7.3 Experiment with RO Test Plant

7.3.1 Installation of RO Test Plant

1. Objectives

To transfer the RO Test Plant from SWCC Yanbu site to the SWCC R&D center to conduct installation work.

2. Results

(1) Preliminary Installation Work

A list of additional parts was repaired based on the results of the inspection conducted at the SWCC Yanbu site in September 1991. The preliminary installation work of the RO test plant was carried out during the period from January 30 to February 22, 1994. After an experimental water flow test, the remaining work and necessary parts required to complete the work were established.

(2) Secondary Installation Work

After obtaining the necessary parts based on the results of the preliminary installation work, the secondary installation work of the RO Test Plant was conducted during the period from July 18 through August 20, 1994.

(3) RO Test Plant Specification

PRETREATMENT

Treated Seawater Capacity

168 m^3/day

Sterilization

Chlorination with NaClO Dosing or ultra violet ray

Coagulation

Line coagulation withe $FeCl_3$ Dosing

Filtration

Dual media pressured flushing automatic device polishing filter

SPIRAL WOUND TYE RO

Product capacity ; $20m^3$/day
Product Salinity ; less than 500ppm
RO Module : Toray SP–120x2 elements
SU–820
Nitto Denko NTR 70SWC–S8

Desalination pass : Single pass applied pressure: 56–70kg/cm^2
Recovery ratio :25–40%
Dechlorination & Deoxidation : Dosing SBS ($NaHSO_3$)

HOLLOW FIBER TYPE RO

Product Capacity : 20m3/day
Product Salinity : less than 500ppm
RO Module : Toyobo Hollosep HR 8255, 8355 each on HM8355

Desalination pass : Single pass applied pressure 56–65kg/cm^2
Recovery ratio : 25–40%
Feed pH control : Dosing H_2SO_4

7.3.2 Performance Test of RO Plant

1. Objectives

Objectives of the study are the suitability of the RO membranes for the MSF–RO Hybrid System by performing tests with an 8 inch commercial size membranes, the establishment of the RO membrane performance evaluation procedures and the methods to achieve this objective

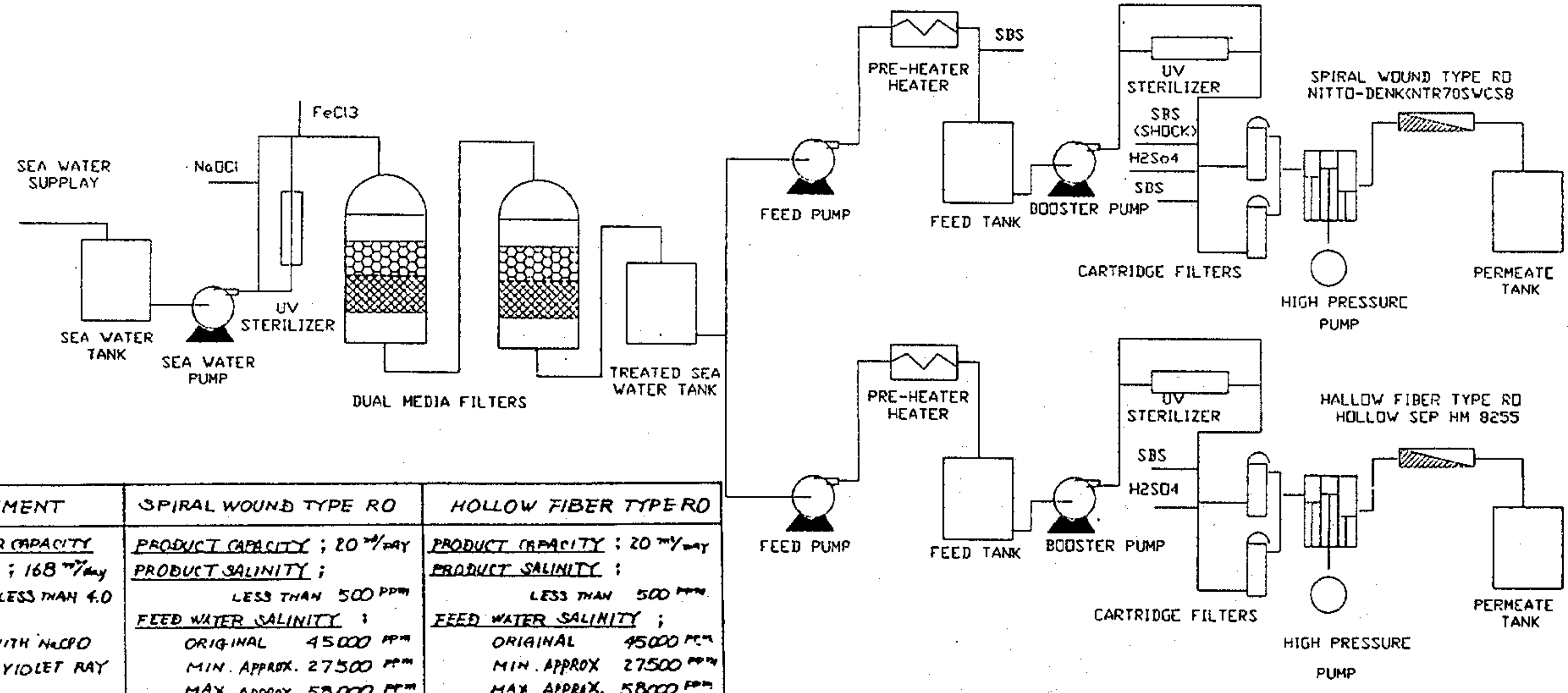
2. Results

(1) The work describes the performance of three commercial size Japanese made SWRO Membranes: TOYOBO cellulose triacetate hollow fine fiber (HFF), TORAY polyamide thin film composite (TFC) spiral wound (SW) and NITTO DENKO polyamide (TFC) spiral wound. Membranes were tested utilizing two independent skid–mounted reverse osmosis (RO) units that receive coagulated filtered water from

two pressure dual media filters connected in series. Plants were commissioned and filtrate SDI was maintained at less than 4.0.

(2) The plant which consist of a pretreatment unit and two independent SWRO plants, was commissioned after lengthy time spent in fixing this 10 years old plant which was moved to SWCC/RDC from Yanbu. Dosage of 3 to 4 mg/L (Fe^{3+}=1 to 1.3) of ferric chloride produced a feed water with SDI less than 4.0 which meets the specifications of the membrane manufacturers TOYOBO, TORAY and NITTO DENKO. For a period of four hours, old TORAY spiral wound membranes (SP-120/PEC - 1000) which were loaded in the module at the time of commissioning, were tested. Permeate flow and conductivity for this membrane were: 0.6 m^3/h and 2,810 μS/cm, respectively. Permeate conductivity was rising as expected. Old TOYOBO hollow fine fiber membranes (Hollosep HM 8255) were tested when loaded in the module in February 1994. Permeate flow and conductivity for this membrane were: 1.07 m^3/h and 1,540 μS/cm, respectiviely. Permeate conductivity, however, was rising with time.

(3) The performance of the membrane (permeate flow and conductivity) with the recently supplied modules were as follows: Toyobo cellulose triacetate hollow fine fiber; Hollosep HM 8355 membrane: 0.8 m^3/h and 250 to 350 μS/cm, respectively, Noyobo Denko spiral wound, fully aromatic polyamide membranes NTR-70SWC-S 8.: 0.8 m^3/h and 550 to 650 μS/cm, respectively, while Toray spiral wound, fully aromatic polyamide composite membrane SU-820: 0.8 m^3/h and 500 - 750 μS/cm, respectively. The spiral wound modules were operated with only two elements instead of 6 elements, due to feed limitation to the high pressure feed pump which did not have sufficient feed flow for 6 element operation.



PRETREATMENT	SPIRAL WOUND TYPE RO	HOLLOW FIBER TYPE RO
TREATED SEAWATER CAPACITY ; 168 m³/day FOULING INDEX ; LESS THAN 4.0 STERILIZATION CHLORINATION WITH NaClO DOSING OR ULTRA VIOLET RAY COAGULATION LINE COAGULATION WITH $FeCl_3$ DOSING FILTRATION DUAL MEDIA PRESSURED FILTER BACK WASHING & FLUSHING AUTOMATIC DEVICE . POLISHING FILTER.	PRODUCT CAPACITY ; 20 m³/DAY PRODUCT SALINITY ; LESS THAN 500 PPM FEED WATER SALINITY ; ORIGINAL 45000 PPM MIN. APPROX. 27500 PPM MAX. APPROX 58000 PPM FEED WATER TEMPRATURE ; 21~50 °C. FEED PREHEATER : 50×10^3 kcal/hr FEED HEATER : 45000 kcal/hr STERILIZATION : SHOCK TREATMENT BY S.B.S DOSING OR ULTRA VIOLET RAY RO MODULE ; TORAY SP-120 x 6 ELEMENTS DESALINATION PASS ; SINGLE PASS APPLIED PRESSURE ; 56~70 kg/cm²G RECOVERY RATIO : 25~40 % DECHLORINATION & DEOXYZATION ; DOSING S.B.S. ($NaHSO_3$)	PRODUCT CAPACITY ; 20 m³/DAY PRODUCT SALINITY ; LESS THAN 500 PPM FEED WATER SALINITY ; ORIGINAL 45000 PPM MIN. APPROX 27500 PPM MAX APPROX. 58000 PPM FEED WATER TEMPRATURE ; 21~30 °C FEED PREHEATER ; 50×10^3 kcal/hr FEED HEATER ; 45000 kcal/hr STERILIZATION ; ULTRA VIOLET RAY OR CHLORINATION WITH NaClO DOSING RO MODULE ; TOYOBO HOLLOSEP HR 8255, 8355 EACH ONE DESALINATION PASS ; SINGLE PASS APPLIED PRESSURE ; 56~65 kg/cm²G RECOVERY RATIO : 25~40% FEED PH CONTROL ; DOSING H_2SO_4

Original Design
Spiral Wound Type RO Element: Toray SP-120 x 6
Hollow Fiber Type RO Element:Toyobo HR8355 X 1 + HM8255 X 2

New Design Base
Spiral Wound Type RO Element:Toray SU-820 X 2
Nitto Denko NTR-70SWC-S8 X 2
Hollow Fiber Type RO Element:Toyobo HR8355 X 1 + HM8255 X 2

Fig. 10 Schematic Flow Diagram of RO Test Plant

(7)

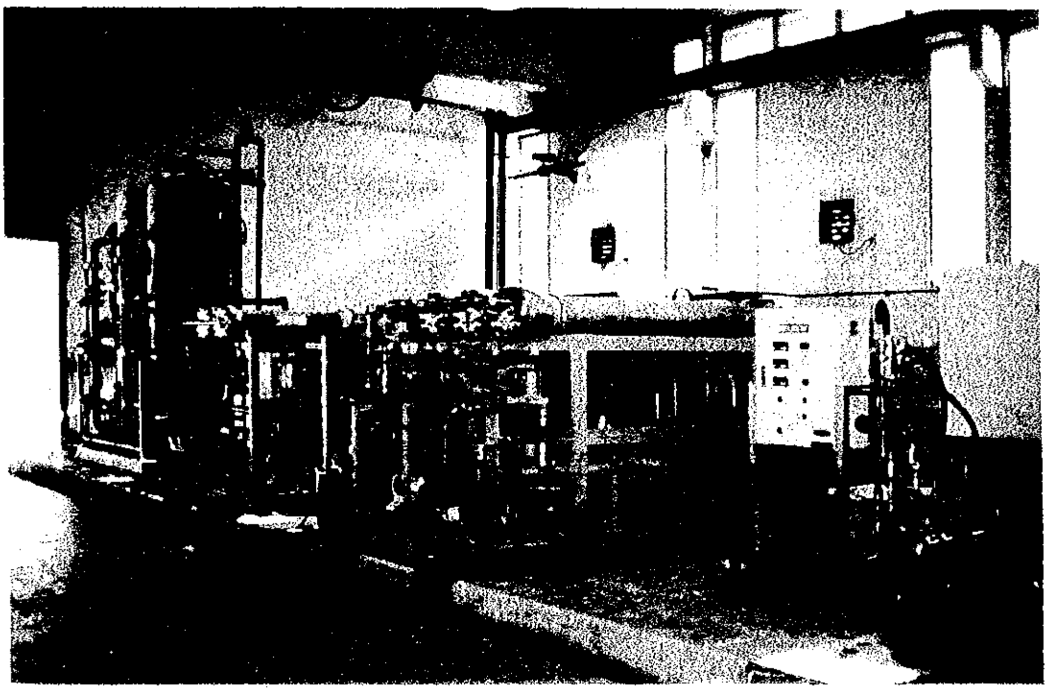


Fig. 11 Photograph of RO Test Plant

7.4 Transfer of Technology

(1) **Objectives**

To implement transfer of technology to SWCC (especially to young Saudi researcher) through the joint research work with JICA and SWCC.

(2) **Method of Implementing Technology Transfer**

The main technology related to this research was broken down into the following technical elements and became the object of the technology transfer. The method of technology transfer was mainly affected by the implementation of joint research by both JICA and SWCC. This became firmly fixed through the processes of on-job-training and the preparation of written experiment reports and manuals and these techniques were prepared and supplied as substantial items for future use.

Main technical elements for the transfer of technology

1) RO membrane performance evaluation
2) Operation and maintenance of the RO test plant
3) Analyses needed for membrane fouling
5) Operation and maintenance of test equipment for RO membrane performance evaluation
6) Operation and maintenance of analytical equipment
7) Analytical technology needed for the analysis of SWRO feed

(3) **Methods and Results of Technology Transfer**

1) Method and result of RO membrane evaluation

A) On-job-training on the operation and performance evaluation of SWRO tests was implemented using RO flat membranes and mini-membrane modules. In all cases, performance test reports and manuals were prepared.

B) Lectures relating to RO membrane appraisal technology and membrane evaluation were delivered as part of the transfer of technology.

C) On-job-training was implemented through the operation of turbidity and chlorine tolerance tests, performance test reports were written and manual were prepared.

