDX of the oxalic acid cleaned membrane.(figure 8)

Figure 9 to 11 show the differential spectrum for which adsorptions of the cleaned membranes are subtracted from those of the fouled membrane. Therefore, those spectrum identify the foulants which were removed by the chemical cleaning.

i) NaOH: Adsorptions with biological origin and Si compounds (at 1000 cm^{-1}) are detected, thus they were effectively removed from the fouled membrane. (figure 9)

ii) HCI: Peaks are generally insignificant. A little absorption of organic with biological origin and some calcium salts (at 1400 cm^{-1}) are observed. (figure 10)

iii) Oxalic acid: The absorption at 400 cm^{-1} is higher than that of figure 9 figure 10, thus iron compounds were well removed with this chemical. The absorption of organic with biological origin and some calcium salts are also detected. (figure 11)

5. Summary

The flat sheet membrane sample taken from Umm Lujj sea water desalination plant was analyzed with SEM, EDX and FT-IR before and after chemical cleaning test.

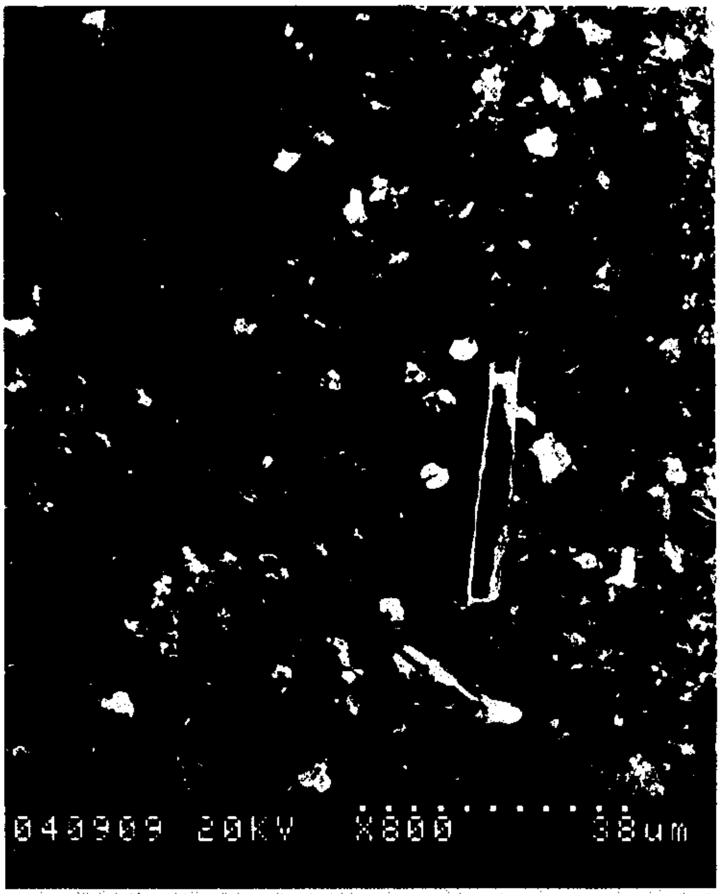
The original fouled membrane showed very low rejection and very high flux which indicate substantial membrane fouling and deterioration.

Through the surface analysis of the fouled membrane, various organic and inorganic foulants were identified. Among them, marine microorganism and iron compounds were dominant. Quantity of the foulants was very significant.

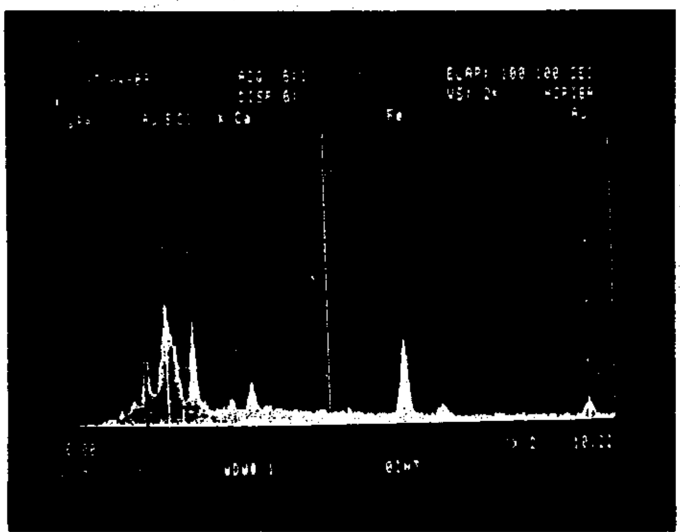
In the chemical cleaning test, oxalic acid was able to improve membrane performance to an extent. Through the SEM, EDX and FT-IR analysis of the cleaned membrane, it is confirmed that oxalic acid effectively removed iron compounds. However, Si compounds and some biological foulants were not cleaned well, since they were still detected from the surface of oxalic acid cleaned – membrane. (Although performance of the original virgin membrane was unknown , it seems to be impossible to fully recover the original performance due to the deterioration of the membrane indicated by the very high flux of the cleaned membrane.)

