

**6. Study on Countermeasures against
Oil Contamination of Product Water
in MSF Process (MSF-2)**



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6. Study on Countermeasures against Oil Contamination of Product Water in MSF Process (MSF-2)

The pollution of the Arabian Gulf by oil is getting worse every year. On the other hand, it became well known that trihalomethanes will be formed by the reaction of the organic substances and chlorine. Therefore, there can be possibility of trihalomethanes and/or oil contamination in product water of MSF plant when the feed seawater was polluted by accidental oil spillage or by the on-going pollution.

This research is to clarify the volatility mechanisms of those contaminants in MSF plant by preliminary study and then construct the computer program for the simulation and prediction of the behavior of the contaminants.

On the other hand, those contaminants were intentionally added to the MSF Test Plant feed seawater and the behavior of those substances was studied. The test results were compared with the computer predictions for the better understanding of the behavior of those contaminants. The purpose of this research is to propose the countermeasures for the prevention of the product water from pollution with those contaminants.

6.1 Investigation and Preparative Experiment

6.1.1 Introduction

A survey for quality of seawater in the Arabian Gulf was initially planned to identify levels of oil contents, hence contamination of feed to MSF desalination plants. Since the levels of oil contaminants were negligible, it was not feasible to correlate oil carry over into product water in actual operating plants at such low levels. Therefore confirmation of the accuracy of the computer simulation program was limited to the MSF test plant data where oil was injected into the brine stream.

6.1.2 Preparative Experiment (Vaporization Mechanism of Organic Contaminants)

1. Introduction

The Oil Carryover Test is the first step of this research and we, therefore, consider the result of this test will establish the basis of this project.

There are some reports that are concerned with quantitative vaporization mechanisms of some pollutants which contaminate water. After due consideration we feel that it would be better to refer to the results of these studies in order to increase the effectiveness of our work.

One useful study was carried out by Hakuta et. al. In that study, he conducted evaporation experiments on hydrocarbon-water mixed conditions, by using a laboratory scale evaporator wherein they defined the relationship between the amount of vaporized hydrocarbons and that of vaporized water. In this study, some volatile hydrocarbons such as n-octane, benzene and cyclohexane were used and it was found that the equation for steam distillation was applicable to those cases where hydrocarbons did not dissolve in water.

2. Experimental

2.1 Equipment

Fig. 1 shows the experimental evaporator used in this study. This was composed of a rotary evaporator including a condenser, a water bath, an impinger, a vacuum pump, a manometer, a controlled water circulator and tubing (Shibata Scientific Instruments, Japan).

2.2 Experimental Method

In the experiments done to obtain the vaporization rates, only the remaining contaminants were quantified. The amount of vaporized contaminants was obtained by subtracting the weight of the remaining from the weight of the initial contaminants.

The general evaporation conditions applied in this study were as follows: The preheating time was 10 minutes. The evaporation conditions were 90 °C and 420mmHg. The evaporation times were from 0 to 60 min.

3. Results

3.1 Material Balance Experiment

In order to comprehend any experimental errors in the evaporation procedures, a material balance experiment was first carried out.

Total recoveries were between 90 to 112% of the initial and therefore it was ascertained that there were no considerable losses of vaporized materials during the evaporation process.

3.2 n-Octadecane Carryover Test

This was conducted in order to clarify the equation to be applied to heavy oil components barely dissolved in water. n-Octadecane is one of the major components in Fuel Oil Type "A".

It was ascertained that water vaporizes at a constant rate. Fig. 2 shows the relationship between the amount of vaporized water (Ww) and that of vaporized n-octadecane (Wo). In this case, a proportional relationship between them has been obtained and therefore the equation for steam distillation is considered applicable.

From this date, R (Wo/Ww) and the vapor pressure of n-octadecane were obtained as 1.1×10^{-3} and 4.2×10^{-2} (mmHg), respectively.

3.3 Bromoform Carryover Test

In order to apply the equation for steam distillation to soluble contaminants, we developed a modified method. The demonstrations of this method were attempted in a "Bromoform Carryover Test" and a follow-up "Toluene Carryover Test".

Bromoform is a kind of trihalomethane and is known to be often detectable in seawater and especially in chlorinated seawater of desalination plants at high concentrations. This is a highly soluble organic.

The evaporation experiments on the bromoform contaminated brine at about 0.4ppm were carried out by varying the vacuum time.

The relationship between the vacuum times and the amounts of vaporized bromoform(W_o) is presented in Fig. 3.

R' is obtained as 0.11 (L/min.) from the slope of the graph in Fig. 4 which represents the relationship between the time and $\ln(C_o)$. By using these values, Henry's constant for bromoform at 90°C is calculated as 3.7×10^{-2} (mol./L•mmHg).

3.4 Toluene Carryover Test

Toluene is contained in crude oil as a major component and is soluble in water at a concentration of less than 500ppm. Therefore, in the case of oil spillage, it dissolves in seawater and may be sucked in by intakes of desalination plants.

In our experiments toluene concentration in the brine was approximately 2ppm where toluene was completely in solution in the brine. The data obtained were analyzed by the same method as that applied in 'Bromoform Carryover Test' and the results are shown in Fig. 5.

R' for toluene is obtained as 0.62. Thus, following the data analysis method, Henry's constant for toluene is calculated as 2.1×10^{-3} (mol./L•mmHg), that is a value 15 times lower than that of bromoform. This means that toluene is more volatile than bromoform.

3.5 Fuel Oil Type "A" Carryover Test

The experiments described above are concerned with various single contaminants. However, in considering an actual oil spillage, we recognize that the vaporization mechanism of a complex contaminant must be understood. In such a case, it is only natural to conclude that some modifications of methods are necessary in order to apply the rule established in the previous sections to the vaporization of a complex contaminant. Here, Fuel Oil Type "A" was used for this purpose.

The Fuel Oil Type "A" carryover test was carried out in the same manner as in the n-octadecane carryover test to measure the vaporized n-octadecane in Fuel Oil Type "A".

It was ascertained that the equation for steam distillation is applicable in this case, even if n-octadecane is one component of the complex contaminants.

The proportional constant in the equation for steam distillation, R (W_o/W_w), for *n*-octadecane as a component of Fuel Oil Type "A", can be seen in Fig. 6. In this case, R is obtained as 2.7×10^{-5} , although R for octadecane is 1.1×10^{-3} in the case where octadecane is the single contaminant.

3.6 Bromoform-Fuel Oil Type "A" Mixture Carryover Test

When seawater is polluted by oily components, it is known that many trihalomethane are generated. Therefore, we must consider cases of complex pollution of seawater with oily components and trihalomethane. The purpose of 'Bromoform-Fuel Oil A Mixture Carryover Test' is to clarify the effect of contaminated Fuel Oil Type "A" on the vaporization of bromoform in solution.

Fuel oil A was added at concentrations of approximately 20ppm and 200ppm and the vaporization of bromoform was carried out under the same conditions as the 'Bromoform Carryover Test'.

It was found that the remaining bromoform was almost equal to that of the single contaminant, even in the case where 200ppm of Fuel Oil Type "A" was added. These results demonstrate that Fuel Oil Type "A" did not considerably affect the vaporization of bromoform.

4. Discussion

In this study, we carried out the evaporation experiments with the experimental batch evaporator on the brine in which some organic substances had been dissolved. As a result, it was shown that the vaporization of the insoluble contaminant, i.e. *n*-octadecane followed the equation for steam distillation. By using this equation, the amount of the vaporized contaminant can be obtained if the temperature and the amount of vaporized water are known. The temperature is necessary in order to obtain the vapor pressures.

In general, the vapor pressure is calculated by using Antoine's equation. However, this equation can usually be applied only to a certain range of temperature, for example the range of the temperature for the vapor pressure of *n*-octadecane is from 173°C to 316°C. This time, in order to obtain the vapor pressure of *n*-paraffin, we applied the data obtained from Antoine's equation to Clapeyron-Clausius's equation. Clapeyron-Clausius's equation

(6)

is described below;

$$\ln P = - \frac{H}{RT} + \text{const.} \quad (\text{Clapeyron-Clausius's equation})$$

where P is the vapor pressure, T is the temperature, R is the gas constant and H is the enthalpy.

From this method, the vapor pressure of n-octadecane at 90°C was calculated as 6×10^{-2} (mmHg) which coincides well with the above value.

It was found that the vaporization rates of insoluble contaminants are constant and independent of the amount in the brine. It is considered that insoluble contaminants vaporize at constant rates till all of them disappear. In this case, the amount of the vaporized contaminant (W_o) is in proportion to time in the same way as the amount of vaporized water (W_w).

However, soluble contaminants vaporize in a different manner. With respect to the vaporization of solute, Henry's law is well known. We established the data analysis method based on this equation.

The vaporization of solute follows the exponential function. Therefore, the vaporization rate depends on the concentration in the brine and they never disappear completely from the brine. This result shows that the data analysis method is the proper method for solubilized contaminants. By using this method, if we obtain the concentration of the contaminant, the temperature of the evaporator and the vaporization rate of water (V_w), the vaporization rate of contaminant (V_o) can be calculated. However, Henry's constants for many organic substances have not been obtained, especially for trihalomethanes. Therefore, it is necessary to measure Henry's constants for some trihalometanes.

In this case, we applied the following equation instead of the equation for steam distillation, because W_o could not be obtained by multiplying V_o by time.

$$\frac{V_o}{V_w} = \frac{M_o \cdot C_o / H_o}{M_w \cdot P_w}$$

(6)

The vaporization of a complex contaminant was also studied in order to compare the vaporization rate of a component of a complex contaminant and the rate where the component existed singly. In the case of n-octadecane in Fuel Oil Type "A", the vaporization rate was considerably affected and reduced by 40times, compared with the result of pure n-octadecane carryover test.

It is considered that n-octadecane is one component of the solution, i.e.. Fuel Oil Type "A" and a modified Raoult's law that is described below, is applicable to define the vaporization:

$$p_i = x_i \cdot P_{oi} \cdot \gamma_i$$

where

p_i : the partial pressure of 'i' component,

x_i : the mole fraction of 'i' component

P_{oi} : the vapor pressure of the pure 'i' component

γ_i : the activity coefficient of 'i' component

From this equation and the modified equation for steam distillation, the following equation is obtained that defines the vaporization of a complex contaminant.

$$\frac{V_{oi}}{V_w} = \frac{M_{oi} \cdot P_{oi} \cdot x_i \cdot \gamma_i}{M_w \cdot P_w}$$

The mole fraction of n-octadecane is calculated as approximately 0.02 from the data of gas chromatography. Therefore, when the activity coefficient is supposed to be 1, R (W_o/W_w) for n-octadecane in Fuel Oil Type "A" is obtained as 2.1×10^{-5} . This coincides well with the value obtained from the experiment that is 2.7×10^{-5} and if we take a more accurate value of the activity coefficient into consideration, the agreement will be better.

On the other hand, a considerable effect of Fuel Oil Type "A" on the vaporization of bromoform was not observed. Therefore, in the case of an actual oil spillage, it is also thought that the vaporization of solubilized contaminants is not affected greatly by the spilled oil.

As described above, we carried out 'Oil Carryover Test' and defined the basic rules of the

vaporization mechanism of some contaminants in the brine. However, taking the actual MSF plants into consideration, we realized the necessity of further studies on the condensation mechanism of vaporized materials in order to anticipate the quality of the product water.

5. Conclusion

1. We demonstrated that the equation for steam distillation (1) was applicable to the evaporation of high molecular weight hydrocarbons such as n-octadecane which is barely soluble in the brine.

$$\frac{W_o}{W_w} = \frac{M_o \cdot P_o}{M_w \cdot P_w} \dots\dots\dots (1)$$

Following this equation, if we know W_w , which is the amount of vaporized water, the amount of vaporized contaminant (W_o) can be obtained.

2. We studied the vaporization of bromoform and toluene, and developed a modified equation that could apply to the vaporization of not only insoluble contaminants (heterogeneous system) but also soluble contaminants (homogeneous system);

$$\frac{V_o}{V_w} = \frac{M_o \cdot C_o / H_o}{M_w \cdot P_w} \dots\dots\dots (2)$$

where V is the vaporization rate.

3. We studied the vaporization of complex contaminants by using Fuel Oil Type "A". In this study, the vaporization rate of n-octadecane was reduced by approximately 40 times, compared with that of the single system, and then it was considered that Raoult's law could be applied to this case and the following equation (3) was proposed:

$$\frac{V_{oi}}{V_w} = \frac{M_{oi} \cdot P_{oi} \cdot x_i \cdot \gamma_i}{M_w \cdot P_w} \dots\dots\dots (3)$$

In this study, it was concluded that this equation can be used as the basis to carry out

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computer simulation studies.

- 4. We examined influences of contaminated Fuel Oil Type "A" on the vaporization rate of bromoform. In our experiments, the influence was negligible.**

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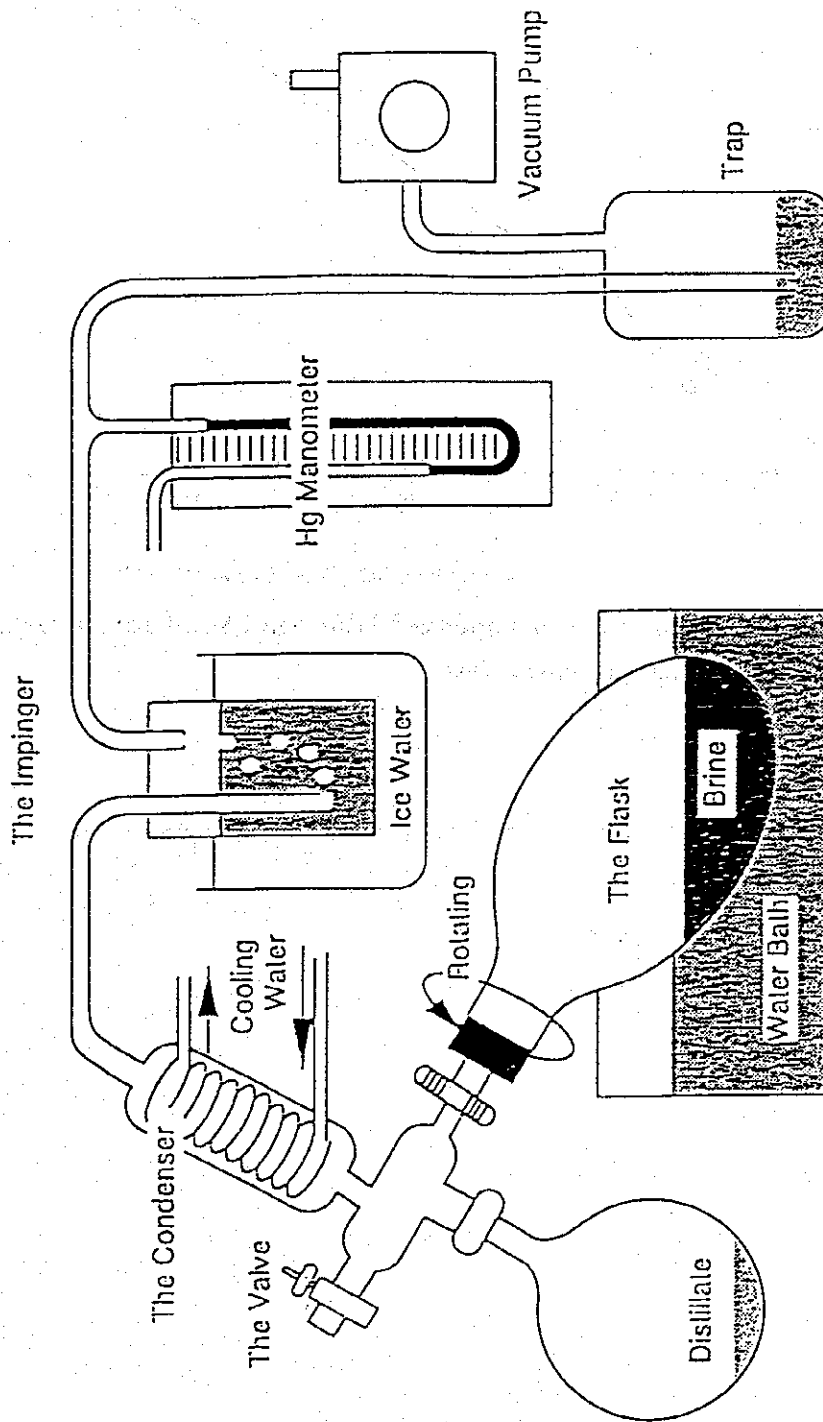