2) Operation and maintenance of the RO test plant

The RO test plant was equipped with the same RO membrane modules as an actual plant and on-job-training in plant operation and membrane evaluation was conducted as part of transfer of technology. In addition to writing performance test reports, manuals ware also prepared.

3) Analyses needed for membrane fouling

Concerning the fouling of hollow fiber and spiral wound RO membrane modules, on–job–training was implemented in respect of the techniques of dismantling the modules and analyzing the membrane surface contaminants. In addition to writing reports, manuals were prepared.

4) Operation and maintenance of test equipment for RO membrane evaluation

With supply by JICA of the following three types of equipment for testing RO membrane performance at different scales from small bench scale to full scale plant membranes, the technology for using all of these equipment for comparing the performance of deteriorated membranes and new membranes has been transferred. The technology transfer was accomplished through on the job training, report writing and the preparation of manuals, etc.

(a) Small scale, flat membrane test equipment
(b) Medium scale, mini module type test equipment
(c) RO test plant for testing actual plant size RO module performance.

Fully equipped with test equipment for measuring the performance of membranes from laboratory scale to full plant scale, the technology for using these units have been established through the results of joint research on the use of these facilities. Furthermore, they are now able to implement the technical investigation of the causes of membrane fouling, the selection of new membranes and research into pre–treatment methods, etc.

5) Operation and maintenance of analytical equipment

The following analytical equipment has been provided by JICA to SWCC and the technology for its operation and maintenance has been established through teaching and the provision of manuals:

- Electron probe micro–analyzer,
- ICP emission spectrometer system,
- Infrared spectrophotometer,
- X–ray analyzer and

- Ion chromatography.

These instruments can be used for water quality analysis, membrane contaminant analysis, fouled membrane analysis as well as for other general analysis conducte in a desalination analytical lab.

6) Analytical technology needed for analysis of SWRO feed

Analytical equipment which has been selected and supplied as a result of investigating methods of analyzing the content of oil, trihalomethane, etc. in seawater, has been used for analyses of these compound in seawater. The results have been reported in a report and manuals have been provided.

Using the equipment and analytical technology, it has been possible to analyze traces of oil and tri-halomethanes in sea water.

8. Study on Countermeasures against Oil Contamination for RO Process (RO−2)

Contents

8.1 Investigations and Preparative Experiments 1
8.1.1 Literature survey on oil and THM in seawater 1
8.1.1.A Oil and Trihalomethane in Seawater 1
8.1.1.B Analytical Method of Trihalmomethane 4
8.1.1.C Removal of Trihalomethane 5
8.1.2 Preparative Experiment with Laboratory Equipment 9
8.1.2.A Analytical Method for Low Concentration Oil 9
8.1.2.B Oil Removal Experiment 11
8.1.2.C Analysis of Trihalomethane and Formation of Trihalomethane 12

8.2 Oil Removal Experiment by Pretreatment with Bench Scale Equipment 15
8.2.1 Installation of Pretreatment Equipment 15
8.2.2 Oil Dosing Experiment 18
8.2.3 Oil Adsorption Experiment 19
8.2.4 Regeneration Experiment for Oil Adsorption Tower 20

8.3 Oil Tolerance Test with a Flat Membrane Tester 23
8.3.1 First Step Flat Membrane Test 23
8.3.1.A Oil Tolerance Test with Membrane after Immersing in Artificially Oil Contaminated seawater 23
8.3.1.B Oil Tolerance Test of Flat Membrane by Continuous Recirculation System 24
8.3.2 Experiment with Combined Pretreatment Equipment and RO Membranes 25

8.4 Experiment with RO Mini-Module (2) 29

8.5 Test with the RO Test Plant 32

8.6 Transfer of Technology 36

List of Tables

Table	Description	Page
Table 1	Concentration of Oil in the Ekofisk Oil Field	3
Table 2	Factors Affecting THM Formation	5
Table 3	Trihalomethane Separating Performance of the UTC–80 Membrane and the Cellulose Acetate Membrane	7
Table 4	Comparison of Various Oil Content Measurement Methods	10

List of Figures

Figure	Description	Page
Fig. 1	Membrane's Performance of Separatng the Triholomethane Added in Seawater	8
Fig. 2	THMs formation under low chlorination (1.6 ppm)	13
Fig. 3	THMs formation under high chlorination (9.0 ppm)	14
Fig. 4	A Schematic Flow Diagram of the Artificial Oil Contamination of Seawater Feed Unit and the Pretreatment Unit for the Oil Removal	16
Fig. 5	Oil Addition Equipment	17
Fig. 6	Oil Adsorbed Tower Recovery Equipment	17
Fig. 7	Oil Tolerance Test using Flat SWRO Membrane Oil Content vs Time	22
Fig. 8	Oil Tolerance Test using Flat SWRO Membrane Permeate Flow vs Time	27
Fig. 9	Oil Tolerance Test using Flat SWRO Membrane (Permeate Flow, and Conductivity vs Time)	28
Fig. 10	Oil Turbidity Tolerance using Nitto NTR70 SWC SWRO Membrane Oil Content in Feed, Brine and Permeate	30
Fig. 11	GC–MS Spectra of Oil in the Feed, Brine and Permeat	31
Fig. 12	Permeate Flow & Recovery of One Element (8") Nitto Denko, Membrane vs Operation Time	33
Fig. 13	Feed and Permeate Conductivity of Nitto Denko (8" element) Membrane	34
Fig. 14	Variation of SDI & Delta P for DMF Filters vs Operation Time	35

8. Study on Countermeasures against Oil Contamination for RO Process (RO-2)

Pollution of seawater in the Arabian Gulf has advanced steadily in recent years, in particular oil pollution of the sea by petroleum outflows during the Gulf War has become a serious problem. Oil has a general tendency to adhere to solid surfaces and in the case of water such as seawater, which contains salt, this tendency is particularly strong with small quantities of oil forming a thin layer covering over a wide solid surface. Also, the reverse osmosis separation function uses extremely thin film surfaces so that a small quantity of oil covering the membrane surface could cause a remarkable deterioration in the separation function. With normal RO desalination equipment, the seawater is pretreated by coagulation and sand filtration but the current practice is that the operation must be suspended if oil is mixed with the intake water, so that with the recent increase in oil pollution, a method is being sought for safe operation even when the seawater is mixed with oil. Oil in seawater is either dispersed as an emulsion in the water or dissolved in the water but the majority of the oil is in the former condition, the amount in solution being comparatively small. Consequently, it is considered that most of the oil in the seawater may be removed by using coagulation and sand filtration to remove the oil emulsion which constitutes the major part of the oil content in the seawater. The present study involves, conducting a literature survey on oil and THM in seawater, establishing an already available analytical method for the analysis of oil and THM, obtaining best method for removal of oil from oil contaminated seawater and evaluating the effect of pretreated oil contaminated seawater on SWRO membranes.

8.1 Investigations and Preparative Experiments

8.1.1 Literature survey on oil and THM in seawater

8.1.1.A. Oil and Trihalomethanes in Seawater

1. Objectives

To collect literature and information concerning oil and trihalomethanes in the ocean and their separation methods. These materials may cause a problems in the operation of RO seawater desalination plants. Trihalomethanes (THM) are carcinogenic agents and are known to cause cancer.

2. Method of Investigation

Information retrieval survey concerning oil, trihalomethane and organic matter dissolved in the ocean seawater was conducted using Japanese information retrieval system JOIS.

3. Results

3.1 Oil content of seawater

There are extremely few articles concerning the oil content of seawater. Table 1 introduces an example of a report of an investigation of the distribution of oil concentrations near a marine oil field

After 50 hours from stopping the oil extraction, the maximum oil concentrations of 0.13 to 0.24 ppm were detected at a point 5 nautical miles (9 km) distant from the point of extraction. Also, 20 nautical miles (37 km) away, the concentration had fallen to the background level (0.07 mg/L).

According to another paper, nearly all measurement of the oil content in the sea near Japan are below 10 μg/L and there is no noticeable difference in marine life between the marine areas. The results of oil measurements in the major bays of Japan show that all the maximum, minimum and mean values for all bay "seawater" in the maritime areas of Japan and its environs have similar levels.

3.2 Trihalomethane in Seawater

According to a paper reporting trihalomethane in seawater, in the case of normal and natural seawater, the formation of THM in desalination plant rates within international standard but, in the case of the polluted seawater caused by the outflow of crude oil, etc., it is necessary to suppress the formation of THM by reducing the level of chlorination and to increase the frequency of measuring THM content in the product water.

Table 1 Concentration of Oil in the Ekofisk Oil Field*1

Distance and direction from rig	Depth (m)	Concentration (ppm)
3 n.m.N. thin sheen	1	0.118
3 n.m.N. thin sheen	2	0.135
3 n.m.N. thin sheen	4	0.121
5 n.m.N. thin sheen	1	0.245
5 n.m.N. thin sheen	2	0.133
5 n.m.N. thin sheen	4	0.133
10 n.m.N. thin sheen	1	0.089
10 n.m.N. thin sheen	2	—
10 n.m.N. thin sheen	4	0.040
15 n.m.N. sheen windrows	1	0.055
15 n.m.N. sheen windrows	2	0.055
15 n.m.N. sheen windrows	4	0.044
15 n.m.N. 3 n.m.W. fiecks	1	0.053
of w/o emulsion	2	0.061
	4	0.043
15 n.m.N. 3 n.m.W. fiecks	1	0.033
of w/o emulsion	2	0.019
	4	0.038
20 n.m.N	1	0.005
No visible sheen	2	0.011
No visible sheen	4	0.028

*Reference: D. Cormack: Response to oil and chemical marine pollution, Applied Science Pulishers Ltd.

***1 Reference : nautical miles**

***2 n.m. : nautical miles**

8.1.1.B. Analytical Method for the Determination of Trihalomethane

1. Objectives

Main objective is to study seawater soluble organic materials and their reaction with chlorine. Concerning the mechanisms for the formation of THM, it is well known that trihalomethane are formed by the reaction of halogens such as chlorine and bromide with organic materials (precursors) which dissolve in seawater but the reaction mechanisms of the intermediate products are extremely complicated. The literature was searched on these points as an aid to considering ways of inhibiting their formation.

2. Survey method

Information retrieval was performed by the data base JOIS using following key words, and the literature, closely related to the subject was selected and summarized.

Key Words for the information retrieval:

(1) Seawater × solution × organic × analysis
(2) Seawater × solution × organic × absorbent
(3) Seawater × halogenated organic compounds × (solubility + analysis + removal + formation mechanism)

3. Results

Outlines of the literatures obtained were introduced according to the following subjects:

(1) Formation mechanism of organic halogen compounds like THM and others
  (1.1) Circumstances of THM control
  (1.2) THM formation and various factors

(2) Analytical methods of trihalomethane
  (2.1) Selection of analytical equipment
  (2.2) Summary and selection of pretreatment methods

(3) Studies of various conditions in measurement methods of THM

(3.1) **GC measurement conditions**
(3.2) **Effect of ion intensity**

(4) **Calibration curves and precision**

(5) **Storage and transportation of test materials**
(5.1) **Effects of residual chlorine during storage**
(5.2) **Chloroform and pH during storage**

4. Conclusion

(1) We were able to gain a knowledge of analytical methods, formation mechanisms, conditions for formation, precision of analysis etc., in respect of halogenated organic compounds, especially trihalomethane.

(2) It was cleared that Gas chromatography (GC) equipped with Electron Capture Detector (ECD) is a highly sensible measurement method for THM analysis.

(3) Factors affecting formation of THM are shown in Table 2.

Table 2 Factors Affecting THM Formation

Factor		Formation Amount
The amount of chlorine added	a lot	considerable
The contact time with chlorine	long	a lot
The temperature of water	high	a lot
pH	high	maximum when pH=10
Water quality (COD, TOC)	bad	a lot

8.1.1.C. Removal of Trihalomethane

1. Objectives

To conduct a literature survey in respect of tolerance to oil–bearing seawater, which could be harmful to RO membranes used in seawater desalination and a literature survey concerning the removal of halogenated organic compounds such as trihalomethane to serve as a guide to the safety of future desalination technology.

2. Method of Investigation

The literature survey were centered on major technical reports.

3. Results

3.1 Separation and Removal of THM

Recently, there is a growing tendency to try to obtain potable water from seawater or brackish water in various countries of the world. In the desalination of seawater and brackish water near large cities, the effect of the pollution on the raw water on desalination has become far from negligible. Allowable limits of THM and bromoform have been added recently to the items of the water quality standards for drinking water, and great importance is now placed on the removal of THM.

3.2 Trihalomethane Separating performance

Separation performance of many kinds of trihalomethane with Aromatic Polyamide membrane (UTC–80) and Cellulose Acetate Membranes (CA) are listed in Table 3.

3.3 Affinity of Trihalomethane to Membranes

(1) Aromatic polyamide membrane (UTC–80) has low affinity for trihalomethane and therefore has high THM rejection.

(2) Cellulose acetate membranes has high affinity to trihalomethane, therefore trihalomethane is easily adhered on the surface or pores of the membrane and permeates through the membrane. The membrane has low THM rejection.

3.4 Trihalomethane Removal Performance of a commercial SWRO Plant

Trihalomethane separation performance tests performed on a commercial RO seawater desalination plant using aromatic polyamide (UTC–80) was as shown in Fig. 1.