Therefore, in order to derive further effect from the chemical cleaning, it is recommended to combine oxalic acid with NaOH which was able to remove Si compounds and biological foulants.

More importantly, since the fouling of the membrane was very significant, it will not be enough to consider the technique of chemical cleaning. To avoid fouling itself rather than conducting frequent chemical cleaning. It is suggested to review your pretreatment system. Iron fouling is often associated with the problems in coagulation and/or media filtration process in the pretreatment system, while biological fouling is usually caused by ineffectiveness of disinfection.



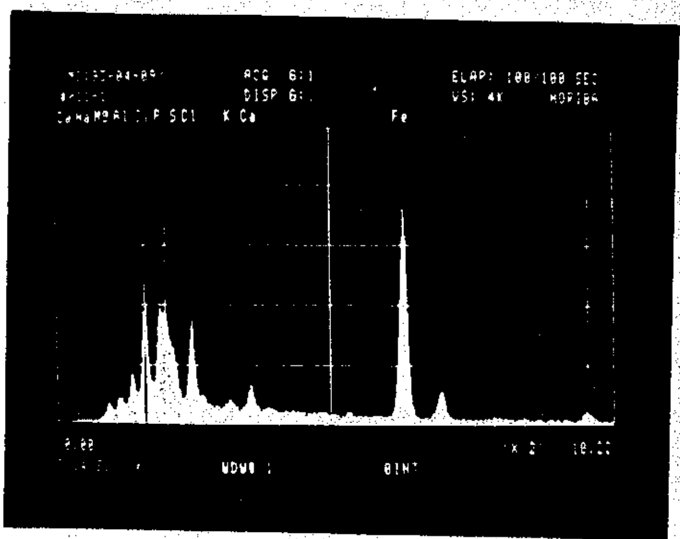
SEM (X800)



EDX SPECTRUM OVER THE ABOVE SCOPE

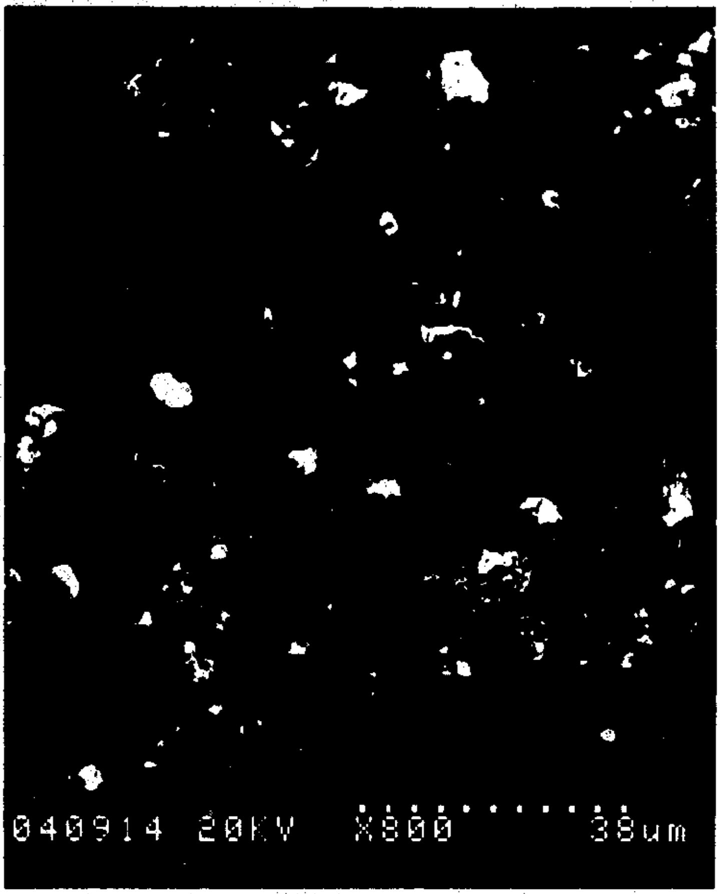
Fig. 1-1 SEM AND EDX OF THE FOULED MEMBRANE (1)