Fig. 1 Schematic Arrangement of Test Equipment

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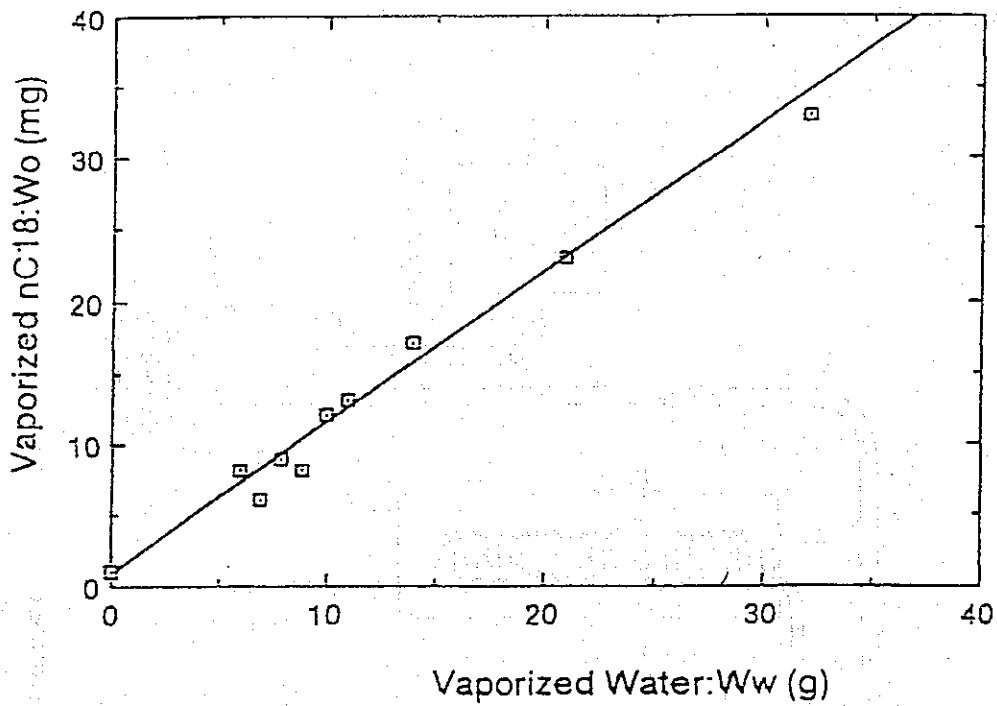


Fig. 2 The Relationship between Vaporized Water and Vaporized n-Octadecane in n-Octadecane Carryover Test

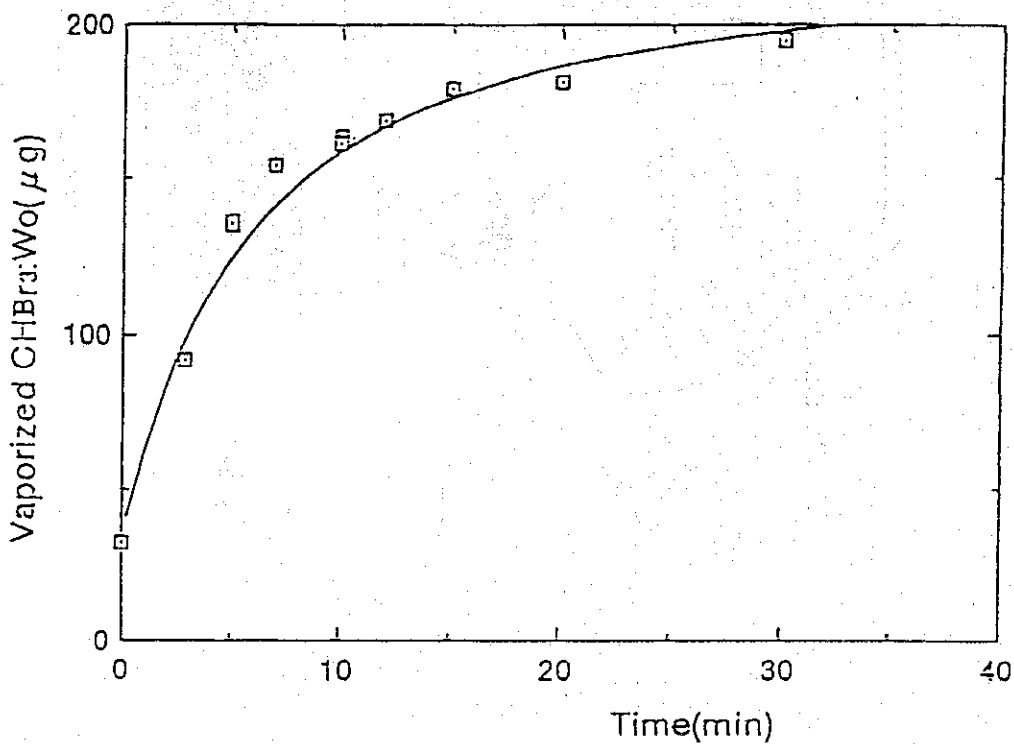


Fig. 3 Time Course of the Amount of Vaporized Bromoform

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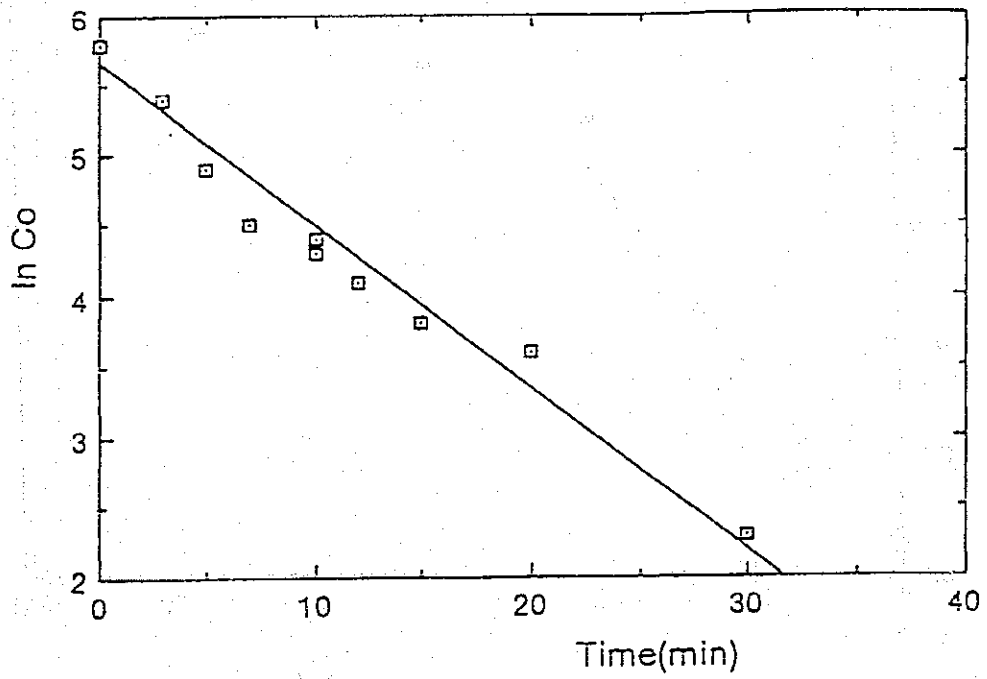


Fig. 4 The Relationship between the Time and ln Co in Bromoform Carryover Test

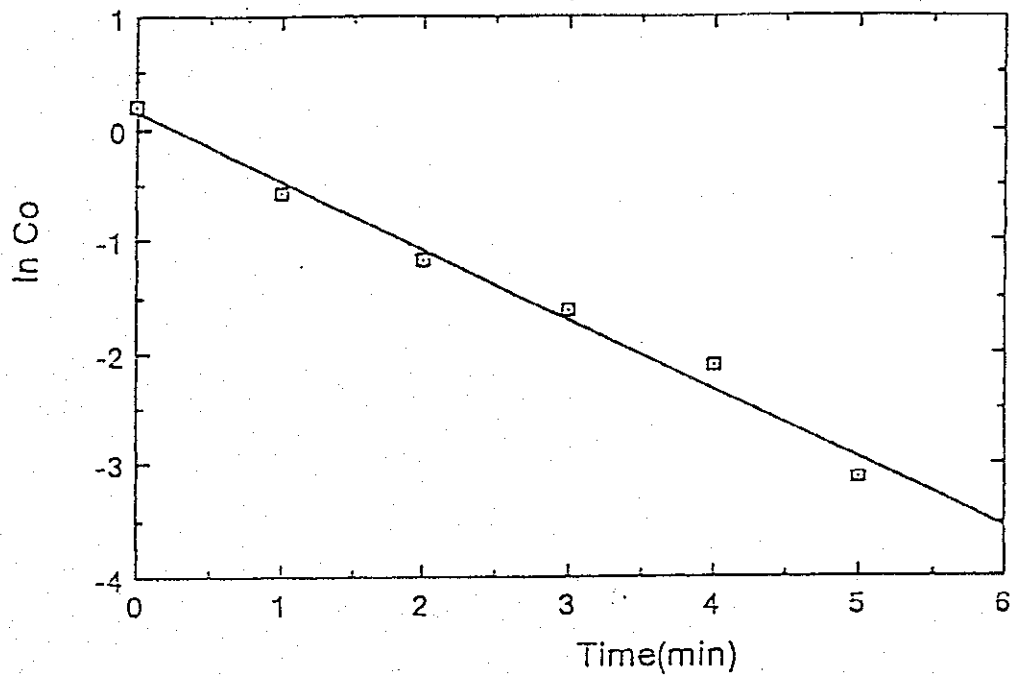


Fig. 5 The Relationship between the Time and ln Co in Toluene Carryover Test

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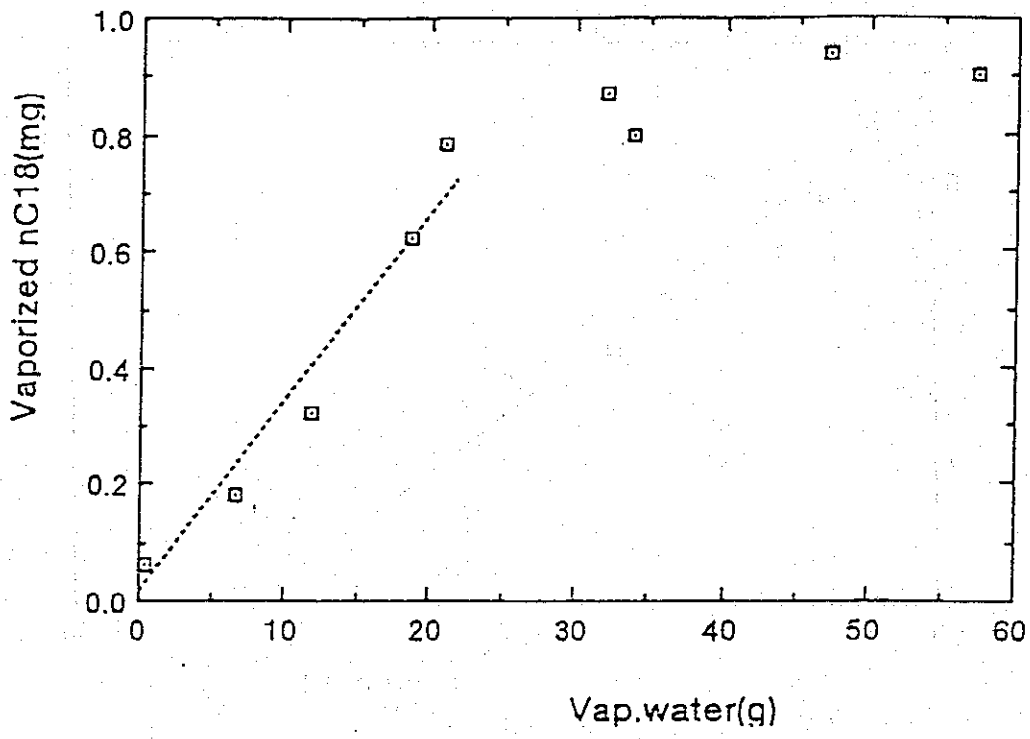


Fig. 6 The Relationship between vaporized Water and Vaporized n-Octadecane in Fuel Oil A Carryover Test

6.2 Measurement of Vapor-Liquid Equilibria

1. Introduction

To have an understanding of the carry over process a computer program for the quantitative estimation of the vaporized contaminants in brine was developed, based on the data obtained from the vaporization mechanism of organic contaminants using a typical fuel and bromoform as pollutants in the preliminary experiments.

During the reported period a study was conducted to determine Henry's Constant using a vapor-liquid equilibrium apparatus. Results of the experiment with this apparatus was expected to improve the reliability of the above mentioned computer program.

The results of the experiment with bromoform selected as a typical organic contaminant to provide a homogeneous system and using the vapor-liquid equilibrium apparatus, are described here. The data is expected to be used, in general, for other organic contaminants.

2. Experiments

To determine Henry's constant by calculation from experimental data on equilibrium concentration, a vapor-liquid equilibrium apparatus (model R-W) was used and is shown in Fig. 7. The vapor liquid equilibrium apparatus essentially consists of three parts (A) Vapor/Liquid Equilibrium system (B) Operation control panel (C) Vacuum/Exhaust system.

2.1 Calculation of Henry's Constant using the Obtained Data

Under a set of selected equilibrium conditions, this apparatus can provide concentrations of bromoform in two phases: i.e., (1) gas phase (condensate)(2) liquid phase. The calculation of Henry's constant is as follows:

(a) Definition of Henry's Constant

$$C_B = H \cdot P_B$$

where

C_B : Bromoform concentration in the liquid phase (mol/L)

P_B : Partial pressure of bromoform in the gas phase (Pa)

(6)

Henry's constant is defined as H (mol/L·Pa) in the above equation.

(b) Calculation of Henry's Constant

- i. Let the concentration in the liquid phase be C_B .
- ii. Calculate the mole fraction of bromoform in the gas phase, Y_B with the bromoform concentration of the condensed phase.
- iii. The partial pressure of bromoform in the gas phase, P_B is given by the following equation.

$$Y_B = P_B / \pi$$

Where π is the total pressure (= saturation pressure of water at the given temperature, the mole fraction of water is approximately 1)

- iv. Henry's constant is obtained by the following equation:

$$H = C_B / P_B$$

For water, $Y_w = P_w / \pi$, $Y_w \approx 1$, then $P_w \approx \pi = P_0$

When P_0 is the vapor pressure of pure water.

2.2 Experimental Conditions

Following experimental conditions were used to obtain Henry's constant.

- (a) Seawater, (concentration Factor, C.F = 1.0)
- (b) Brine, (Concentration Factor, C.F. =1.4)
- (c) Temperature -- 40°C, 65°C, 90°C
- (d) Bromoform concentration -- 10 and 100 ppm

3. Results

Temperature and pressure at which experiments were carried out are given in Table 1. Calculated Henry's constants are also given in Table 1.

