

Fig.4.2.4 Computer reconstructed ion chromatogram of first fraction of 10mg/l oil test

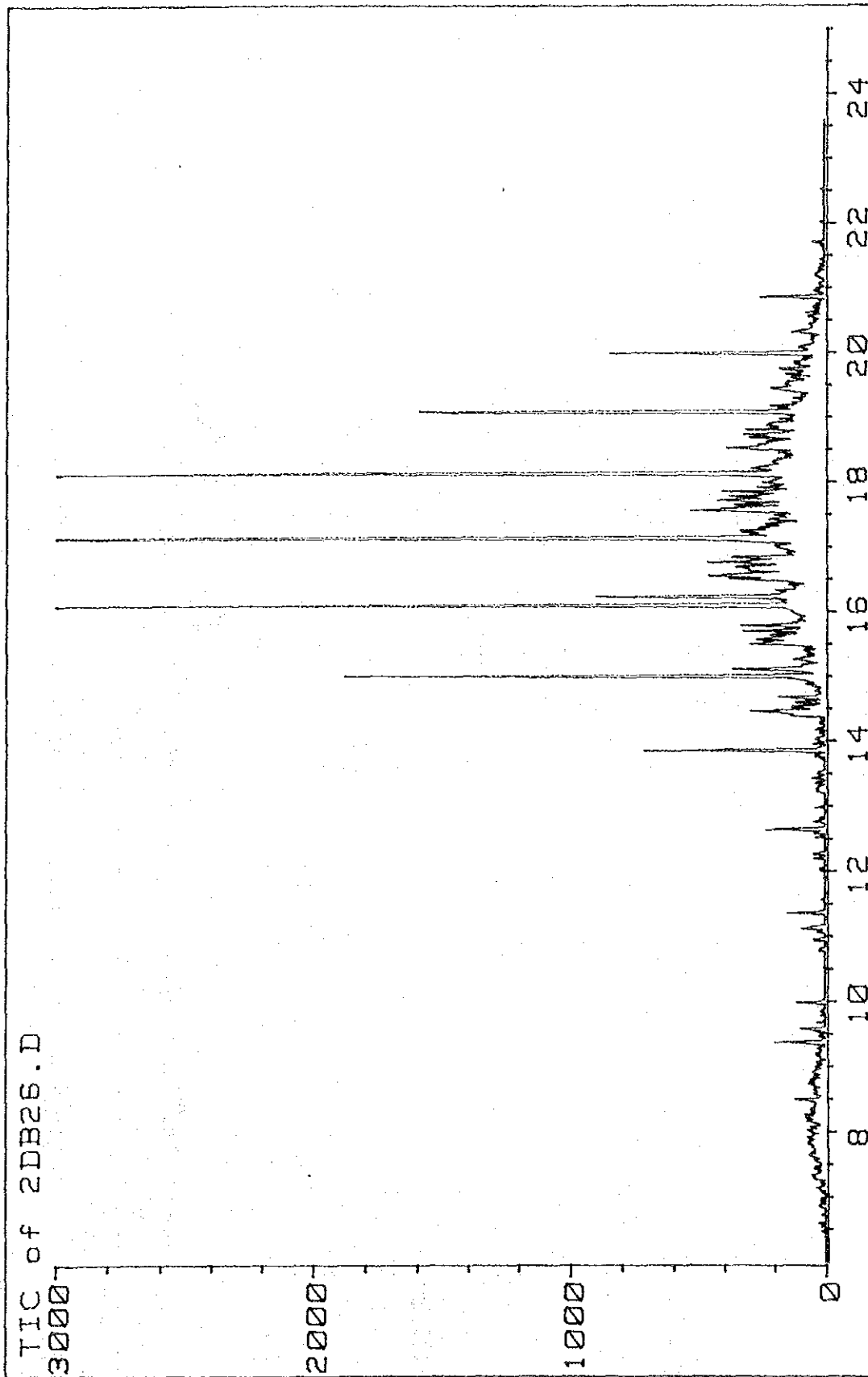
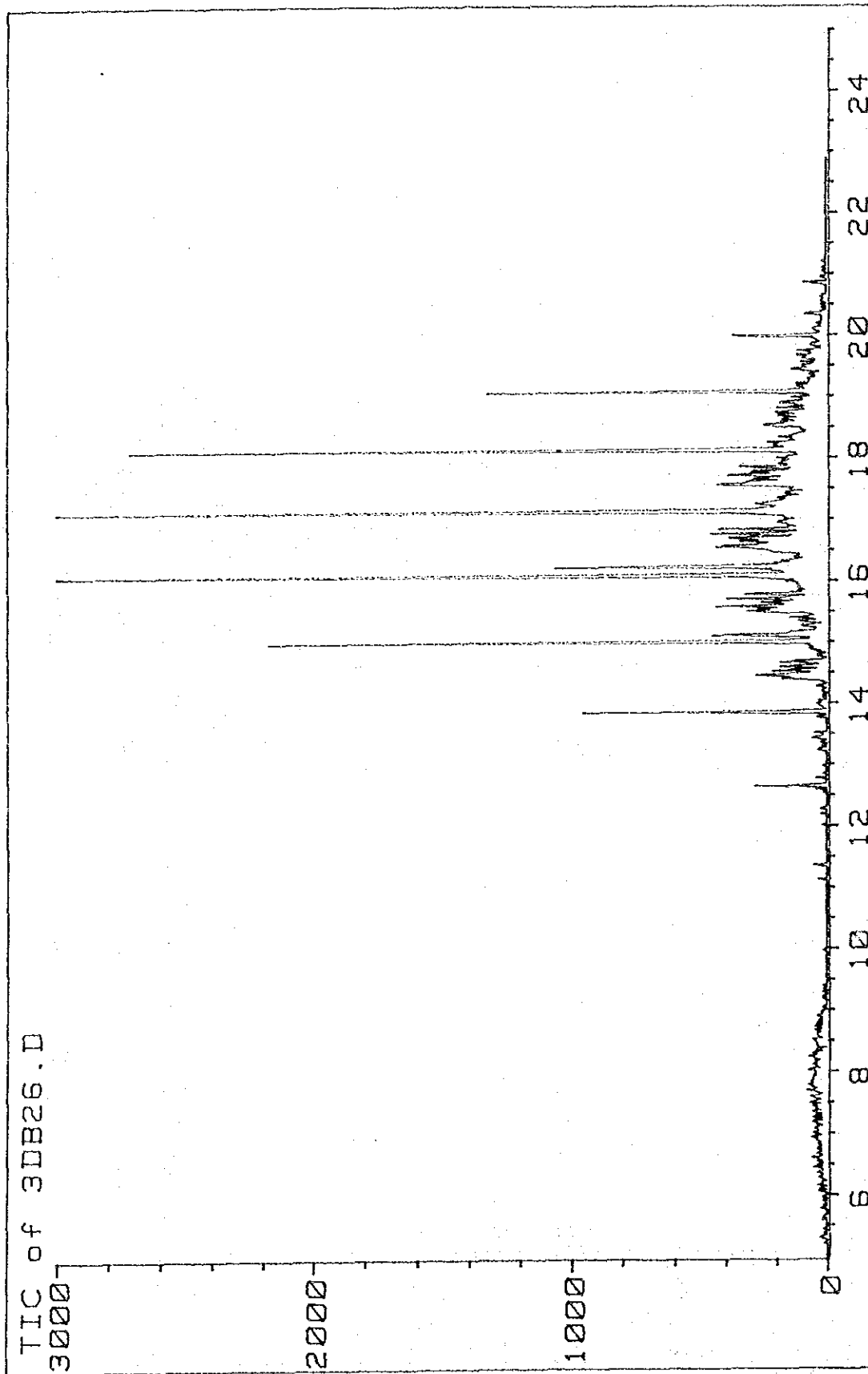


Fig.4.2.5 Computer reconstructed ion chromatogram of second fraction of 10mg/l oil test



3.2.26

Fig.4.2.6 Computer reconstructed ion chromatogram of third fraction of 10mg/l oil test

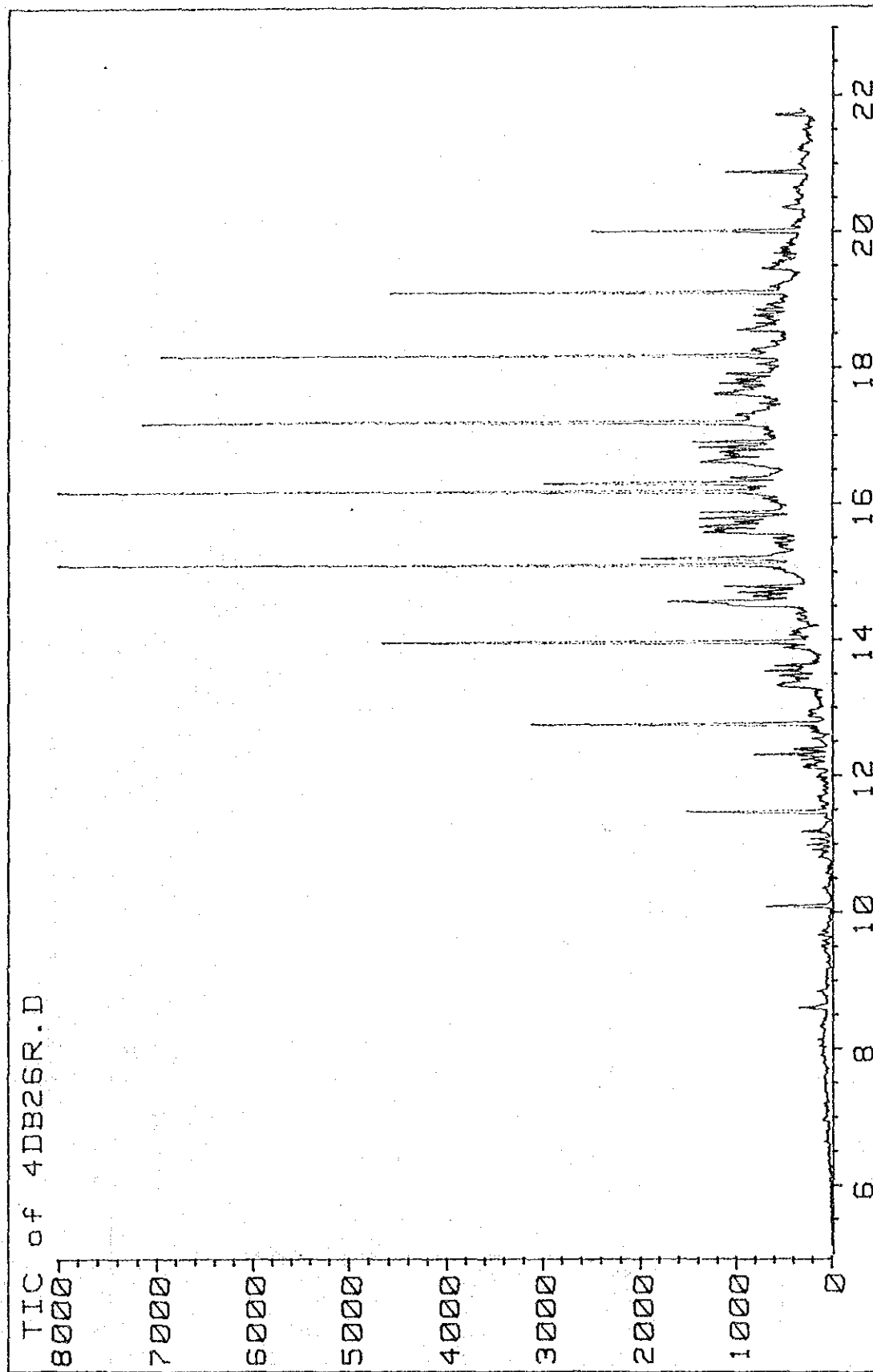


Fig.4.2.7 Computer reconstructed ion chromatogram of brine fraction of 10mg/l oil test

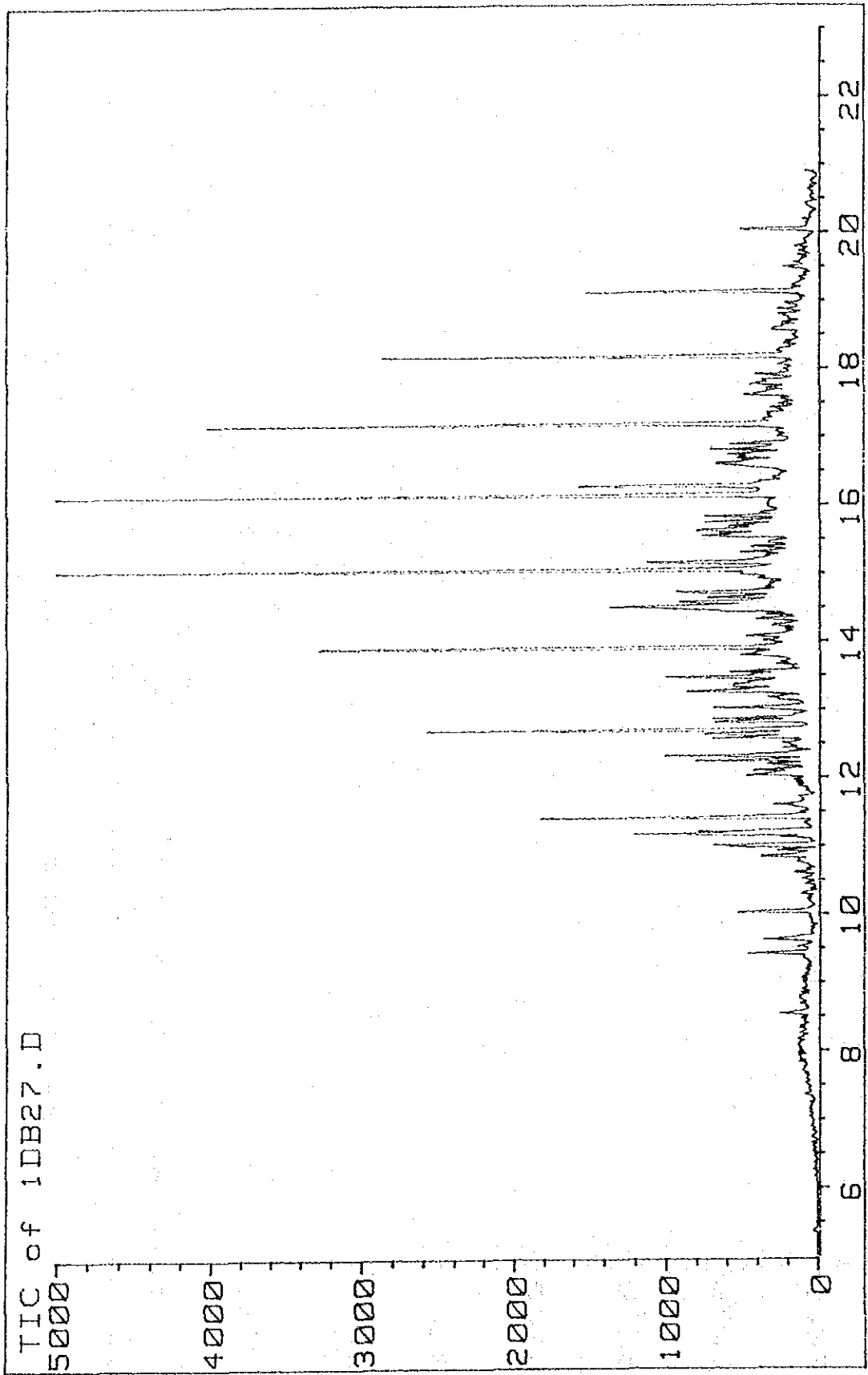


Fig.4.2.8 Computer reconstructed ion chromatogram of first fraction of 50mg/l oil test