SEM (X4000)

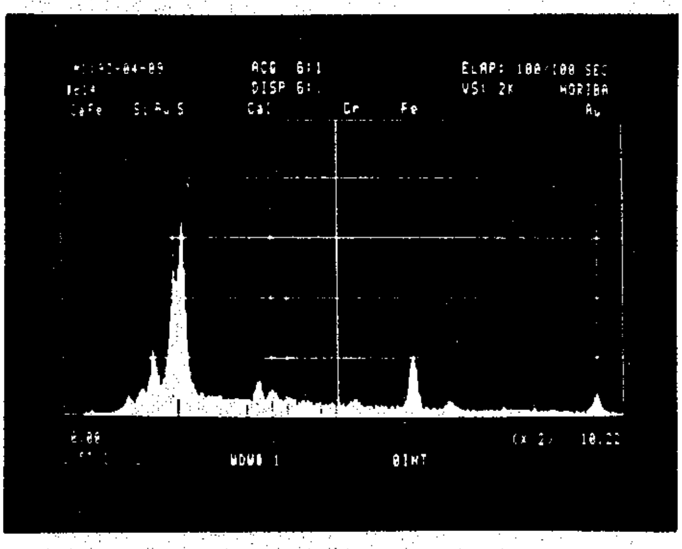


EDX SPECTRUM OF THE ARROWED SPOT

Fig. 1-2 SEM AND EDX OF THE FOULED MEMBRANE (2)



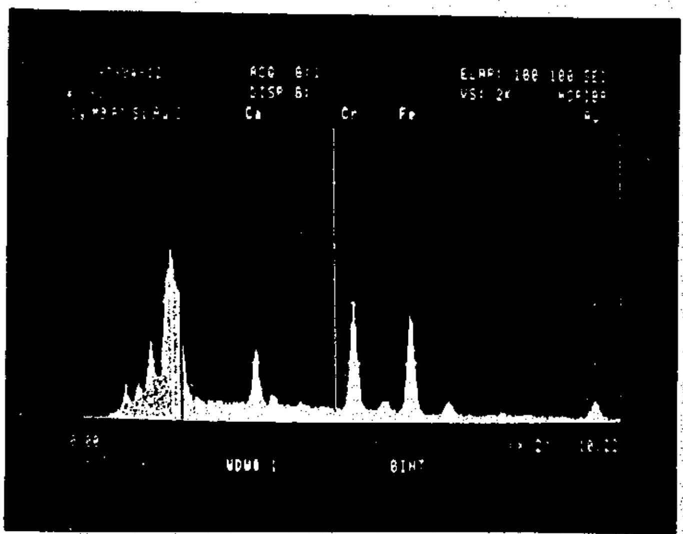
SEM(X800)



EDX SPECTRUM OVER THE ABOVE SCOPE

Fig. 2-1 SEM AND EDX OF THE NaOH CLEANED MEMBRANE.(1)

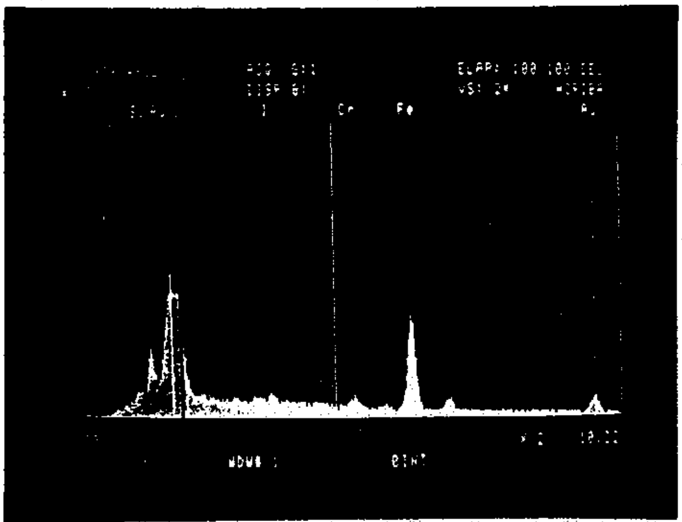
SEM (X4000)