4. Conclusion

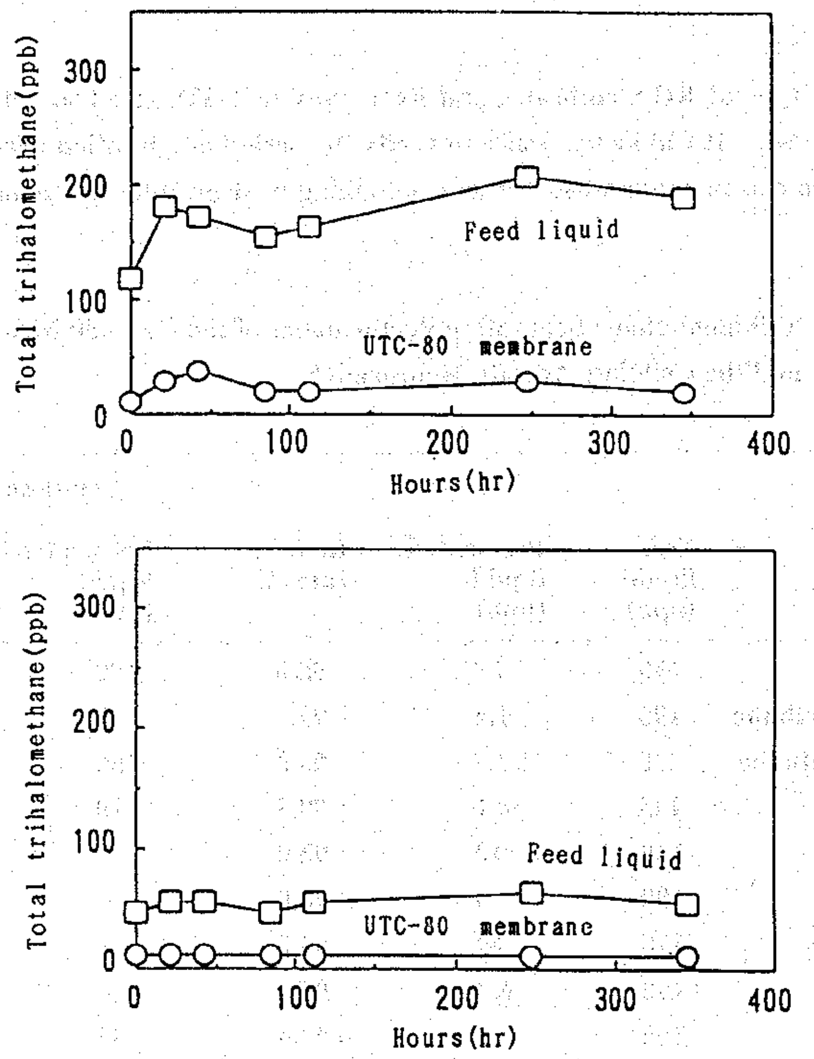
Depending on the type of RO membrane, and its affinity to THM, removal ratio as high as 90.6% were observed. It will be necessary to verify the period of operation over which such high removal ratio can be maintained without damaging or degrading the membrane THM rejection.

Table 3 Trihalomethane Separating Performance of the UTC-80 Membrane and the Cellulose Acetate Membrane*

Trihalomethan	UTC-80			Cellulose Acetate	
	Feed liquid (ppb)	Permeated liquid (ppb)	Removal rate (%)	Permeated liquid (ppb)	Removal rate (%)
Chloroform	190	9.5	95.0	190	0
Chlorodibromomethane	195	1.4	99.3	150	23
Bromodichloromethane	175	3.7	96.0	150	14
Bromoform	145	< 1	>99.3	120	17
Dichloroacetate	130	<10	>92.0	-	-
Trichloroacetage	190	3	98.0	-	-
Chloroacetonitrile	170	69	59.0	-	-
Chloralhydrate	190	6.4	97.0	-	-
Trichloroethylene	150	< 1	>99.3	88	41
Trichloroethane	130	< 1	>99.2	95	27
Tetrachloroethylene	135	<0.5	>99.6	60	56
Membrane performance	99.67%-0.55m^3/m^2 day			97/1%-0.49m^3/m^2 day	

Measuring conditions: 3.5% NaCl, 25℃, pH6.5, 5.5Mpa
Measurement was carried out after adding trihalomethane substances in the feed liquid.

*Reference: D. Cormack: Response to oil and chemical marine pollution, Applied Science Pulishers Ltd.



Measuring equipment : Ehime Test Plant
Measuring conditions : sea water, 25℃, pH6.5, 5.5MPa
Measurement was carried out after adding trihalomethane substances in the feed liquid (sea water).

Fig. 1 Membrane's Performance of Separating the Trihalomethane Added in Seawater

*Reference: M. Kurihara: "Spiral RO membrane," proceeding of Seawater Desalination Seminar, Sponsored by WRPC, Japan Nov. 29~30, 1993

8.1.2 Preparative Experiment with Laboratory Equipment

8.1.2.A. Analytical Method for Low Oil Concentration

1. Objectives

Conventional standard analytical methods of oil in water are n–Hexane (mass) method, Carbon Tetrachloride–Infrared method, and TOC methods are proposed for the analysis of low concentrated oil in seawater. However, detection limits of those method are relatively high (order of parts per million), takes long time to analyze and inorganic carbon interferes with the TOC analysis method.

Object of this survey is to select the most suitable analytical method for oil determination in seawater, especially with regard to low oil concentration, short time analysis, and a small determination sample quantity.

2. Results

Following several analytical methods were investigated and advantages and disadvantages of those methods are compared in Table 4. Analytical methods investigated:

(1) n–Hexane–Mass method
(2) Carbon Tetrachloride–Extraction–Infrared method
(3) Simplified Carbon Tetrachloride–Extraction–Infrared method using "Oil Meter "
(4) TOC method
(5) Gas Chromatography (GC) method
(6) Fluorophotometry method

3. Conclusion

Fluorophotometry method is a suitable method for this study, because of its quick response, high sensitivity and good reproducibility. The method, however, is very sensitive to aromatic structures but insentive to aliphatic structures in oil and, therefore, at low oil concentration the GC–MS which detects both aromatic and aliphatic structures is much more superior and is a more reliable method than the Fluoro photo metric method.

Table 4 Comparison of Various Oil Content Measurement Methods

Method	Advantages	Disadvantages	General appraisal of implementation at SWCC *
n-hexane (Mass method)	·Universal ·Established technology	·Low sensitivity ·Long measuring time (several tens of minutes per sample) ·Low boiling points oils evaporate	x
Carbon tetrachloride extraction (IR method)	·Universal ·Established technology	·Large samples needed (1 liter for 1 ppm) ·Lack of good carbon tetra-chloride at SWCC gave high background ·Long measuring time (several tens of minutes per sample)	x
Simple oil content	·Quick (5 minutes per sample), simple	·Data reliability questionable ·Lack of good carbon tetra-chloride at SWCC gave high background	x
TOC method	·Small samples (several tens of microliters) ·Quick (10 minutes per sample), simple	·High background in sea water samples gives lower detection limit of several ppm ·Poor reproducibility in SWCC equipment (due to manual injection ?)	△
GC method	·Nothing special	·Low sensitivity (lower detection limit 5 ppm) ·Long measuring time (several tens of minutes per sample)	x
Fluorophotometry	·High sensitivity (lower detection limit 10 ppb) ·High reliability ·Good reproducibility ·Quick (10 minutes per sample)	·Complex operation ·Needs large samples (50 ml)	○ △～x (Beaker scale)

* × no good
△ applicable in some case
○ good

8.1.2.B Oil Removal Experiment

1. Objectives

In the previous laboratory scale research by ferric chloride coagulation and filter paper filtration preliminary experiment, it was cleared that coagulation and filtration process is promising for the pretreatment of RO process removing oil in seawater.

Object of this experiment is to confirm the effectiveness of the coagulation and filtration method for the removal of oil in seawater using bench scale continuous equipment.

2. Experimental

Coagulation	:	Ferric chloride is added in the feed line before the feed pump.
Filtration column	:	20mm dia. × 1,000 mm
		Height of filter media: 500 mm
Filter media	:	sand
Coagulant	:	Ferric chloride 10ppm (as $FeCl_3$)
Feed water	:	80 L/h, (LV=19m/h, SV=20m/h)

Carbon distribution of artificially oil contaminated seawater feed and filtrate of the coagulation/filtration outlet were analyzed using GC-MS.

4. Results

(1) As a result of this experiment, it was confirmed that the direct coagulation-filtration method using ferric chloride as a coagulant is generally the most effective procedure for pretreatment of SWRO feed.

(2) Flocs formed by the addition of Ferric Chloride flocculant are physically very fragile, and residence time before filtration was not enough to make the flocs large. The more effective filtration effuent could be obtained if an empty column was placed before the filtration column to form larger floc.

8.1.2.C. Analysis of Trihalomethane and Formation of Trihalomethane

1. Objectives

Chlorine is injected to prevent the blocking of seawater desalination plants with the adherence of shellfish in the vicinity of the intake. However, the chlorine may cause a chemical reaction of certain types of organic matter in the seawater, forming trihalomethane, a carcinogenic substance. Using such seawater in the untreated state in a seawater desalination plant may cause a problem. Formation and elimination of trihalomethane were studied.

2. Experimental

1.6ppm and 9ppm of NaClO was added to artificially oil contaminated seawater and concentration of the formed trihalomethane was analyzed after 96 hours.

3 Results

Fig. 2 and Fig. 3 show THM formed at the low (1.6 ppm) and high (9.0 ppm) NaClO concentration. At the concentration of $CHBr_3$, the final formed substance in the series of THM formation reactions, was the highest among the various trihalomethanes.

4. Conclusion

(1) The amount of trihalomethane formed in oil-dispersed in seawater increased the duration with the increase in its reaction time with chlorine.

(2) In all test samples, the concentration of $CHBr_3$, which is the final substance formed in the series of THM formation reactions was the highest among the various trihalomethane species.

(3) It was observed that there is a tendency for an increase in THM's formation as both the oil content in seawater and its reaction time are increased.

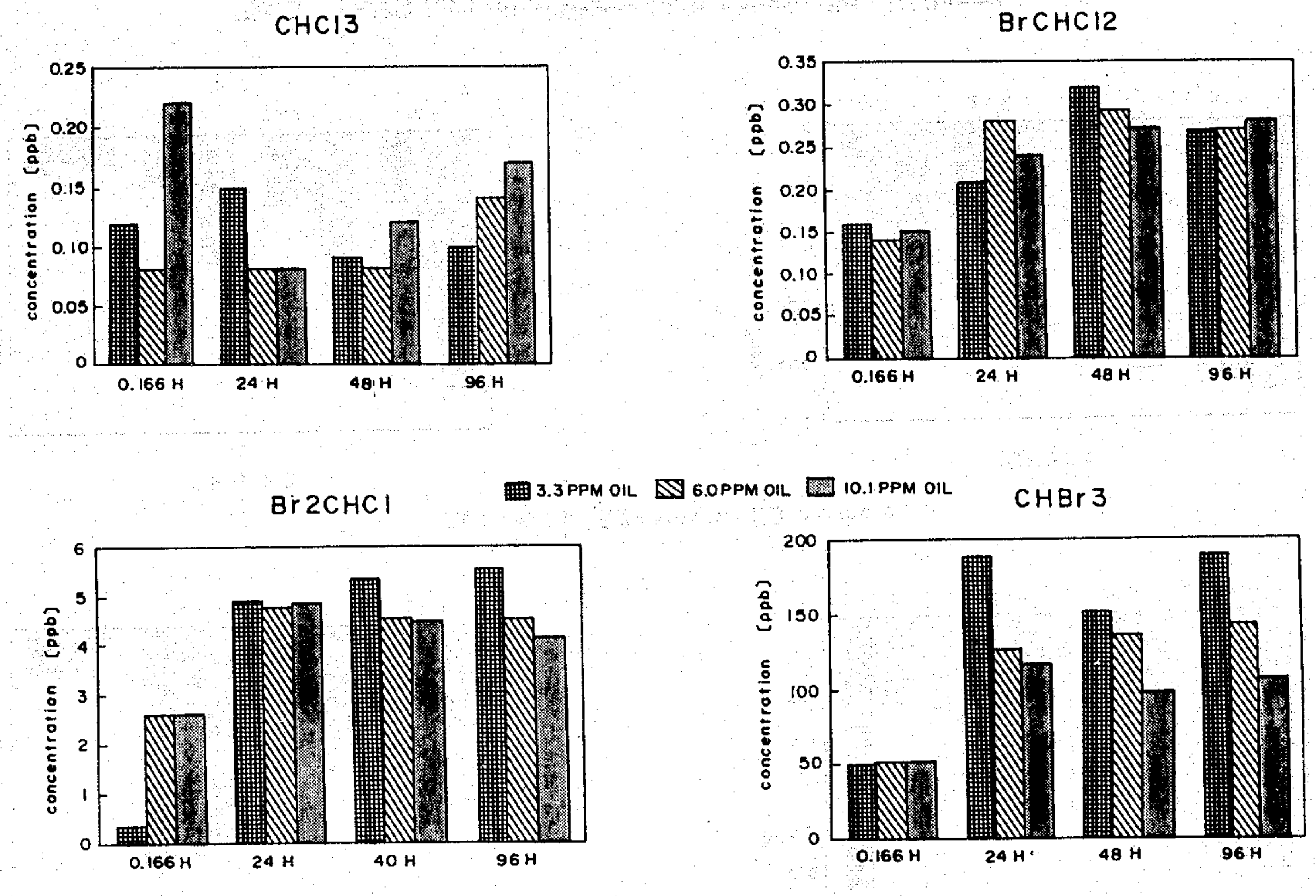


Fig. 2 THMS formation under low chlorination (1.6ppm)