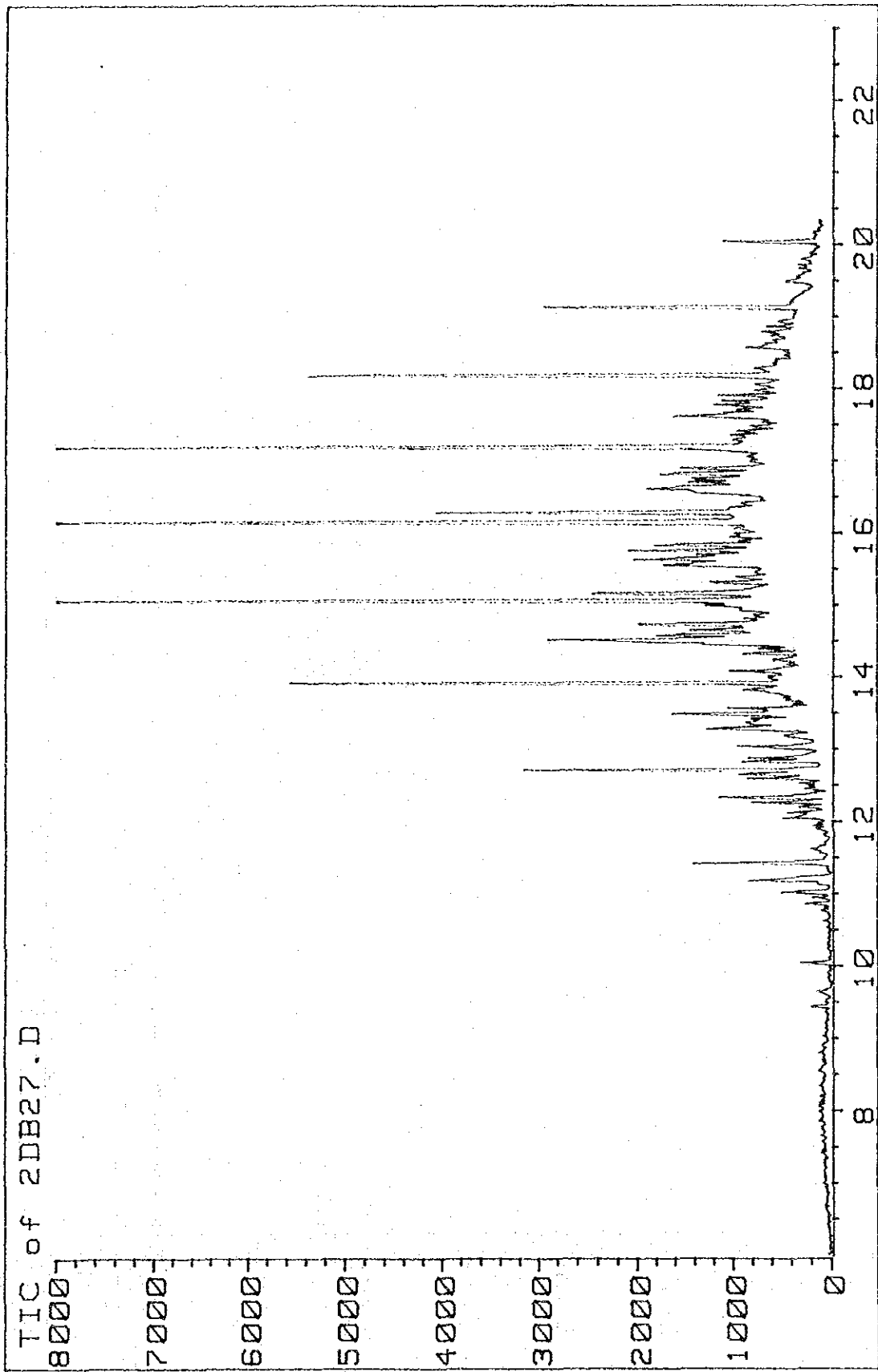


Fig.4.2.9 Computer reconstructed ion chromatogram of second fraction of 50mg/l oil test

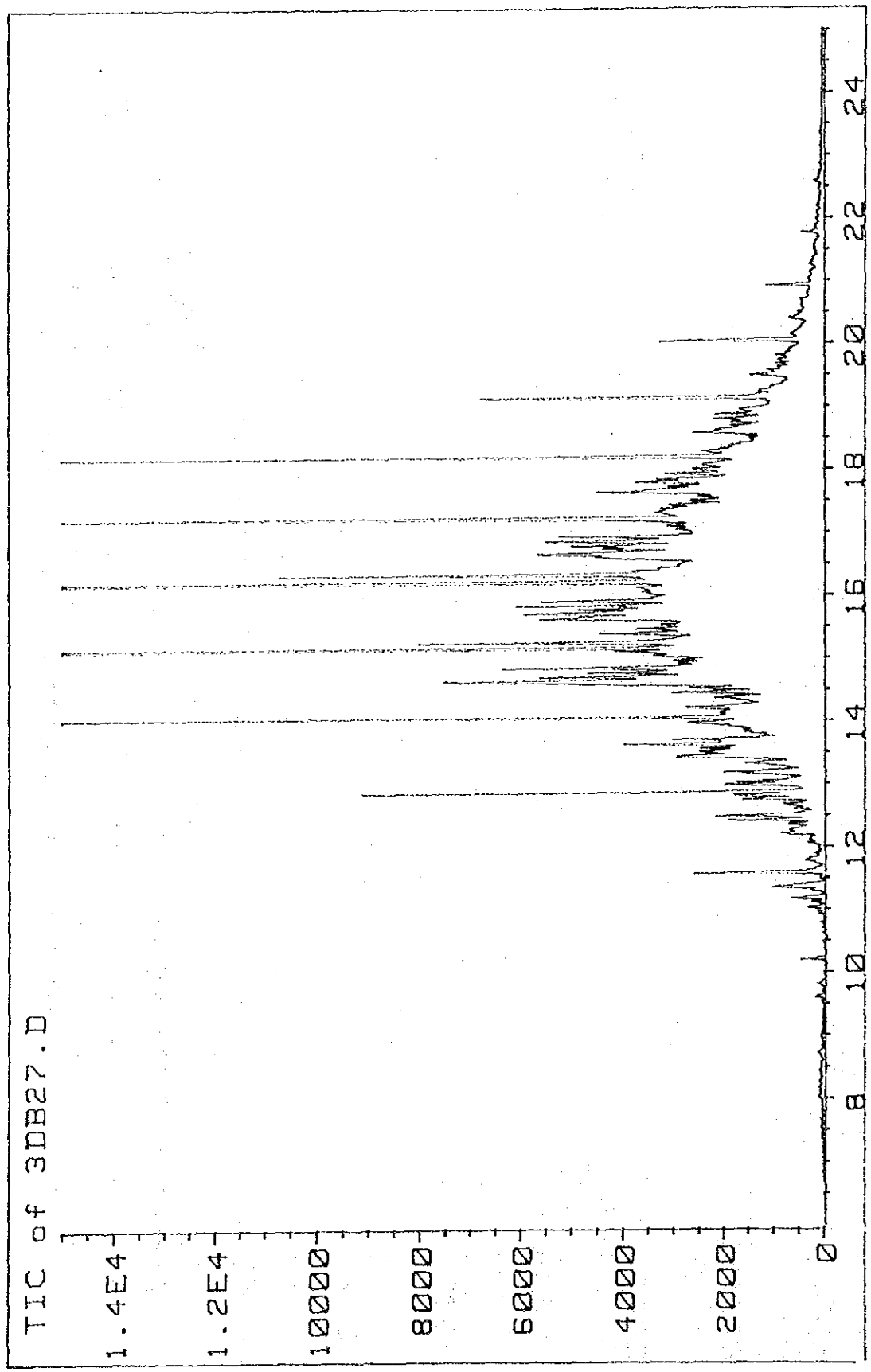


Fig.4.2.10 Computer reconstructed ion chromatogram of third fraction of 50mg/l oil test

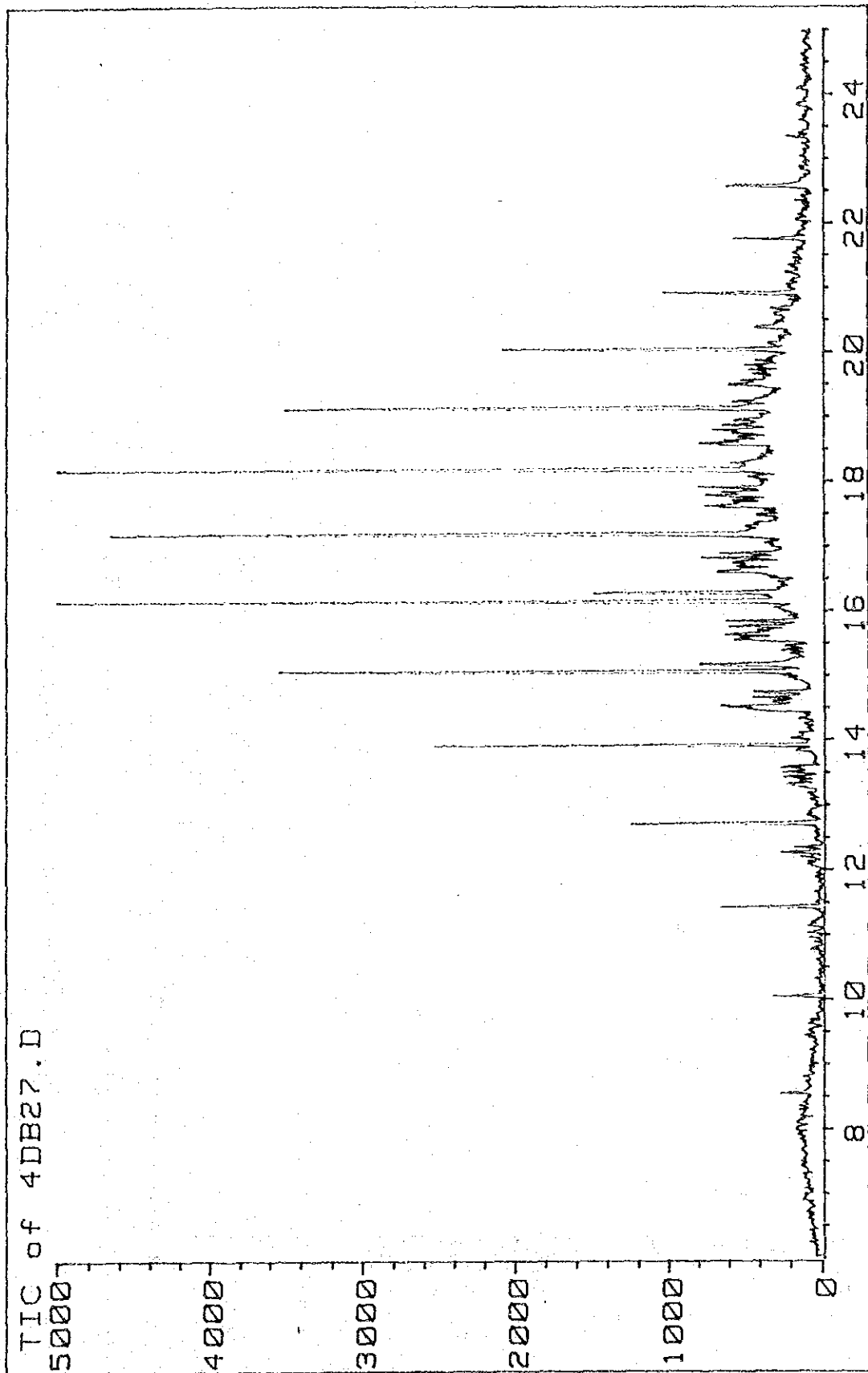


Fig.4.2.11 Computer reconstructed ion chromatogram of brine fraction of 50mg/l oil test

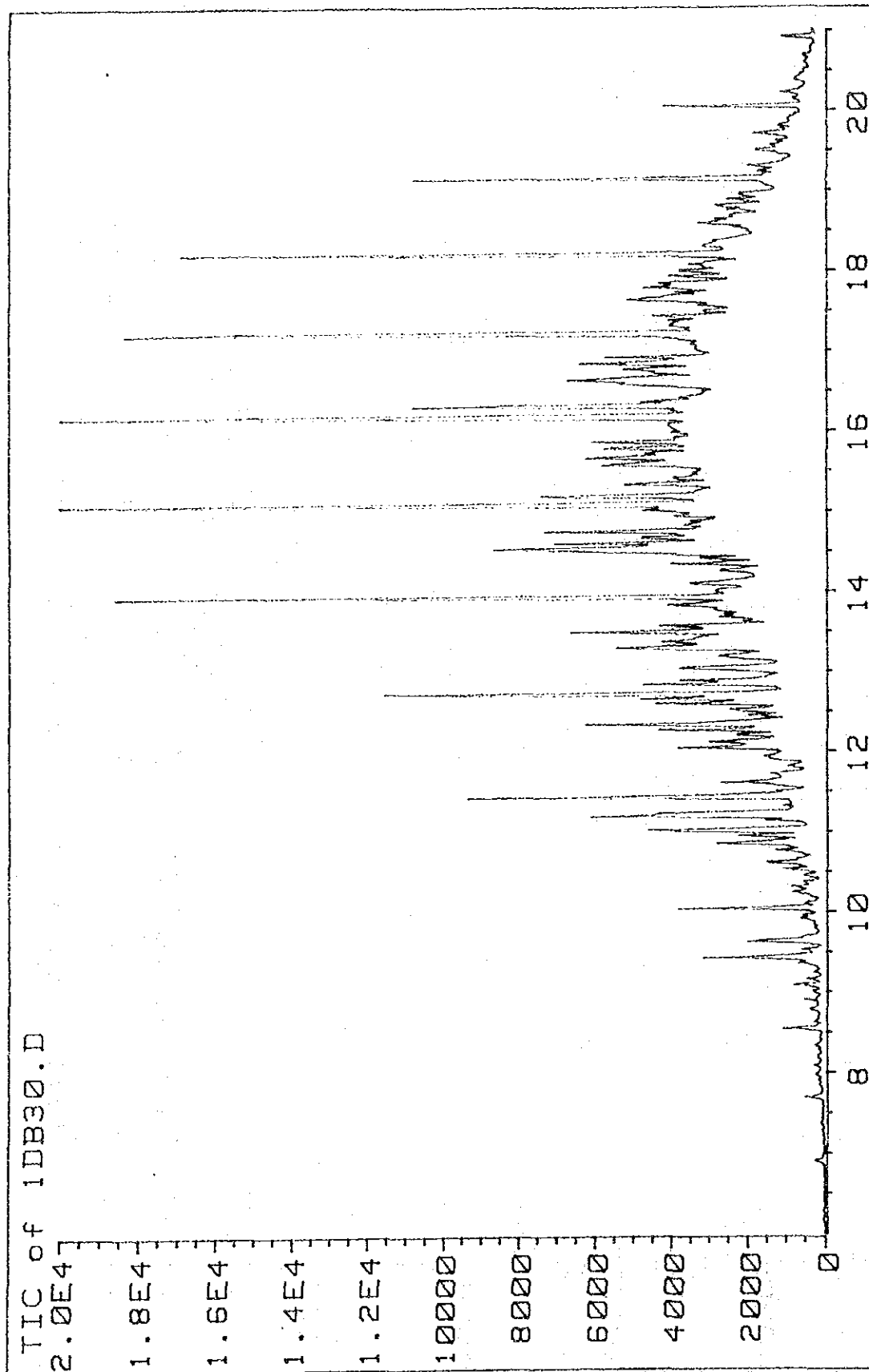


Fig.4.2.12 Computer reconstructed ion chromatogram of first fraction of 100mg/l oil test

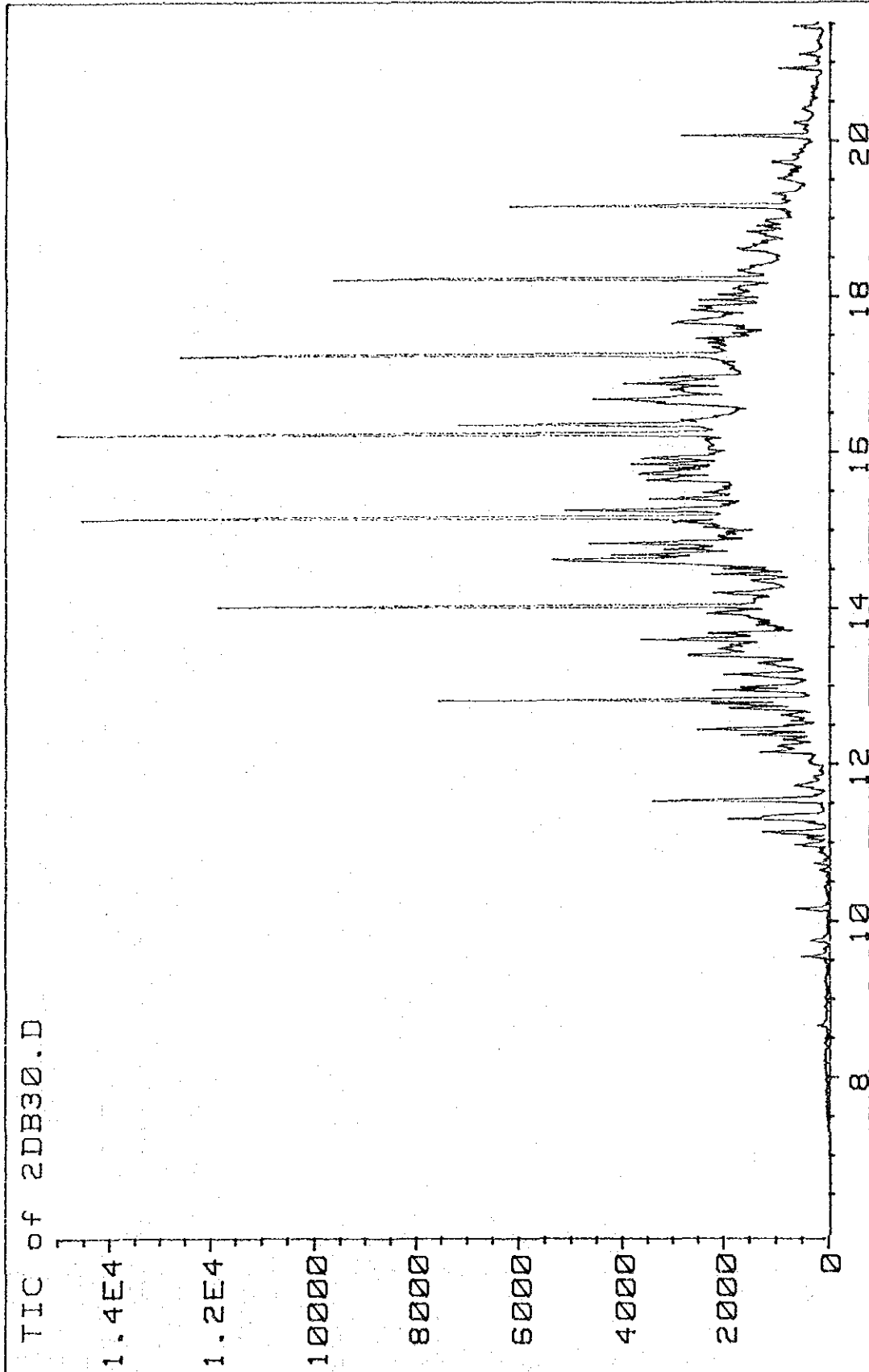


Fig.4.2.13 Computer reconstructed ion chromatogram of second fraction of 100mg/l oil test