EDX SPECTRUM OF THE ARROWED SPOT

Fig. 2-2 SEM AND EDX OF THE NaOH CLEANED MEMBRANE (2)

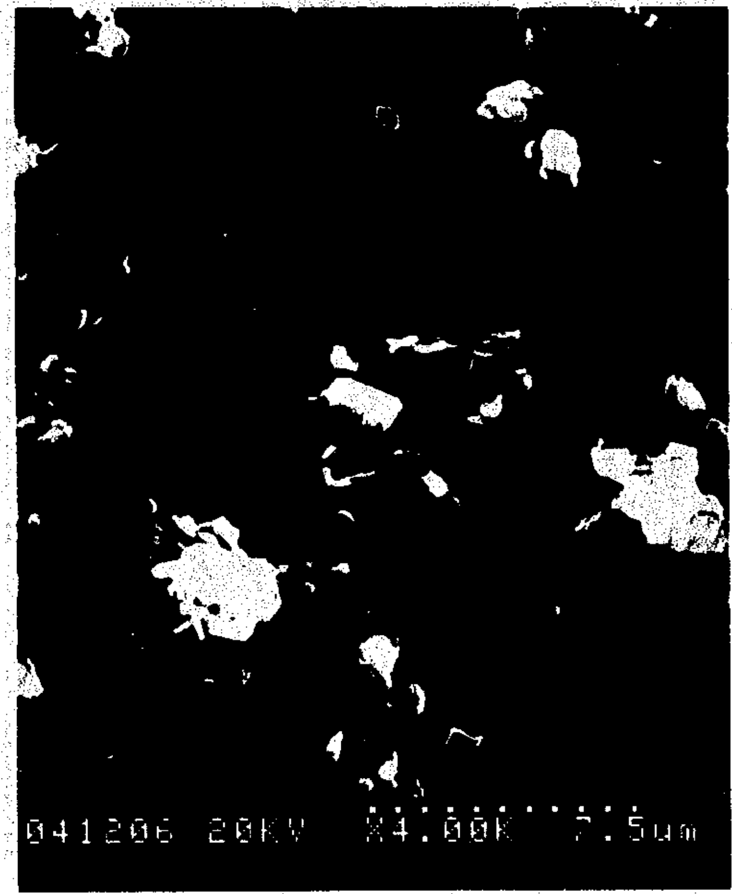
SEM (X800)



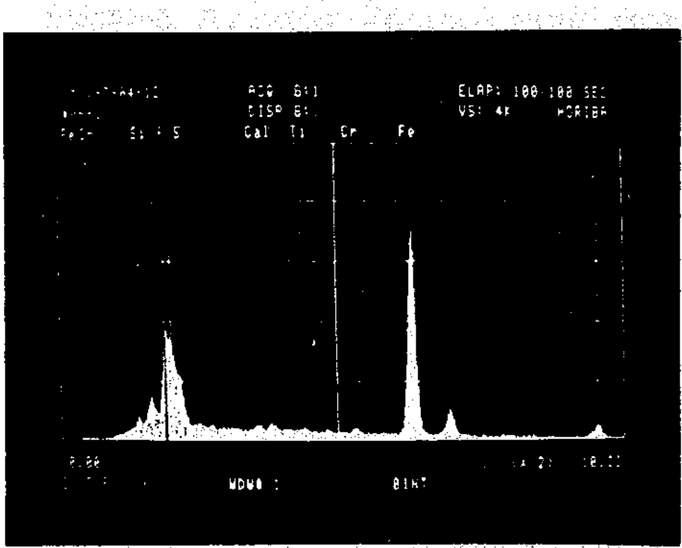
EDX SPECTRUM OF THE ABOVE SCOPE

Fig. 3-1 SEM AND EDX OF THE HCL CLEANED MEMBRANE (1)

(7.1.2.B)