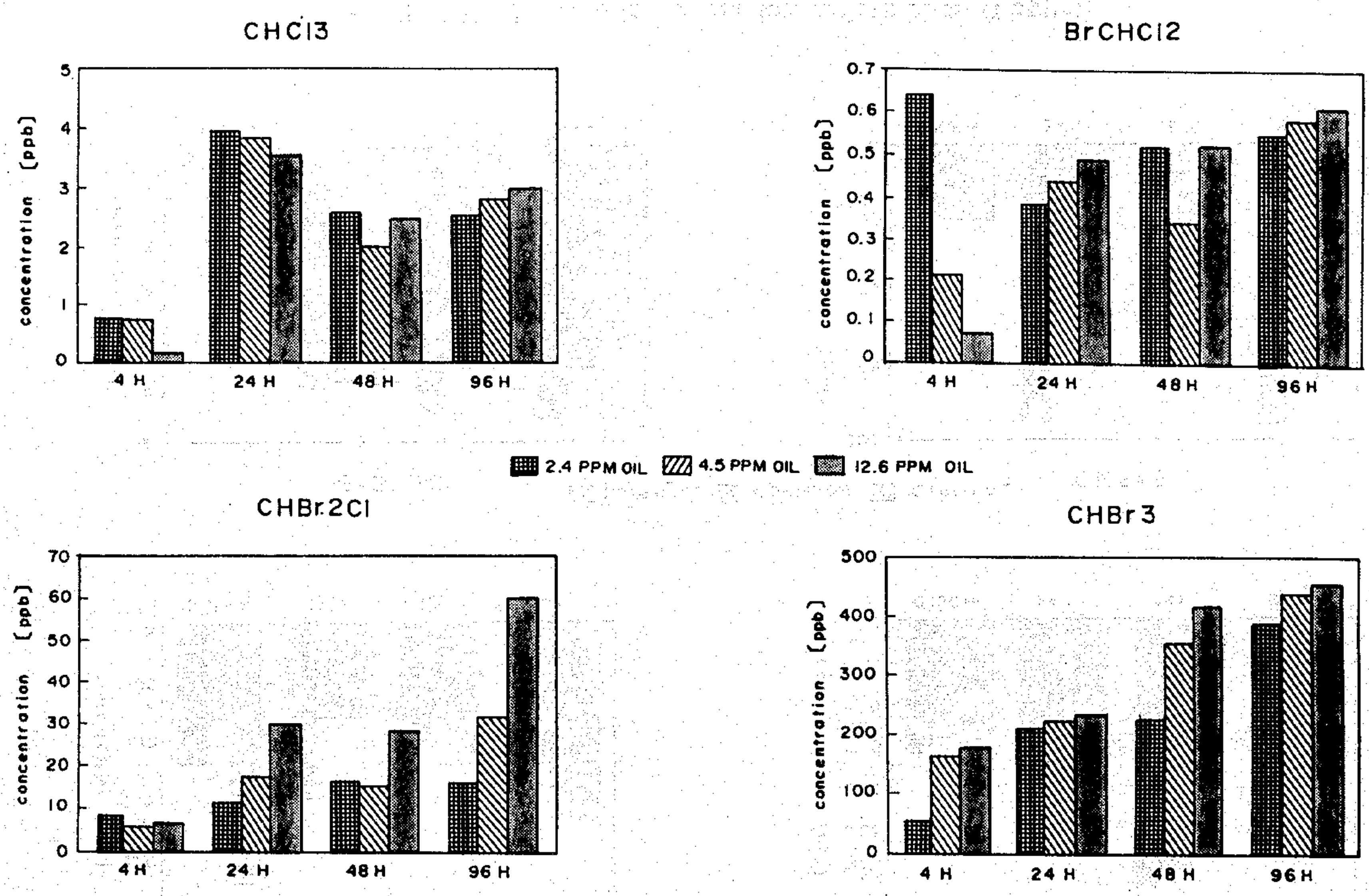


Fig. 3 THMS formation under high chlorination (9.0ppm)

8.2 Oil Removal Experiment with Bench Scale Equipment

8.2.1 Installation of Pretreatment Equipment

For the oil removal experiment, and oil feed control unit with 4 m^3/h of seawater, an oil-removal unit and an oil filter tower regeneration unit were installed at R & D Center, Al-Jubail SWCC, August 1994.

A schematic flow diagram and the photograph of the pretreatment equipment are shown in Fig. 4, Fig. 5 and Fig. 6.

The equipment consists of the following three parts:

(1) **Oil addition Adjusting Equipment:**
Oil is dispersed in seawater using ultra sonic homogenizer to make artificially oil contaminated seawater.

(2) **Oil Adsorption and Oil Recovery Equipment:**
Coagulation/filtration equipment to remove oil in seawater and a filter unit.

(3) **Adsorbed Oil Removing Equipment:**
Oil removal experiment was performed using activated carbon, high polymer resins and sand.

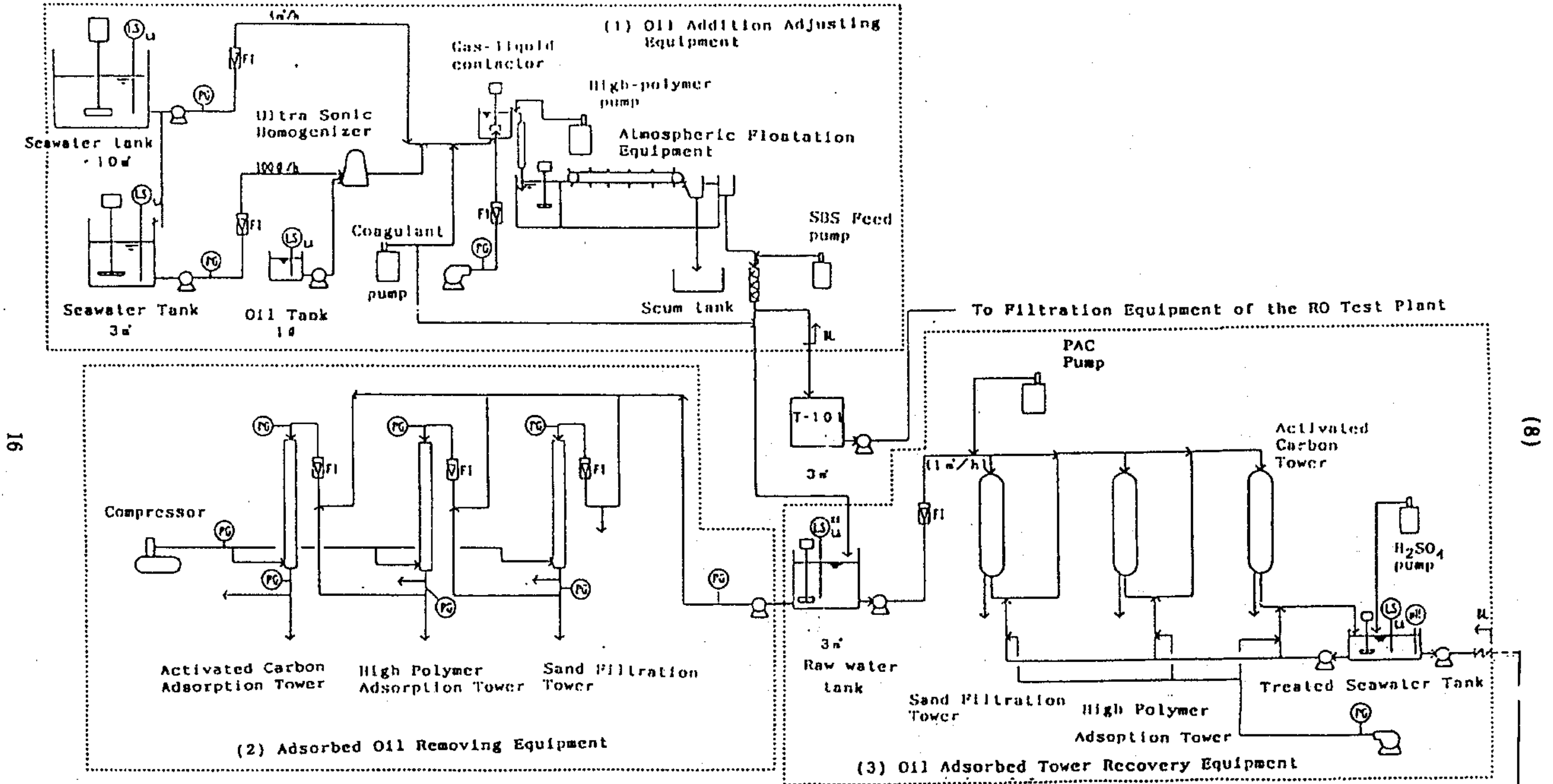


Fig. 4 A Schematic Flow Diagram of the Artificial Oil Contamination of Seawater Feed Unit and the Pretreatment Unit for the Oil Removal

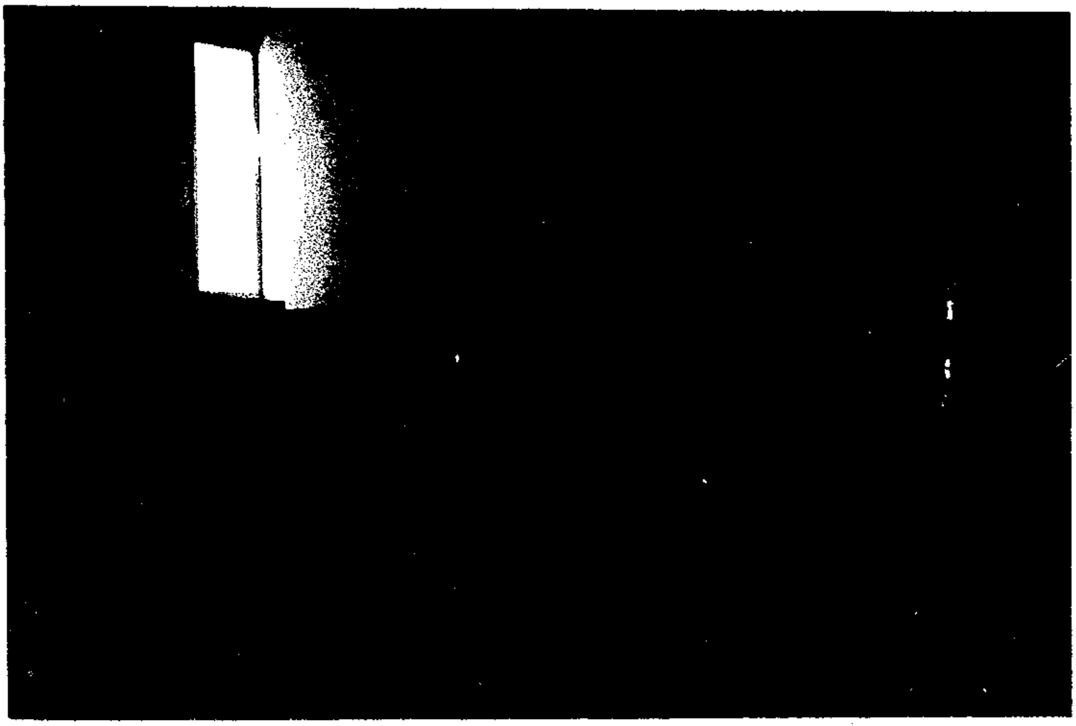


Fig. 5 Oil Addition Adjusting Equipment

Fig. 6 Oil Adsorbed Tower Recovery Equipment

8.2.2 Oil Dosing Experiment

1. Objectives

Use of the pretreatment experimental plant to establish stable oil dispersion method for the preparation of $4m^3/h$ of an oil contaminated seawater feed.

2. Results

2.1 Specification of Oil Content in Artificial Oil-Contaminated Seawater

From the results of the literature survey, it was established that the concentration of oil in the feed shall be around 10 ppm.

2.2 Selection of type of Oil to be used in the Artificially Oil Contaminated seawater Feed

Carbon distribution of Fuel Oil type A (Japanese Standard) and Diesel Oil No. 2 (ASTM) were analyzed.

2.3 Studies with the Ultrasonic Wave Method

Oil dispersion experiment was performed using ultrasonic method and distribution of oil in seawater and stability of oil in seawater was measured.

3. Conclusion

(1) Both fuel oil type A and diesel oil type II have carbon distribution similar to that of fuel oil discharged into the ocean and therefore they are suitable oils to be used experimentally.

(2) Both mixer and the ultrasonic mehtods were tried in artificially preparing oil dispersion but the ultrasonic method has the advantages of requiring less preparation time and more stable oil dispersion.

(3) Use of the ultrasonic method in preparing oil dispersion wassatisfactory in handling the volumes needed for large scale examinations ($4m^3/h$) at oil concentration (10 ppm).

8.2.3 Oil Adsorption Experiment

1.1 Objectives

This investigation aims to ascertain the performance of three types of filter media, sand, anthracite and polymer, regarding the removal of oil from oil-dispersed seawater by means of direct filtration, using the coagulation conditions established so far. The backwash regeneration performance of the three media was also compared. In addition, the characteristics and composition of oil components that cannot be removed via the direct filtration method was also be investigated.

2. Experimental

Oil-dispersed seawater with a concentration of about 5-10 ppm was prepared by the use of an ultrasonic homogenization treatment, and was passed through a filter column filled with an anthracite or polymer or sand after adding a flocculant. Oil concentration and pressure difference were measured vs time. A GC-MS analysis was also carried out on some samples.

3. Results

(1) While almost all the oil content was removed by the coagulation/filtration method, some components, mainly low-molecular-weight aromatic possibly water soluble compounds, could not be removed with anthracite or sand, which are typical ordinary filter media.

(2) The breakthrough time was about 22 hours with anthracite filter media as compared to 10 hours with the polymer, and more than 90 hours with sand medium.

(3) The rise in differential pressure (Δp) was greater with anthracite than with polymer. Unlike the anthracite, it also flattened out at a certain point when using the polymer medium. As far as oil removal is concerned, sand and anthracite performed identically.

4. Conclusion

The filter media combination for the pretreatment system will be determined taking the following steps into account:

(1) A guard column is needed to protect the RO membrane from being blocked by flock in the event of the breakthrough of the filter medium.

(2) Direct coagulation/filtration is capable of removing at least the dispersed oil components irrespective of the filter medium used. If this is sufficient for the RO membrane, no further high level treatment is necessary.

(3) In case where soluble oil components adversely affect the RO membrane, a post treatment of the feed by the use of polymer or activated carbon may be considered.

8.2.4 Regeneration Experiment for Oil Adsorption Tower

1. Objectives

The present study aims at evaluating the efficiency of oil adsorption tower consisting of two sand media filter in removing the oil by coagulation – filtration method from the artificial oil contaminated seawater. The study also includes establishment of the operating conditions for the removal of oil from oil–contaminated seawater using the coagulation–filtration method and also to achieve suitable regeneration method for the filter media.