4. Discussion

One can see from Table 1 that Henry's constant (H) is temperature and pressure dependent. Plot of $\log H$ as function of temperature (°C) was found to be linear (Fig. 2). Relation

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between Henry's constant and temperature ($T^{\circ}\text{C}$) can be mathematically expressed as

$$\log H = 1.0511 - 0.0245(T)$$

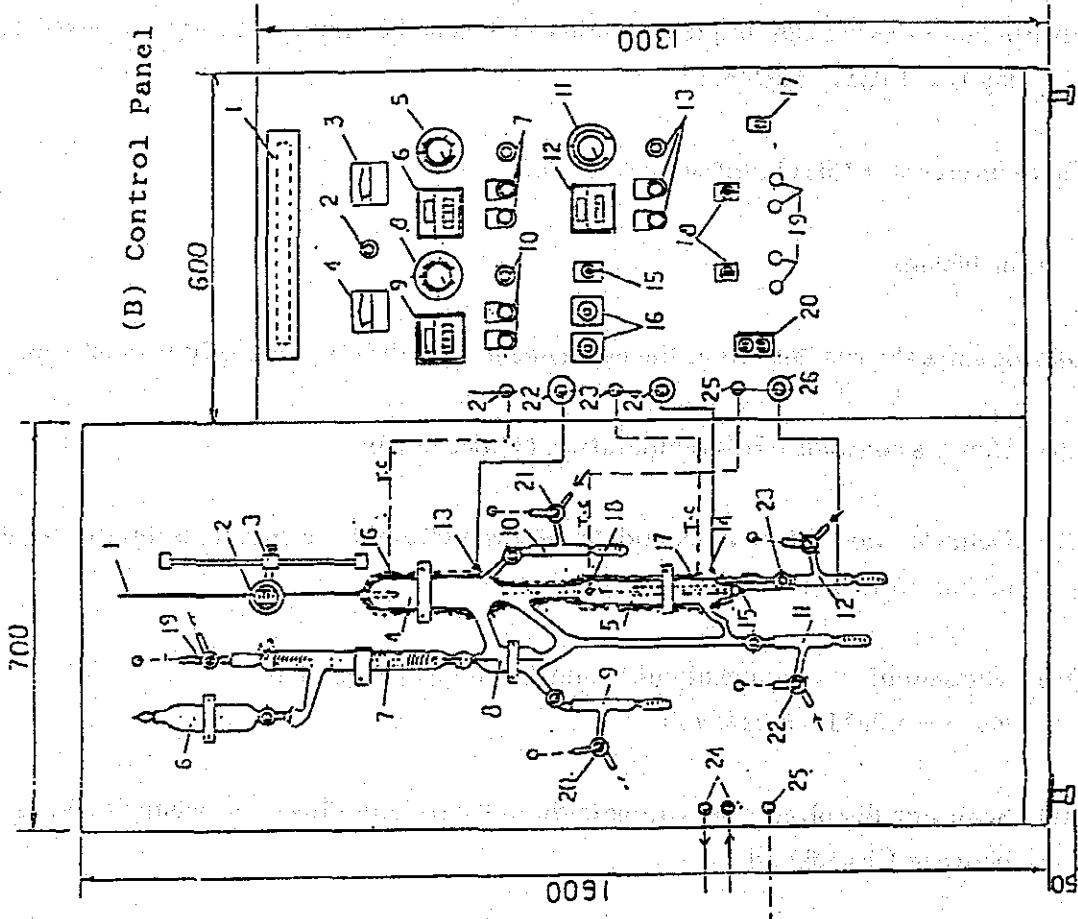
Where intercept = 1.0511 and slope = -0.0245.

5. Conclusions

Following are the conclusions of the experimental results obtained with bromoform:

- (i) Henry's constant (H) is temperature (T) dependent.
- (ii) Henry's constant is independent of bromoform concentrations in the tested range of concentration.
- (iii) Mathematical relationship of H and T can be expressed as
 $\log H = 1.0511 - 0.0245 (T)$
- (iv) Seawater dissolved salts contents do not have any effects on Henry's constant values between CF=1.0 and 1.4.

(A) Vapor/Liquid Equilibrium System



(C) Vacuum/Exhaust System

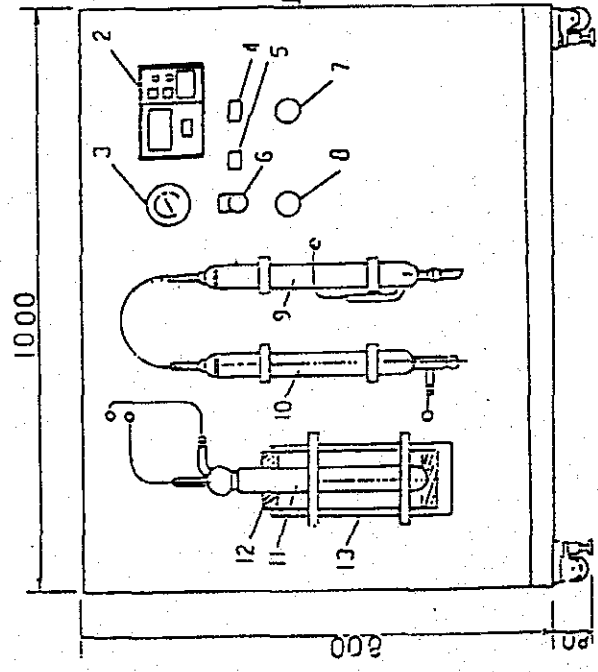


Fig. 7 Vapor-Liquid Equilibrium Apparatus (Model R-W)

Table 1 Calculated Henry's Constant of various conditions

S. No	Run No.	Temperature		Pressure	Concentration Factor	Bromoform Concentration	Henry's Constant
		°C	°K	mmHg	-	ppm	mol/L·mmHg
1	9	35	308	43	1	7.92	1.85
2	11	40	313	55	1	102	1.06
3	5	44	317	70	1	7.92	0.86
4	8	45	318	70	1	9.62	0.92
5	10	46	319	72	1	103	0.96
6	6	52	325	97	1	10.46	1.10
7	7	54.8	327.8	98	1	9.65	0.56
8	13	62	335	187	1	105.2	0.19
9	12	80	353	355	1	108	0.16
10	14	61	334	149	1.4	7.432	0.43
11	15	66	339	187	1.4	7.437	0.24

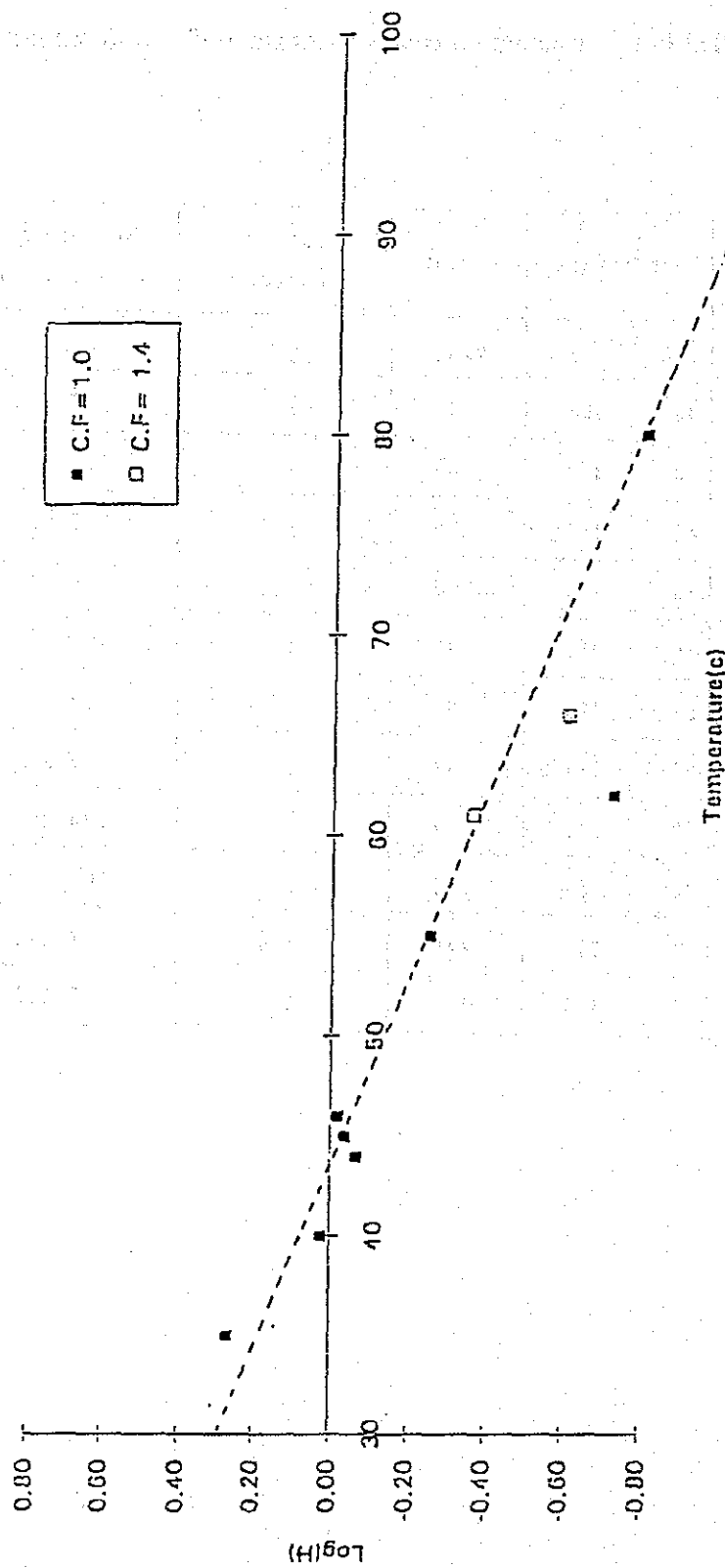


Fig. 8 Relationship between Temperature and Henry's Constant

6.3 Simulation and Prediction of Contamination

6.3.1 Relational Expression

1. Introduction

The purpose of the MSF-2 is to estimate the quality of the product water in case when the oil contaminated seawater has been fed into the MSF Plant. It has been done through the analysis of the evaporation phenomena of the volatile organic contaminants in the feed seawater.

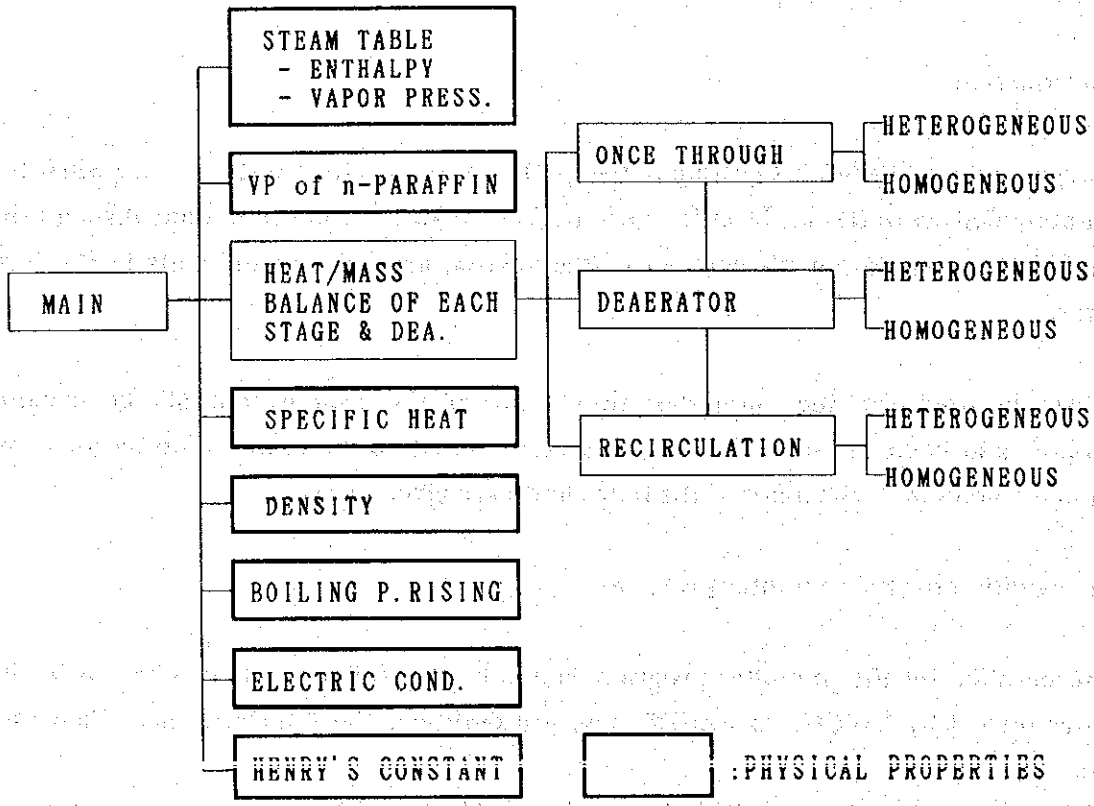
The formula used for the computer simulation of the evaporation of the organic contaminants in brine are described in this section, based on the evaporation mechanisms shown in 6.1 and 6.2. The items of the flow charts are given here.

2. Precondition for the computer program

The precondition for the computer program should be that the program can be run by the computer owned by SWCC. To satisfy this precondition, the followings are taken into account.

- **HARD WARE** : PC type IBM Compatible, 386/486 based machines operating under DOS/Windows
- **SOFT WARE** : FORTRAN Language
- **HD Space** : less than 200MB

3. Structure of the Program



4. How to Set Up Symbols for the Formulas

4.1 Fundamental rule for setting up the above mentioned symbols

I	II	III	IV
---	----	-----	----

I	F: Flow rate of brine, water & contaminants	(kg/h)
	C: Concentration of the constituents	(kg/l)
	T: Temperature	(C)
	P: Pressure	(Pa)
	S: Electric conductivity	(S/cm)
II	X: Mole fraction	
	B: Seawater, brine	
	W: Water	
III	O: Aliphatic hydrocarbonic & homogenous contaminants	
	E: Vapor generated by evaporation & distillation	
	L: Liquid (Water, seawater, brine)	
IV	M: Make-up	
	D: Inlet of deaerator	
	T: Outlet of Last stage	
	C: Recirculation brine	1:#1 stage 4:#4 stage
	B: Blow brine	2:#2 stage 5:#5 stage
	O: Outlet of brine heater	3:#3 stage 6:#6 stage

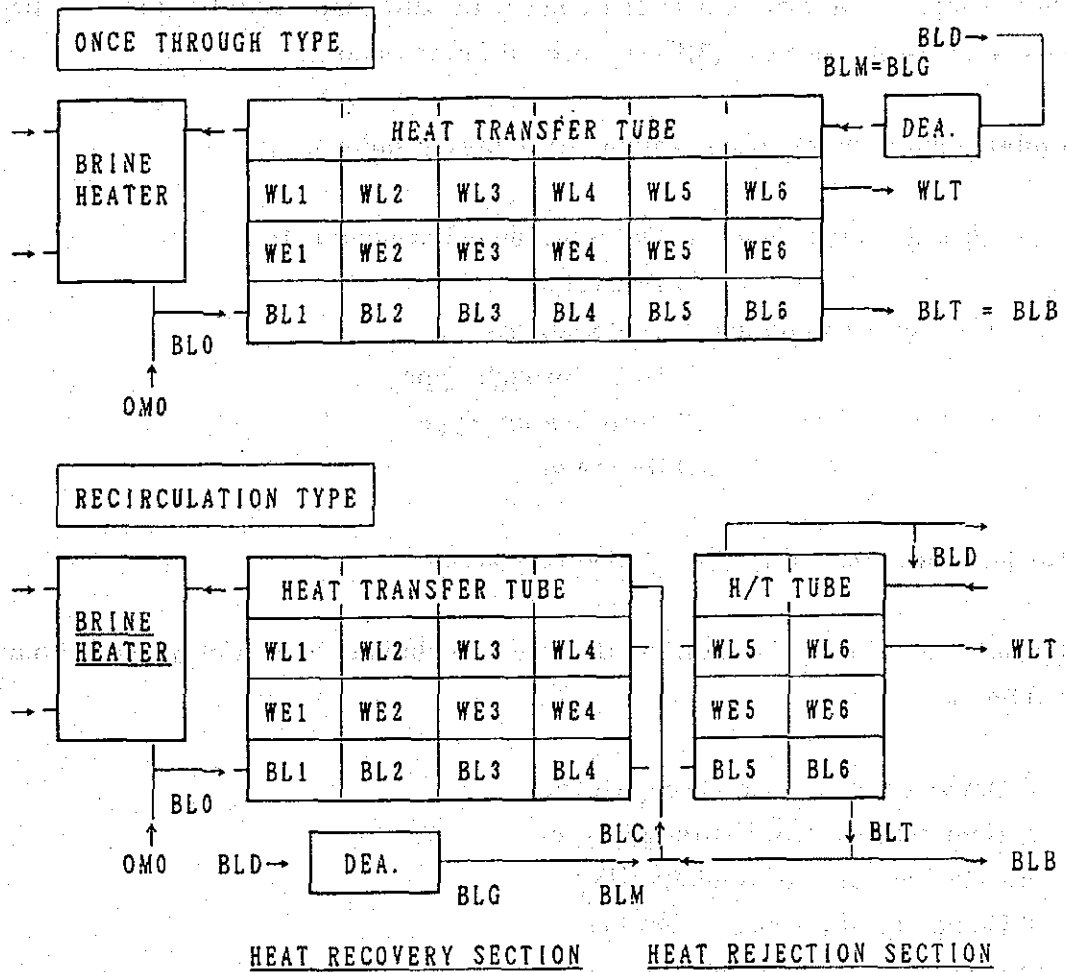
4.2 Physical properties, etc. (The symbols are not treated the same as a fundamental rule)

D	: Density	(kg/l)
H	: Henry's constant	{mol/(l·Pa)}
ENT	: Enthalpy	(kJ/kg)
CP	: Specific heat	{kJ/(kg·C)}
MW, MO	: Molecular weight of water & contaminants	
EC	: Electric conductivity of the brine at 25°C	(S/cm)
ONTD	: Overall NETD	(C)
NTD	: NETD based on the equipment structure	(C)
BPR	: Boiling point rising	(C)
N	: Number of carbons of paraffin (Aliphatic hydrocarbon)	

4.3 Symbols which are Added on the Top or the End of Four Figures

- 'A' added on the top : The assumed value & the value obtained by the convergence calculation
- 'B' added on the top : The final results obtained by assuming the A
- 'NE' added on the top : The value of #6 stage obtained by calculation based on the once through type
- 'BB' added on the top : The final results obtained by the 'NE'
- '1...9, a...z' added on the end : Number of carbons in paraffin, where, 'a...z' indicate the number of carbons 10...35

4.4 Flow of MSF Test Plant and Symbols of II, III, IV Groups



(FUNDAMENTAL MASS BALANCE OF MSF PROCESSES)

$$FBLM = FBLB + FWLT + \alpha$$

$$(FBLM)(CBLM) = (FBLB)(CBLB)$$

$$FBLB = FBLM(CBLM/CBLB) = FBLM - FWLT$$

Where, α indicates the amount of non-condensable gasses.