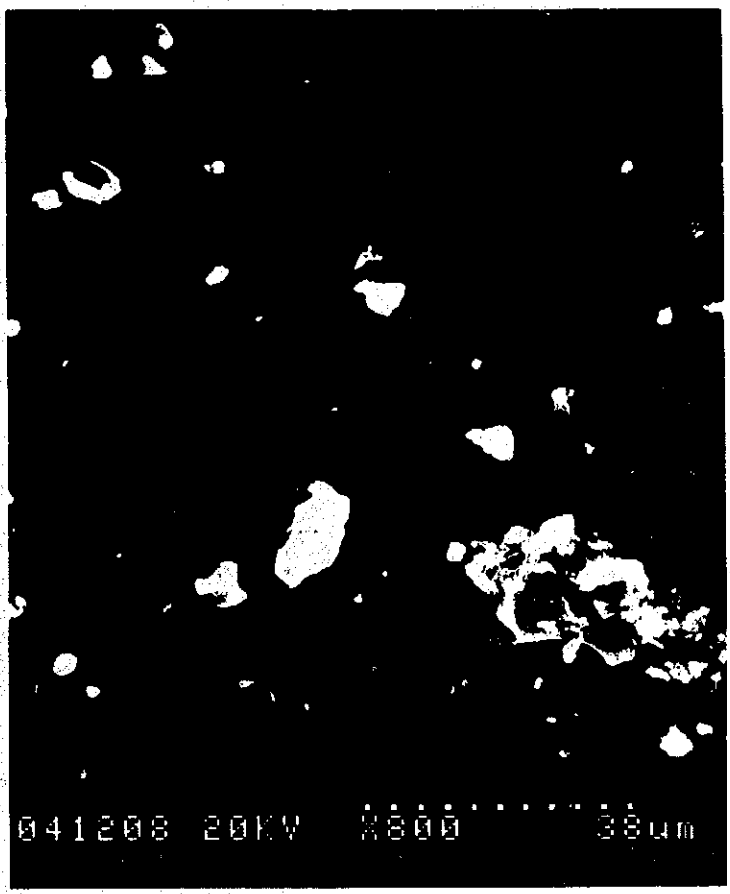


SEM (X4000)

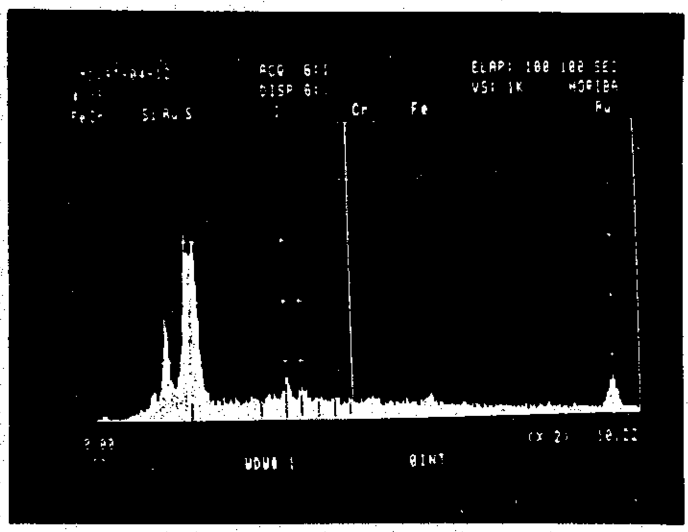


EDX SPECTRUM OF THE ARROWED SPOT

Fig. 3-2 SEM AND EDX OF THE HCL CLEANED MEMBRANE (2)



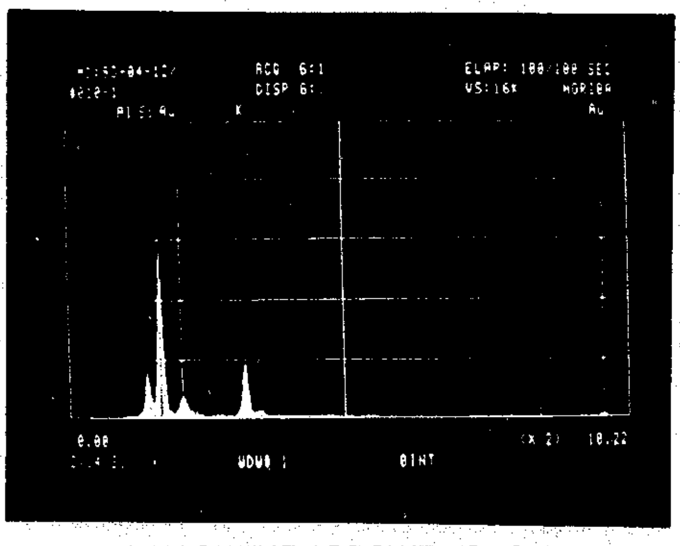
SEM (X800)