2. Experimental

Artificial oil–contaminated seawater preparation unit as described in section 8.2.3. in this experiment, instead of the three small experimental column, four large adsorption tower were used in series. Each of the towers was of 400mm diameter and 1500mm height. The first tower was kept empty and second one was filled with coarse sand (particle size 0.7 – 1.3 mm) and fine sand (particle size 0.6 – 0.8mm) at height of 1000mm (at 1:1 ratio). The third tower was filled up to 1000mm using fine sand (particle size 0.6 – 0.8mm) and last one was kept empty.

Experimental Procedure

Artificially oil contaminated seawater (about 10 mg/L of oil) was passed through the four adsorption tower in series after dosing coagulant $FeCl_3$ (10 mg/L) at a flow rate of 1.25 m^3/hr. Samples were collected from feed and the filtrate from the two sand filters for oil content analysis using spectrofluorophotometer. Initially these analysis were conducted every 8 hours and prior to backwash later on. Backwash was conducted using raw seawater at a flow rate of 6m^3/hr for 5 minutes followed by air scouring for 19 minutes and finally by raw seawater wash for another 10 minutes.

3. Results

The results of oil content analysis using spectrofluorophotometer in the feed and filtrate from two sand filters for a period of about 390 hours are summarized in Fig. 7. Backwash of the filters was conducted when the differential pressure reaches 0.9kgf/cm^2. Backwash of the first sand filter was conducted at an average of every 26 hours.

4. Conclusion

The present study reveals that oil adsorption tower consisting of sand media filters are capable of removing most of the oil from oil–contaminated seawater alter its coagulation. Also the back washing procedure followed in this experiment is sufficient for the regeneration of sand filter media with backwash flow of 6 m^3/h (LV=48m/h) for 5 minutes.

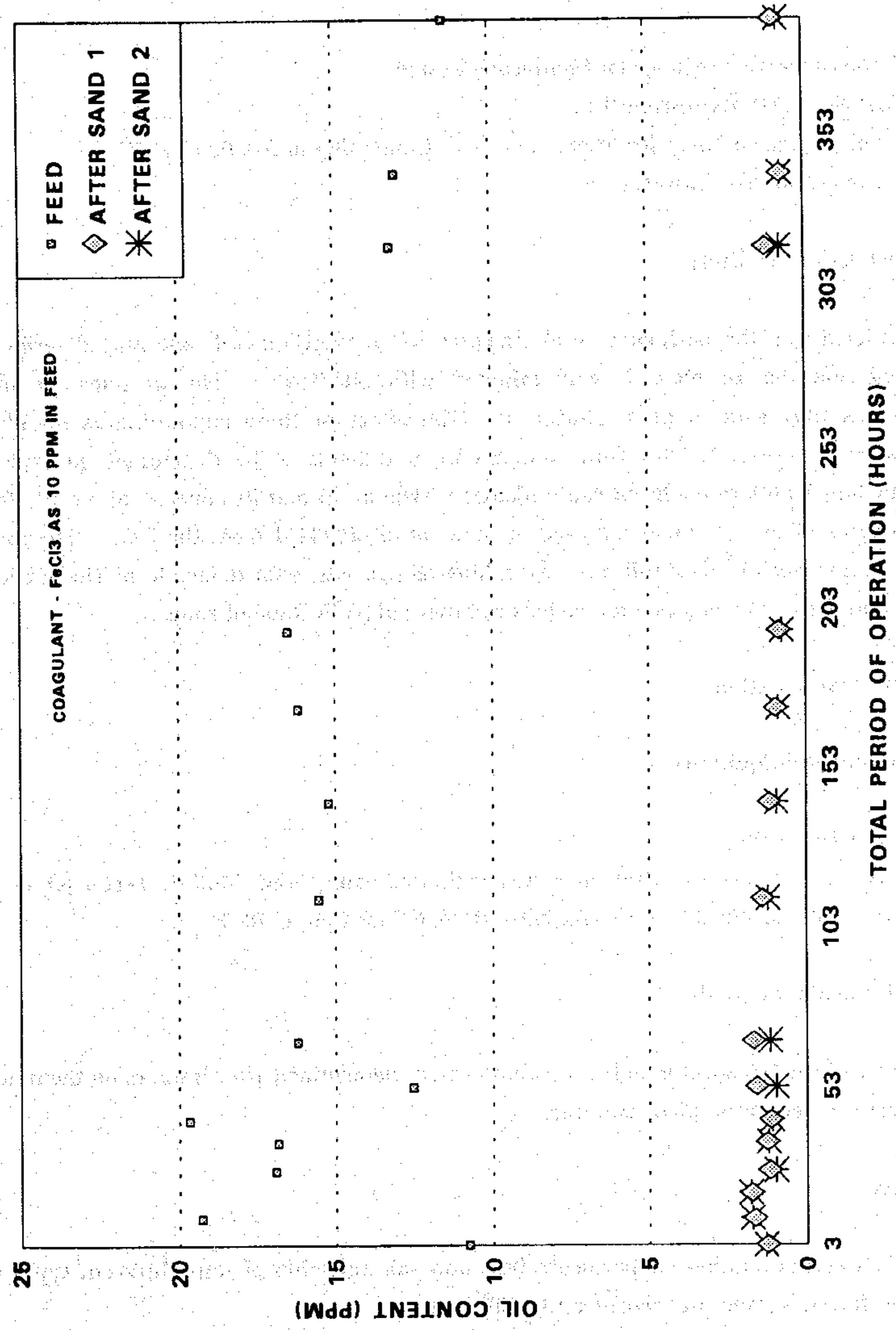


Fig. 7 Oil Tolerance Test using Flat SWRO Membrane
(Oil Content vs Time)

8.3 Oil Tolerance Test with a Flat Membrane Tester

8.3.1 First Step Flat Membrane Test

8.3.1.A Oil Tolerance Test with Membrane after Immersing in Artificially Oil Contaminated Seawater

1. Objectives of the Study

It is postulated that the performance of seawater RO (SWRO) membrane may deteriorate when feed seawater to plant is contaminated with oil/THM . The presence of such contaminants may lead to plant shutdown. The effect of those contaminants on plant performance , however, is not fully understood, and tends to be dependent on type of membrane and its tolerance to oil contamination, type of oil and its concentration, it's feed and the degree of pretreatment followed in removal of oil/THM from the feed. The main objective of this work is to establish the experimental procedure for determining the effect of oil/THM and their concentration on various commercial SWRO membranes.

2. Experimental Methods

2.1 Experimental Equipments

Mini Module Tester (2)
The performance of various membranes was evaluated using Mini–Module Tester RUW–5. The four test cells used in this test were: Nitto RO/UF Test Cell, C 70–F.

2.2 Experimental methods

Performance of the flat sheet membrane samples were determined after immersing them into the artificially oil contaminated seawater.

3. Results

Effects of oil contamination on permeate flow and salt rejection of four different types of membrane, however, were not significantly different.

4. Conclusion

The present study involves the performance evaluation (flux and salt rejection) of four different types of membranes and the effect of their exposure to oil contaminated seawater on their performance. The results did not give any conclusive evidence of the effect of oil as the values obtained were not significantly different. To detect the effect of oil on membranes, oil contaminated seawater need to be fed to the membrane continuously.

8.3.1.B Oil Tolerance Test of Flat Membrane by Continuous Recirculation System

1. Objectives

In the previous research activity, oil tolerance test was performed by measuring performance of flat sheet membrane before and after immersing them into the oil contaminated seawater. Fuel oil type A of Japanese standard was used to prepare an artificial oil contaminated seawater. Both TOC meter and Turbidity meter were used to analyze oil in the contaminated seawater. However, the results show that the data obtained was not sufficient. It was recommended that another experimental method with continuous water flow is needed to know the effect of oil in seawater membrane performance. Analytical methods used in this experiments such as TOC and turbidity meter did not give accurate oil concentration. A higher sensitivity analytical method is required to obtain more accurate oil concentration data, especially for the analysis of low oil concentration in seawater.

The objectives of this experiment are as follows:

(1) To analyze the effect of oil contaminated seawater on the performance of various membranes and to perform preparative experimental of oil tolerance test, recirculating pretreated seawater to flat membrane of Mini–Module tester (2).

(2) To determine the type of oil to prepare artificial oil contaminated seawater.

(3) To analyze oil contaminated seawater using newly installed low concentration oil measuring instrument, i.e. Fluorophotometric meter and confirm that it is useful to perform practical anlysis in experimental work.

2. Results

2.1 Oil concentration of the continuous recirculating feed water changes as time passes by, and it was cleared that it is difficult to keep the feed oil concentration at constant value.

2.2 Carbon distribution of Diesel Oil No. 2D (ASTM) was determined by GC-MS measurements to select a suitable oil used for preparing artificial oil contaminated seawater.

2.3 Oil concentration change of continuous recirculating oil contaminated seawater was analyzed using newly installed fluorophotometric meter.

4. Conclusion

(1) Continuous feed recirculation to flat sheet membranes can be utilized as a preparation step for the more accurate continuous operation of RO-mini modules fed oil contaminated feed.

(2) Diesel oil No.2-D is a suitable oil for the preparation of artificially oil contaminated seawater as feed to RO-2 membranes.

(3) Oil tolerance test can be performed by recirculating oil contaminated seawater to Mini-Module tester

8.3.2 Experiment with Combined Pretreatment Equipment and RO Membranes

1. Objectives

The present study aims at evaluating the effect of soluble oil present in the pretreated oil-contaminated seawater on various flat sheet RO membranes. In this experiment performance (flux and salt rejection) of three different flat sheet membranes obtained from different manufacturers were monitored for a period of time with the pretreated seawater feed supplied from the oil removal unit.

2. Experimental

Equipment

Mini module tester (2) Model RUW-5 was used to evaluate the performance (flux and salt rejection) of three different types of flat sheet membranes. The test cells used in the tester were RO/UF test cell.

3. Results

The results of performance evaluation (permeate flow and conductivity) of three different membranes for a period of 220 hours are shown in Fig. 9. Permeate flow for Toray 80M and 80S with temperature corrections are shown in Fig. 8.

4. Conclusion

The present study reveals that all the three types of flat sheet membranes viz, Toray 80M, Toray 80S and Nitto NTR 70SWC are unaffected by the presence of trace amount of oil in the oil contaminated seawater feed which is supplied to the membranes from the oil removal pretreatment unit.