5. Flow Chart

The flow chart of the program is constructed by two major substructures. They are (1) Mass and Heat Balance and (2) Carry-over of Contaminants.

Each substructure consists of subordinate structures as follows.

- Heat & Mass Balance
 - 1) Once-through/recirculation type
 - 2) Deaerator
- Carryover Estimation of Contaminants
 - 1) Once-through Type
 - 2) Recirculation Type
 - 3) Deaerator

6. The Formulas adopted for Calculation/Estimation

The formulas adopted for "Heat/Mass Balance Calculation" and "Carryover Estimation" are as follows:

- 1) Heterogeneous, Once Through Type
- 2) Homogeneous, Once Through Type
- 3) Heterogeneous, Recirculation Type
- 4) Homogeneous, Recirculation Type
- 5) Deaerator
 - A. Heterogeneous
 - B. Homogeneous
 - C. Heat/Mass Balance

6.3.2 Simulation for Behavior of Oil Contaminants

1. Introduction

The basic structure and the formulas used in each block has been reported in the previous section.

This section reports main and subroutine program structure, variables, physical properties and chemical constants.

2. Structure of the program

The program is made up primarily of 5 parts as shown below:

- Input processing
- Deaerator calculation
- Heat and mass balance calculation
- Carryover calculation
- Output processing

Each part is made up of a number of subordinate subroutines.

3. Variables

Variables are made up primarily of 6 groups:

- Heat and mass balance calculation
- Designate calculation options
- Carryover calculation
- Store log data
- Iteration in heat and mass balance calculation
- Deaerator calculation

(6)

4. Physical Properties and Chemical Constants

Physical properties and chemical constants used in the program:

- **Function of temperature** : **Henry's constant**
Saturated steam pressure,
Latent heat of vaporization
- **Function of TDC concentration** : **Electric conductivity**
Boiling point elevation of brine
- **Function of TDC conc. and temp.** : **Specific heat of brine**
Brine density
- **Function of temp. and carbon-number-dependent 3 constants** : **Saturated n-paraffin pressure**
- **Function of molecular weight** : **Carryover constant**

6.4 Test with the MSF Test Plant

6.4.1 Modification of the MSF Test Plant

1. Introduction

The purpose of the test with the MSF test plant is to evaluate the carryover of contaminants in product water, and compare the results to those obtained from the computer program. Consequently, the modification of the MSF test plant was introduced to add sampling facilities to the MSF test plant.

2. Installation

The installation works were as follows.

- (1) **Installation of the pumps for the sampling of brine**
To sample brine at each stage from No. one to five, five pumps were installed at the loop seal pipe. The piping work was carried out accordingly.
- (2) **Installation of pumps for the sampling of product water**
To sample product water at each stage from No. one to six, five pumps were installed at the loop seal pipe, and one pump was installed at the drain pipe of product water and then the piping work was carried out accordingly.
- (3) **Installation of the pump for oil injection**
To inject oil into the brine, the pump for oil injection was installed at the pipe after the brine heater and then piping work was carried out.
- (4) **Installation of the oil separator and the pump for oil-contaminated seawater transfer**
A FRP tank was installed because it was decided that the separated oil from the oil-contaminated seawater should be stored in the oil tank.
- (5) **Electrical and instrumental installations.**

To measure temperature of vapor at each stage from No. one to six and of brine at each inlet of stage from No. one to five, RTDs were installed at each optimum point.

(6)

And each sensor was connected with recorder in the center control panel.

The start and stop control of the sampling pumps for the brine and the product water are manipulated at the center control panel. The start and stop control of the transfer pump for the oil contaminated seawater manipulated at the satellite control panel.

3. Confirmation of Actuation

Confirmation of each actuation were as follows.

(1) Brine sampling pumps

After flushing the pipe, the direction of rotation of the pumps were checked.

(2) Product water sampling pump

After flushing the pipes, the direction of rotation of the pumps were checked.

(3) Oil injection pump

After confirmation of the direction of rotation, the pump was calibrated.

(4) Oil separator

- 1) The direction of rotation of the transfer pump for the oil contaminated seawater was checked.
- 2) The interlock between the oil contaminated seawater transfer pump and the level meter was checked.
- 3) The interlock between the valve for oil discharge at the oil separator and the level meter was checked.

(5) Fixation of numbers between the recorder and sensors

The range of temperature at the recorder was fixed from 0 to 150°C. The record numbers of each sensor which consists of a resistance thermometer bulb are as follows.

vapor temperature : CH-1, CH-2, CH-3, CH-4, CH-5, CH-6
brine temperature : CH-11, CH-12, CH-13, CH-14, CH-15

(6)

(6) Air test

The air test was carried out and the air tightness was confirmed at a pressure of 0.75 kg/cm²•G.

4. Others

Matters to be attended under operation are as follows.

(1) Brine sampling pumps

Because these pumps are not for normal continuous operation, one person should wait at that place to open the outlet valve as soon as the pump starts.

(2) Oil separator

When the blow down water is fed into the oil separator during the carryover testing, the manual valve should be closed slowly.

6.4.2 Mixture of Bromoform and Product Water

1. Introduction

Based on the vaporization mechanisms of the organic contaminants obtained by 6.1 and 6.2, the flow chart and the formula used in the computer program for the prediction of the volatile contaminants from brine have been introduced and the structure of the program has been reported in 6.3.

In order to predict the behavior of bromoform in MSF plant, bromoform has been intentionally dosed in the MSF test plant and its behavior has been investigated. The experimental results obtained from the MSF test plant has been compared with the computer calculation.

2. Test Plan

The bromoform carryover test by the MSF Test Plant has been conducted as RUN 6, and the test conditions are shown in Table 6 in 5.3.3.

There was vaporization of bromoform at the deaerator. To certify the phenomena, RUN 6 was divided to two parts, RUN 6-1 and 6-2. The bromoform has been injected at the outlet of the brine heater for RUN 6-1 and at the inlet of the deaerator for RUN 6-2. The operation conditions of RUN 6-1 of the MSF Test Plant was identical to that of RUN 5-2 since the both runs were carried out simultaneously.

The test conditions are shown in Table 2 together with the oil carryover test conditions. The amount of oil injected in RUN 6-1 was 0.5mg/L, however, that of RUN 6-2 has been increased to 2.75 mg/L, which is five times more than RUN 6-1, taking the vaporization of bromoform in the deaerator into account.

(6)

Table 2 Test Conditions of MSF-2

RUN NO.		6-1	6-2	7	9
1. Operation Mode		Recir.	Recir.	Once	Once
2. Scale Control Method		Hybrid	Chemi.	Chemi.	Chemi.
3. Top Brine Temperature	°C	112	112	112	112
4. Flow Rate					
-Make up Seawater	m ³ /h	2.45	2.30	6.40	6.40
-Recirculation Brine	m ³ /h	6.50	6.50	6.40	6.40
-Product Water	m ³ /h	0.81	0.86	0.90	0.90
5. Chemical Constituents of Brine					
-pH at 25C		8.04	8.52	8.24	8.24
-M-alkalinity as CaCO ₃	mg/L	55-60	180	128	128
-Chloride ion	mg/L	32,730	33,320	23,360	23,360
-Concentration Factor	mg/L	1.39	1.40	1.01	1.01
6. Dosing Rate of Chemicals					
-Scale Inhibitor (PPN(M))	mg/L	1	2	2	2
-Acid (98% H ₂ SO ₄)	mg/L	72	None	None	None
-Trihalomethane (CHBr ₃)	mg/L	0.5	2.75	None	None
-Oil (Light Diesel Oil #2)	mg/L	None	None	10	2.5
7. Injection Point of Contaminants		After	Before	After	After
		B.H	Dea.	B.H	B.H

3. Discussions

3.1 Mass balance of bromoform

The mass balance of the bromoform has been calculated from the test results of RUN 6-1 and carryover test.

The flow rate of the seawater, product water and blow brine are as follows.

- Make up seawater : 2,450 kg/h
- Product water : 780 kg/h
- Blow down brine : $2,450 - 780 = 1,670$ kg/h

The amount of bromoform dosed in RUN 6-1 and 6-2 are 0.5mg/L and 2.75mg/L, respectively.

The average concentrations of bromoform measured during the experiments and used for the calculation of the discharge rate are shown below.

RUN No.	Initial Conc.	Product Water Conc.	Blow Down Brine Conc.
6-1	0.5 mg/L	0.0137 mg/L	<0.0001 mg/L
6-2	2.75 mg/L	0.1538 mg/L	<0.0001 mg/L

RUN 6-1

- Feed rate of bromoform : $2,450\text{kg/h} \times 0.5\text{mg/L} \times 0.97\text{L/kg} = 1,188\text{mg/h}$
- Discharge rate from blow down brine : $1,670\text{kg/h} \times 0.0001\text{mg/L} \times 0.97\text{L/kg} = 0.162\text{mg/h}$
- Discharge rate from product water : $780\text{kg/h} \times 0.0137\text{mg/L} \times 0.97\text{L/kg} = 10.36\text{mg/h}$
- Ejection rate out of the system : $1,188 - (0.162 + 10.36) = 1,178\text{mg/h}$
- Percent Ejection out of the system : $(1,178/1,188) \times 100 = 99.2\%$

RUN 6-2

- Feed rate of bromoform : $2,450\text{kg/h} \times 2.75\text{mg/kg} = 6,535\text{mg/h}$
- Discharge rate from blow down brine : $1,670\text{kg/h} \times 0.0001\text{mg/L} \times 0.97\text{L/kg} = 0.162\text{mg/h}$
- Discharge rate from product water : $780\text{kg/h} \times 0.153\text{mg/L} \times 0.97\text{L/kg} = 116.4\text{mg/h}$
- Ejection rate out of the system : $6,535 - (0.162 + 116.4) = 6,419\text{mg/h}$

(6)

• Percent ejection out of the system : $(6,419/6,535) \times 100 = 98.2\%$

It has been revealed that most of the bromoform will be ejected out of the system from the ejector.

3.2 Mass balance of water and bromoform based on computer calculation

The results of the computer calculation based on the test conditions of 3.1 are shown in Table 3.

The calculated value for the mass balance of bromoform of RUN 6-1 will be as follows.

- Feed rate of bromoform : $2,450\text{kg/h} \times 0.5\text{mg/L} \times 0.97\text{L/kg} = 1,188\text{mg/L}$
- Discharge rate from blow brine : $1,670\text{kg/h} \times 0.0895\text{mg/L} \times 0.97\text{L/kg} = 145.0\text{mg/h}$
- Discharge rate from product water : $780\text{kg/h} \times 1.321\text{mg/L} \times 0.97\text{L/kg} = 999.5\text{mg/h}$
- Convergence calculation error : $1,183 - (145.0 + 999.5) = 43.8\text{mg/h}$

The comparison of the measured and calculated values are shown below.

Items	Bromoform concentration		Amount of Product Water
	Product Water	Blow Down Brine	
Test Results (RUN 6-1)	0.0137 mg/L	0.0001 mg/L	810 kg/h
Calculated Value	1.321 mg/L	0.0895 mg/L	779 kg/h

The calculated value of the product water is in good agreement with the measured value, within 96% accuracy, thus it can be said that the computer program can predict the behavior of the product water in MSF test plant.

However, the bromoform concentration in the blow down brine became 0.0895mg/L by the calculation while that of measured value was below 0.0001mg/L.

In order to adjust the bromoform concentration of the blow down brine, the Henry's constant has to be lowered to 1/3.4 of the measured value, as shown below.

(6)

Item	Bromoform concentration		Amount of Product Water
	Product Water	Blow Down Brine	
Calculation Value (Using Henry's constant: 1/3.4)	1.526 mg/L	0.74E-4 mg/L	779.5 kg/h

On the other hand, the concentration of the product water remain far higher than the actual value despite the change in Henry's constant. This is because the computer program assumed that all the evaporated bromoform will condensate back into the product water.

Consequently, it can be assumed that the condensation rate of the bromoform is far less than that of water. However, the difference in condensation rate of water and bromoform remain unknown.

If the factors affecting the condensation rate of bromoform become clear, it will become easy to predict the condensation rate, and will be helpful to reduce or prevent the bromoform in product water by improving, for example, the vent system.

(6)

Table 3 Summary of computer output

RUN 6-1 COMM = 0.5 mg/L. Henry's Constant: Log H = 0.24-0.024T

Stage	Dea.	1	2	3	4	5	6
Product W.		2.2742	1.9082	1.7311	1.5867	1.4481	1.3215
Brine		0.1724	0.1488	0.1327	1.1649	0.0977	0.0089

RUN 6-1 COMM = 0.5 mg/L. Henry's Constant: H' = H/3.4

Stage	Dea.	1	2	3	4	5	6
Product W.		6.0418	3.6617	2.8005	2.2265	1.7685	1.5264
Brine		0.0021	0.0009	0.0005	0.0002	0.0001	0.00007

RUN 6-2 COMM = 2.75 mg/L. Henry's Constant: Log H = 0.24-0.024T

Stage	Dea.	1	2	3	4	5	6
Product W.	14.565	12.081	10.137	9.1960	8.4338	7.6928	7.0202
Brine	2.6682	0.9161	0.7909	0.7050	0.6188	0.5191	0.4778

RUN 6-2 COMM = 2.75 mg/L. Henry's Constant: H' = H/3.4

Stage	Dea.	1	2	3	4	5	6
Product W.	49.522	29.707	18.004	13.770	10.948	8.6956	7.5052
Brine	2.4719	0.0103	0.0048	0.0027	0.0014	0.0005	0.0003

4. Conclusions

The computer calculation and the experiments by MSF Test Plant have been conducted to clarify the behavior of bromoform, representing the trihalomethane, in the MSF plant. The results are as follows.

- (1) The computer program can predict the amount of product water with sufficient accuracy.
- (2) In order to predict the behavior of bromoform in MSF plant, not only the equilibrium analysis but also dynamics of the condensation of bromoform has to be taken into account.
- (3) The prevention of bromoform in product water would be accomplished by the optimization of the design and power of the vent system including deaerator, which could eject out the bromoform without contaminating the product water.