EDX OVER THE ABOVE SCOPE

Fig. 4-1 SEM AND EDX OF THE OXALIC ACID CLEANED MEMBRANE (1)

SEM (X4000)



EDX OF THE ARROWED SPOT

Fig. 4-2 SEM AND OF THE OXALIC ACID CLEANED MEMBRANE (2)

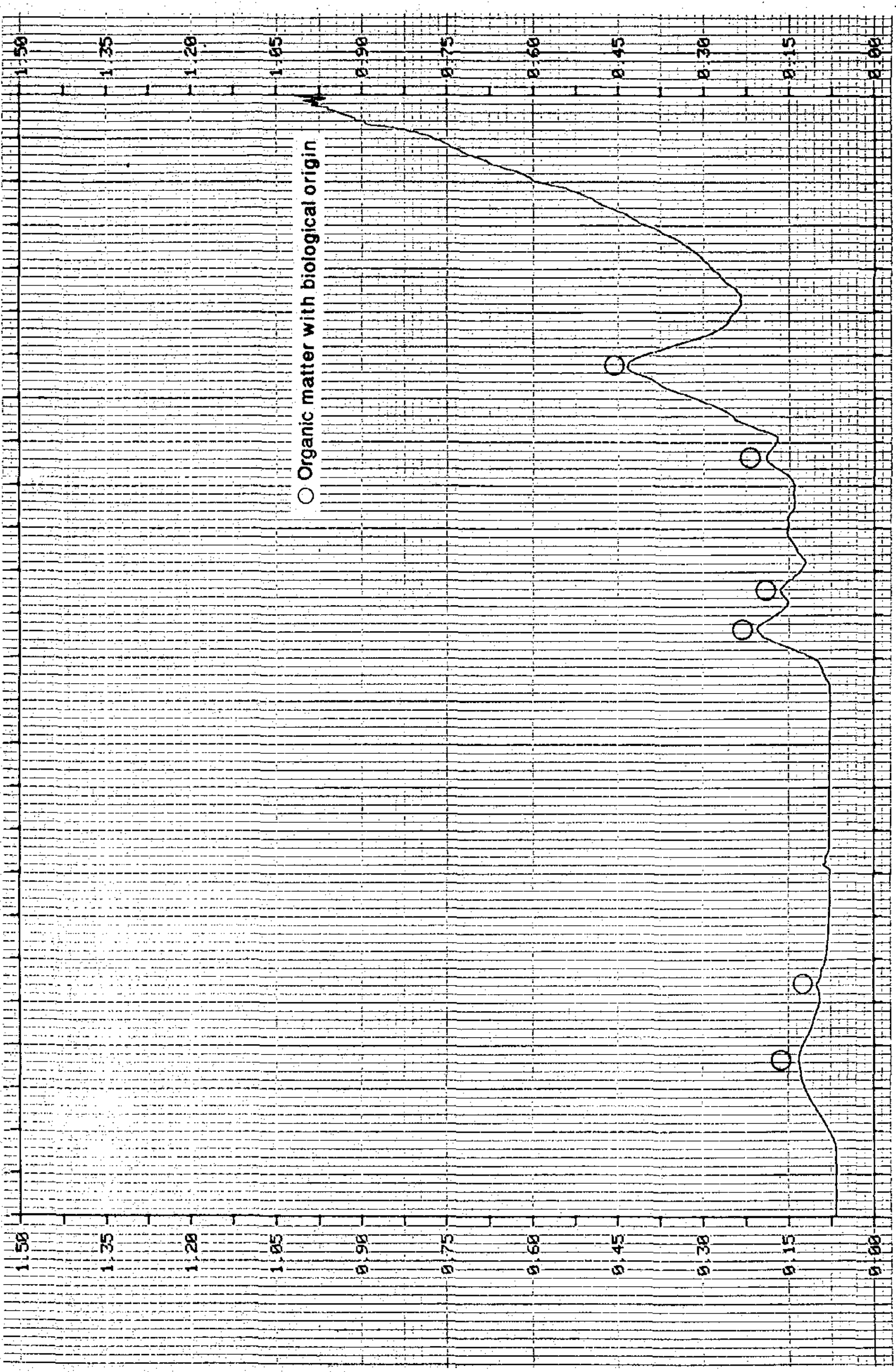


Fig. 5 IR CHART OF THE ORIGINAL FOULED MEMBRANE

(7.1.2.B)