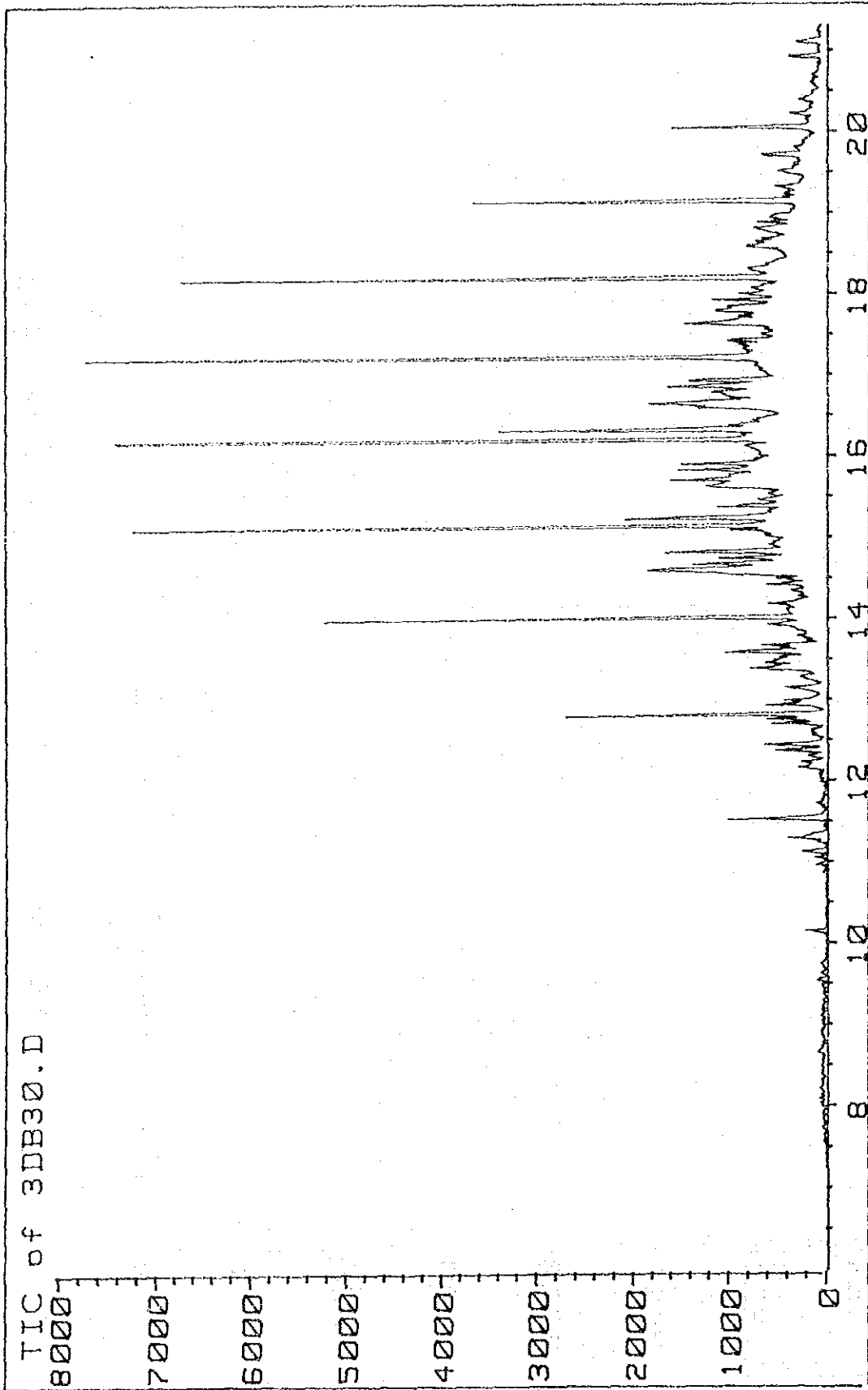


Fig.4.2.14 Computer reconstructed ion chromatogram of third fraction of 100mg/l oil test

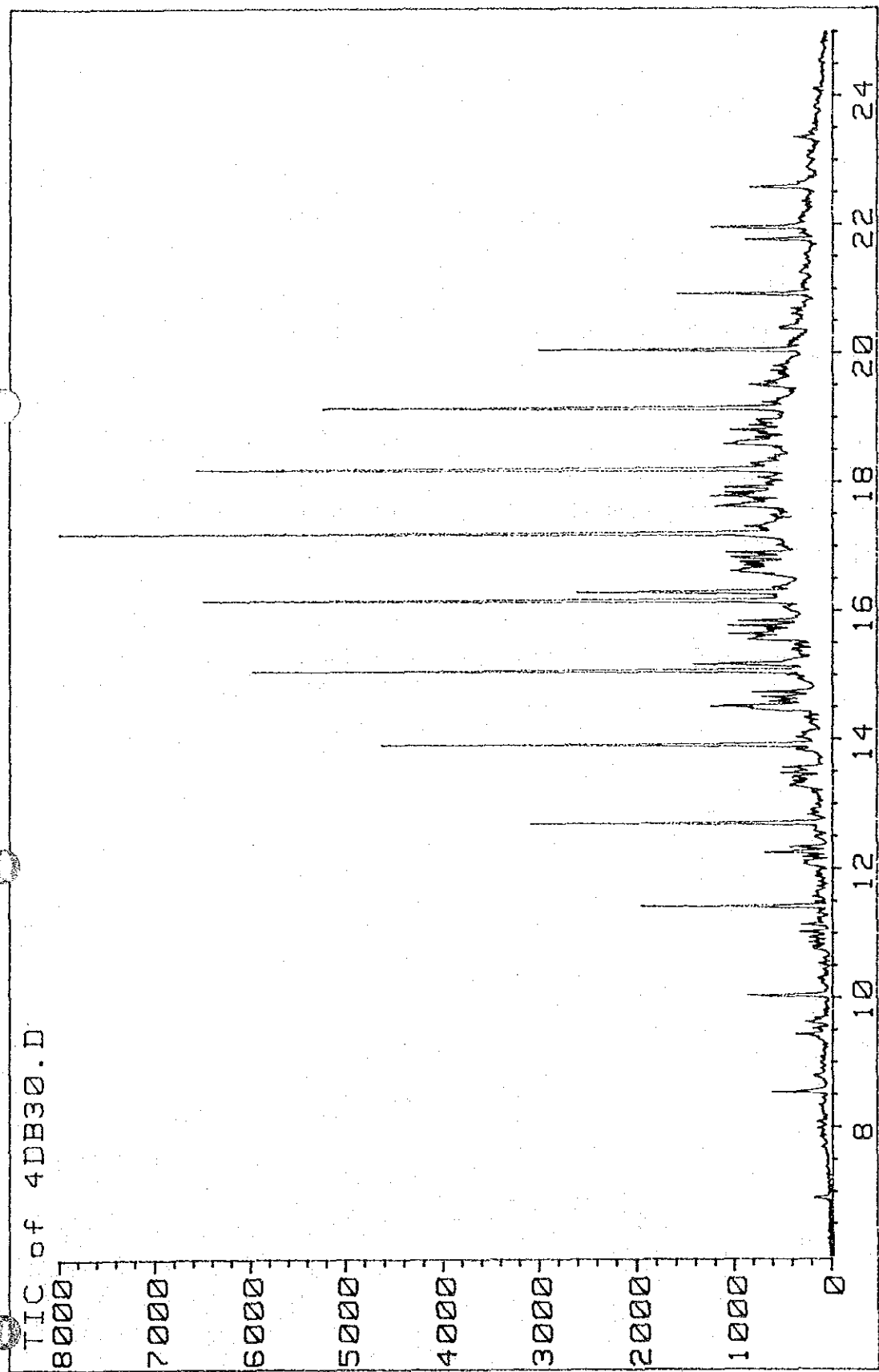
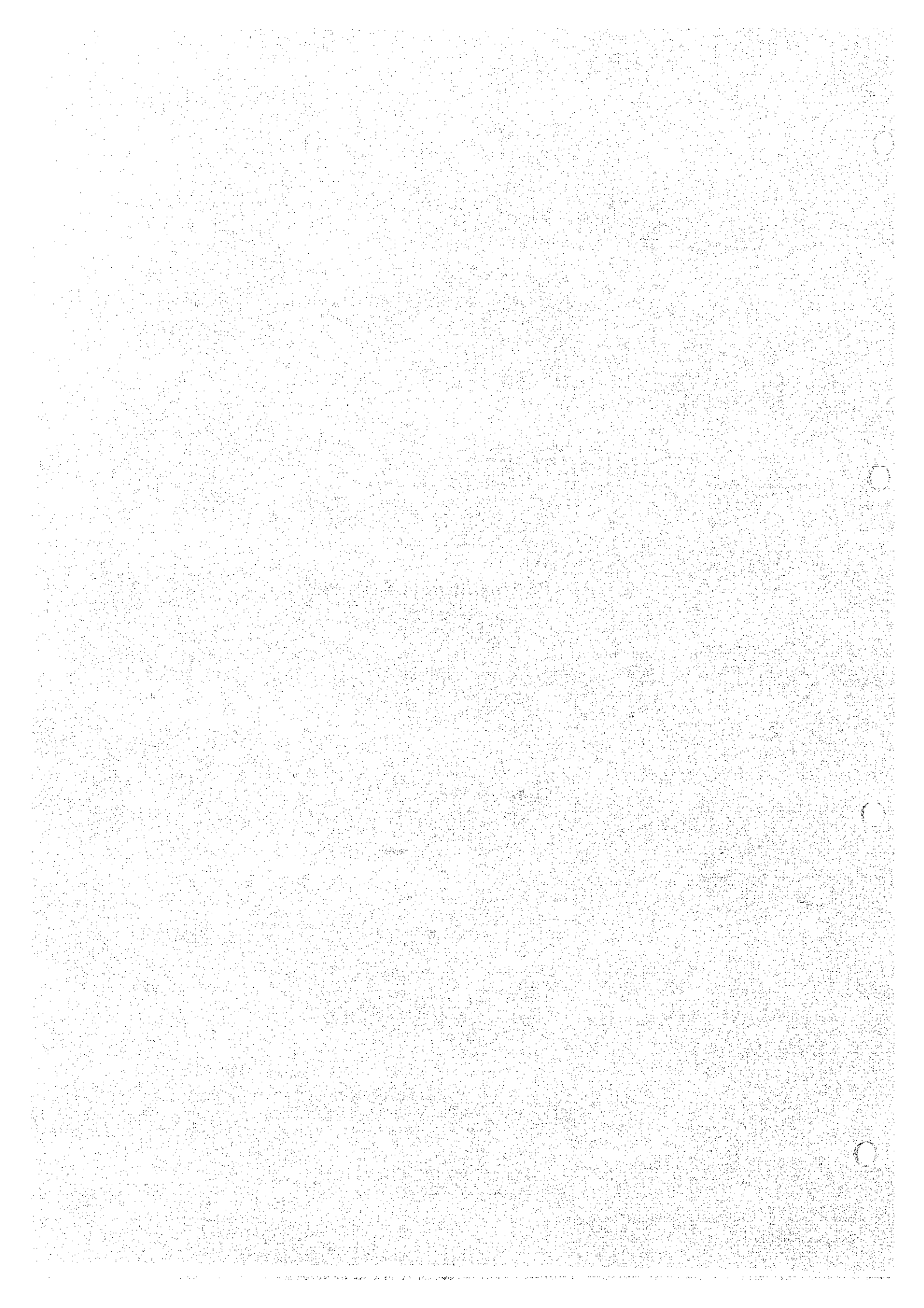


Fig.4.2.15 Computer reconstructed ion chromatogram of brine fraction of 100mg/l oil test

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3.3 R-2 Pretreatment of Seawater



**RO DESALINATION
EXPERIMENTAL RESEARCH No.3, R-2**

PRETREATMENT OF SEAWATER

**"Effect of Coagulants on Removal of Oil from Oil
Contaminated Seawater"**

JULY 1992

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1. Introduction

Desalination is a major source of water in the Gulf Cooperation Council (GCC) countries. The capacity of installed desalination plants in GCC countries is excess of 7 million cubic meters per day, almost 60% of world total¹. The majority of these plants are based on seawater feed. The industry is still growing at a rapid pace and is expected to remain in the future the major, and in some cases the only water source for the GCC countries.

In the past, desalination plants were designed with the assumption that the seawater is non-polluted and remains relatively clean. However, the purity of seawater feed to desalination plant is not always guaranteed, particularly in the Gulf region where hundreds of million tons/year of crude petroleum are produced and transported through the Gulf sea. Thus, the tendency of seawater oil pollution is very great. The pollution could arise from oil spillage from tankers, or from off-shore oil wells, or because of war destruction of oil installation and oil carriers. The many refineries and other oil production facilities on the coastal zone are also sources for possible oil pollution. In general, there is a slow and gradual build-up of oil pollution in the Gulf seawater. Indeed, in the Gulf two environmental problems are faced by the desalination industry : accidental oil spillage in the short-term and a gradual build-up of seawater pollution in the long-term.

As mentioned above, oil pollution is becoming a serious problem. We already have much information for the removal of suspended solids (See APPENDIX R2-1). Therefore the subject discussed in this report is limited to the pretreatment of oil polluted seawater.

SWRO membranes may be damaged if contacted with oil. Until now however no major damage to SWRO membranes due to oil pollution has been reported even in the plants built in proximity to sites with high oil pollution tendency².

In a few cases minor damage has been reported but this has been corrected by proper measures, e.g., membrane cleaning and/or proper intake design. DuPont, a membrane manufacturing company, reported that if the oil is soluble in the seawater feed it is unlikely to cause membrane fouling or damage. Part of the oil passes through the membrane, the remainder is rejected to the drain. This hypothesis is true if none of the oil fractions react with the membrane. On the other hand, immiscible oil should not be permitted in the feed of the membranes². In general oil sticks to solid surfaces and in case of seawater there is a strong tendency for a small quantity of oil to thinly cover a large surface area. In case of oil contaminated SWRO feed even a small amount of oil may cover a large surface area of membrane and could drastically reduce the membrane performance. Several of the membrane companies which have been contacted in a survey are not able to give the maximum oil tolerance level of their membrane, but all recommend complete removal of oil from the feed to SWRO plant.

In any way, to avoid possible membrane damage by oil, the study of oil pollution in

seawater intake should be carried out on a continuous basis. Although, little attention has been paid in the past for the protection of desalination plants against oil pollution and oil spillage, now it is necessary not only to look into best means of oil pollution prevention but also to make better plant and seawater intake design. The development of plants less susceptible to damage caused by oil spill and seawater oil pollution is highly desirable. The conventional counter measures for oil removal in case of oil spillage require considerable time for their application. For a steady water supply, proper pretreatment of feed for the removal of oil from polluted feed is very essential and should be considered seriously during the plant design and construction.

In some plants active carbon filters are used to remove low concentration soluble as well as suspended oil¹⁰. A low cost procedure other than active carbon, however, is desired for the removal of oil pollutant from RO feed. One possibility is through the coagulation - filtration process which now constitutes an essential part of the pretreatment process used in RO desalination.

The effect of the coagulation-filtration process on oil removal from oil contaminated feed has not been precisely determined. This report describes work done jointly by researchers from "Japan International Cooperation Agency" (JICA) and their counterpart from "Saline Water Conversion Corporation" (SWCC) on the evaluation of various coagulant on the removal of oil from oil contaminated seawater feed. In this laboratory experiment, coagulation-filtration was used to remove oil from an artificially induced oil contamination of seawater. Four different coagulant were employed in this investigation: ferric chloride, poly-aluminium chloride (PAC), aluminum sulfate, and hydroxy-ethyl-cellulose (HEC). Properties of oil flocs in seawater, their shape and size are also examined in this report.

2. Literature Survey

2.1 Oil Solubility in Seawater

In the initial stages of oil spillage in the sea, the low molecular weight fraction of the oil evaporates leaving behind the larger molecular weight hydrocarbons. Under normal, natural conditions nearly all the oil fraction with a boiling point less than 270°C are believed to evaporate within 24 hours.

This fraction corresponds to the straight chain saturated hydrocarbons having a carbon number of 15 or less. A second fraction tends to form heavy residue (tar balls) which sinks to the bottom of the sea or deposits on the coastal area. A third fraction forms emulsion and disperses in the seawater. Oil is made of hydrocarbon compounds which practically have very low solubility in water.

It is not clear in what form this last third oil fraction exists in seawater, whether it is in the soluble or very fine emulsion states. For convenience this fraction shall be defined as the

miscible fraction and may be loosely defined also as the soluble fraction. This is shown in Table 2.1.1. Crude oil solubility is less than 30 mg/l in seawater and tends to increase as the amount of aromatic compounds in the oil is increased³.