6.4.3 Mixture of Crude Oil Components into Product Water

1. Introduction

Following the analysis of bromoform in the previous section, oil was added to the MSF Test Plant and the behavior of oil in the plant was analyzed in this section. The computer prediction was compared with the experimental results.

2. Test Plan

The oil carry-over tests with the MSF Test Plant were conducted as RUN 7 and RUN 9 at two concentrations as shown in Table 6 of 5.3.3. In order to prevent oil contamination in the deaerator and heat transfer tubes, the operation mode was turned from recirculation to once-through, and oil was fed to the outlet of the brine heater.

3. Test Conditions

The oil dosing rate in the feed seawater was 10mg/L for RUN 7 and 2.5mg/L for RUN 9.

4. Discussion

4.1 Material Balance from Experimental Data

The material balance was calculated from the experimental data of oil carry-over in RUN 7 and RUN 9. The flow rates of feed seawater and brine were as follows.

- Feed seawater flow rate : 6,400kg/h
- Product water flow rate : 900kg/h
- Blow down brine rate : $6,400 - 900 = 5,500$ kg/h

The oil dosing rate was 10 mg/L for RUN 7, and 2.5 mg/L for RUN 9. The values of the second and latter experiments in each run were adopted as reliable data to estimate the ejection rate of oil out of the plant. The mean values of oil concentration are as follows.

(6)

RUN No.	Feed Seawater	Product Water	Blow Down Brine
7	10 mg/L	18.4 mg/L	0.93mg/L
9	2.5 mg/L	0.43 mg/L	Not Detected

RUN 7

- Oil Feed Rate : $6,400\text{kg/h} \times 10\text{mg/L} \times 0.97\text{L/kg} = 62,080\text{mg/h}$
- Discharge Rate by Blow Down Brine : $5,500\text{kg/h} \times 0.93\text{mg/L} \times 0.97\text{L/kg} = 4,961\text{mg/h}$
- Discharge Rate by Product Water : $900\text{kg/h} \times 18.4\text{mg/L} \times 0.97\text{L/kg} = 16,063\text{mg/h}$
- Ejection Rate out of Plant : $62,080 - (4,961 + 16,063) = 41,056\text{mg/h}$
- Percent Ejection : $(41,056/62,080) \times 100 = 66.13 \%$

RUN 9

- Oil Feed Rate : $6,400\text{kg/h} \times 2.5\text{mg/L} \times 0.97\text{L/kg} = 15,520\text{mg/h}$
- Discharge Rate by Blow Down Brine : Not Detected
- Discharge Rate by Product Water : $900\text{kg/h} \times 0.043\text{mg/L} \times 0.97\text{L/kg} = 23.92\text{mg/h}$
- Ejection Rate out of Plant : $15,520 - (23.9 + 0) = 1,549.1\text{mg/h}$
- Percent Ejection : $(1,549.1/15,520) \times 100 = 99.7 \%$

As shown above, about 66% of the added oil was ejected out of the MSF Plant via the ejector in RUN 7 whose oil concentration was 10 mg/L. However, more than 99% of the oil was ejected out in RUN 9 whose oil concentration was 2.5 mg/L.

4.2 Material Balance from Computer Calculation

The results of computer calculation based on the conditions given in 4.1, are shown in Table 1 along with the experimental values for comparison.

In the case of 10 mg/L oil dosing rate, the oil concentration in brine was expected to be 0.8042 mg/L by calculation, but 3.13 mg/L from the experiments, which means that the calculated value was considerably lower or showed more volatile than the experimental one. If the vapor pressures of hydrocarbons in oil are assumed to be 1/3 of the values calculated by Antoine's equation, or one third of volatility is assumed, the calculated value of oil concentration in product water is of the same magnitude as the experimental one (see the Table 4). The oil concentration in the blow down brine has the similar trend.

**Table 4 Comparison between Experimental and Calculated Values
(Oil Dosing Rate: 10 mg/L)**

Experimental Values								(mg/L)
Stage	Deaerator	1	2	3	4	5	6	
Product Water	---	20.0	24.7	20.3	20.4	43.4	18.4	
Brine	---	3.13	3.02	0.27	1.15	0.83	0.93	

Calculated Values								(mg/L)
Stage	Deaerator	1	2	3	4	5	6	
Product Water	---	302.54	187.80	144.27	123.37	87.24	75.64	
Brine	---	0.8042	0.0572	0.0	0.0	0.0	0.0	

5. Conclusion

Computer calculation of oil concentration in the MSF Test Plant was conducted in order to predict the behavior of oil, one of the pollutants in the Arabian Gulf when the feed seawater is contaminated with oil. The following are the results.

- (1) The behavior of water can be predicted by the present computer program. However, the condensation rates of oil seems considerably small than that of water. This difference of rate must be considered in computer calculation.
- (2) The vapor pressures of hydrocarbons used, must be reviewed again.
- (3) Accuracy of experiments must be improved, especially for low concentrations of oil.
- (4) The countermeasures against oil contamination will be established after the above problems are solved. The countermeasures will be dependent on total concentrations of oil and distribution of carbon number of hydrocarbons. We could define "volatility index of oil" after computer predictions are conducted for various total and distribution concentrations of hydrocarbons, and the similar principle will be extended to other pollutants.

6.5 Transfer of technology

(1) Objective

The technology transfer is aimed especially for the young researchers in SWCC for their improved understandings on the carryover behavior of oil contaminants in seawater fed into MSF plant by conducting cooperative research work between JICA and SWCC.

(2) Procedure of technology transfer

The oil contamination of seawater is becoming crucial problem for the Gulf countries. The quantitative analysis of carryover behavior of oil contaminants to product water when contaminated seawater had been fed into MSF plant was conducted. The basic experiments of laboratory scale and bench scale test by MSF test plant had been conducted as cooperative research work. The results would be prepared to a full paper by applying the chemical engineering technology approach for the potential up of the research capability of young researchers.

Subjects for the cooperative research work.

- 1) Evaluation technology of MSF plant oil contamination
(Preparative work)
- 2) Evaluation technology by Vapor/Liquid equilibrium apparatus
(Simulation)
- 3) Evaluation technology by simulation and prediction
(Computer simulation)
- 4) Evaluation technology of contaminants carryover by MSF test plant
(Confirmation)

(3) Results

1) Evaluation technology of MSF plant oil contamination (Preparative work)

The sophisticated data analysis procedure and water analysis method had been established for the evaluation of the oil contaminants in MSF plant.

The results was prepared to a full paper for publication.

2) Evaluation technology by Vapor/Liquid equilibrium apparatus

The vapor/liquid equilibrium apparatus had been instrumented and basic research was conducted. The better understanding of mass balance of the phenomena was achieved and the operation manual of the apparatus has been accomplished.

(6)

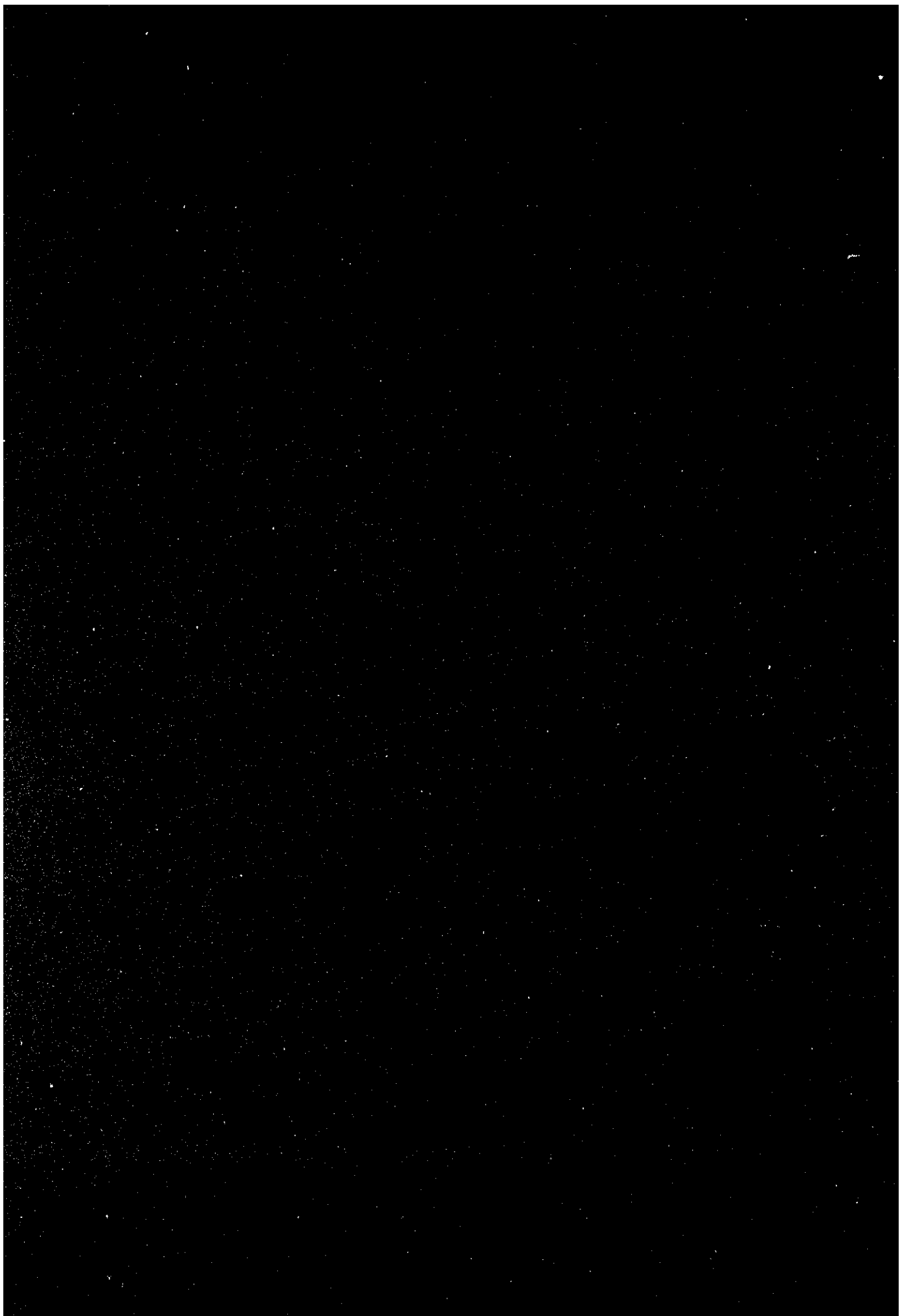
3) Evaluation technology by simulation and prediction

The computer program for the simulation and prediction of the behavior of oil contaminants in MSF plant had been established by applying those related formula.

4) Evaluation technology of contaminants carryover by MSF test plant

The test with oil contaminants had been conducted by MSF test plant. The obtained test data had been analyzed and compared with computer calculation. The effect of various parameters had been studied. The understanding of the seawater contamination has been deepened through the evaluation.

7. Selection of RO Membrane for Hybrid System (RO-1)



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Study on Selection of RO Membrane for Hybrid System (RO-1)

7.1 Investigation and Preparative Experiment

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

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

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

7.1.1 Investigation on Commercial RO Modules for Hybrid System

A. Collecting Information and Evaluation

1. Objectives

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

2. Investigation Methods

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

3. Results

- (1) From a literature survey on performance of seawater desalination reverse osmosis membranes (SWRO) from seven manufacturers, Toyobo, Toray, Nitto Denko, Fluid Systems, DuPont, Hydranautics and FilmTec, it was found that most of the standard RO membranes on the market are made to give high salt rejection. Obtaining, and testing low rejection, high flux membranes suitable for an MSF/RO hybrid systems is not available in the market. (Ready-made products would be required)
- (2) All of the SWRO membrane examined had their specified feed salinity levels in the range of 30,000 – 35,000 ppm, and their performance with seawater with salinity levels of 43,000- 46,000 ppm, as in the case of seawater off the Saudi Arabia coast, is not given. Therefore, it is necessary to establish the physical, chemical and biological durability for the latter case through actual tests.
- (3) By conducting performances tests on membrane products which are actually available, useful information can be obtained regarding the manufacturing of SWRO membranes suitable for a Hybrid System(MSF/RO).
- (4) Through this investigation, it was possible to collect large amount of useful information and data regarding ways of utilizing SWRO membranes, and the future direction of the study.

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

1. Objectives

To study computer projection of a 10,000m³/d SWRO plant to be used as part of hybrid MSF-RO plant which is part of joint SWRO desalination research under the Japan-Saudi Arabia desalination technical cooperation. This report discusses the result of a computer simulation of the performance of a SWRO plant under different operating conditions and also the performance of as applicable to spiral wound RO membrane element.

2. Results

- (1) The report shows the result of a computer simulation of the performance for the RO plant operating under various operating parameters as well as the performance of available seawater desalination spiral RO elements.
- (2) From the RO plant simulation using seawater from the Arabian Gulf, Saudi Arabia, under conditions of 35°C temperature, 40% recovery rate, 60kgf/cm² operating pressure and design flux rates from 0.28 to 0.23m³/m²d, the resulting RO water TDS obtained varies from 860 to 1100mg/L. Based on these data and setting an upper limit of 1250mg/L for RO water quality, we see that a blend ratio of RO:MSF=1:1.5, or MSF water blend ratio of 60% would be a generous upper limit. It will be necessary to set actual ranges to be applied in the future, based on specific restrictions on blending operations and engineering considerations.

7.1.2 Performance Evaluation of Fouled Membrane

7.1.2.A. Visit and Survey of SWCC Plants

1. Objective

For the purpose of analysis of contaminated RO membranes, SWCC/JICA team visited four RO plants (Jeddah, UMM Lujj, Duba and Haql) to make an on-site survey, to see whether or not some fouled membranes can be obtained from a SWCC SWRO plant and also to see whether or not a RO tests could be established at the SWRO plant, in order to be used for research at SWCC's R&D Center.

2. Results

- (1) On the whole, the operating records were faultless, the availability was high and the SDI of the pretreated seawater was a good and ranges between 1 to 3. (See Table 1)**
- (2) All of the plants indicated that they could provide contaminated and worn up membranes and that on-site testing would be possible.**
- (3) The team had friendly technical discussions everywhere they went and there were keen interchanges of questions and answers. There were also questions and answers at the lecture given by the JICA Team at the SWCC R&D center (Jubail), which was well-attended.**

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

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

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

1. Objectives

To analyze the flat sheet membrane sample taken from Umm Lujj seawater desalination plant using SEM, EDX and FT-IR analytical methods before and after chemical cleaning test.

2. Results

- (1) The original fouled membrane showed very low rejection and very high flux which indicate substantial membrane fouling and deterioration.**
- (2) Through the surface analysis of the fouled membrane, various organic and inorganic foulants were indicated. Among them, marine microorganism and iron compounds were dominant. Quantity of the foulants was very significant.**
- (3) In the chemical cleaning test, oxalic acid is able to improve membrane performance to an extent. From the SEM, EDX and FT-IR analysis of the cleaned membrane, it is confirmed that oxalic acid effectively removed iron compounds. However, Si compounds and some biological foulants were not cleaned well, since they were still detected on the surface of the oxalic acid cleaned-membrane. Although performance of the original virgin membrane was unknown, it seems to be impossible to fully recover the original performance due to the deterioration of the membrane as indicated by the very high flux of the cleaned membrane. Therefore, in order to derive further effect from the chemical cleaning, it is recommended to combine oxalic acid with NaOH which is able to remove Si compounds and also biological foulants.**
- (4) More importantly, since the fouling of the membrane was very significant, it will not be enough to consider the technique of chemical cleaning. To avoid fouling itself rather than conducting frequent chemical cleaning, it is suggested to review the pretreatment system. Iron fouling is often associated with the problems in coagulation and/or media filtration process in the pretreatment system, while biological fouling is usually caused by ineffectiveness of the disinfection system.**

7.1.2.C. Fouled Membrane Analysis of Duba and Jeddah SWRO Plant

1. Objectives

The present study aims at identifying the foulants on the fouled membrane surfaces and also the causes of membranes deterioration. Various techniques such as scanning electron microscope (SEM) and ion chromatography were used to analyze membranes with poor performance and the foulants on the membranes. Also the effectiveness of various chemical cleaning agents which can be used for the performance restoration of the fouled membranes was evaluated. The report describes the autopsy and analysis of a hollow fine fiber membrane obtained from Jeddah SWRO plant and a brackish water spiral wound membrane obtained from Duba second stage SWRO plant.