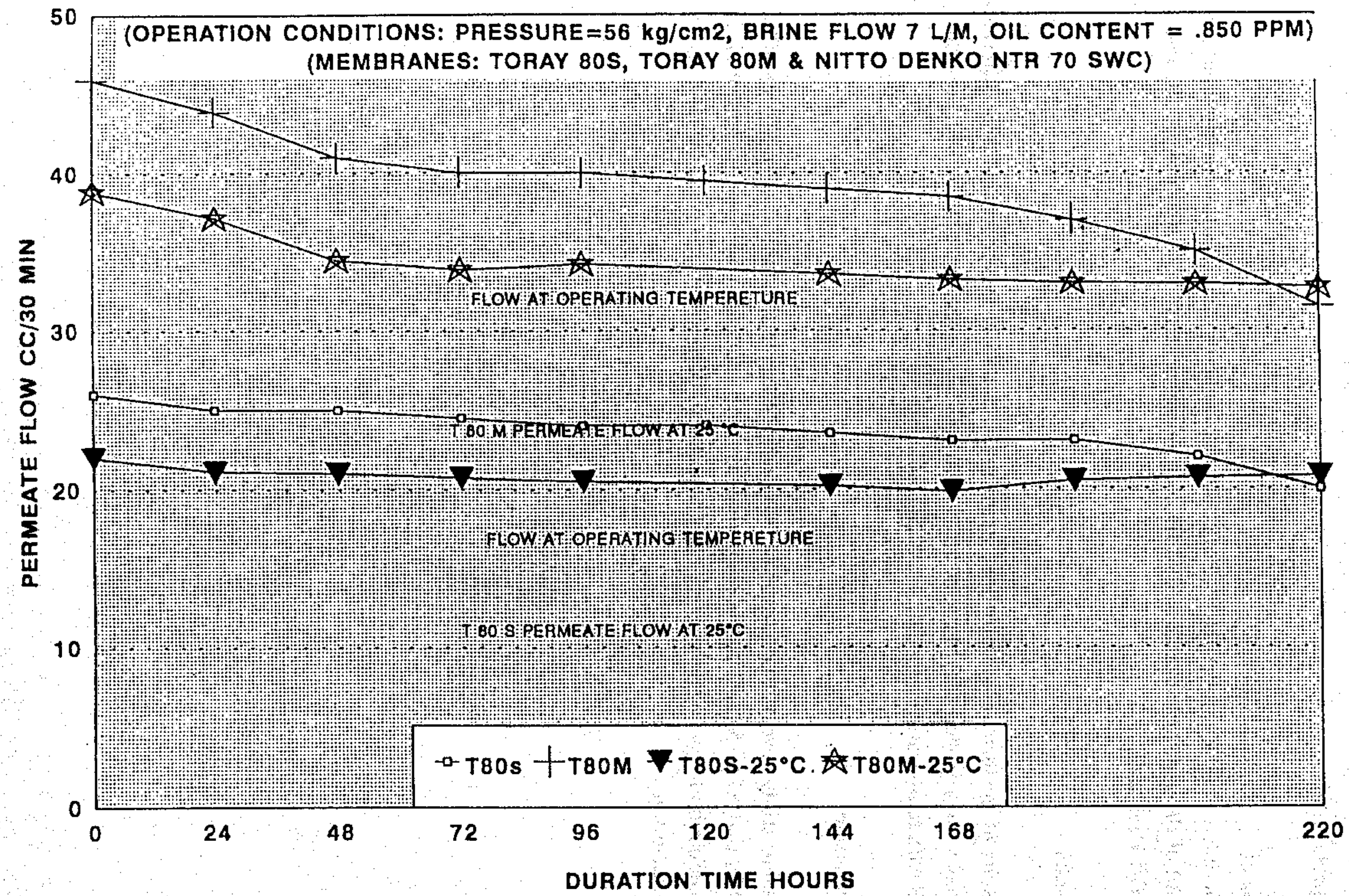


Fig. 8 **Oil Tolerance Test using Flat SWRO Membrane (Permeate Flow vs Time)**

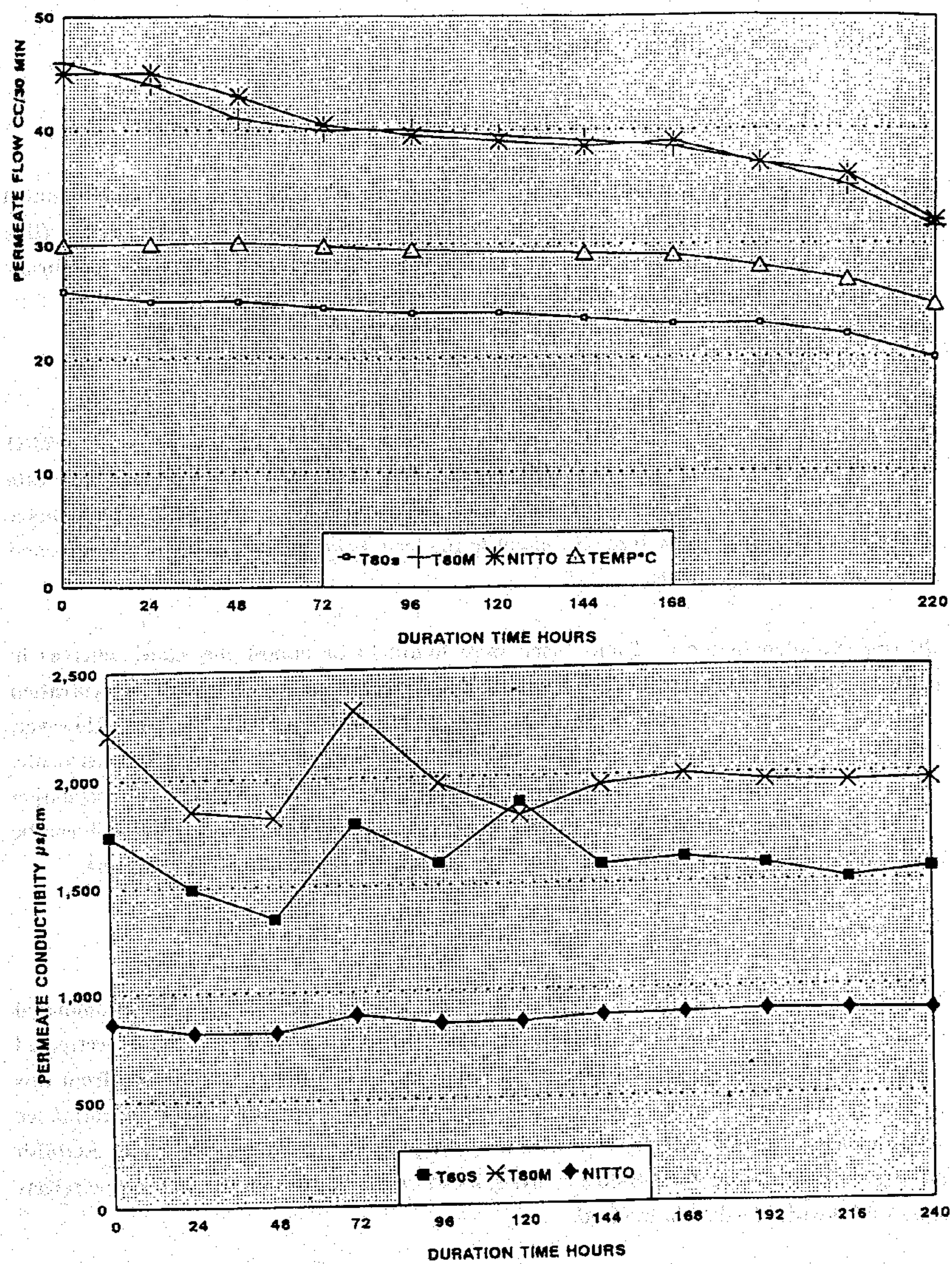


Fig. 9 Oil Tolerance Test using Flat SWRO Membrane Permeate Flow, and Conductivity vs Time (Flow is corrected for Temperature 25℃)

8.4 Experiment with RO Mini-Module (2)

1. Objective

The present study aims at evaluating the effect of the oil in the pretreated oil-contaminated seawater on 2.5" x 40" SWRO membrane module. In this experiment performance (flux and salt rejection) was monitored for a period of time, during which feed to the membrane was supplied to the membrane from the pretreated seawater oil removal unit.

2. Experimental

Mini-module tester (2) was used to evaluate the performance of the 2.5"x40" SWRO membrane module, using pretreated oil-contaminated seawater feed. The feed flow rate was maintained at 7 L/min. Oil in permeate was determined using spectrofluorophotometer. GC-MS was also used to analyze oil content in the feed, brine and permeate in the start and at the end of the experiments.

Oil concentration in the feed and brine were found to be almost the same, whereas in permeate it was almost zero in the beginning but there was slight increasc in concentration later on. The measurements using spectrofluorometer are shown in Fig. 10. However, GC-MS analysis contradicted the spectrofluorometric analysis results for the permeate. Here, GC-MS spectra for the feed, brine and permeate were quite identical in the beginning and also at the end of the experiment (see Fig. 11). Since GC-MS is more reliable, it can be said that the soluble oil present in the feed were completely rejected by the membrane.

4. Conclusion

The performance evaluation of a 2.5"mini-module using pretreated oil contaminated seawater reveals that membrane performance was affected by the feed. Since pretreated seawater used in this experiment had high SDI value, it is difficult to conclude from this study that which factor (high SDI value or presence of oil) is responsible for the performance deterioration. Further investigation with low SDI pretreated feed is necessary to establish the actual cause. From the GS-MS analysis, it can be concluded that the membrane rejects almost all the dissolved oil in the feed.

Fig.10

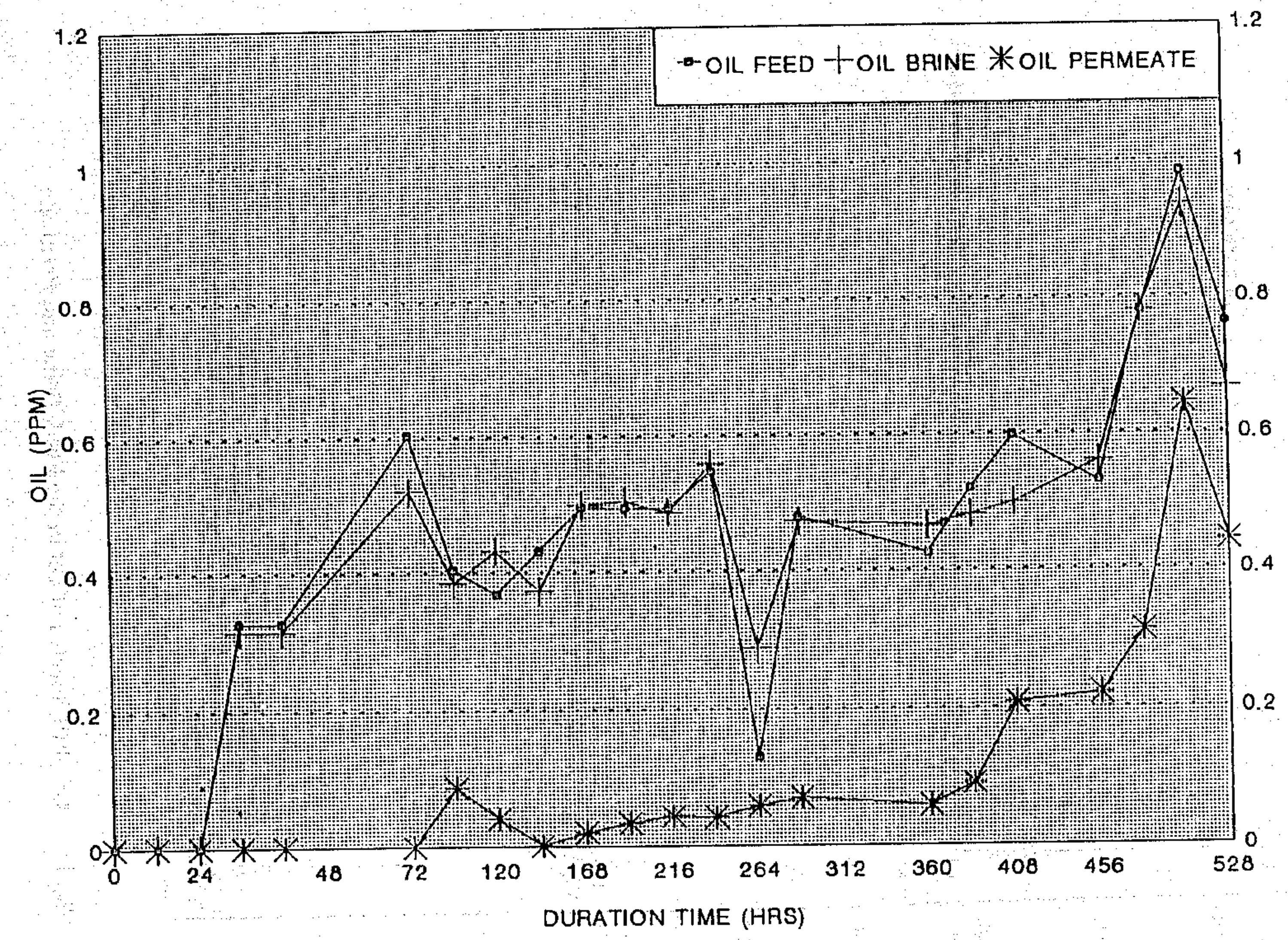


Fig. 10 **Oil Turbidity Tolerance using Nitto NTR 70 SWC SWRO Membrane (2.5" × 40" module)**
Oil Content in Feed, Brine and Permeate (ppm) vs Time

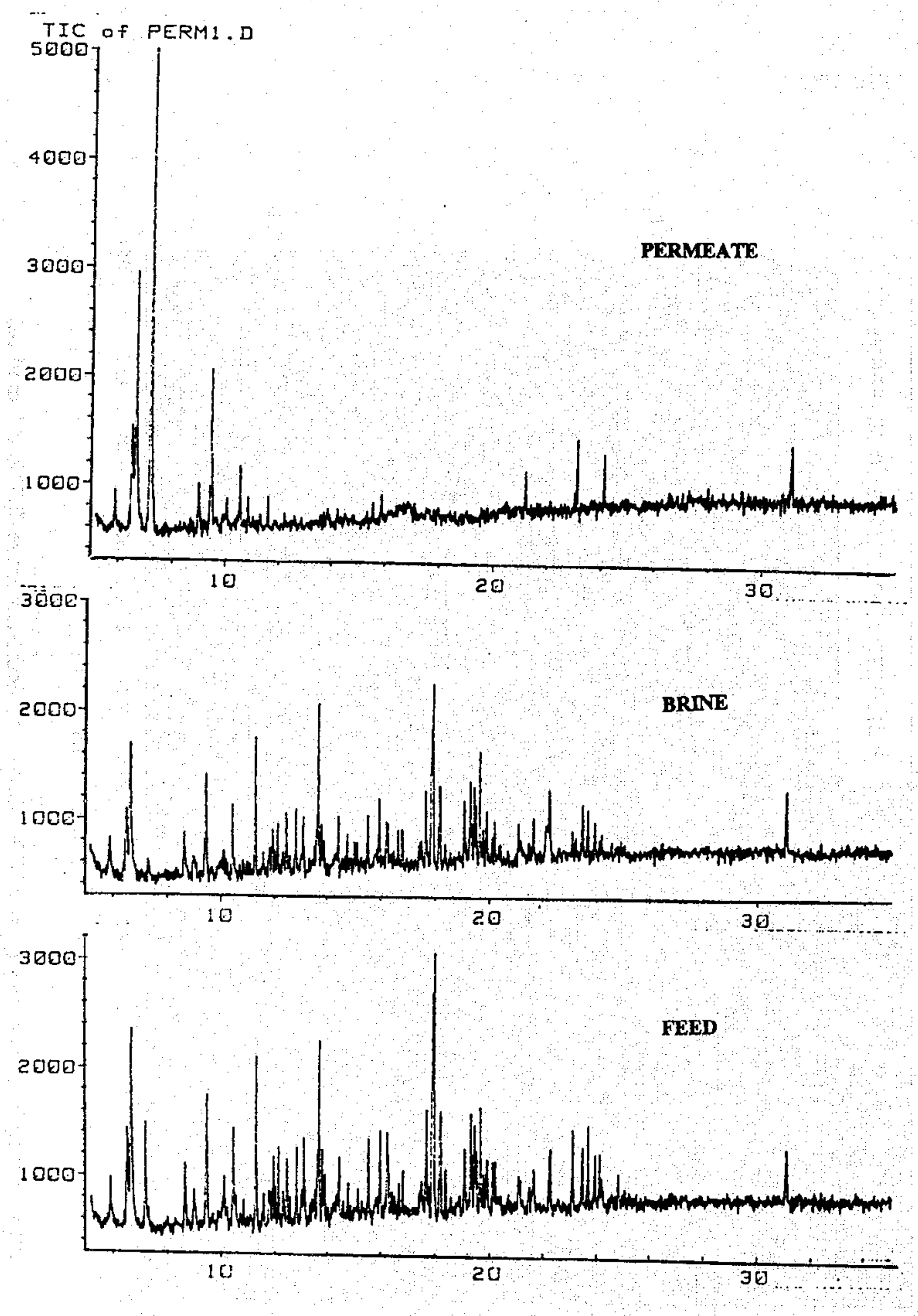


Fig. 11 GC–MS Spectra of Oil in the Feed, Brine and Permeate

8.5 Test with the RO Test Plant

1. Objective

The present study aims at evaluating the effect of soluble oil present in the pretreated oil-contaminated seawater on commercial size 8" SWRO membrane module. In this experiment performance (flux and salt rejection) of the membrane was monitored for a period of about 117 hour using the pretreated seawater obtained from oil removal unit after blending it with raw seawater, and the coagulation-filtration of the blend using the large filter of the RO Test Plant.