Other reports show a much lower crude oil solubility in seawater of 0.1–0.4 mg/l⁸ and 5–10 mg/l⁵. Light oil tend to have a much higher solubility in seawater than the crude oil (Table 2.1.1). In general, solubility of hydrocarbon compounds in water increases as the degree of unsaturation is increased. For example cyclohexene has a solubility of 213 mg/l as compared to only 55 mg/l for cyclohexane solubility in water⁶. Meanwhile, benzene which has a higher degree of unsaturation than cyclohexene has a much greater solubility of 1650 mg/l (see Table 2.1.3). Low molecular weight hydrocarbon molecules have greater solubility in seawater than large molecular weight hydrocarbon molecules.

Also, hydrocarbon molecules with large polarity and low molecular weight tend to dissolve more easily in water than those with less polarity and larger molecular weight.

As seawater is usually fed from intake at the water depth of 4–10m under the seawater surface, oil particles having a large diameter could be separated by flotation. Floating velocity of an oil particle calculated by Stokes' Law shows that the floating velocity of an oil particle having diameter of 20 micro-meter is 19 cm/hr. In other words, it takes 5.26 hr to float it up from a 10 meter depth, (Table 2.1.2). An experiment measuring floating velocity of fuel oil "B" in artificial seawater shows that the experimental floating velocity is always higher than the calculated velocity. This is caused by formation of large particles formed by the combination of the small particles during flotation¹².

Normally, oil particles with a diameter of 100 μ m form a primary emulsion which is generally unstable and easily separated by gravity when the emulsion is settled. If the emulsion is subjected to stronger energy a secondary emulsion with a particle size of 25 μ m or less is formed which remains stable for one week to one month and is hard to separate.

2.2 Present Pretreatment at SWCC SWRO Plants

Presently there are five major SWRO plants built by SWCC on the Red Sea :

- * The 2275 m³/d Al Birk plant, commissioned in March, 1983,
- * The 4400 m³/d Umm Lujj SWRO plant, commissioned in May, 1986,
- * The 56800 m³/dJeddah-I, commissioned in April, 1989,
- * The 4400 m³/d Duba SWRO plant, commissioned in June, 1989 and
- * The 4400 m³/d Haql SWRO plant, commissioned in October, 1989.

The five plants employ seawater intakes at depths of 4–12 m below seawater level. The

Table 2.1.1 Concentration and particle size of oil in seawater

Sample of oil in water	Concentration of oil (mg/l)	Concentration of Particle size of oil (μm)	Literature
Concentration of crude oil in seawater	20 - 28		4
Concentration of light oil in 2% salt water	40.5		
100T of Kuwait crude oil were discharged. After 24 hours samples at various depth were analyzed.	0.1 - 0.4		8
Crude oil was mixed with artificial seawater using magnetic stirrer	5 - 10		2
Concentration of light oil in seawater at 20 °C	5 - 20		3
Concentration of fuel oil "B" at room temperature and 50 °C	30 - 70	< 5 μm : 84% 5 - 10 μm : 16%	12
Concentration of fuel oil in seawater	50 - 100		14
Solubility of hydrocarbons in water	n-Hexane: 9.5 n-Octane: 0.66 Cyclohexane: 55		1

Table 2.1.2 Oil particle size vs. floating velocity

Diameter of Oil particles (micron)	Floating velocity (cm/hr)	Oil floating time from 10 m depth (hr)
100	476.	0.21
40	75.	1.31
20	19.	5.26
10	4.76	21.0
8	2.82	35.5
6	1.58	65.3
4	0.71	141.
2	0.18	555.
1	0.48	2080.

Table 2.1.3 Solubility of hydrocarbons(mg/l) in water⁶

Straight chain hydrocarbon(C ₈)	Straight chain hydrocarbon(C ₆)	Cylic hydrocarbon(C ₆)
n-Octane 0.66	n-Hexane 9.5	Cylohexane 55
Octene-1 2.7	Hexene-1 50	Cyclohexene 213
		Benzene 1650

pretreatment consists of : disinfection, coagulation–flocculation, filtration, dosing of antiscalant and removal of chlorine in one plant⁸.

Ferric chloride (1.7 ppm) is used as a coagulant at Jeddah–1, while ferric sulfate at a concentration of 0.57 ppm and 3 ppm is used as a coagulant at Haql and Duba plants, respectively (Table 2.2.1). Magnifloc 573C is dosed at the rate of 2.3 ppm in the feed to Al–Birk SWRO plant. No coagulant, however, is added to the feed of Umm Lujj, although in earlier runs intermittent use of ferric chloride was employed in the coagulation step⁸.

As shown in Table 2.2.1, differences exist among the plants filtration system. The Jeddah–I SWRO plant has only one stage of gravity–type dual media filter. By comparison, the Al–Birk, Haql and Duba plants each have two stages of filtration, both of which are pressure–type dual media filters. The Umm Lujj plant has a combination of gravity dual media filter in the first stage and a pressure dual media filter in the second stage.

The media depth and particle size are different (see Table 2.2.1). For example, at Umm Lujj the media depth for the sand layer is 20.32 cm and the particle size is 0.55–0.65 mm. By comparison, the sand layer thickness in the Jeddah–I SWRO dual media gravity filter is 60 cm or a difference of about 40 cm in sand thickness and with a slightly finer sand particle size of 0.45 mm. At Al–Birk the sand layer depth in the first pressure dual media filter is 72 cm with a much coarser sand particle size of 1.35 mm. Coarse sand is also used in the first pressure dual media filters of Duba and Haql where the sand particle size is 0.71–1.25 mm. Differences in sand layer thickness and particle size are also noticed among the second stage pressure sand filters of the various plants.

At the end of the pretreatment plant process a fine cartridge filter is used to remove the very fine materials that are not removed by the dual media filters. Cartridge filter particle size separation falls between 5 and 20 μm . Different housing materials are used in the cartridge filter of the five plants. RTR and FRP materials are used at Jeddah–I and Al–Birk SWRO plants while stainless steel housing is used in the cartridge filters of the remaining plants at Umm Lujj, Haql and Duba plants.

Luckily, the Red Sea water is free of oil pollution and so far no membrane damage or reduction in membrane performance due to oil pollution has been observed. Although, the Gulf seawater is more exposed and liable to oil pollution, so far no SWRO plant damage due to oil has been reported.

It can be concluded that in SWCC SWRO desalination plants the coagulation filtration step is used as part of the feed pretreatment. Several coagulant: ferric chloride, ferric sulfate or polyelectrolyte polymers is used as coagulant. Sand, Anthracite and in some case active carbon are used in the dual media system.

Ferric chloride or aluminum sulfate or poly–aluminium chloride or water soluble poly–

mers such polyethylene oxide and hydroxyethylcellulose are used as coagulant in waste water treatment. The first three coagulant are used in coagulation-sedimentation processes while hydroxyethyl cellulose is employed as a coagulant aid in the air-flotation of oily waste water. The optimum range for each of these coagulant is given in Table 2.2.2¹³. Generally speaking, these coagulant are effective in air-flotation processes but it is not established if they are equally effective in the coagulation-filtration process of oil contaminated seawater feed. This is to be investigated in this study.

3. Experimental Procedures

3.1 Composition of Oil Used in this Experiments

As mentioned earlier in the initial stages of an oil spill in the sea, low molecular weight components evaporate and dissipate into the air. Components of oil with a boiling point of less than 270°C are believed to evaporate within 24 hours. Gasoline, kerosene and about 50% of the contents of gas fall into this category.

In this experiment fuel oil "A" (in the Japanese Industrial Standard corresponds to No. 4 in ASTM) was used to simulate oil in oil contaminated seawater.

Composition of the fuel oil "A" was analyzed using gas chromatography. The instruments used, results and boiling point of saturated straight chain hydrocarbons are summarized in Table 3.1.1, and are shown in Fig.3.1.1 and Fig.3.1.2. Fuel oil "A" may be considered as a suitable oil to simulate the behavior of oil in seawater contaminated by crude oil.

3.2 Seawater Used in this Experiment

The seawater used in this series of experiments was chlorinated seawater taken from the feed to SWCC seawater desalination plants, Al-Jubail, the Kingdom of Saudi Arabia. The average seawater composition prior to chlorination is as shown in Table 3.2.1. The seawater intake facilities consist of : intake pumps, bar screens, traveling screens and chlorination units, injecting 2 to 2.4 mg/l of chlorine as disinfectant. Residual Chlorine (Cl₂) concentration in the feed prior to deaeration ranges between 0.1 to 0.2 mg/l.

3.3 Preparation of Oil Contaminated Seawater

For this experiment, attempts were made to have a stable emulsion for a duration of at least 30 minutes with oil concentration of 30 -50 mg/l and oil particle size ranging between 2-20 micrometer. To prepare this emulsion with the above properties, 900 ml of chlorinated seawater and 1 ml of Fuel oil "A" were mixed for 15 minutes in a blender (National Mixer MX-M1) maintaining the emulsion temperature below 35°C. The emulsion was allowed to stand for 5 minutes prior to siphoning of 700 ml from the lower layer into another beaker.

Table 2.2.1 SWCC SWRO plants-coagulation filtration systems

Description	Jeddah-I	Umm Lujj	Haql	Duba	Al-Birk
<u>Coagulant</u>					
Chemical	FeCl3.6H2O	None	Fe2(SO4)3	Fe2(SO4)3	Magnifloc 573C
Dosing rate (mg/L)	1.2-1.3		0.57	3	2.3
<u>Filter #I</u>					
Type	Gravity	Gravity	Pressure/Vertical	Pressure/Vertical	Pressure/Vertical
Material	Concrete	Concrete	Rubber lined steel	Rubber lined steel	Rubber lined steel
Anthracite Particle size (mm)	0.9	0.85-0.95	1.14-2.5	1.40-2.5	-
Anthracite Depth (cm)	60	20.32	50	60	
Sand Particle size (mm)	0.45	0.55-0.65	0.71-1.25	0.71-1.25	1.35
Sand Depth (cm)	60	20.32	50	50	72
<u>Filter #II</u>					
Type	None	Pressure/Vertical	Pressure/Vertical	Pressure/Vertical	Pressure/Vertical
Material		Rubber lined steel	Rubber lined steel	Rubber lined steel	Rubber lined steel
Anthracite Particle size (mm)		0.8-0.9	Nil	Nil	0.82
Anthracite Depth (cm)		25.4			40
Sand Particle size (mm)		0.45-0.55	0.4-0.8	0.4-0.8	0.6
Sand Depth (cm)		25.4	90	90	40
<u>Cartridge Filter</u>					
Size (micron)	10	20	5	5	5
Change rate	Once/2-3 months	Once/3 months	Once/6 months	Once/6 months	Once/month
Housing material	RTR	317L	316L	316L	FRP

Table 2.2.2 Coagulants used in the experiments and optimum pH

Coagulants		Optimum pH
Ferric Chloride	FeCl ₃	5 - 11
Aluminium Sulfate	Al ₂ (SO ₄) ₃	5 - 7.3
Poly Aluminium Chloride	PAC	5.3 - 7.3
Hydroxyethylcellulose		

Table 3.1.1 Carbon distribution of fuel oil "A" and boiling point of saturated straight chain hydrocarbon for each carbon number

Numbers of Carbons	Composition %	Summation %	Boiling Point Degree C	Solubility mg/l
8	0.22	0.22	125.7	0.66
9	1.90	2.12	150.5	
10	3.48	5.60	174.0	
11	4.28	9.88	196.7	
12	4.88	14.76	216.3	
13	5.88	20.64	235.4	
14	8.19	28.83	253.7	
15	10.69	39.52	270.6	
16	10.66	50.18	287.1	
17	9.06	59.24	301.8	
18	8.42	67.66	316.1	
19	7.68	75.34	329.7	
20	6.14	81.48	343.2	
21	5.07	86.55	356.5	
22	4.07	90.62	368.6	
23	3.05	93.67	380.2	
24	2.42	96.09	391.3	
25	1.59	97.68	401.9	
26	1.09	98.77	412.2	
27	0.65	99.42	442.2	
28	0.31	99.73	431.6	
29	0.18	99.91	440.8	
30	0.08	99.99	449.7	
31	0.02	100.01	458.3	

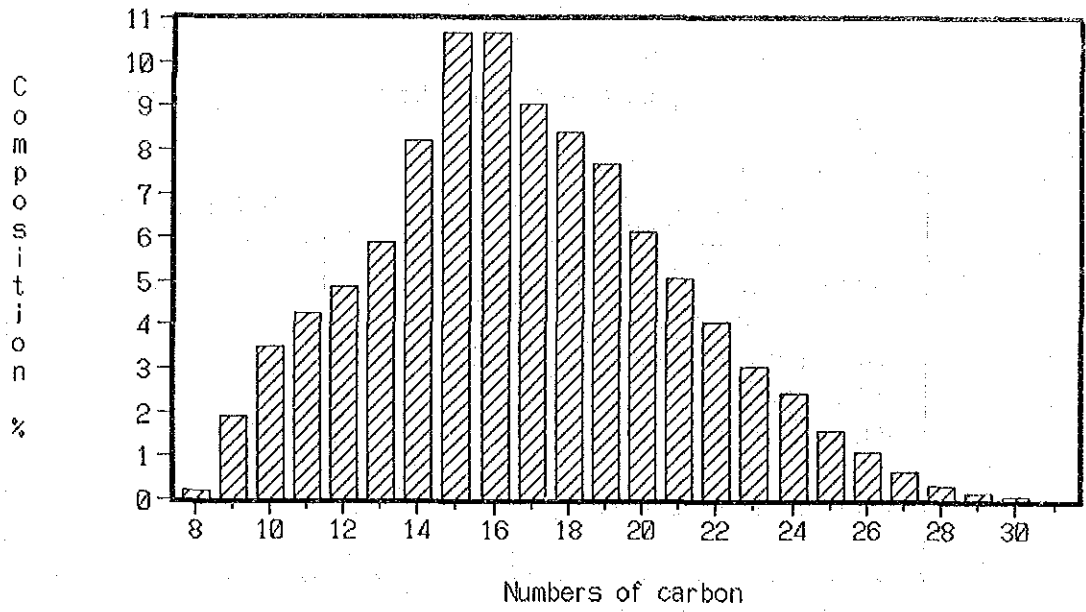


Fig. 3.1.1 Carbon distribution of fuel oil "A"

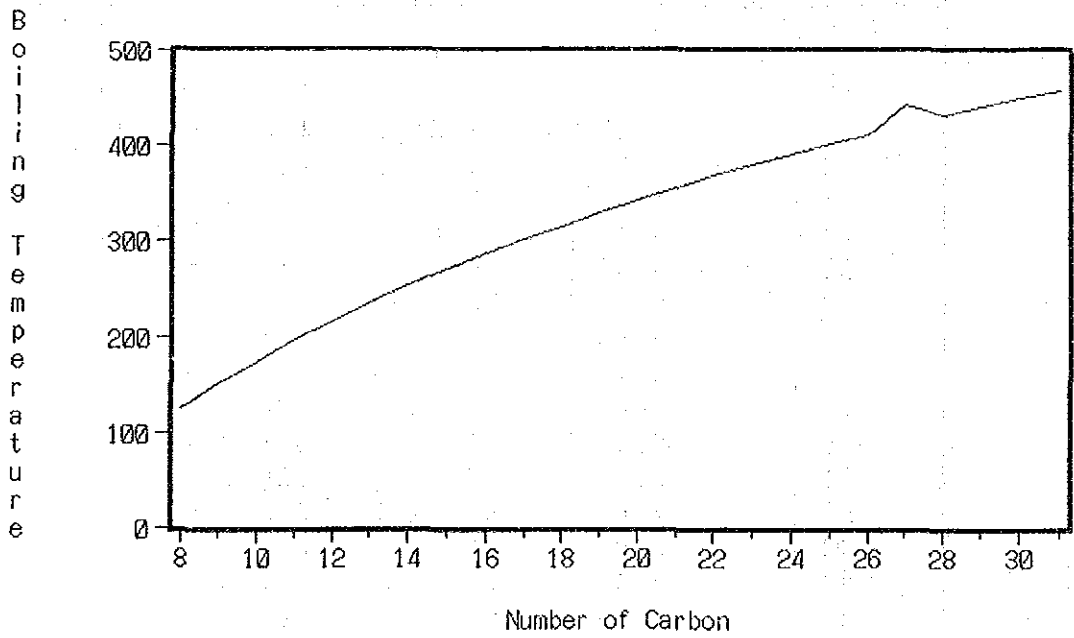


Fig. 3.1.2 Carbon number and boiling point of fuel oil "A"

Table 3.2.1 Composition of seawater used in the experiment

Temperature			26.5
pH			8.1
Conductivity		μ S/cm	62,800
Dissolved Oxygen	(O ₂)	mg/l	6.6
Total Dissolved Solids	(TDS)	mg/l	43,800
Total Alkalinity	(CaCO ₃)	mg/l	144
Carbon Dioxide	(CO ₂)		2
Total Hardness	(CaCO ₃)	mg/l	8,010
Calcium	(Ca ⁺⁺)	mg/l	508
Magnesium	(Mg ⁺⁺)	mg/l	1,618
Sodium	(Na ⁺)	mg/l	13,440
Potassium	(K ⁺)	mg/l	483
Strontium	(Sr ⁺⁺)	mg/l	17
Bicarbonate	(HCO ₃)	mg/l	176
Chlorine	(Cl ⁻)	mg/l	24,090
Sulphate	(SO ₄ ⁻⁻)	mg/l	3,384
Bromide	(Br ⁻)	mg/l	83
Fluoride	(F ⁻)	mg/l	1

This method allows the larger oil particles to float on the surface and only the miscible meaning the suspended, or emulsified or dissolved oil is transferred in the seawater. The 700 ml of emulsion was allowed to stand for 60 minutes after which 500 ml was siphoned again from the lower layer keeping behind the larger oil particles floating on the surface of the remaining 200 ml. The 500 ml collected emulsion was homogenized for an additional 5 minutes keeping the temperature below 35°C. A sample of 200 ml of the homogenized emulsion was then mixed with 800 ml of seawater. The mixture was continuously stirred at 100 rpm until the coagulant was added.