2. Experimental Method

2.1 Equipment

Scanning electron microscope (SEM) and energy dispersive X-ray spectroscope (EDX) were used for foulants analysis. Quantitative analysis of the inorganic foulants was done using atomic absorption spectroscope (AAS) and ion chromatograph.

2.2 Materials

Autopsy was performed on the hollow fine fiber Toyobo HM 10155 membrane element from module No. 91 of Train E of Jeddah SWCC, SWRO plant which was in operation for about 5 years and a spiral wound element which was obtained from Duba plant. The latter membrane was removed long time ago and was not preserved for proper autopsy and analysis.

Sodiumhexametaphosphate (SHMP) (1% wt), oxalic acid (0.2% wt, pH = 4), hydrochloric acid (pH = 4), citric acid (2% wt, pH = 4) and ethylenediaminetetra-acetic acid disodium salt (EDTA) (1.5%) were used in the membrane cleaning.

2.3 Experimental Procedure

The spiral wound element was analyzed for the foulants using SEM and EDX. The hollow fine fiber element was cut open and physically examined. Samples of fibers of length 50cm

were cut from the inner (closer to the feed tube), the middle and the outer portion and it was preserved in 0.5% formalin in a plastic bag. A portion of heavily fouled membrane was cleaned by immersing it for 24 hours in one of the above mentioned cleaning agents prior to SEM and EDX analysis along with the uncleaned membranes. AAS and ion chromatograph analysis were conducted on samples dissolved in water, or oxalic acid or HCl.

3. Results

- (1) The analysis of foulants on Duba second stage spiral wound membrane using SEM and EDX reveals that it contains mainly Fe, Cr, and O which are produced as a result of corrosion of stainless steel part and also due to the deposition of carbonates on membrane. The cleaning solution used in this study were not effective in improving the performance of the fouled membranes. This could be due to the fact that the membrane was deteriorated as it was not properly preserved. A new sample from a preserved membrane was obtained from the second stage Duba plant on 18/10/94. The above analysis was repeated at SWCC R&D Center. A parallel analysis was conducted in Japan by JICA team.
- (2) the analysis of hollow fine fiber membranes reveals that it has large deposits of ferric from the coagulant. Also it has silt, anthracite and asbestos like material on the membrane surface. The study also reveals that oxalic acid could be as a cleaning agent as it removes most of the foulants.

7.1.2.D. Fouled Membrane Cleaning of Duba SWRO Plant

1. Objectives

This study aims at evaluating the effectiveness of various chemical cleaning agents which can be used for the performance restoration of the fouled membranes.

2. Experimental

2.1 Equipment

Mini-Module Tester (2) type RUW-5 made by NITTO DENKO Corporation, Japan. The test cells for flat sheet membrane used in the tester were NITTO RO/UF test cell model C70F.

2.2 Cleaning solutions

Sodiumhexametaphosphate (SHMP) (1% Wt), oxalic acid (0.2% wt, pH=4), hydrochloric acid (pH=3) and citric acid (2% wt, pH=4).

2.3 Procedure

The performance (flux and salt rejection) of the fouled membranes were determined using feed water having conductivity of 2000 μ S/cm. The membranes were then cleaned with various cleaning agents (by immersing for 24 hours) and performance were determined at similar condition.

3. Results

It can be established from the results that all the chemicals used for cleaning did not improve the salt rejection and flux of the fouled membranes except sodiumhexametaphosphate (SHMP) which improved the flux by about 15%. Hydrochloric acid (HCl) damaged the membrane. This could be due to the low pH (pH=3) which aids in the hydrolysis of the membrane.

7.1.2.E. Foulant Analysis and Flat Membrane Performance of Duba SWRO Plant (2nd sample)

Results

- (1) The following work was completed: Obtaining a Second sample of deteriorated membrane element from Duba Desalination Water Plant, analysis of foulants and their observation on membrane surface and conducting RO performance tests on the flat sheet membrane samples.**
- (2) From the comparison of the location of flat sheet membrane samples in the leaf of the autopsied element to its performance, it was obvious that the upper stream portions has lower rejections and higher fluxes than the down portions. On the other hand, there were no changes between outer and inner side within the leaf.**
- (3) It was concluded from the wave strips on the membrane surface of SEM photos that these originate from the RO operation. The ultrasonic sound generated from high pressure feed pump most likely created the mechanical damage leading to membrane deterioration. It is well documented that the strength of ultrasonic sound affects more the upper stream side more than the down stream side.**

7.1.3 Comparison Test of Flat Membrane

1. Objectives

Objectives of the tests are to study the performance Comparison of testing methods using the flat membrane tester and to evaluate the performance of the flat membranes for use in MSF-RO Hybrid system.

Comparison of flat membrane performance were conducted utilizing four sheet sheet SWRO membranes: Toray 80M & UTL 80S, Nitto Denko NTR 70SWC and Fluid System TFCL S7721, respectively. As first screening test the comparison was conducted in closed condition by circulating both the brine and permeate to the feed tank. The temperature was maintained at 20°C, pressure at 56 kg/cm² and brine flow at 7 L/min. Flux was calculated on effective surface area of the membrane. Contrary to the known concept of an increase membrane flux increased with an increase in applied pressure, no increase in flux was noticed when the applied pressure.

2. Experimental

The main testing equipment used in this experiment is the Mini-module Tester(2) model RUW-5, which consists of four testing cells, model C-70F, having membrane diameter 75 mm, with an effective area of 32 cm².

The four cells are connected in series and the product from each cell is collected, measured and analyzed separately. Conductivity, temperature and pH of the feed and product were monitored and measured every 30 minutes using standard equipment.

Membrane samples 75mm in diameter were cut evenly taking care not to contaminate or destroy the active surface, and are loaded into the cells.

3. Results

As shown in Table-2 at pressure of 56.6 kg/cm², both Toray membranes, UTC 80S and 80M have salt rejection in excess of 99.4% as compared to 98.62% for Nitto Denko 70 SWC and 98.8% for Fluid System membranes, respectively. At the same pressure, the highest flux, however was obtained from Fluid System membrane followed by Toray 80S, while Nitto

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Denko membrane has the least flux. Noticeable increase in flux resulted upon increasing the applied pressure only with Fluid System and Toray 80M membrane. From the test results it is observed that in general membranes with high rejection tend to have low flux.

Table 2
Performance Test Results of Different Commercial RO Flat Sheet Membranes

Equipment: Mimi-Module Tester(2), Model RUW-5

Test Cell : Model C70F, diameter 70mm

Effective area 32cm²

Operating conditions:

Concentrate flow : 7 L/min

Temperature : 25°C ± 3°C

pH : 7

Seawater EC : 59750 μS/cm

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

* Temperature of the tests controlled at 25°C

* Tests done at two different pressures i.e. = 56.6kg/cm² & 60.3kg/cm²

7.1.4 Tolerance Test of Chlorine and Turbidity with Flat Membrane Tester

7.1.4.A. Chlorine Tolerance Test

1. Objectives

The main objective of this work is to establish the experimental procedure to select a chlorine tolerance membrane for use in Hybrid System. For this purpose only some preliminary experiments were carried out.

2. Experimental

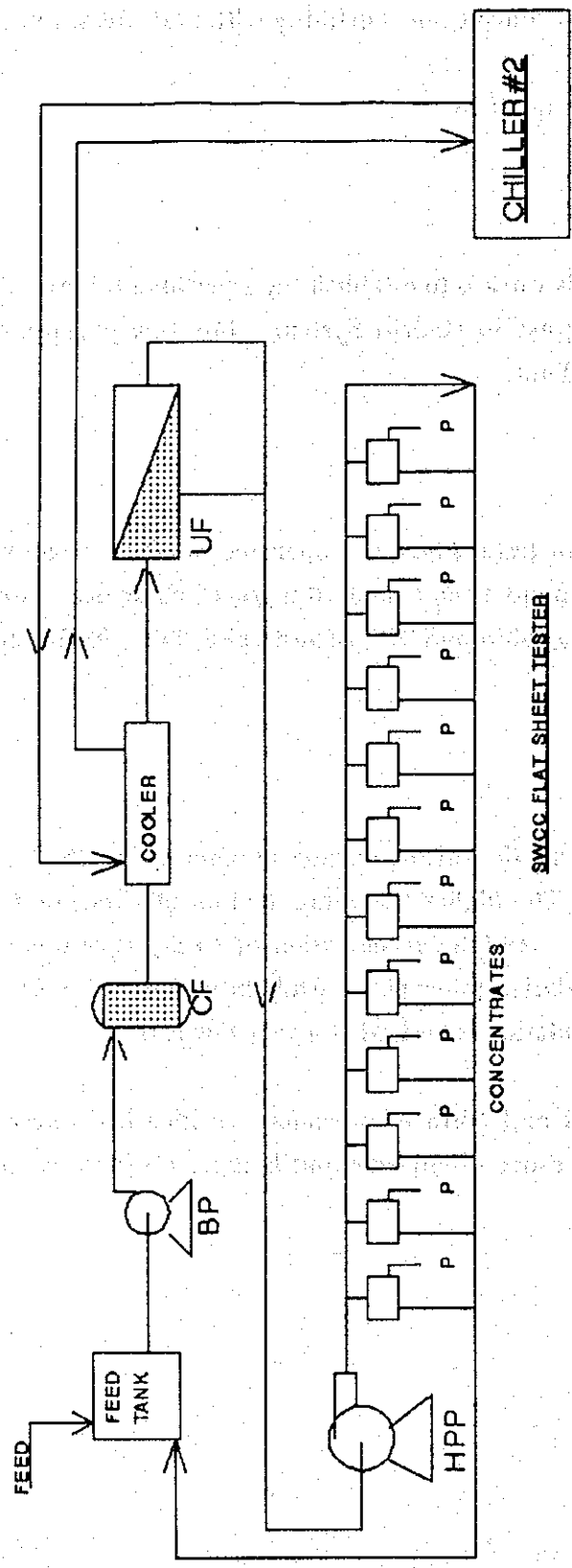
The SWCC flat membrane tester Fig. 1 was operated to measure salt rejection and flux using feed water containing around 1 mg/L and 10 mg/L of chlorine. Three types of membrane samples were tested (Toray 80M and 80S, Nitto Denko NTR 70SWC and Fluid System TFCL S7721).

3. Results

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

(2) Both Toray 80M and Nitto membranes has identical tolerance to chlorine, while Toray 80S has lesser tolerance to chlorine and is more effected by the presence of residual chlorine in the feed.

FIGURE : SCHEMATIC FLOW DIAGRAM OF SWCC FLAT SHEET TESTER



- SYMBOLS
- UF - ULTRAFILTRATION FILTER
 - CF - CARTIDGE FILTER
 - P - PERMEATE
 - BP - BOOSTER PUMP
 - HPP - HIGH PRESSURE PUMP

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

7.1.4.B. Turbidity Tolerance Test

1. Objectives

The main objective of this experiment is to establish a procedure to select a membrane, having comparatively more tolerance to turbid materials in feed water, for use in hybrid desalination system. Turbid materials increase membrane resistance to passage of permeate and cause the permeate flow to decline sharply. With this aim in mind, relation between feed flow rate and accumulation of turbid materials upon the surface of raw non-pretreated seawater having $SDI \approx 6.4$. Three types of flat membranes were evaluated: Toray UTC 80S, Toray UTC 80M and Nitto NTR 70WC and Hydrantsutics-NYR-70SN.

2. Experimental

Fig. 2 shows a schematic flow diagram and Fig. 3 shows the photograph of Mini-Module Tester (2) type RUW-5, the main test unit used in this experiment which can be arranged to allow for the connection and testing of one 2.5"x40" membranes instead of the four flat membrane test cells. With the help of a computerized control panel, the RPM of the high pressure pump can be controlled to the desired level to adjust the feed pressure. Feed temperature of the experiment was controlled to a fixed value, 25°C , with the help of an automatic temperature control computerized device.

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

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

Operation conditions were maintained at pressure $56\text{ kg}/\text{cm}^2$, temperature $25 \pm 0.2^{\circ}\text{C}$. Brine flow was varied from 1, 3, 7 and raised up to 15 L/m, while test duration time was 24, 20.4 and 20 hours, respectively. After 68 hours of operation the unit was run with 2.7 L/m

of brine flow for another 180 hours under the same conditions.

3. Results

Unlike membrane salt rejection which is not highly changed by a change in brine flow, the permeate flow is dependent on brine flow and tends to decrease as brine flow is decreased. Among the three membranes tested Toray 80S, Toray 80M and Nitto Denko NTR 70SWC, Toray UTC 80S membrane seemed to be the highest affected with high turbidity feed followed by Toray 80M and Nitto Denko.

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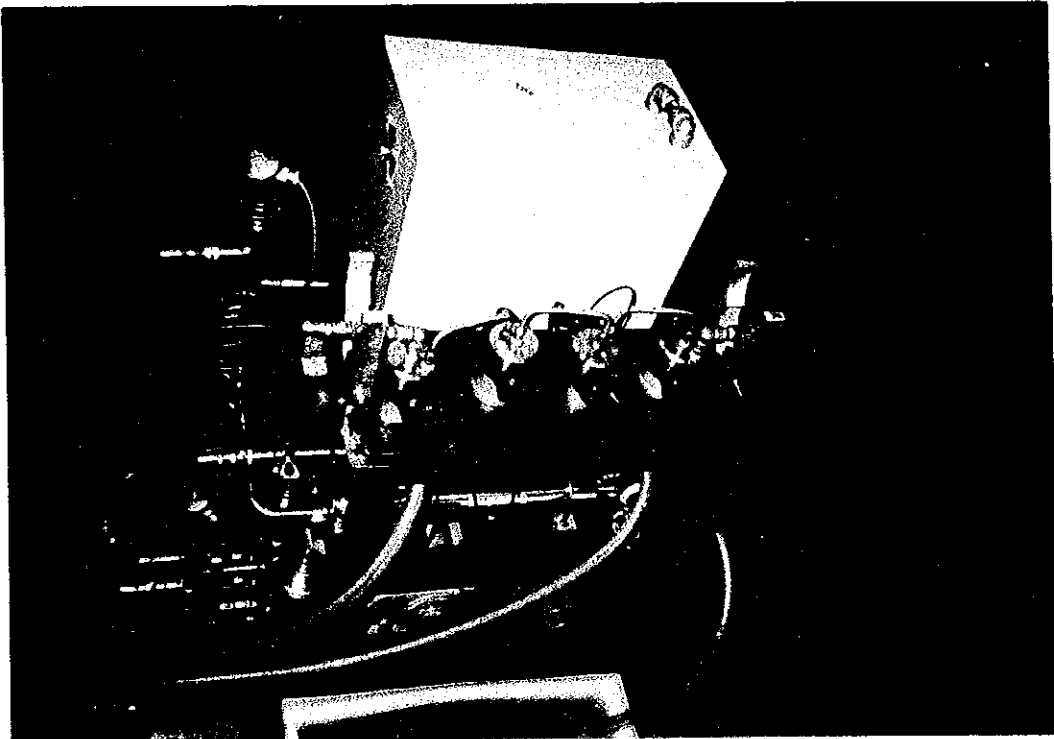
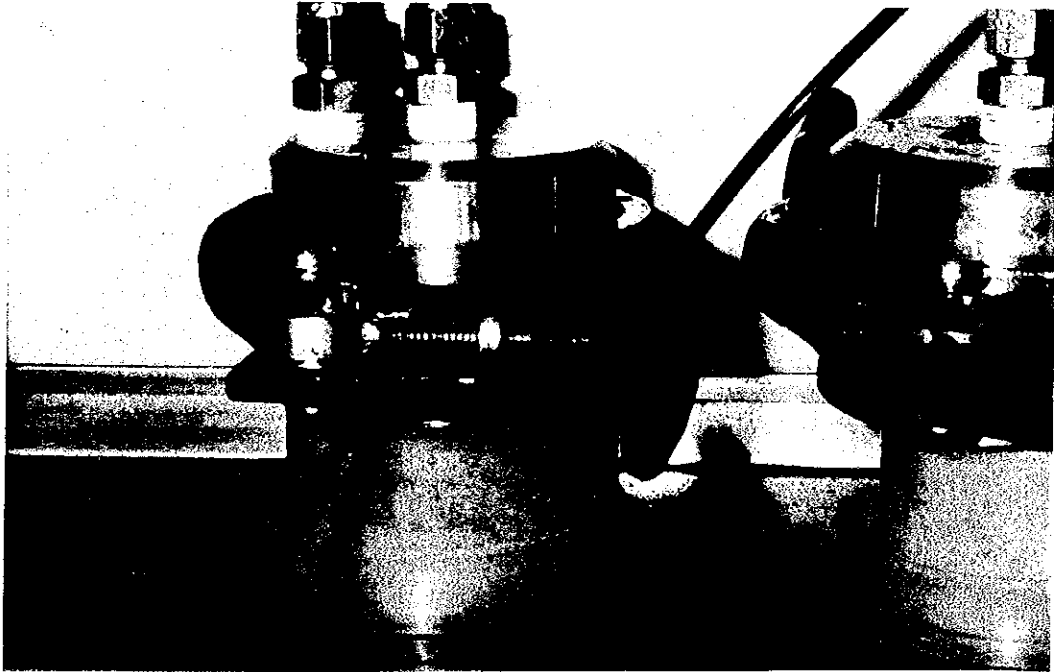


Fig. 3 Photograph of Mini-Module Tester (2) Model-RUW-5

7.1.5 Tolerance Tests of Turbidity with Mini-Modules

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

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

1. Objectives

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

2. Experimental Methods

2.1 Preparation of seawater turbid materials samples deposited on the SDI measuring filter paper

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

2.2. Analysis of sample

Samples analysis by SEM and EDX was made at both R&D Center and Japan.