2. Experimental

The performance (flux and salt rejection) of the 8" commercial SWRO membrane module was determined using pretreated oil-contaminated seawater feed after blending it with raw seawater at 1:2.5 ratio and then passing through the pretreatment unit of the RO Test Plant. The feed flow rate was maintained. Oil contents in the feed, brine and permeate were determined using spectrofluorophotometer and in the permeate using GC-Mass measurements.

3. Results

The results of membrane performance evaluation (salt rejection and permeate flow) of the 8" commercial RO module for a period of about 117 hours are given in Fig. 12 and 13. Fig. 14 shows pretreatment data of the test unit.

4. Conclusion

Performance evaluation of 8" commercial SWRO membrane using pretreated oil contaminated seawater having SDI<3, reveals that performance of the membrane was unaffected. This suggests that the pretreatment process used in this experiment was quite effective in oil removal from the oil contaminated SWRO feed.

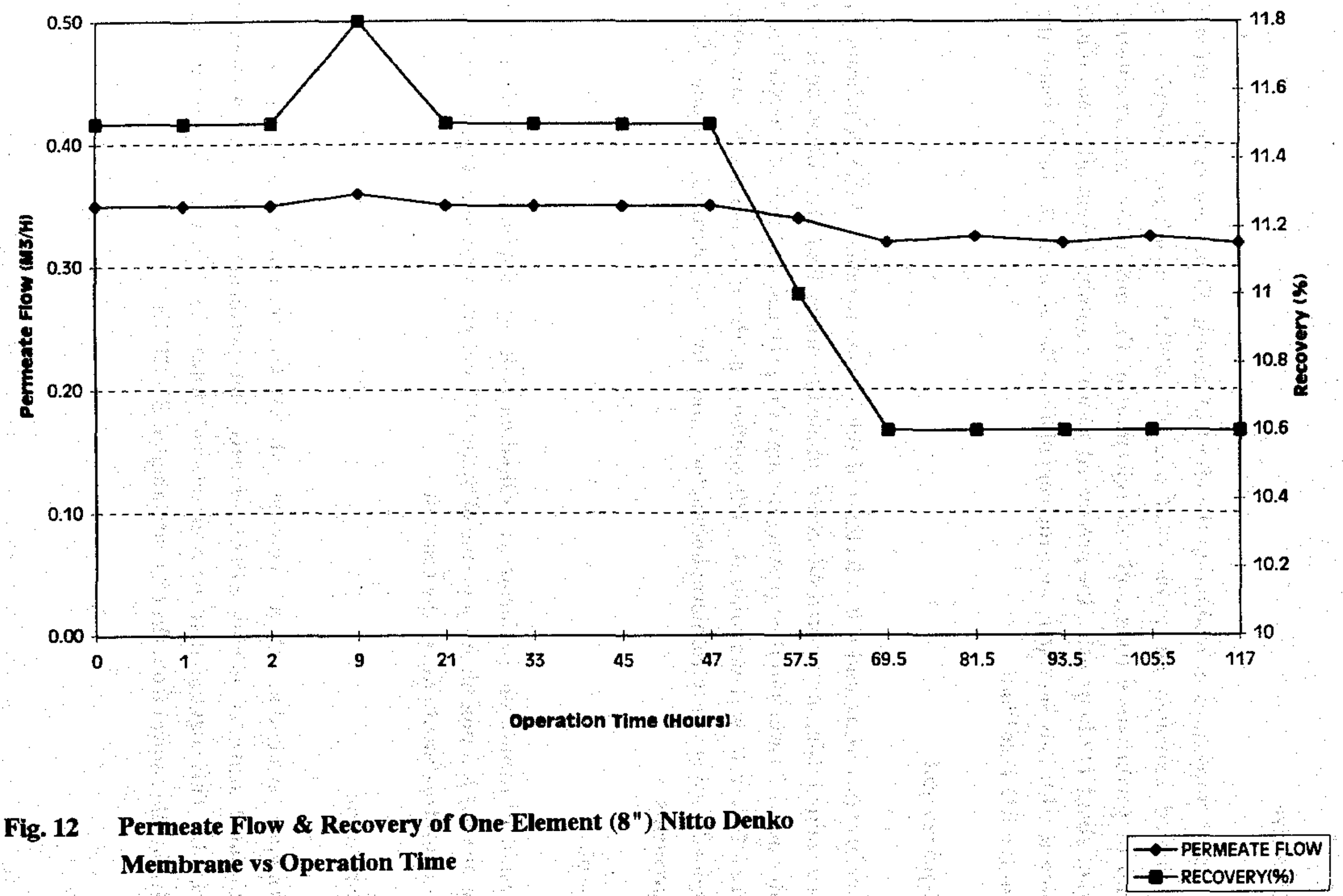


Fig. 12 **Permeate Flow & Recovery of One Element (8") Nitto Denko Membrane vs Operation Time**

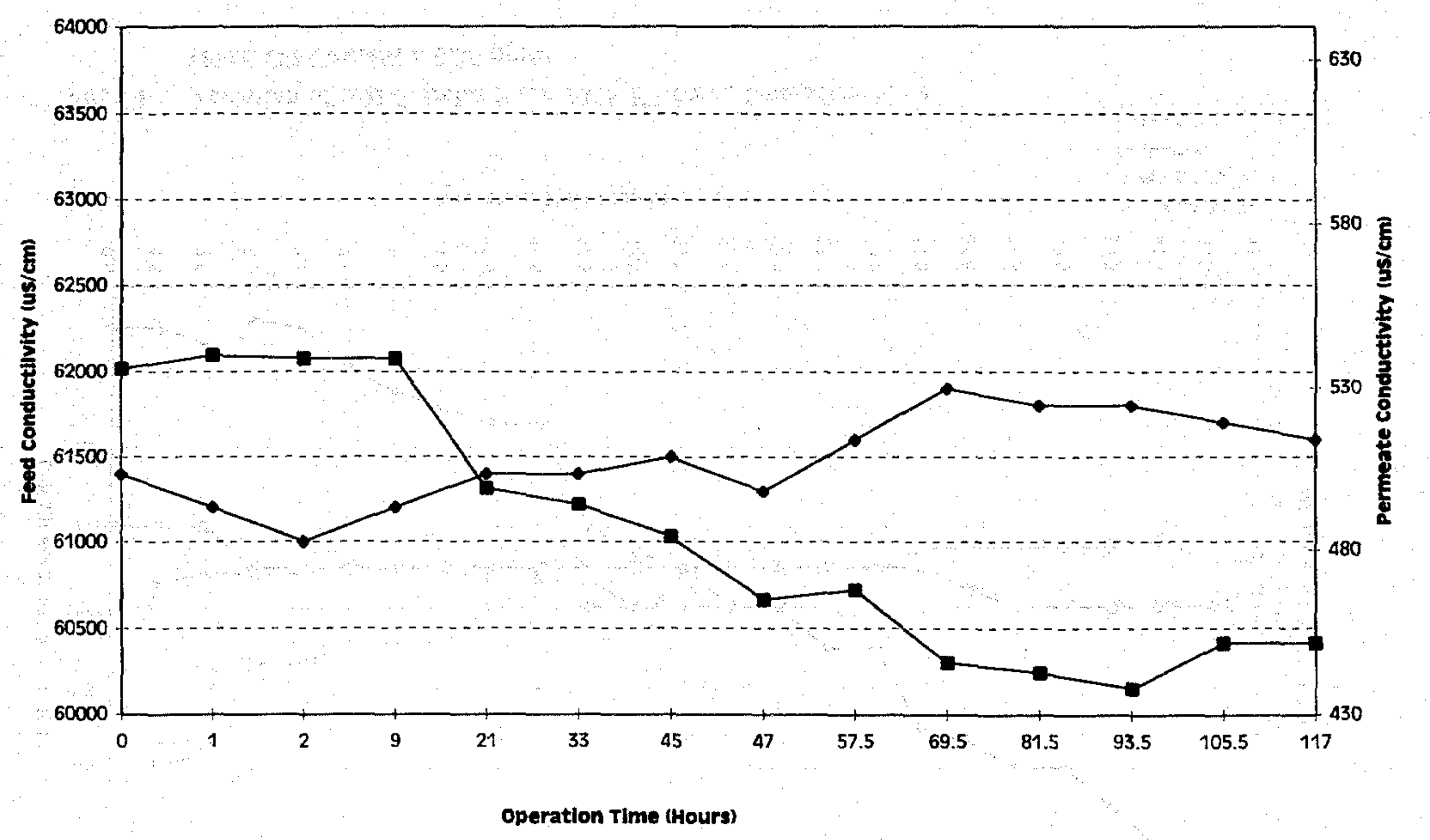


Fig. 13 **Feed and Permeate Conductivity of Nitto Denko (8" element) Membrane vs Operation Time**

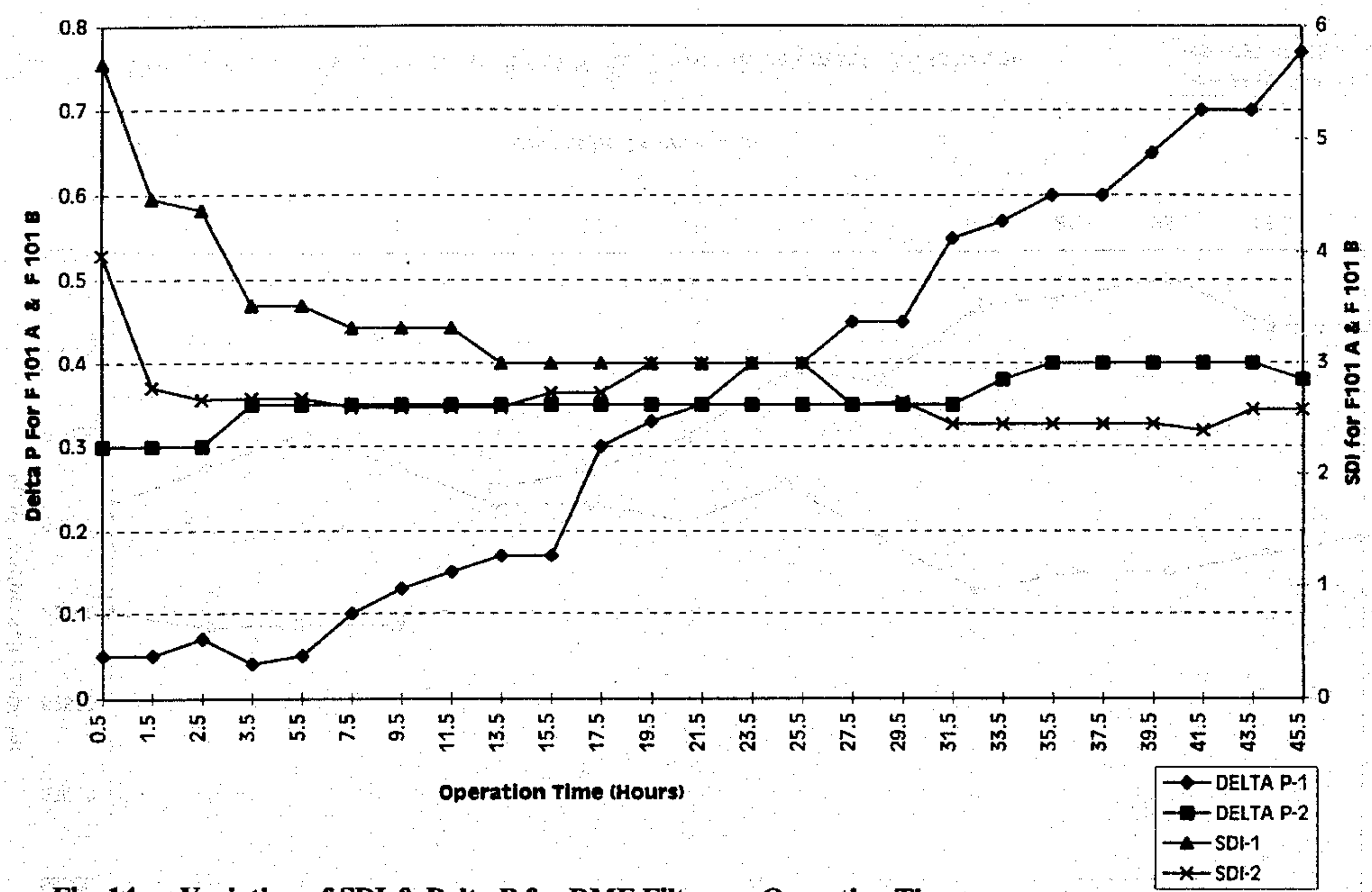


Fig. 14 Variation of SDI & Delta P for DMF Filters vs Operation Time (Feed Oil Content = 0.35 ppm)

8.6 Transfer of Technology

1. Objectives

Concerning research relating to measurements dealing with oil pollution in the reverse osmosis process, JICA has transferred the knowledge to the young SWCC engineers in particular Saudi engineers in the course of implementing this collaborative research.

2. Method of Implementing Technology Transfer

The main technology related to this research was broken down into the following technological elements and became the object of the technology transfer. The method of technology transfer was carried out mainly by the implementation of the collaborative research by both JICA and SWCC. This became firmly fixed through the processes of on-job-training and the preparation of written experiment reports and manuals. These techniques were prepared and supplied as substantial items for future use.