The emulsion prepared by the above procedure was stable for 25 minutes, having an oil concentration of 44 to 45 mg/l (Table 3.3.1) and a particle size of 0.5 to 3.0 micrometer. Table 3.3.2 shows the particle size distribution of the emulsion before settling 60 minutes and the emulsion prepared.

3.4 Oil Coagulation and Filtration of the Coagulated Floccs

3.4.1 Filtration of Coagulated Floccs

In SWRO desalination plants the pretreatment process is used to remove finely suspended particles of inorganic, organic and biological matter from the feed. Normally the pretreatment consist of an in-line coagulation step followed by dual media and micron filtration(see section 2.2). Antiscalant chemicals are also dosed during this step prior to micro filtration. In this experiment it is anticipated that the coagulation-filtration steps may remove the oil from oil contaminated seawater feed.

The first work done in this experiment was the selection of a suitable filter media that simulates the work of the dual media filter normally used in the pretreatment of feed to the SWRO plant with the restriction that this filtering material does not retain the suspended oil. The main problem here is the size of the experimental sample which is very small (1 liter) and posed restriction on the selection of the filter medium. Several types of filter materials were tested to select the most suitable filter material that does not remove the emulsified oil from the emulsion. Table 3.4.1 shows the various filter media investigated. Glass wool fiber was selected for reasons given later in section 4.1.

3.4.2 Coagulation

The coagulation test was performed using the standard jar test, ASTM D2035 for coagulation-flocculation process¹¹.

To 800 ml of seawater was added 200 ml of the fine stable emulsion described in section 4.3 with stirring at 100 rpm using a multi-stirrer unit (Phipps & Bird Inc. Richmond) with variable speed from 20-100 rpm. The beakers were located off center in such a way so that the

Table 3.3.1 Stability of oil emulsion in oil contaminated seawater

Time minutes	Oil concentration mg/l
0	44
15	45
25	45

Table 3.3.2 Particle size distribution of the oil contaminated seawater used in the coagulation-filtration experiment

Diameter micron	Distribution of number of particles			
	Before Settling 60 minutes		Prepared Oil contaminated Seawater	
	%	Summation %	%	Summation %
0.5~ 1.0	29.0	29.0	26.6	26.6
1.1~ 2.0	39.8	68.8	70.8	97.4
2.1~ 2.0	19.4	88.2	2.7	100.1
3.1~ 2.0	3.2	91.4		
4.1~ 7.0	4.3	95.7		
7.1~10.0	3.2	98.9		
10.1~	1.1	100.0		

Table 3.4.1 Effect of various filter media on oil removal

Filter Media	Oil Concentration (mg/l)		Filter Test of Floccs formed 10mg/l of FeCl ₃
	in raw seawater	in filtrate	
Filter paper (glass fiber GA-200)	32	0.7	Clear filtrate
	238	0.5	
	49	0.5	
Sintered glass 40 - 60 (ASTM)	21	13.1	Clear filtrate
Sieves 200, 100, 150 mesh	33	-	Floccs passed through
Glass wool weight 0.9g thin layer	33	5.6	Clear filtrate
Glass wool weight 0.18g thick layer	33	8.0	Clear filtrate
Glass wool weight 0.18g thin layer	31	19.0	Clear filtrate
Glass wool weight 0.18g thin layer	30	23.0	
Glass wool weight 0.18g thin layer	1	0.8	Clear filtrate
Glass wool weight 0.10g thin layer	30	-	Floccs passed through

Table 3.4.2 Effect of various coagulants on oil removal from oil-seawater emulsion

Coagulation-Filtration Process
 (Filter: 0.18g of glass wool)
 (Oil concentration before coagulation: 19 - 38 mg/l)

Dosage	1.5	3	5	10	20
FeCl ₃	1.1	< 0.25	< 0.25	< 0.25	< 0.25
PAC * (1)			0.2	3.0	3.4
Al ₂ (SO ₄) ₃			* (2)	* (2)	* (2)
HEC * (3)			5	2.8	1.3

Remarks:

- * (1) Poly Aluminium Chloride
- * (2) Can not be determined as the fine floccs in the filtrate passed through the glass wool filter
- * (3) Hydroxyethylcellulose

paddles are able to clear the beaker walls by about 1 cm. Temperature was recorded at the start of the test. The coagulant was added and the stirring speed was maintained for one minute at 100 rpm.

To allow for floc formation without their destruction by fast agitation the stirring rate was reduced to 40 rpm and maintained for 20 minutes after which the paddles were removed and the flocs were allowed to settle. Floc formation was observed during this period of coagulation.

The type of coagulant added to the oil-seawater emulsion and their concentration are as shown in Table 3.4.2. The coagulant employed were ferric chloride, aluminum sulfate, poly aluminum chloride and hydroxyethylcellulose at the rate of 1.5, 3.0, 5, 10, and 20 mg/l.

3.5 Analysis of Oil in Seawater

Non dispersive Infrared oil analyzer OCM-220 was used to analyze oil extracted from the emulsion in Carbon tetrachloride solvent. A separatory funnel attached to the oil analyzer was used for the analysis of oil. The oil analyzer meter was calibrated using Fuel Oil "A" as standard. The minimum detectable limit of this equipment was determined to be 0.25 mg/l of oil.

4. Results and Discussion

4.1 Selection of Filter Media

The filtration performance of filter paper No 5 C is approximately similar to that of dual media filter provided the size of the filtrate is quite large.

However in this experiment because the amount of treated emulsion of oil in seawater is very small (1 liter) it became obvious during experiment that almost all the oil in the seawater-oil emulsion was absorbed by the No 5 C filter paper, thereby making this filter paper unsuitable in determining the effectiveness of the coagulant. Several other filter media (see Table 4.1.1) were investigated. Glass fiber filter GA 200 retained nearly all the oil (32 mg/l) in the sample allowing only for 0.7 mg/l to pass through the media into the filtrate. By comparison sintered glass 40-60 ASTM allowed for the passage of most of the oil in emulsion, 13.1 mg/l in the filtrate out of 21 mg/l in the unfiltered emulsion. Glass wool (0.18 gms dry weight of the filter medium) also allowed for the passage of most of the oil in emulsion, i.e., 23 mg/l of oil passed into the filtrate from a emulsion containing 30 mg/l of oil.

Glass wool filter was employed in these experiments since it allowed for a rapid rate of filtration which was not possible with the sintered glass 40-60 ASTM, with the latter the filtration rate was very slow.

4.2 Oil Concentration and Particle Size of Oil in Seawater

Oil concentration in the filtrate is shown in Table 4.2.1 and Fig 4.2.1 as a function of

settling time (in hours) while the effect of settling time on particle size distribution is given in Table 4.2.2. The oil concentration in the filtrate decreases gradually with time from 69.46 mg/l after one hour of settling to 66.65 mg/l after four hours and decreases drastically reaching a value of 6.11 mg/l after 70 hours. These results were obtained by blending of 15 ml of fuel oil "A" in 1,000 ml seawater mixed using the blender, then diluted with 9,000 ml of seawater, then settle in a 10,000 ml beaker. As seen from Table 4.2.2 nearly none of the particle size exceeds 8 micrometer when settling time is 70 hours, although some relatively large size particles in excess of 9 micrometer are noticed when the settling time was only 2 hours. In either case of the 2 hours and 70 hours settling time the majority of the oil particles have sizes less than 6 micrometer. The percentage number of oil particles with sizes less than 6 micrometer represents 92.7% of the total oil particles in the two hours settling time sample and rises slightly to 97.8% of the total particles when the settling time is 70 hours.

4.3 Effect of Coagulant on Oil Removal

Table 3.4.2 shows the effect of the various coagulant examined on oil removal from oil contaminated seawater. It can be concluded that ferric chloride is the most effective coagulant. At concentration as low as 3 mg/l of ferric chloride the oil is nearly completely removed from emulsion and the oil concentration in the filtrate is below the oil meter's detectable limit of 0.25 mg/l. The increase in the level of Ferric Chloride to 5, 10, 20 mg/l gives the same conclusion that no oil is detected in the filtrate of the coagulated emulsion as determined by the present analytical method. Other coagulant even when used at higher levels of coagulant concentration up to 20 mg/l does not reduce the oil content in the filtrate to the same level as with the addition of 3 mg/l of ferric chloride to the emulsion of oil in seawater.

Addition of any of the three coagulant PAC, HEC and aluminum sulfate, even at the higher concentration of 20 mg/l does not eliminate entirely the oil in the filtrate. The oil concentration in the filtrate is 3.4 mg/l, 2 mg/l and 1.3 mg/l when using PAC, aluminum sulfate and HEC, respectively.

5. Conclusion

Four different coagulant: 1) ferric chloride. 2) poly aluminum chloride. 3) aluminum sulfate. 4) hydroxyethylcellulose were applied in the coagulation-filtration of oil in oil contaminated seawater. Oil employed was Fuel Oil "A" according to Japanese Industrial Standard corresponding to No 4 in ASTM. A emulsion in seawater containing 33 mg/l of Fuel Oil "A" was prepared by blending for a total period of 20 minutes. Ferric chloride was the most effective coagulant in the removal of oil from the oil-seawater emulsion using glass wool which has relatively low oil retention as filter medium. No detectable oil which was measured using nonde-

Table 4.2.1 Settling time vs. oil concentration of fuel oil "A"--seawater

Settling Time Hr	Oil concentration mg/l	Remarks
1	69.46	(1)
2	68.07	
4	66.65	
8	42.37	
24	14.92	
48	8.03	(1)
70	6.11	
70	0.18	(2)

Remarks:

- (1) Particle size distribution is shown in Table 4.2.3
- (2) Oil concentration of the filtrate, filtered using filter paper having pore size 0.45 micron to determine 'solubility' of oil in seawater

Table 4.2.2 Settling time vs. oil particle size distribution

Settling time Particle size micron	2 Hr		70 Hr	
	Number of Particles	Distribution %	Number of Particles	Distribution %
1 - 2	303	39.6	112	59.6
2 - 3	212	27.7	38	20.1
3 - 4	108	14.1	24	12.8
4 - 5	55	7.2	3	1.6
5 - 6	31	4.1	7	3.7
6 - 7	18	2.3	3	1.6
7 - 8	12	1.6	1	0.6
8 - 9	5	0.6		
9 - 10	5	0.6		
10 - 11	6	0.8		
11 - 12	2	0.3		
12 - 13	1	0.1		
13 - 14	4	0.5		
14 - 15	0	0.0		
15 - 16	0	0.0		
16 - 17	2	0.3		
17 - 18	1	0.1		
18 -	1	0.1		
Concentration of oil	68.07 mg/l		6.11 mg/l	

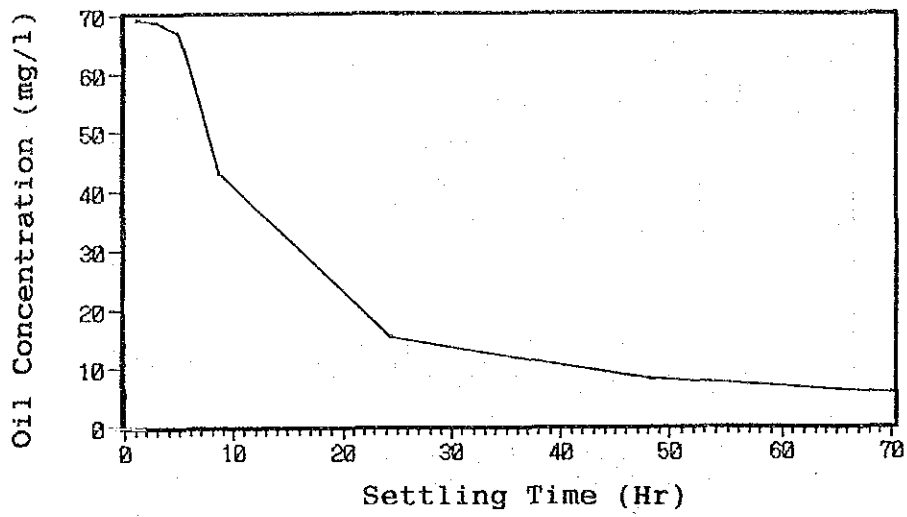


Fig. 4.2.1 Settling time vs. oil concentration of fuel oil "A" in seawater

structive infrared oil meter OCM 220 was observed in the filtrate even when the ferric chloride was added to the oily emulsion at concentration as low as 3 mg/l. Remaining coagulant failed to produce the same result even at a higher coagulant concentration of 20 mg/l.

6. Recommendation for Future Work

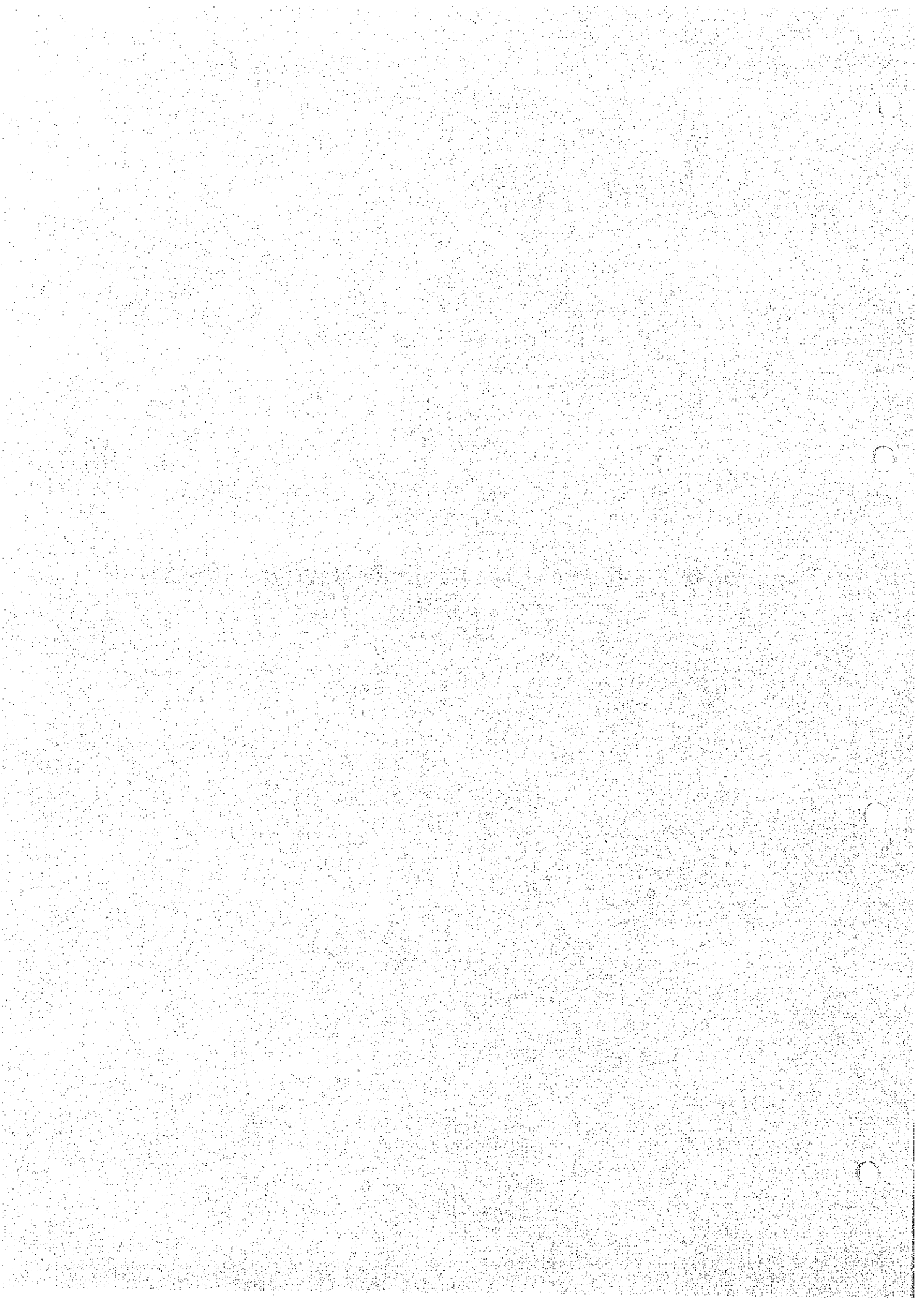
It is recommended that:

1. Coagulation-filtration experiment is to be continued to confirm that indeed the oil in oil contaminated seawater can be removed through the coagulation-filtration process using ferric chloride at concentration of 3 mg/l.
2. The concentration of oil in the filtrate is to be measured by using other more sensitive analytical technique other than the oil meter in the new experiment to confirm that the oil concentration in the filtrate from coagulated system is indeed less than 0.25 mg/l.
3. The glass wool filter used in this experiment is to be replaced by an experimental dual media filter(Anthracite & Sand).
4. The design configuration of the dual media filter such as height of the filter bed, media particle size, and the linear velocity of seawater in the dual media filter, is to be established in the new experiment.
5. The membrane oil tolerance level and means of cleaning is to be established.
6. Quick and reliable method to analyze the oil concentration of seawater should be prepared. The method must make it possible to analyze even a very low concentration of oil.
7. Finally, in the proposed experiment actual crude oil should be utilized in preparing the oil contaminated seawater instead of fuel oil "A" as used in this experiment.