3. Results

- (1) **The analysis results for both pretreated and raw seawater turbid materials collected on the surface of the 0.45 micron Milipore filter paper shows, almost in all cases that the peak of Ca is the most intense followed by that of Si, Al and Mg and the Fe peak is the least intense.**
- (2) **Although the operation time was short and the seawater has a higher turbidity than the seawater in the Red Sea, it shows that steady operation with SWRO membranes (Toray and Nitto Denko) is possible by feeding pretreated seawater using the same method of pretreatment as before.**
- (3) **It is necessary to continue the operation of the test plant to verify the suitability of the pretreatment and behavior of membrane at long run operation.**

7.1.5.B. Analysis of Raw seawater, RO feed water, permeate and concentrate

1. Objectives

Long run tolerance test operation for turbidity with Mini-module tester(1) was performed to measure the effects of turbidity on the performance of RO modules. Constituents of raw seawater, permeate, brine, and concentrate were analyzed during the long run tolerance test operation.

2. Experimental

Analytical equipment

- 1- Atomic absorption model varian - AA - 972**
- 2- Ion Chromatography model shimazu - HIC - 6A**
- 3- Autotitrator model - model FISHER 465**

Analytical Methods:

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

3. Results

Constituents of the raw seawater and permeate, brine, concentrate in Mini-modules tester(1) are shown in Table 3 – 7.

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Table 3 Analysis of Feed Water

		mg/l	mg/l as CaCO ₃
		Cation	Na ⁺
K ⁺	494		632
Ca ⁺⁺	505		1263
Mg ⁺⁺	1545		6358
Total Cation			35835
Anion	M-alk		
	Cl ⁻	23000	32440
	Br ⁻	80	50
	SO ₄ ⁻	3030	3156
	Total Anion		35775

T.D.S = 46843 mg/l

Salinity = 41.54 gm/kg

**Table 4 Analysis of Toray Mini-module
No.3 Permeate**

		mg/l	mg/l as CaCO ₃
		Cation	Na ⁺
K ⁺	5.7		7.3
Ca ⁺⁺	0.4		1.0
Mg ⁺⁺	0.729		3.0
Total Cation	181.829		391.7
Anion	M-alk		
	Cl ⁻	262	369.5
	SO ₄ ⁻	1	1.0
	Total Anion	263	391.1

**Table 5 Analysis of Nitto Denko Mini-module
No.3 Permeate**

		mg/l	mg/l as CaCO ₃
		Cation	Na ⁺
K ⁺	2.6		3.3
Ca ⁺⁺	0.2		0.5
Mg ⁺⁺	0.243		1.0
Total Cation	80.043		172.2
Anion	M-alk		18.9
	Cl ⁻	105	148.1
	SO ₄ ⁻	1	1.0
	Total Anion	106	168.0

(7)

**Table 6 Analysis of Toray Mini-module
No.3 Brine**

		mg/l	mg/l as CaCO ₃
Cation	Na ⁺	16900	36739.1
	K ⁺	567	725.1
	Ca ⁺⁺	600	1500.0
	Mg ⁺⁺	1973.16	8120.0
	Total Cation	20040.16	47084.2
Anion	M-alk		132.0
	Cl ⁻	30200	42595.2
	SO ₄ ⁻	3674	3827.1
	Total Anion	33874	46554.3

**Table 7 Analysis of Nitto Denko Mini-module
No.3 Brine**

		mg/l	mg/l as CaCO ₃
Cation	Na ⁺	14400	31304.3
	K ⁺	500	639.4
	Ca ⁺⁺	528	1320.0
	Mg ⁺⁺	1744.74	7180.0
	Total Cation	17172.74	40443.7
Anion	M-alk		112.0
	Cl ⁻	25497	35961.9
	SO ₄ ⁻	3317	43455.2
	Total Anion	28814	39529.1

7.2 Experiment with RO Mini-Module(1)

7.2.1 Installation of Mini-module Tester

1. Objective

After assessing the performance of membrane material with the flat membrane test equipment, their performance as assembled in modules was measured using 2.5"x40" experimental elements.

2. Mini-module Tester (1)

Mini-Module Tester (1) has a set of six RO modules and the number of modules used can be reduced to suit the experimental conditions. It can be operated with permeate and concentrate circulation. A chiller is connected to the concentrated water outlet and the water temperature can be adjusted while it is being circulated.

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

3. Mini-module Tester (2) Model RUW-5

Mini-module Tester (2) Model RUW-5 can be operated for single RO module performance test, Flat sheet test and UF modules test.

7.2.2 RO Module Selection Test

1. Objectives

Objectives of the tests are to perform a comparative study on the performance of various SWRO membrane elements (2.5"dia. x 40" in length) based on the performance information of flat sheet SWRO membranes, already evaluated, to select the one suitable for Hybrid desalination system.

SWRO membrane elements, diameter 2.5 inch, which were received from various membrane manufacturers were investigated using Mini-module Tester (1) and (2). This was done

after completion of flat membrane comparison test utilizing SWCC flat sheet tester and Mini-Module Tester (2). Pretreated seawater from SWCC pretreatment unit was used as feed in Mini-Module Tester (1), and 3.5% NaCl solution was used as feed in all tests conducted by the Mini-Module Tester (2). Membranes were investigated at different pressures, temperatures and brine flow rates. After completion of evaluation tests which was done for a short period for all the available membranes, only two membranes: Toray SU-806 and Nitto Denko NTR 70 SWC were selected to evaluate on continuous operation. The test is continuing utilizing Mini-module Tester (1), arranging the membrane in two parallel lines. First line contains three elements of Toray arranged in series, while the second line has three elements of Nitto Denko, also arranged in series.

2. Experimental

Fig. 4 shows a schematic flow diagram of the Mini-Module tester and Fig. 5 shows the photograph of the same Mini-Module Tester (1) which consists of a feed tank, a permeate tank, two booster pumps, two cartridge filters and two high pressure pumps. PVC and SS316 piping are used in the low and high pressure sections, respectively. The high pressure pump supplies feed to the SWRO unit which consists of two parallel lines and each of them can contain up to three 2.5 x 40inch SWRO membrane modules arranged in series. The tester is equipped with a cleaning system and a control panel.

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

Mini-Module Tester (2) allows for the testing of 2.5"x40" membrane holding pressure vessel or 4 flat sheet membrane test cells. Feed was prepared by dissolving 3.5 kg of NaCl in 96.5 liters of potable water. This feed was used with all tests done by using the Mini-module Tester (2).

3. Results

Table 8 summarizes the evaluation results for all membranes at pressure of 56 kg/cm^2 , brine

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flow 7 L/m, and temperature $(25 \pm 3)^\circ\text{C}$. Seawater was used as feed. Modules were arranged in series during the tests with two elements per line. Table 9 summarizes the evaluation results of four types of membranes tested using 3.5% NaCl solution as feed. From Table 9 it appears that Fluid System membrane has the highest permeate flow followed by Filmtec SW 30HR, Toray, Hydranautics and Nitto Denko. The lowest permeate flow from Nitto Denko membrane is probably due to low surface area of this membrane elements. However, the permeate conductivity shows higher value for Fluid system followed by Hydranautics, Filmtec SW 30 2540, Toray SU 806 (type-1), Nitto Denko NTR 70 SWC, Toray 806 (type-2) and Filmtec SW 30 HR 2540.

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

Due to the different nominal membrane area 2.6m^2 versus 1.7m^2 the product flow obtained from Toray SU806 membrane is higher than that of Nitto Denko NTR 70S SWC-S2 membrane at same operating conditions and same feed flow and feed quality. However, Nitto Denko 70S SWC-S2 membrane has higher salt rejection compared to Toray SU806 under the same conditions.

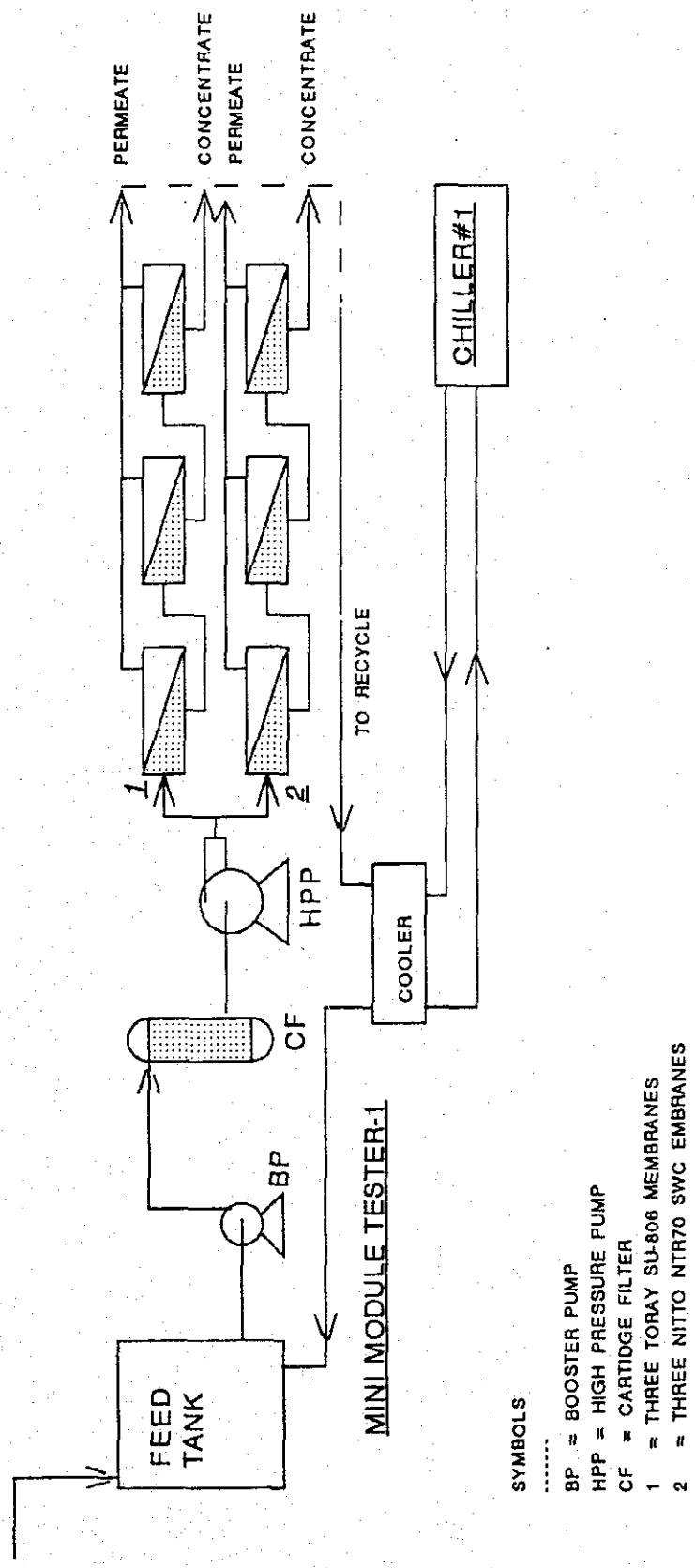


Fig. 4 Schematic Flow Diagram of Mini-Module Tester(1)

**Table 8 Summary of Performance Evaluation Test of SWRO Elements
(2.5 inch dia.) Using Pre-treated Seawater**

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

Operation conditions:

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

**Table 9 Summary of Performance Evaluation of Test SWRO Elements(2.5 inch dia.)
Using 3.5% NaCl Solution**

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

Duration of test = 1 hr
Pressure = 56 kg/cm²
Temperature = 25°C
Brine flow = 7 l/m

7.2.3 Tolerance Test in Chlorine and Turbidity with Mini-module

1. Objectives

Chlorine tolerance tests for mini-modules were scheduled in the initial plan. Results of the tolerance tests for chlorine with flat sheet membranes showed that performance of membranes were deteriorated drastically in presence of chlorine in seawater feed at concentration of 0.3 to 10mg/L of chlorine. It was concluded that it is useless to perform the chlorine tolerance test using the limited number of RO mini-module samples. It was decided that chlorine tolerance run test with mini-modules is to be canceled and only turbidity tolerance test with mini-module to be performed. Since we have no exact informations concerning RO module tolerance for turbidity.

Long run tolerance test operation for turbidity with mini-modules was performed and effects of turbidity on the performance of RO modules were measured. Turbid materials in seawater were collected and analyzed to determine the composition.

2. Experimental Methods

Long run tolerance test operation for turbidity with mini-modules was performed and effects of turbidity on the performance of RO modules were measured. Turbid materials in seawater were collected and analyzed to determine the composition.

(1) Experimental equipment:

Same Fig. 4 and Fig. 5 in section 7.2.2.

(2) Feed:

Pretreated seawater, $SDI=2.5 \pm 0.5$, $pH \sim 6.8$, continuously supplied from SWCC pretreatment plant

(3) Test Conditions:

Pressure=56kg/cm², Feed flow to each series= 10L/min.

(4) 2.4 Analytical methods

same as in section 7.2.2/

(7)

- (5) Result of the turbidity tolerance test, feeding pre-treated seawater ($SDI=2.5 \pm 0.5$, $pH=6.8$) to RO Mini-module Tester(1) continuously, shows that membrane performance after more than 5,000 hours of operation was satisfactory.

3. Experimental Results

(1) Turbidity tolerance test operation data:

The result of the long run turbidity tolerance test operation for 5720 hours with Mini-module Tester(1) is shown in Fig. 6, Fig. 7, Fig. 8 and Fig. 9.

(2) analysis of raw seawater, RO feed water, permeate and concentrate analysis data obtained was as shown in section 7.1.5.B.

(3) Analysis of seawater turbid materials accumulated on Millipore Filter Analysis data was as shown in section 7.1.5.A.

4. Results

At same operating conditions and same feed flow and feed quality, the product flow obtained from Toray SU-806 element is higher than that of Nitto Denko NTR 70S SWC-52 element. This is mainly because of the Toray element has about 1.5 times larger nominal membrane area as the latter one. In order to conduct further investigation on all the membranes, it is necessary to obtain its actual membrane area as well as the feed velocity. However, Nitto Denko 70S SWC-52 membrane have higher salt rejection compared to Toray SU-806 under the same conditions.