Main technological elements for the transfer of technology

1) Information concerning soluble and insoluble oil in sea water
2) Information concerning halogen compounds such as the tri-halomethanes
3) Technology of desalination pre-treatment by RO membrane
4) Pre-treatment of low concentrations of oil in sea water
5) Analysis of low concentrations of oil in sea water
6) Experimental equipment for pre-treatment
7) Technology for the general appraisal of oil contamination
8) Analytical equipment
9) General research activities

3. Methods and Results of Technology Transfer

(1) Information concerning soluble and insoluble oil in seawater

In addition to the training related to the various types of information which have been gathered and on-job-training in techniques for the operation and care of additionally provided analytical equipment (methods of oil analysis by fluorospectrophotometer) which were selected as a result of data surveys, analytical reports were written and analytical manuals were prepared.

(2) **Information concerning halogen compounds such as the trihalomethanes**
In addition to implementing analyses through on the job training based on analytical methods selected from the results of data searches, the technology was established by writing reports and the preparation of manuals.

(3) **Technology of pretreatment process for RO membrane**
In addition to on-job-training in the collaborative operation of the test plant, the technology was established by writing operating reports and the preparation of a plant operation manual.

(4) **Pre-treatment of low concentrations of oil in sea water**
In addition to on-job-training through the joint conduct of introductory laboratory scale experiments followed by experiments using a bench scale test equipment, the technology was established through the writing of reports of experiments and the preparation of plant operating manuals.

(5) **Analysis of low concentrations of oil in sea water**
In addition to on-job-training concerning the operation and care of the fluorophotometer used for analyzing the oil content of sea water and the writing of reports of analyses, an analytical manual was prepared.

(6) **Experimental equipment for pre-treatment**
In addition to on-job-training through the joint operation of the RO test plant using artificially oil-contaminated and pre-treated sea water, the technology was established through the writing of reports of experiments and the preparation of plant operating manuals.

(7) **Effect of oil contaminated feed on membrane performance**
The following three types of equipment for RO membrane performance testing at different scales were provided to enable membrane performance testing at each stage from a small bench scale to a full scale RO plant membranes. In addition to on-job-training through joint research activities using this experimental equipment to investigate the effect of contaminated sea water on RO membranes, technology transfer was accomplished through report writing and the preparation of manuals, etc.

(a) **Small scale, flat membrane test equipment**

(b) Medium scale, mini-module type test equipment
(c) RO test plant for testing actual plant size RO module performance.

The technology has been established through the results of joint research on the use of this complete set of test equipment for measuring oil contamination from a laboratory scale to a full plant scale and it is now possible for them to implement research on measures to counter oil contamination.

(8) Analytical equipment

The following analytical equipment has been provided and the technology for its operation and maintenance has been established through teaching and the provision of manuals:

- Electron probe micro-analyzer,
- ICP emission spectrometry system,
- Infrared spectrophotometer,
- X-ray analyzer,
- Ion chromatograph, and
- Fluorophotometer.

These instruments can be used for analyzing the oil content of sea water, water quality analysis, membrane contaminant analysis, fouled membrane analysis, as well as in other general analysis conducted in a R&D desalination laboratory.

(9) Research activities

On-job-training on the experience of research activities was achieved by actually conducting experimental research methods through the joint implementation by JICA and SWCC of research activities such as data collection and analysis, research planning, conducting experiments, supervision of research processes, analysis of experimental results, preparation of data sheets, and report writing.

9. Summary

Chapter 9 SUMMARY

The present project started in May, 1992 after the end of the former project. Both SWCC and JICA experts studied jointly the research themes which are required in the field of seawater desalination particularly suited for the Kingdom of Saudi Arabia, with close cooperation between both sides. JICA not only provided additional equipment and materials necessary for the present project, but also arranged and supervised installations of the MSF and RO Test Plants as well as equipment which were already provided earlier. SWCC provided the JICA experts with office rooms, accommodations, transportation of equipment and personnel, import tax exemption in order to implement their research activities smoothly. In addition to these, SWCC supplied operators most by sandis for the continuous operation of plants and utilities. A total of 4 research themes were studied under the cooperation of SWCC and JICA; 2 dealt with the MSF process and 2 dealt with the RO process:

1. Study on Scale Control for MSF Process (MSF-1)
2. Study on Countermeasures against Oil Contamination of Product Water in MSF Process (MSF-2)
3. Study on Selection of RO Membrane for Hybrid System (RO-1)
4. Study on Countermeasures against Oil Contamination for RO Process (RO-2)

Below is a summaries of the results obtained from the four research themes.

MSF-1 Study on Scale Control for MSF Process

The first step in this study was the laboratory scale experiments on how to estimate the scaling prevention capacity of scale inhibitors available in the market. Six scale inhibitors were tested in this step at various concentrations in artificially prepared brines similar to that in the Al-Jubail Phase II MSF plants. Tests were carried out at 95℃ and 110℃, where changes in residual M-alkalinity was measured along with elapsed time. It was assumed that the higher the residual M-alkalinity is, the greater is the scaling prevention capacity. The results were in good agreement with the past experience in the commercial plants, which means that the method adopted in the present study was effective and suitable for preliminary evaluation of performance of the scale inhibitors.

The next step in this study was experiments on scale inhibiting capability under conditions closer to the actual case, that is, scaling tests with heat flux on the inner tube surface of a shell and tube heat exchanger with recirculating brine. Based on the results of the above fundamental experiments, the best among the scale inhibitors was tested in the heat exchanger. It was estimated that a scale inhibitor with the least decrease in overall heat transfer coefficient was the most effective one.

The scale inhibitor selected by the heat transfer test equipment was further tested with the MSF Test Plant (20 m^3/day). The experiments were conducted with both single scale inhibitor and scale inhibitor with acid (hybrid). The scale inhibitor used was PPN(M).

The effectiveness of the scale inhibitor was judged by the rate of change in overall heat transfer coefficient or fouling factor in the tubes. When a detectable decrease in overall heat transfer coefficient was observed; i.e. fouling factor was reached to a predetermined value, a ball cleaning was carried out, and effectiveness of ball cleaning was also studied. Summary of the results are as follows.

In case of 112℃ top brine temperature and 1.2 concentration factor, a little decease in overall heat transfer coefficient was observed up to 300 hour operation. However, in case of 1.4 concentration factor, a rapid increase in fouling factor due to scaling was observed. It was found that ball cleaning was effective for recovery of heat transfer quality; i.e. performance ratio. One had better conduct ball cleaning before a significant decrease of overall heat transfer coefficient. This fact agrees with the experience of the commercial plants.

The next is the hybrid case. In the kingdom, SCECO'S MSF plants (4,000 m^3/day x 3) at Qurayyah were operated in the past by the hybrid method. Therefore, the SWCC and JICA experts visited the plant for their reference.

In case of hybrid method, pH of brine was kept at 8.0 instead of 8.5 for the single scale inhibitor, and the concentration of added scale inhibitor was 1 mg/L against 2 mg/L for the single scale inhibitor case. In the continuous operation with 1.2 concentration factor, the decrease in overall heat transfer coefficient was almost the same as that of the single scale inhibitor. However, in the case of 1.4, a rapid decrease was observed and the decreasing rate was larger than that when using the single scale inhibitor.

As mentioned above, the joint team of SWCC and JICA were able to establish a systematic

method to evaluate the performance of scale inhibitors from laboratory scale experiments to tests conducted with the MSF Test Plant.

MSF-2 Study on Countermeasures against Oil Contamination of Product Water in MSF Process

The study consists of measurements of the distribution of organics between brine and vapor phase using a vapor-liquid equilibrium equipment, computer simulation on the behavior of pollutants in MSF plants, and pollutant addition experiments with the MSF Test Plant.

Measurements of vapor-liquid equilibrium data are classified into two; one is a homogeneous system of soluble pollutants in brine and the other is a heterogeneous system of insolubles in brine. Bromoform represents the former, and fuel oil "A" represents the latter. The evaporation mechanism of pollutants was studied with simple distillation experiments in laboratory. As a result, it was found that the heterogeneous system could be explained by a steam distillation process. Following this, the vapor pressures of pollutants was measured and their reliability was confirmed by the values in the literatures. On the other hand, it was found that the homogeneous system followed Henry's law, and therefore Henry's constants of soluble pollutants were measured.

The vapor-liquid equilibrium measurement apparatus is an equipment to measure Henry's constant directly. With this equipment, the constants of bromoform, a representative of the homogeneous system, were obtained, and the values were compared with the ones measured by the simple distillation experiments. The good agreement showed the reliability of the simple distillation experiments.

Based on the above evaporation mechanism and physical and chemical constants of water and pollutants, a computer program which simulates the behaviors of water and pollutants in MSF plants is being developed.

An additional dosing line for pollutants and sampling lines necessary for product water and brine were installed in the MSF Test Plant. Then, bromoform, a representative pollutant of homogeneous systems, was added to the feed seawater at concentrations of 0.5 mg/L or 2.75 mg/L. It was found that the behavior of water was in agreement with the computer simulation results. Most of bromoform went out of the system via ejectors. It showed that the condensation rate of bromoform was slow, and it could be considered as a non-

condensable gas even if water condensed well.

When light diesel oil No.2, a representative of heterogeneous systems, was added to the MSF Test Plant at 2.5 mg/L or 10 mg/L concentration, similar trend was observed. The results show that the behavior of water can be explained by vapor–liquid equilibrium only, but those of bromoform and hydrocarbons require both equilibrium and kinetic considerations.

It is assumed that the effective prevention measures for product water pollution are to increase capacity of the vent systems including the deaerator and to improve the chamber geometry.

RO–1 Study on Selection of RO Membrane for Hybrid System

A large quantities of technical information on SWRO which is available worldwide were collected. Based on this information a computer simulation program on RO performance in a Hybrid System (MSF–RO) was conducted from which it was calculated that maximum blend ratio of RO:MSF of 1:1.5 product water would be possible using the Arabian Gulf seawater.

A SWCC/JICA team visited four RO plants (Jeddah, Umm Lujj, Duba an Haql) to make an on–site survey. Test samples of membrane elements were collected by the team and membrane autopsy and foulants analysis were conducted at SWCC–RDC and in Japan on both a Hollow Fine Fiber membrane and a Spiral Wound membrane. Oxalic acid was found to be an effective chemical cleaning method and effectively removed iron compounds. It was also able to improve membrane performance to a considerable extent.

As a result of this study, it is possible to conclude that with the equipments available at SWCC facility, we were able to find out the cause of the membrane deterioration, and with the present fine technique it should be also possible to study membrane deterioration at SWCC SWRO plant in future.

The second study dealt with membrane chlorine and turbidity tolerance. In these studies a flat membrane followed by mini–module test were conducted primarily to evaluate membrane durability. As a result of those preliminary tests it was found that slow membrane degradation is noticed in case of 0.3 ppm of residual chlorine in the feed seawater. However, it is necessary to confirm the membrane durability through longer continuous

operation at lower chlorine concentration in the feed.

It was confirmed that stable service with RO membrane would be possible by feeding seawater pretreated using dual media filtration and dosing a coagulant.

Finally, performance test of RO plants with three commercial size SWRO membrane modules were conducted. Those membrane modules were tested utilizing two independent skid mounted RO units that received filtered water from dual media filter with a capacity of 168m^3/d.

It was found that dosage of 1.0 – 1.3 ppm of Fe^{+3}, produced a feed water with SDI less than 4.0 which meets the specifications requirement of the two hollow fine and spiral wound membranes.

Permeate conductivity for three commercial size Japanese–made SWRO membrane modules (NITTO DENKO, TOYOBO, TORAY) were 250 – 750 μS/cm. It was confirmed that this high quality of permeate can be obtained and maintained constant at applied pressure of 56kg/cm^2.

It is important to confirm the stability of the system in order to be adopted in the actual plant. Further tests to confirm the stability of the membrane and the quality of the product water in long term period utilizing the testing method established by this cooperative research are recommended.

RO–2 Study on Countermeasures against Oil–contamination for RO Process

This research aims at establishing a method of operation RO seawater desalination plants safely even if the feed seawater is contaminated with oil.

The first step was to review analytical methods of oil and trihalomethane measurement in seawater in order to establish a sensitive analytical procedure for the measurements of those contaminants at low concentrations. After trial of several analytical methods, success was achieved by using spectrofluorometric and GC–MS method.

Earlier experiments were conducted using flat sheet membrane to evaluate their tolerance to oil present in the oil–contaminated seawater. Then, the research was proceeded to mini–

module tests. At the stage, it became apparent, as expected, that the long term membrane test with combination of pretreatment system of oil-contaminated seawater is important.

A specially designed pilot plant was used for preparing the oil-contaminated seawater and for its removal from the feed by coagulation and filtration. The oil-contaminated seawater was artificially prepared by dispersing oil with high reproducibility.

By using this artificially oil-contaminated seawater, it was confirmed that the oil can be removed by the Fe^{+3} coagulation followed by sand filtration. Polymer and anthracite also showed good oil removal performance.

Nearly all the oil are removed by the coagulation-filtration process, with only traces of less than 0.5 ppm remaining in the feed. The filtrate was fed to an 8" commercial membrane modules. Plant performance were steady and unaffected by the presence of oil residue in the feed. Furthermore, no oil can be detected in the permeate. From these important results it can be concluded that the present coagulation-filtration pretreatment process is adequate for oil removal at the above level and is not affecting the membrane performance.

The testing procedure of the pretreatment of the oil contaminated seawater and 8" membrane module has been established by this cooperative research work. Further testing is recommended to confirm the above finding and to determine if the stability of the system will be maintained after long term operation by using the testing method.

As described above, we have almost achieved our purpose of the four research themes. However, it was impossible to confirm the stability or the deterioration of the system in course of time which requires long run operations since the time was limited. As the testing equipments and technologies have been established in SWCC, we are expecting the future progress in those field.

All the research themes in the project are the most up-to-date, and the researches have been conducted from fundamentals to applications, systematically and in a well-organized manner with close cooperation between SWCC and JICA. Consequently, the obtained results are to attract much attention in the world of desalination technology. In addition, it should be emphasized that this project was carried out from user's viewpoint, that is to optimize the use of the existing plants, to estimate manufacturer's proposals and to solve environmental problems while most of the past researches were done from manufacturer's

viewpoint. We are proud of our achievement as the first milestone, and confident of future success.