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3.4 R-6 Selection of Membrane for Hybrid RO Process



**RO DESALINATION
EXPERIMENTAL RESEARCH NO. 4, R-6**

SELECTION OF MEMBRANE FOR HYBRID RO PROCESS

"Evaluation of Different Japanese SWRO Membrane"

JULY 1992

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1. Introduction

The capacity of all the desalination plants constructed so far in the world is 13,348,376 m³/day. The majority of this capacity is derived from dual purpose thermal (Power-MSF) plants and only 30% of this capacity, i.e., 4,114,073 m³/day is produced from Reverse Osmosis (RO) plants¹. This compares to 20,000 m³/day produced by the RO process in 1979 and to 1,000,000 m³/day in 1980 and finally exceeded 4,000,000 m³/day in 1990.

The Kingdom of Saudi Arabia is the leading country in the world in desalination. Its daily production from various desalting plants built so far is 3,621,243 m³/day of fresh water which represents 27.1% of world total. About 24% of this capacity, i.e., 884,771 m³/day, is produced from RO Plants, while the rest of this desalination capacity is produced mainly from dual purpose power MSF plants i.e., 71.5% of total. The RO plants are of the single purpose type dedicated mainly to fresh water production. Only at the Jeddah site, is there both a MSF and SWRO plant, where the products from both plants are blended. Although, the plants are not completely integrated, this arrangement represents some sort of hybrid plant system.

Recently and for many good reasons, the idea of hybrid desalination plant is becoming an attractive approach to seawater desalination²⁻⁷. A hybrid desalination plant normally consists of a thermal desalination plant, such as an MSF plant, existing side by side with a SWRO plant. The low salinity product from the MSF plant, TDS of maximum 50 ppm, is mixed with the product of a SWRO plant, normally less than 1000 ppm. The final mixed product is designed to be less than 500 ppm. One way of optimization of the hybrid plant to yield maximum product, can be achieved by maximizing the SWRO plant productivity while maintaining its product TDS at a reasonably low value. In this optimized case, it is best to use the SWRO plant membranes with the highest possible flux but with a reasonable good salt rejection, e.g. less than 1000 ppm, rather than using a membrane with a very high salt rejection and low flow. Usually membranes with high salt rejection tend to have a relatively low flux.

The objective of this preliminary investigation is to establish the best SWRO membranes that fit the above criteria. Five different types of SWRO membranes, all made in Japan, were evaluated for this purpose for use in future hybrid MSF-SWRO plants. This report summarizes the results which were obtained at SWCC RDTC by a joint Saline Water Conversion Corporation (SWCC) and JICA researchers utilizing a flat membrane tester, OSMO 16Y-100F-TCB.

2. Literature Survey

The hybrid process is one of the processes which has aroused people's interests in the desalination field recently. This hybrid process is combined with power generation in the distilla-

tion process, other desalination processes and the solar energy utilizing system. besides the above, it also includes concentrating separation by combining reverse osmosis(RO) membranes and ultrafiltration(UF) membranes, and RO membranes and electrodialysis(ED) membranes.

Among these, the combination of the RO process and the distillation process arouses the greatest interest, and it has already been put into practical use. As the result of literature retrieval on the current state of the hybrid process, literature on the RO process is the most plentiful. 18 out of 23 papers have been written about the RO process in the past 10 years.

Among these 23 papers, 6 have been written on the combination with MSF. Beside the above, there are four papers about combination with pervaporation(PV) process, three papers about the ED process, two papers about the UF process and three papers for other combinations.

After literature retrieval, no experiments on the evaluation of membranes for the hybrid process could not be found.

According to various kinds of trial calculation, the hybrid process combining the RO process with the MSF process can lower the construction and operating costs of the RO process by 10% compared to the costs of the RO process alone. The hybrid process combining the RO process with the MSF process incorporating power generation has the following merits.

- a) Common seawater intake is used.
- b) Electrical power to drive the RO plant is taken from the power plant.
- c) The product waters from the MSF and RO plants are blended to obtain water that meets WHO standards.
- d) Product cost can be lowered by 10 – 15% in comparison with that of the RO process alone.
- e) Seawater intake and pretreatment related costs can be lowered due to the high recovery rate.
- f) The second stage of the RO process becomes unnecessary.
- g) Membrane replace rate lowers.
- h) Energy consumption rate lowers.

However, to adapt the RO process to the hybrid process mentioned above, RO membranes which are durable against a high pressure of 80kg/cm^2 , are necessary, and a sufficient salt rejection enabling high recovery rate operation is also necessary.

Furthermore, the recent development of RO membranes has been centered on synthetic polymer composite membranes. The quantity of permeate desalted from these membranes is greater than those of previous membranes, and salt rejection often enables single stage seawater desalination. To verify whether or not these membranes can be used for the hybrid process is one of subjects to be studied.

3. Experiment

3.1 Equipment

The major equipment used in this experiment was the OSMO 16Y-100F-TCB flat membrane test unit. A flow diagram of the test unit is shown in Fig.3.1.1. The unit consists of: a storage feed tank of 200 liters, a low pressure pump, a cartridge filter, a heat exchanger, an ultra filtration system to remove potential membrane foulants and a high pressure pump to supply feed at pressure upto 1050 psi to 12 identical test cells. A common header provides feed to the 12 cells which are fully plumbed and individually controlled. Each cell is equipped with its own pressure gauge and brine flow meter.

The product from each cell is collected, measured and analyzed separately. Piping in the low pressure section is made of PVC while 316 SS is used in the high pressure section tubes and fittings. The pump material is made of 316 SS and glass filled Noryl internals. Wetted pressure gauges and switches are made of 316 SS.

To maintain the feed water temp. below 35°C an external tank complete with pump and associated plumbing were connected to the heat exchanger in the equipments. This arrangement allowed for continuous operation of the unit for a long period of time.

Membrane samples, 5 cm in diameter, were cut evenly taking care not to contaminate or destroy the active membrane surface. The membrane samples were first placed into the test cell (see Fig.3.1.2), with the active surface down. The porous SS disc was placed above the membrane sample. The top half of the test cell was then placed above the porous disc and inserted into the cell block. The cell itself was secured to the block which was held firmly to the frame by tightening the screw.

Conductivity, temperature and pH of the feed and product, were monitored and measured using standard equipment.

3.2 Membranes

Cellulose acetate, polyamide and thin film composite membranes are the membranes in use in SWRO plants. Recently, new thin film composite membranes with excellent performance, i.e., high flux, high salt rejection as well as other good desalination properties, have been introduced in the market. Some of these membranes could be potential candidates for use in SWRO plants in hybrid desalination systems.

Five SWRO membranes have been provided for research by JICA with the objective of evaluating their performance for potential use in hybrid plants. Another membrane, brackish water type ("UTC 70"), was also provided by JICA and was examined along with the five SWRO membranes. The material composition, structure, and membrane manufacturer's name, are listed in Table 3.2.1 along with the membrane's flux and salt rejection as determined by the manufacturer under the test conditions shown in the same table.

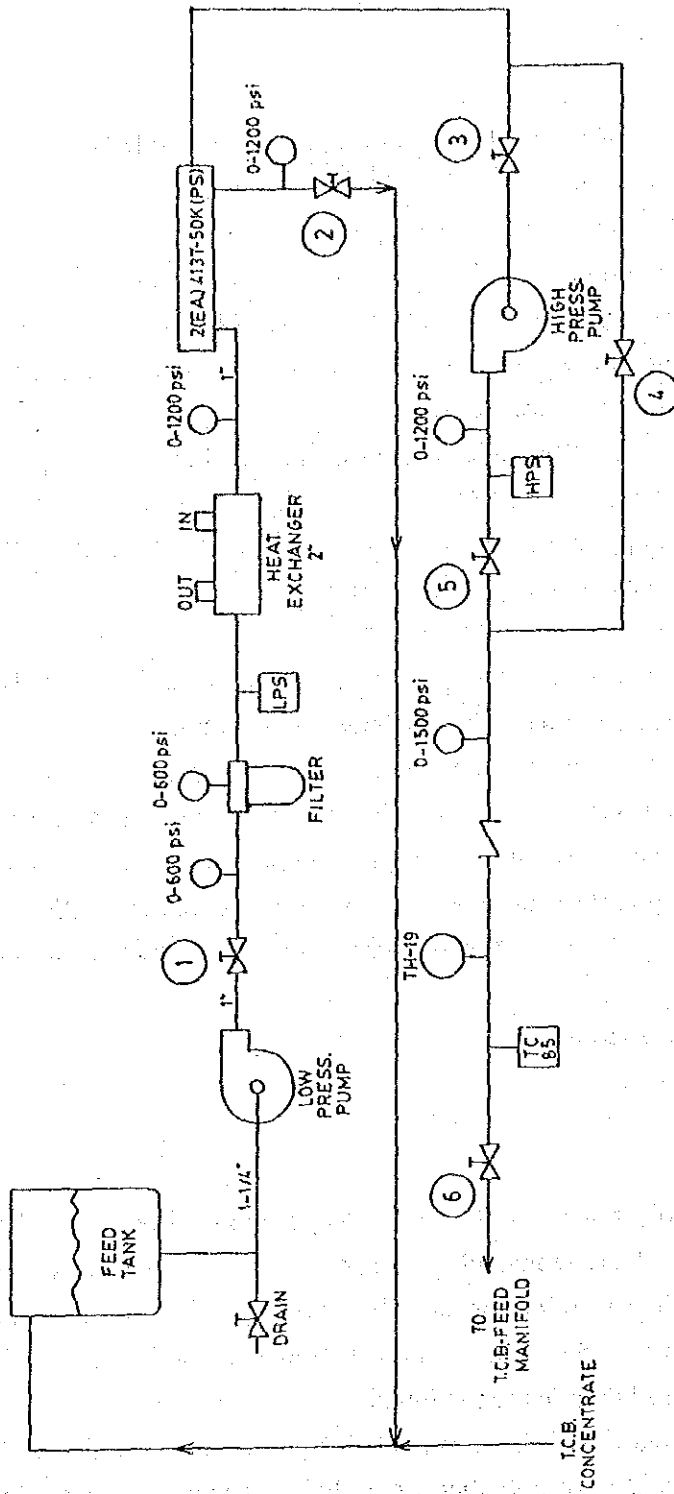
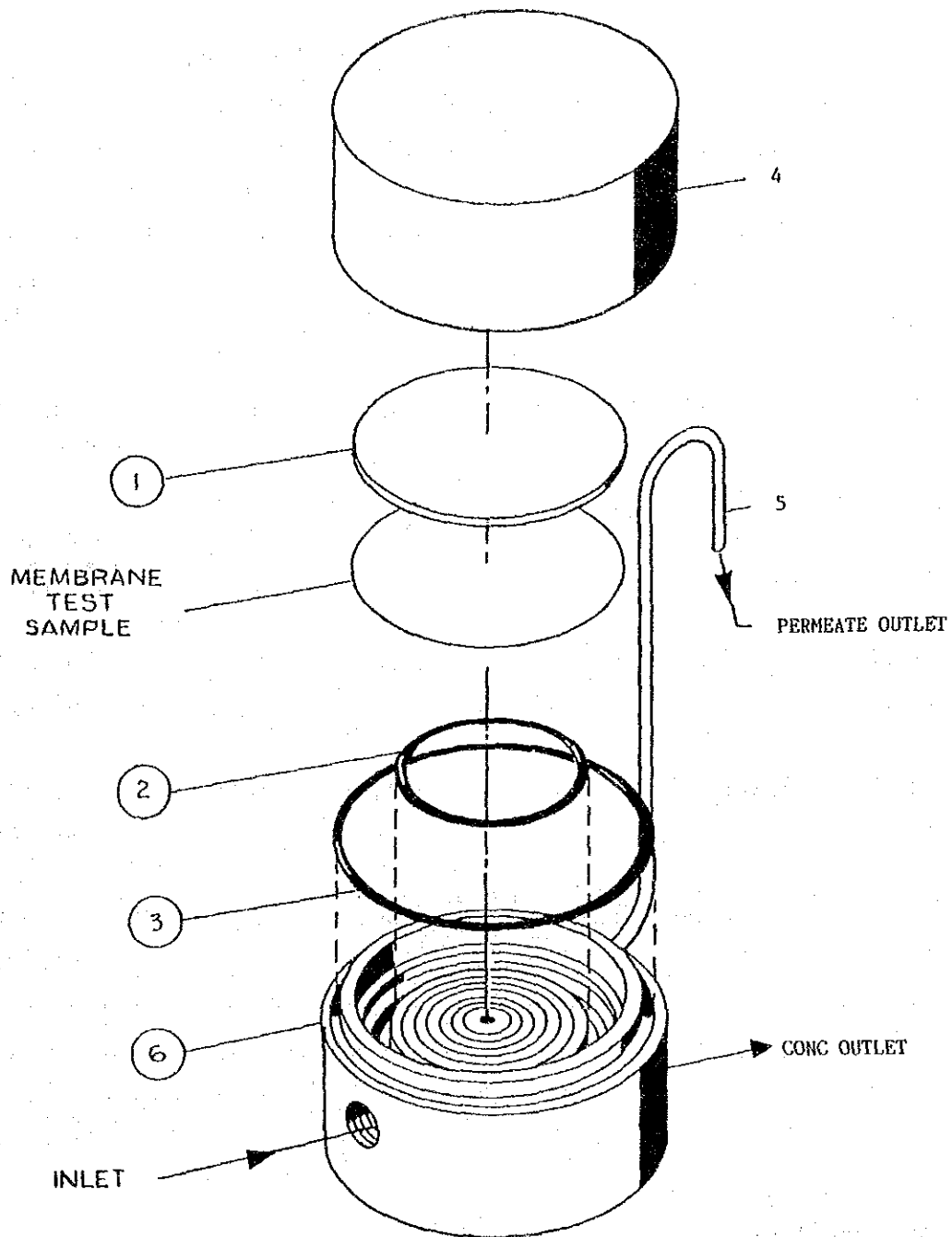


Fig.3.1.1 Flow Diagram of OSMO 16Y-100F-TCB Flat Membrane Test Unit



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

Fig.3.1.2 Arrangement of Cell Block in 16Y-100F-TCB Flat Membrane Test Unit

Table 3.2.1 Specification of Flat Sheet-RO Membranes

Name	Material	Structure	Rejection* %	Flux* m ³ /m ² day	Test Condition
NTR759HR NITTO	Polyamide	Composite	99.0	0.60	3.2%NaCl 56Kg/cm ²
NTR759SW NITTO	Polyamide	Composite	99.0	1.00	3.2%NaCl 56Kg/cm ²
SC8000 TORAY	Cellulose acetate	Asymmetric	98.1	0.52	3.5%NaCl 56Kg/cm ²
UTC80HF TORAY	Polyamide	Composite	99.3	0.90	3.5%NaCl 56Kg/cm ²
UTC80HR TORAY	Polyamide	Composite	99.6	0.57	3.5%NaCl 56Kg/cm ²
UTC70** TORAY	Polyamide	Composite	99.6	1.15	0.15%NaCl 15Kg/cm ²

* As recorded by the manufacturer under the test conditions shown above.

** A brackish water membrane, the remaining five membranes are SWRO membranes.

3.3 Test Conditions

Test conditions are as shown in Table 3.3.1. Saline feed water to SWRO membrane was prepared using 3 to 4% sodium chloride (99.9% purity, industrial grade) in deionized water. The feed to the brackish membrane was prepared similarly but using 0.15 % sodium chloride. The pH of the feed water was adjusted to 6.5 by addition of 0.10 N HCl. For the SWRO membranes, test temp. was maintained between 25–30°C and the feed pressure was varied from 4.9 to 6.4 MPa, i.e., from 50–65 bars. For the brackish water membrane the applied pressure was fixed at 1.5 MPa(16bars) and the test temperature was maintained at 25–

30°C. Flow and conductivity was measured after 30 minutes of operation. At least two more measurements were made thereafter during the days run.

Table 3.3.1 Membrane Test Conditions

Test	Membrane Name	Conditions (Feed)	
		Salt Concentration (NaCl.%)	Pressure (MPa)
Trial	SC8000	3.0	5.5
Primary	NTR759HR	3.0, 3.5	5.5
	NTR759SW		
	SC8000		
	UTC80HF		
	UTC80HR		
Main	UTC70	3.0, 3.5, 4.0	4.9, 5.5
	NTR759HR		
	NTR759SW		
	UTC80HR		
Main	UTC80HF	0.15	5.9, 6.4
	UTC80HR		
Main	UTC70	0.15	1.5

3.4 Investigation into Cooling System

3.4.1 Measurement of Calorific Value

Calorific values have been calculated by measuring temperature rise while operating the

test equipment without cooling.

3.4.2 Calculation of Calorific Value

Temperature rise : $9.5^{\circ}\text{C} / 35\text{min}$.