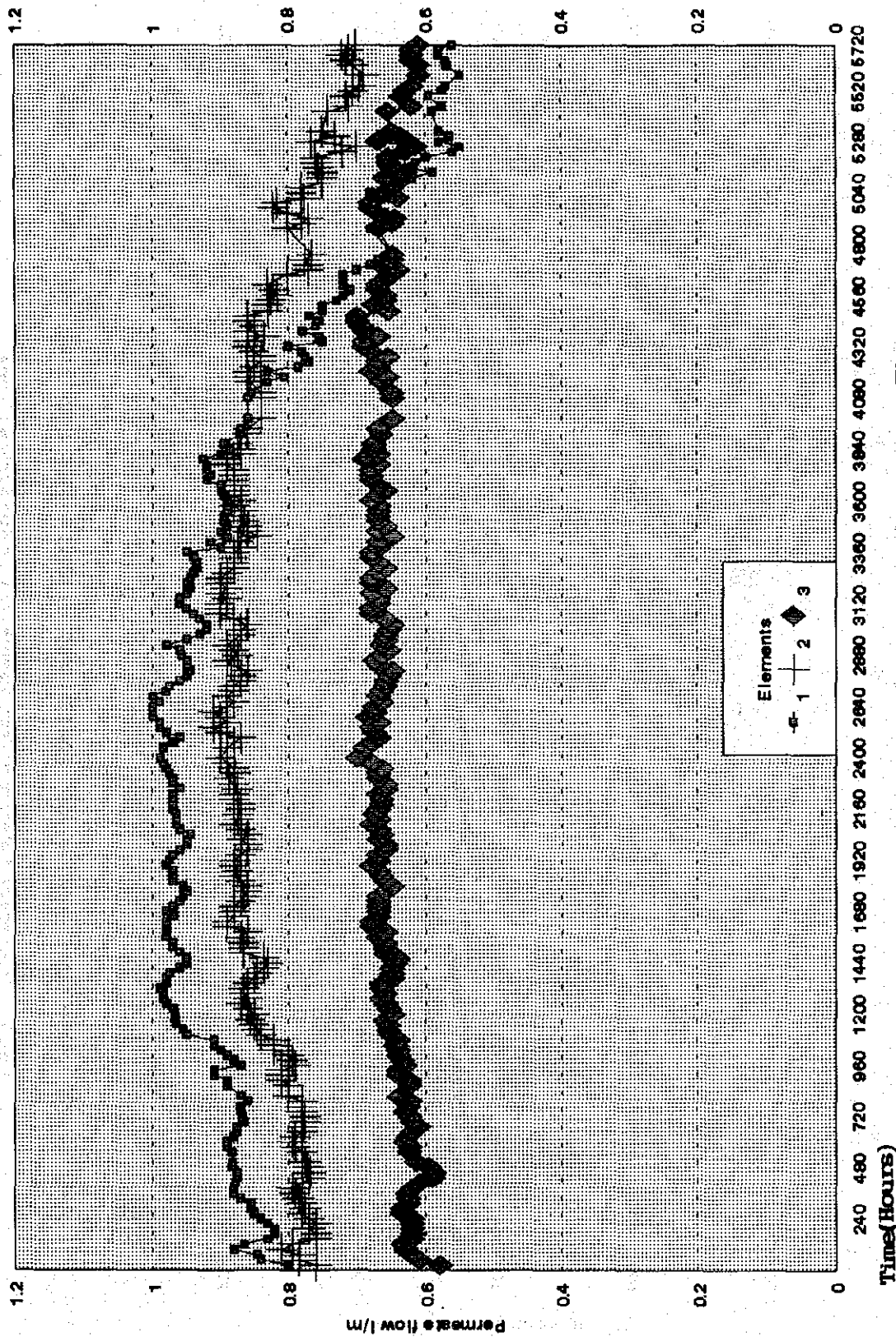


Fig. 6 Turbidity Tolerance Test, Permeate Flow vs Time
(Toray 2.5 Inch Elements SU 806 (Type-1))

(TEST CONDITIONS: THREE ELEMENTS, 25 EACH ARRANGE IN SERIES; SEA WATER SDI<3, pH=6.8, PRESSURE=56 kg/cm²)

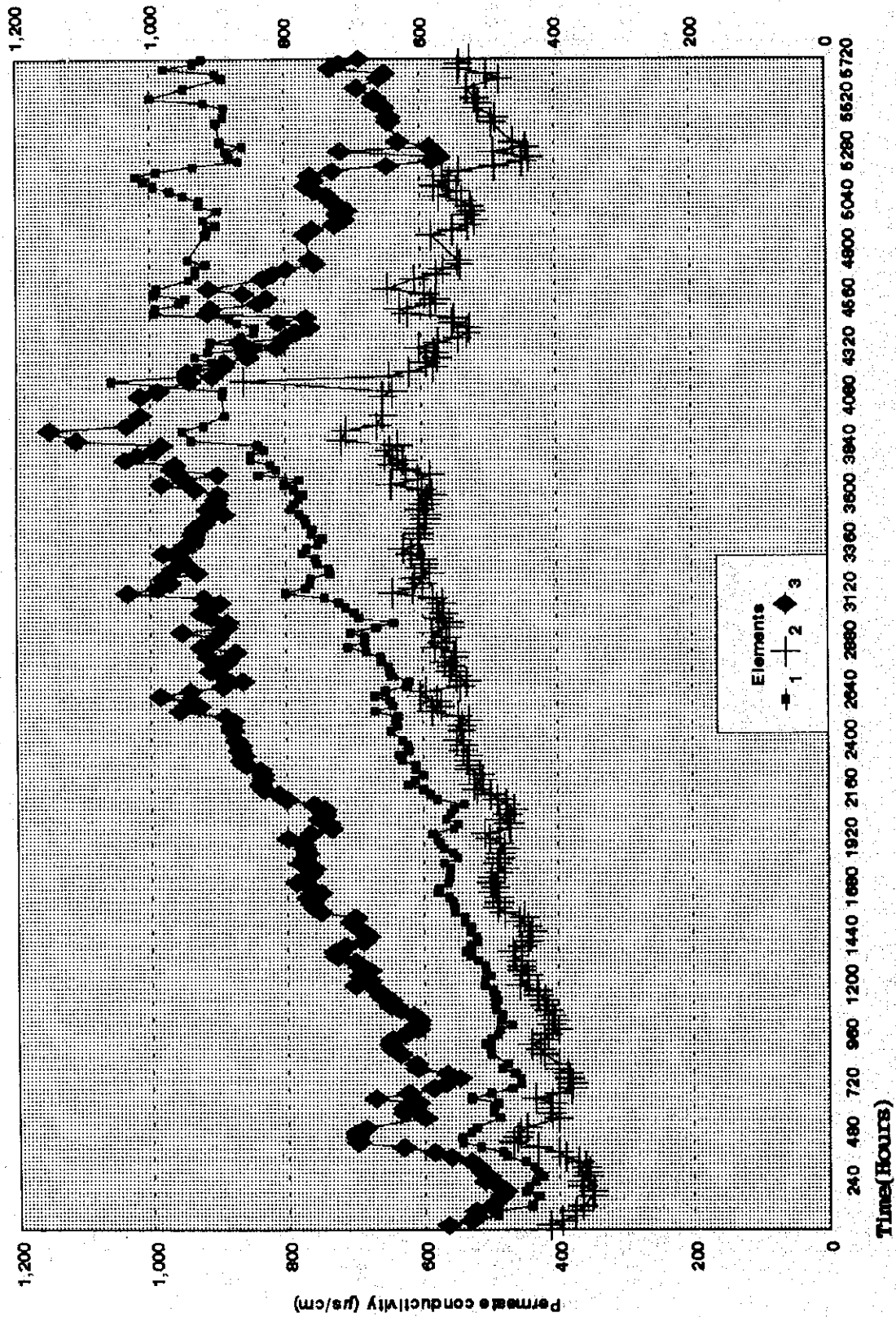


Fig. 7 Turbidity Tolerance Test, Permeate Conductivity vs Time

(Toray 2.5 Inch Elements SU 806 (Type-1)

(TEST CONDITIONS: THREE ELEMENTS, IN SERIES; SEA WATER SDI<3, pH=6.8, PRESSURE=56 kg/cm²)

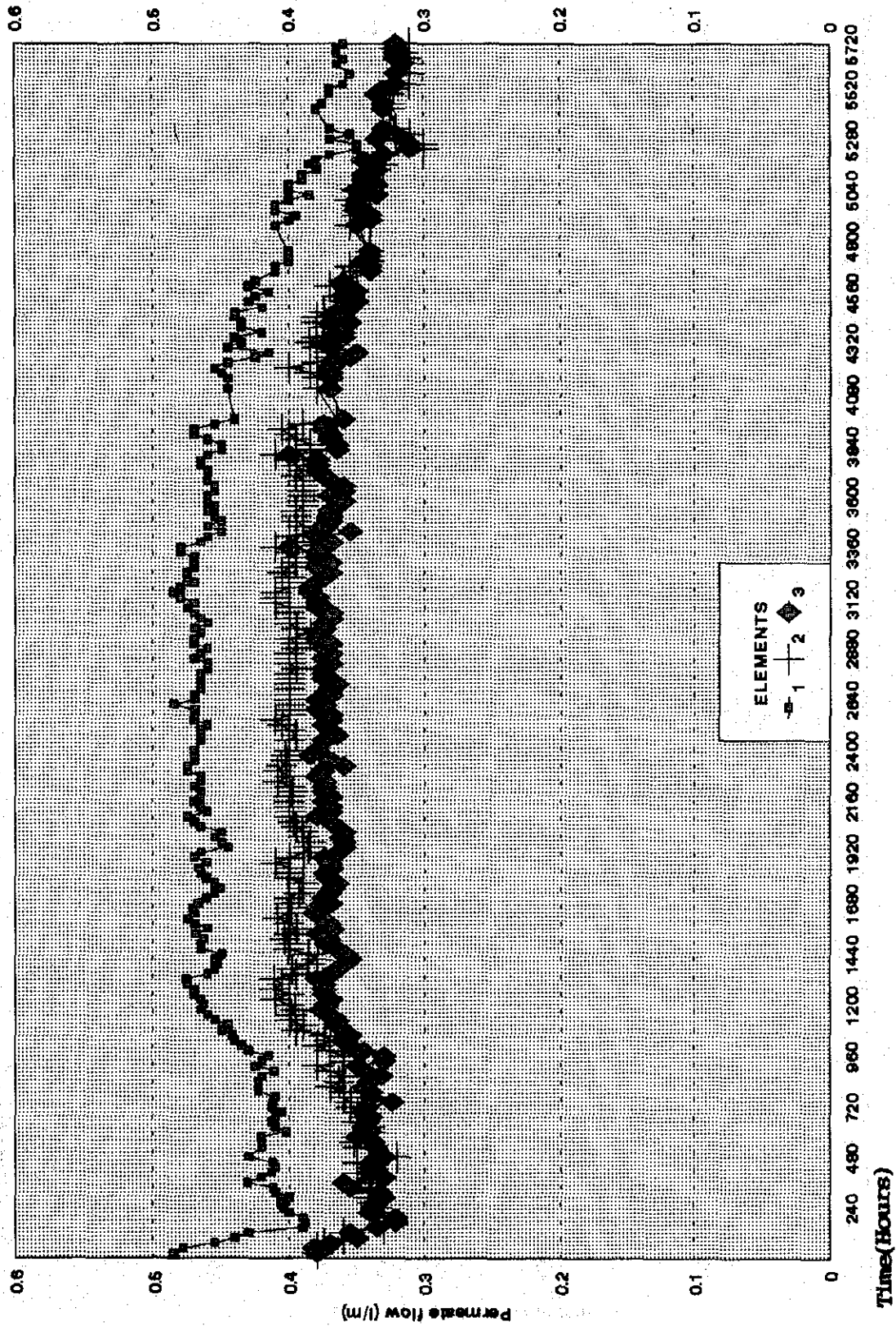


Fig. 8 Turbidity Tolerance Test, Permeate Flow vs Time
(Nitro Denko 2.5 Inch Elements NTR 70S SWC-S2)
(TEST CONDITIONS: THREE ELEMENTS, ARRANGED IN SERIES, FEED SDI<3, pH=6.8, PRESSURE=56 kg/cm²)

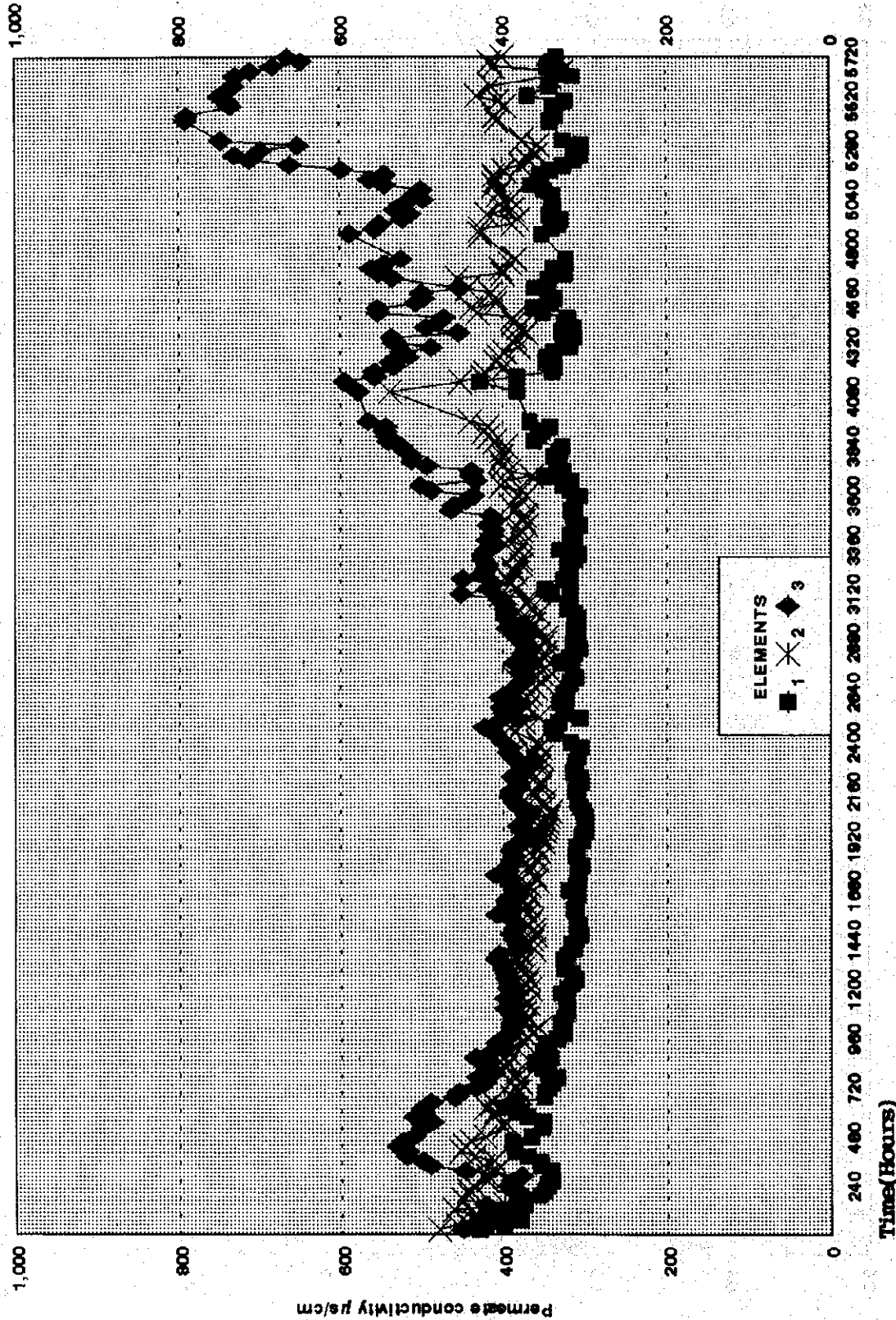


Fig. 9 Turbidity Tolerance Test, Permeate Conductivity vs Time
 (Nitto Denko 2.5 Inch Elements NTR 70S-SWC-S2)

(TEST CONDITIONS: THREE ELEMENTS, ARRANGED IN SERIES, FEED SDI<3, pH=6.8, PRESSURE=56 kg/cm²)