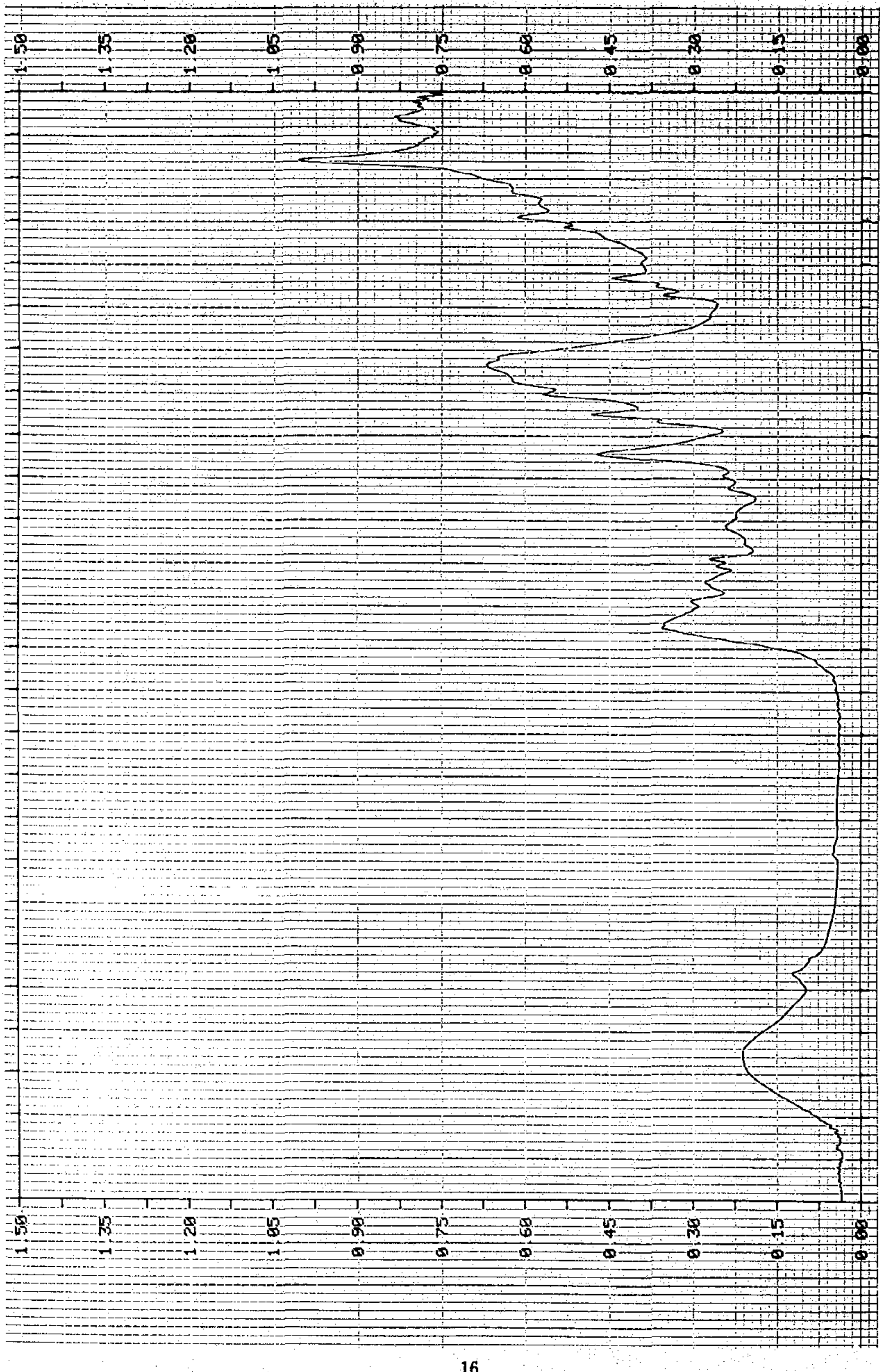


Fig. 6 IR CHART OF THE NaOH CLEANED MEMBRANE