Volume of feed tank : 167 L

Volume of piping and others : 10 L

Calorific value per hour is ;

$$1.0 \text{ kcal/kg}^{\circ}\text{C} \times 177 \text{ kg} \times 9.5^{\circ}\text{C} \times 60/35 = 2,883 \text{ kcal/hr}$$

3.4.3 Investigation into Heat Exchanger

The capacity of the heat exchanger has been investigated a jacket type heat exchanger made of stainless steel attaches to the flat sheet membrane testing equipment. Its area of heat transfer surface and overall heat transfer coefficient has been calculated in the following information assuming that a pipe of 30 mm in diameter goes in, bends back, and bend back again, inside it.

It is assumed that this existing heat exchanger has enough heating/cooling capacity because its heat transfer coefficient is similar to the general heat transfer coefficient of stainless steel (730 to 1,460 kcal/m²°C hr).

Calorific Value : 2,880 kcal/hr

Area of heat transfer surface : $= 0.03\text{m} \times 3.14 \times 0.6\text{m} \times 3 = 0.17\text{m}^2$

Temperature difference : 15°C

Overall heat transfer coefficient : $= 2,880 \text{ kcal/hr} / (0.17\text{m}^2 \times 15^{\circ}\text{C}) = 1,129 \text{ kcal/m}^2\text{C hr}$

3.4.4 Investigation into Cooling System

It has been assumed that cooling takes place by circulating cooling water through the existing heat exchanger. The temperature of the cooled water is kept constant by putting ice in it when necessary.

The quantity of ice required at this time, has been calculated in the following information, assuming that heat of fusion of ice to be 80 kcal/kg. A pump with a capacity of about 2.0m³/hr has recently been prepared for circulating cooling water.

Quantity of ice required : $2,880\text{kcal/hr} / (80\text{kcal/kg} + 10\text{kcal/kg}) = 32 \text{ kg/hr}$

Assuming operating time per day to be five hours, ice of about 150 kg is needed.

4. Results and Discussion

4.1 Performance of SWRO Membrane

Table 4.1.1 lists the flux and salt rejection of the various membranes examined, while the membranes salt rejection versus their flux are shown in Fig.4.1.1. The test conditions employed in evaluating those membranes are also given in Table 3.3.1. For all the SWRO membranes the feed salt concentration was 35,000 mg/l and the applied pressure was 5.5 MPa.

Table 4.1.1 Salt Rejection(%) and Flux of Membrane as determined at SWCC RDTCLaboratory

Membrane	Standard Data		Standard Condition	
	Flux m ³ /m ² .day	Rejection %	Concentration mg/L	Pressure MPa
UTC80HR	0.8	99.36	35,000	5.5
UTC80HF	1.067	98.96	35,000	5.5
NTR759SW	0.82	98.66	35,000	5.5
NTR759HR	1.067	98.8	35,000	5.5
SC8000	0.56	96.74	35,000	5.5
UTC70	1.29	97.88	1,500	1.5

Under these conditions the highest flow of $1.067 \text{ m}^3/\text{m}^2\cdot\text{day}$ was obtained from the membranes "UTC80HF" and "NTR759HR" followed by a flow of $0.82 \text{ m}^3/\text{m}^2\cdot\text{day}$ from the membranes "NTR759SW" and $0.803 \text{ m}^3/\text{m}^2\cdot\text{day}$ from the "UTC80HR". The least flow of $0.56 \text{ m}^3/\text{m}^2\cdot\text{day}$ was obtained from the membrane "SC8000" which also had the least salt rejection of 96.74% in the SWRO membrane series.

The highest salt rejection of 99.36% was obtained for the product from the membrane "UTC80HR" followed by salt rejection of 98.96% for the product from the membrane "UTC80HF". The membranes "NTR759HR" and "NTR759SW" have salt rejections of 98.8% and 98.66%, respectively. Considering the overall membrane performance in terms of flux and salt rejection, it can be concluded that both the polyamide composite membranes; the high flux membrane "UTC80HF" and the high recovery membrane "NTR759HR", are the best two performers in the series. This is shown clearly in Fig. 4.1.1.

The membrane with the least performance is the "SC8000" which is an asymmetric membrane prepared from a cellulose acetate polymer. The performance of the remaining two membranes: the membranes of high rejection "UTC80HR" and the seawater membrane "NTR959SW" falls in between. Those two last membranes are composite membranes and made of polyamide. The first two membranes with the highest performance are most suitable for the production of large quantities of product and are the best potential candidates for use in hybrid plants. Their salt rejection of about 99% for the membrane "UTC80HF" and of 98.8% for the membrane "NTR759HR" can be classified as a reasonably good salt rejection rate.

This test which was of limited duration, 5 days each membrane, was not sufficient to draw a definite conclusion on the long term performance of the various membranes. From this initial data, however, it can be concluded that the membranes "UTC80HF" and "NTR759HR" may be considered as the best in overall performance and may be used in a single purpose SWRO plant or in a combined hybrid triple purpose Power-MSF-SWRO plant.

4.2 Performance of Brackish Water Membrane

One brackish water membrane "UTC70" was used in this investigation. The membrane was a polyamide, thin film composite membrane, and as claimed by the manufacturer, it has a high salt rejection of 99.6% and also a high flux of $1.15 \text{ m}^3/\text{m}^2\cdot\text{day}$ see (Table 3.2.1). The actual performance is shown in Table 4.1.1 where the salt rejection is only 97.88%, which is less than claimed by the manufacturer, while the flux of $1.29 \text{ m}^3/\text{m}^2\cdot\text{day}$ is slightly higher than that claimed by the manufacturer. By comparison to other brackish membranes, even with 97.9% salt rejection, the performance of the membrane is considered satisfactory.

4.3 Effect of Pressure on Membrane Flux and Salt Rejection

The Figs. 4.3.1–4.3.10 show the effect of increasing the applied pressure on membrane flux and salt rejection. In all cases, and as is expected, the membrane flux increases with an increase in pressure. Similarly, the membrane salt rejection rises as the pressure increases, mainly because the water flow through the membrane is pressure dependent while the passage of salt through the membrane is independent of applied pressure. The flow of salt through the membrane is dependent on feed salt concentration.

5. Conclusion

The performance of five different types of seawater flat sheet membranes: "NTR759HR", "NRT759SW", "UTC80HF", "UTC80HR", "SC8000" and one brackish water membrane "UTC70" was established using an OSMO 16Y–100F–TCB flat membrane test unit that allows for the testing of twelve membrane samples at the same time. All the membranes are made of polyamide and are of the thin film composite type, except for the membrane "SC8000" which is made of cellulose acetate and has an asymmetric structure.

The membrane type and membrane maker are listed along with membrane structure and membrane performance in Table 3.2.1 which also lists the test conditions. With the exception of membrane "UTC70" which is a brackish water membrane, the remaining five are SWRO membranes. Amongst the SWRO membranes, the highest flux of $1.067\text{m}^3/\text{m}^2\cdot\text{day}$ was obtained from the membranes "UTC80HF" and "NTR759HR" followed by the membranes "UTC80HR" and "NTR759SW", which have a flux of $0.8\text{ m}^3/\text{m}^2\cdot\text{day}$ each. The least flux of $0.56\text{ m}^3/\text{m}^2\cdot\text{day}$ was obtained from the "SC8000" membrane which also has the least salt rejection in the membrane series.

The highest salt rejection of 99.4% was obtained from the membrane "UTC80HR" followed by the membrane "UTC80HF" with salt rejection of 99%. This test which was of limited duration, 5 days per membrane, was too short to draw a definite conclusion on the long term performance of the various membranes.

In order to evaluate whether these tested RO membranes are suitable for the hybrid RO membrane process, the process design simulation was calculated for these membranes, and it was found that the polyamide composite membranes with a slightly lower salt rejection rate, were suitable for the hybrid RO membrane process.

From this initial data, however, it can be concluded that the membranes "UTC80HF" and "NTR759HR" may be considered as the best in overall performance and may be used in a single purpose SWRO plant or in a combined hybrid Power–MSF–SWRO plant.

From this simulation study, we found that it is very important to consider not only permeate quality but also water flux to get the sufficient net driving pressure within a reasonable system design flux range in an evaluation of the hybrid RO process.

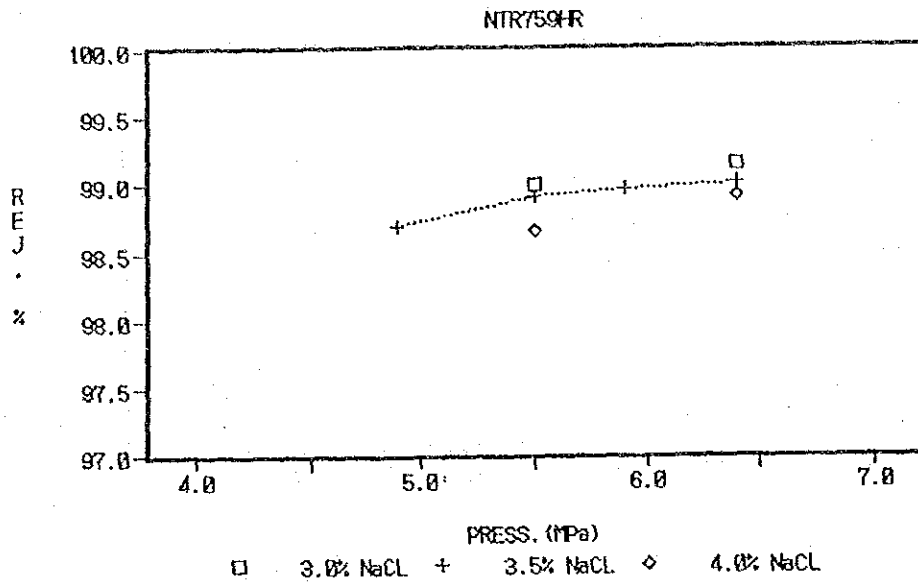


Fig.4.3.1 Pressure vs Salt Rejection for Membrane "NTR759HR"

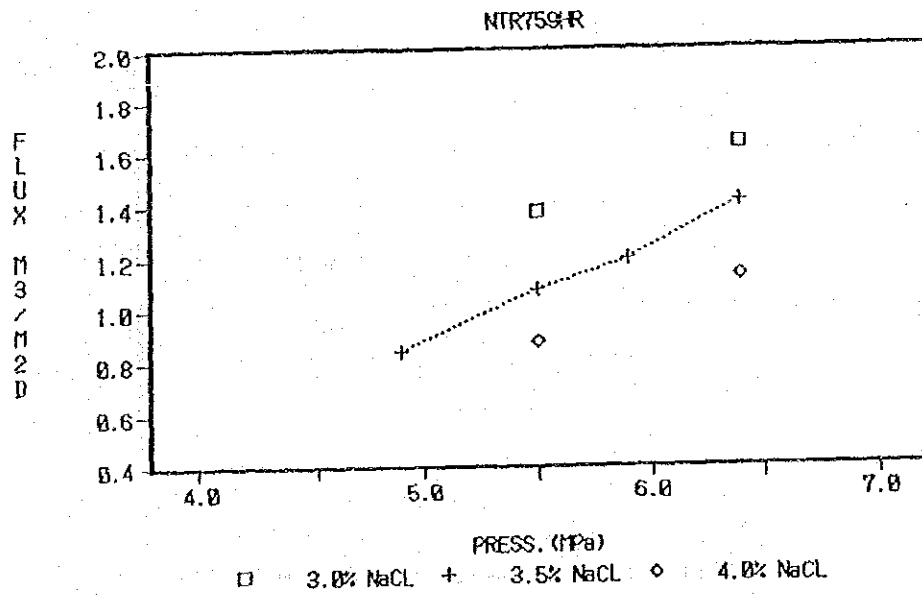


Fig.4.3.2 Pressure vs Flux for Membrane "NTR759HR"

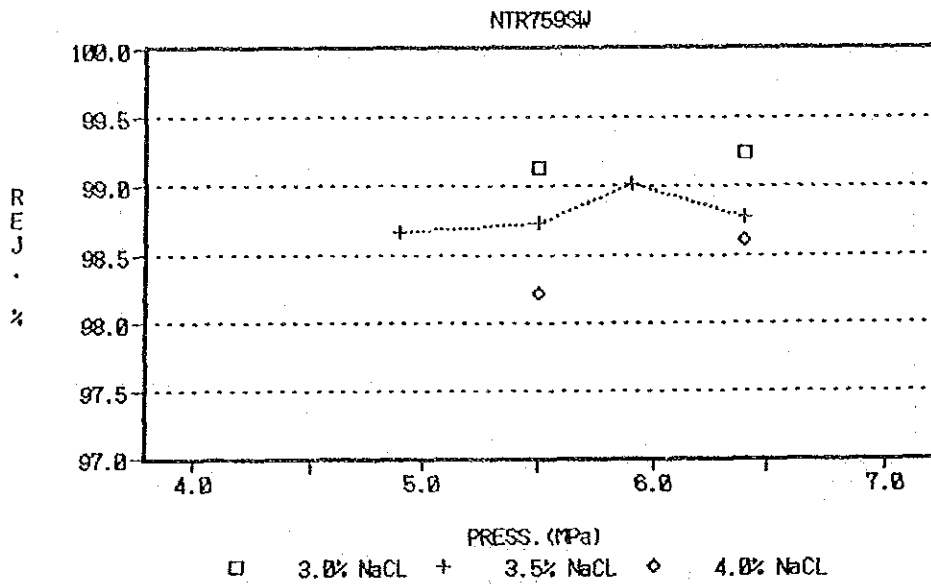


Fig.4.3.3 Pressure vs Salt Rejection for Membrane "NTR759SW"

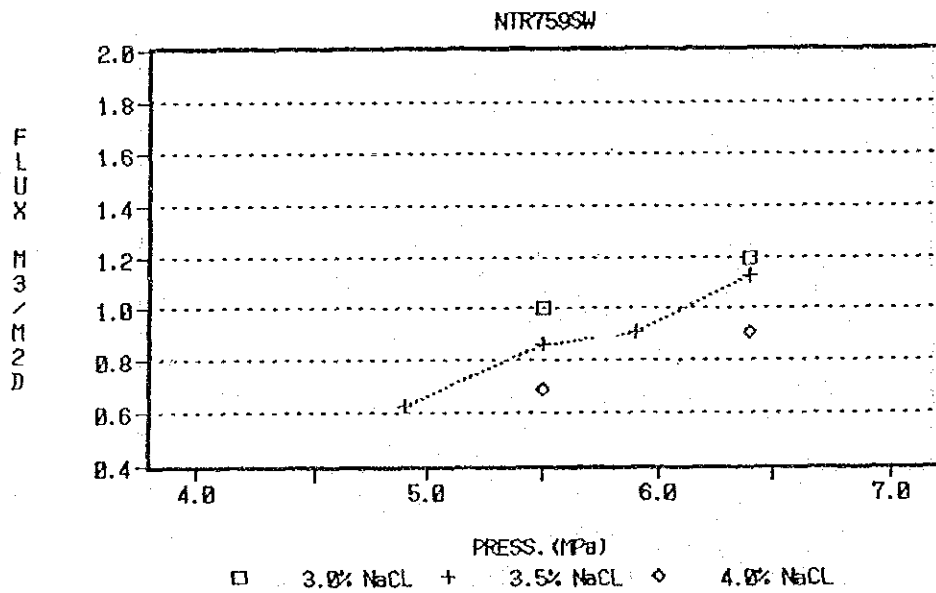


Fig.4.3.4 Pressure vs Flux for Membrane "NTR759SW"

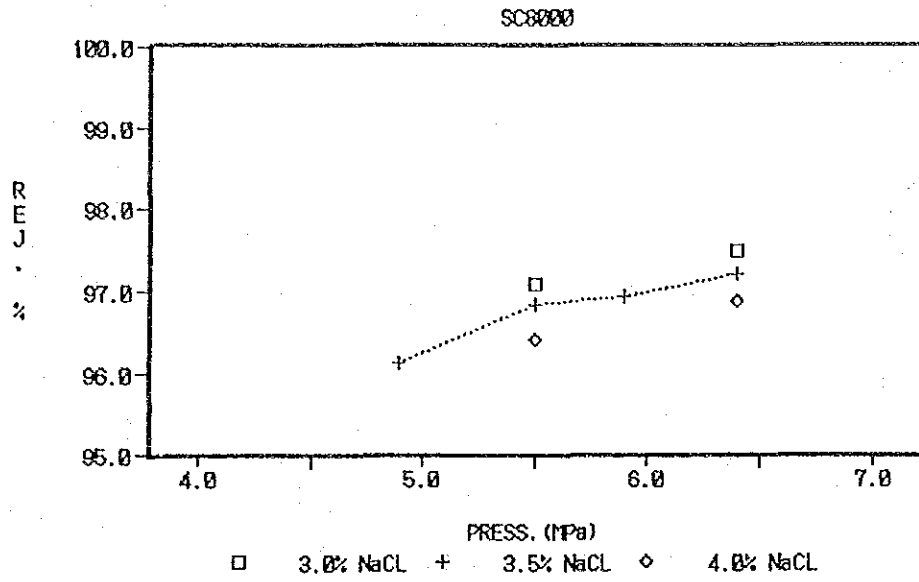


Fig.4.3.5 Pressure vs Salt Rejection for Membrane "SC8000"

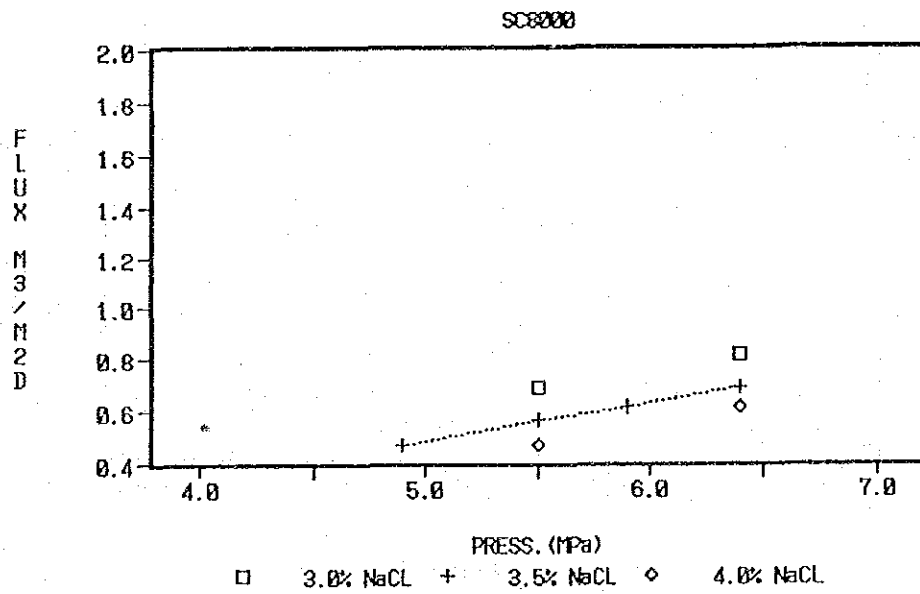


Fig.4.3.6 Pressure vs Flux for Membrane "SC8000"

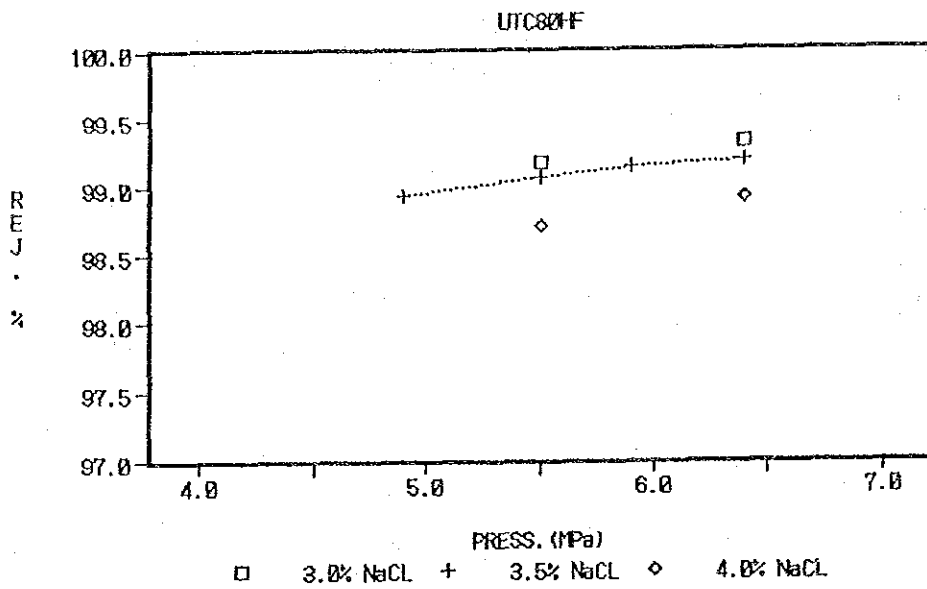


Fig.4.3.7 Pressure vs Salt Rejection for Membrane "UTC80HF"

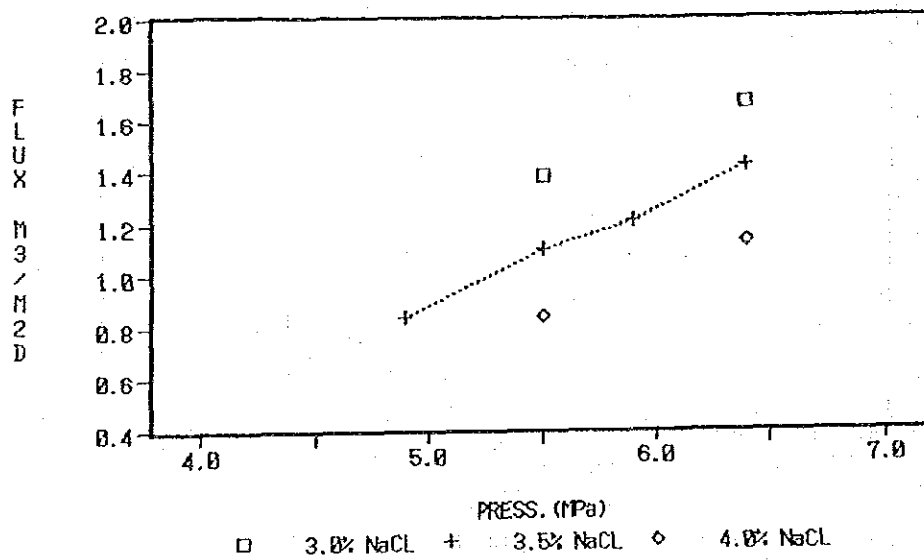


Fig.4.3.8. Pressure vs Flux for Membrane "UTC80HF"

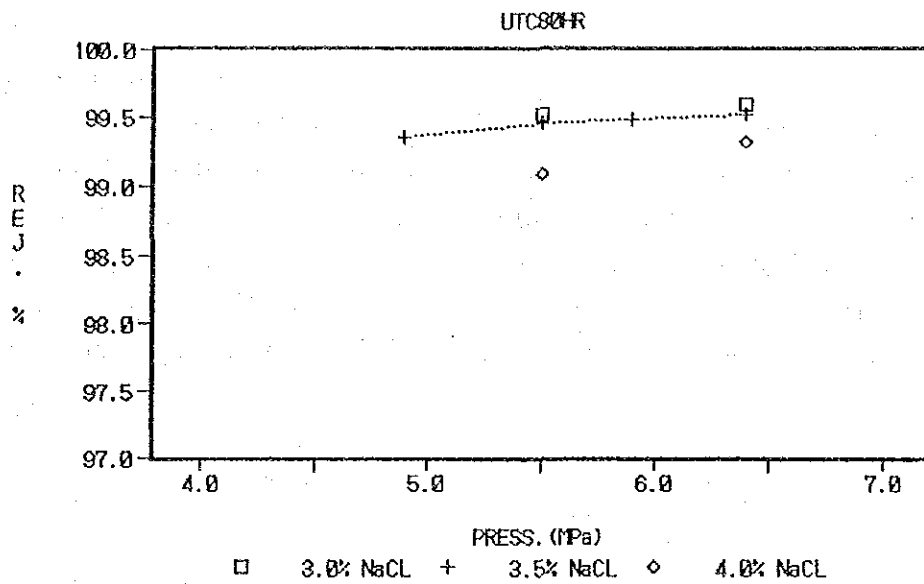


Fig.4.3.9 Pressure vs Salt Rejection for Membrane "UTC80HR"

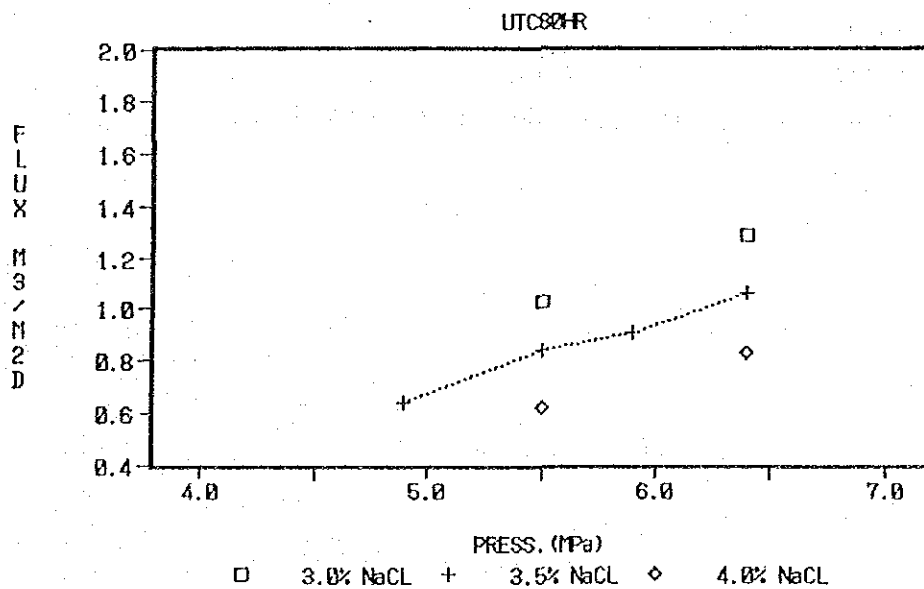


Fig.4.3.10 Pressure vs Flux for Membrane "UTC80HR"

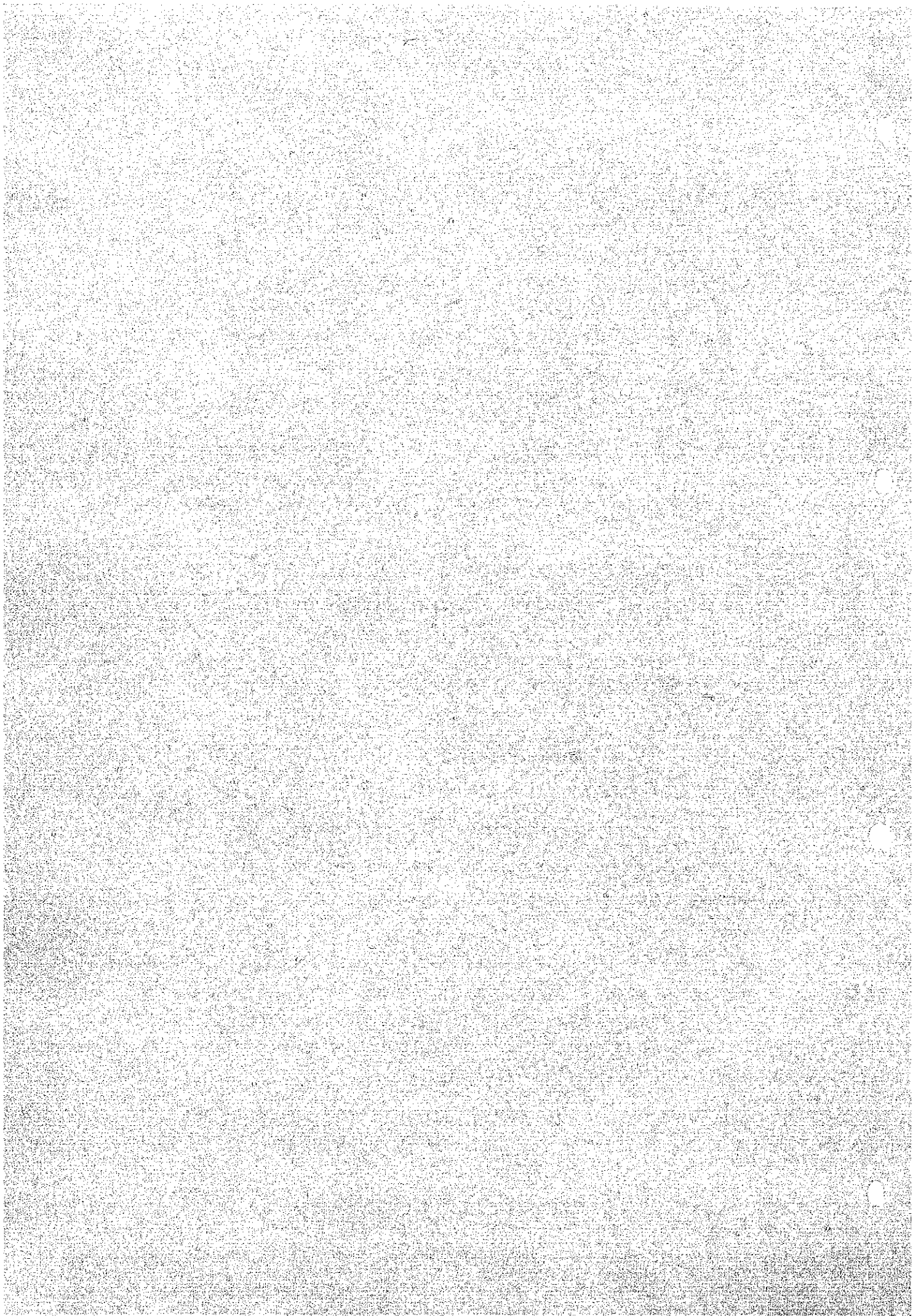
6. Recommendation for Future Work

- (1). To establish the long term performance of the two best performing membranes ("UTC80HF" and "NTR759HR") in this screening experiment, a long term testing of those two membranes is to be carried out on a pilot plant scale using large size modules. Evaluation shall also include the determination of the membrane properties in resisting fouling, and in resisting chemicals etc., along with establishing their temperature and pH tolerance.
- (2). Other high performance commercial membranes, not necessarily of Japanese origin, are also to be evaluated in this proposed joint JICA/SWCC study along with the above two membranes.

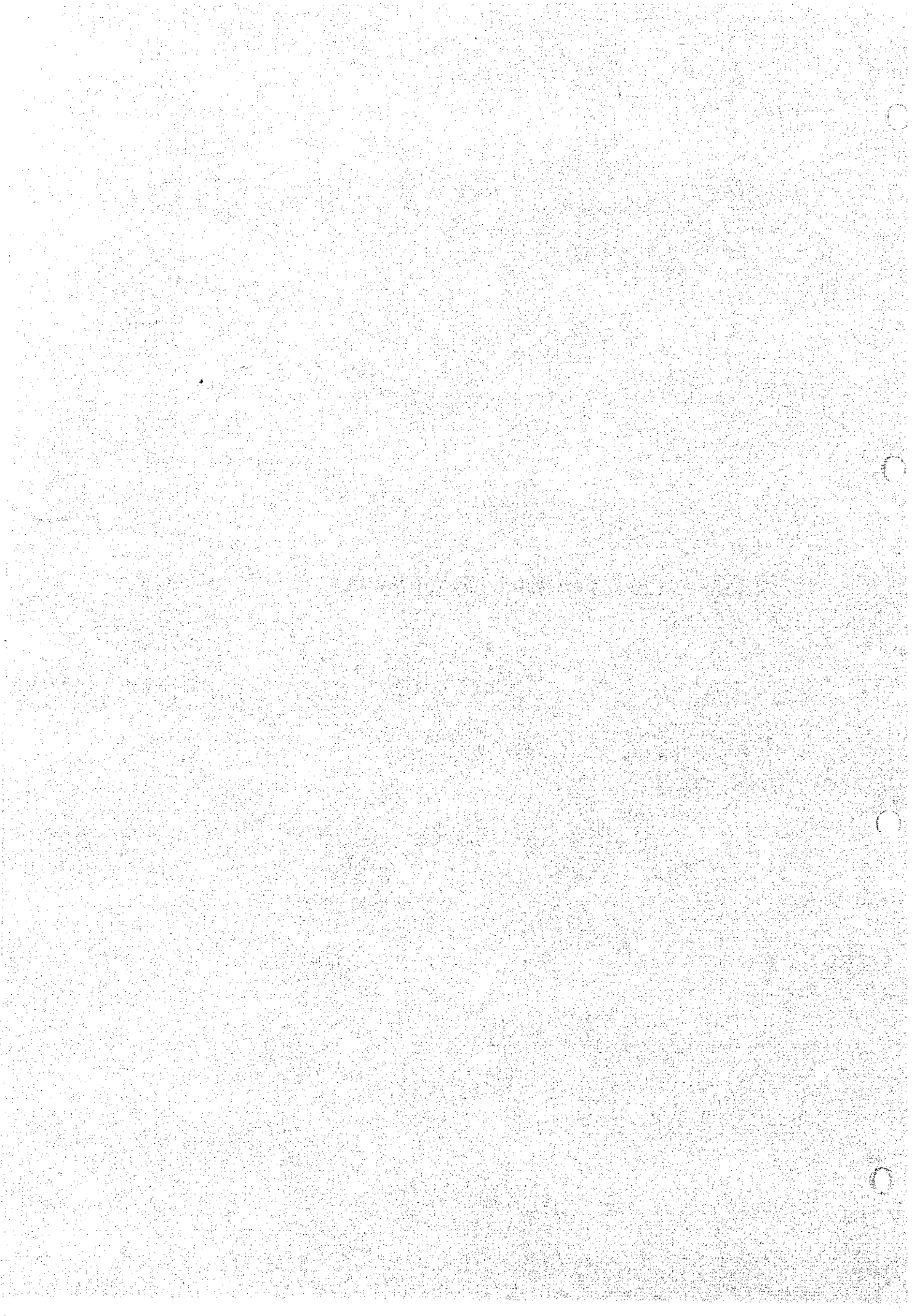
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Chapter 4 Literature Survey



4.1 M-2 Corrosion Tendency for Some Kind of Materials



**MSF DESALINATION
LITERATURE SURVEY NO. 1, M-2**

CORROSION TENDENCIES FOR SOME KIND OF MATERIALS

JULY, 1992

By

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SALINE WATER CONVERSION CORPORATION

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