

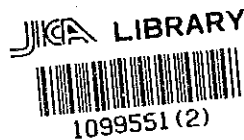
No. 27

THE
JOURNAL OF
THE
SOCIETY OF
APPLIED
PSYCHOLOGY

THE KINGDOM OF SAUDI ARABIA

RESEARCH COOPERATION FOR
THE PROJECT OF THE SEA WATER DESALINATION TECHNOLOGY
BETWEEN
SALINE WATER CONVERSION CORPORATION (SWCC)
AND
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

FINAL REPORT
APPENDIX



JULY 1992

24113

JAPAN INTERNATIONAL COOPERATION AGENCY

国際協力事業団

24113

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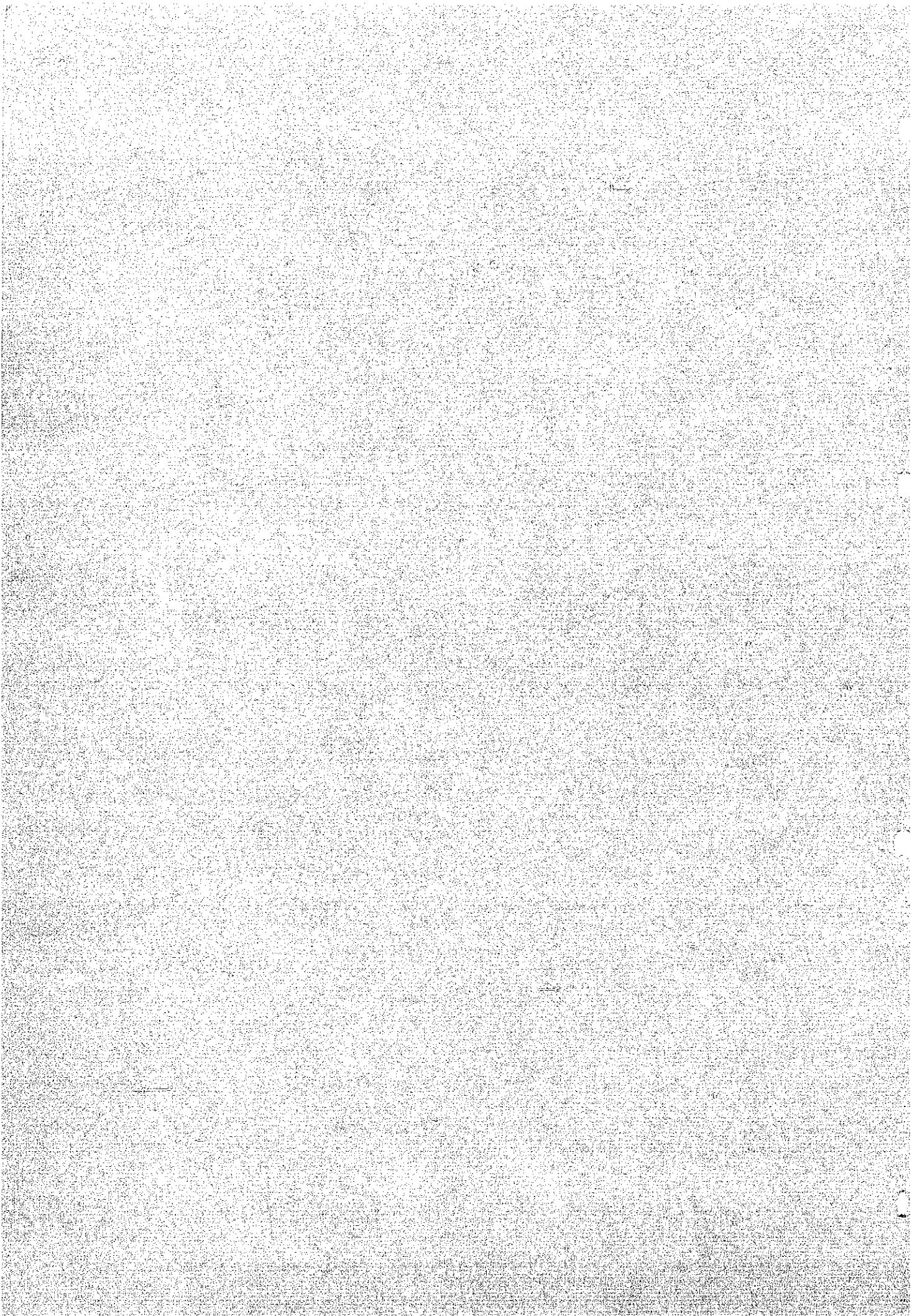
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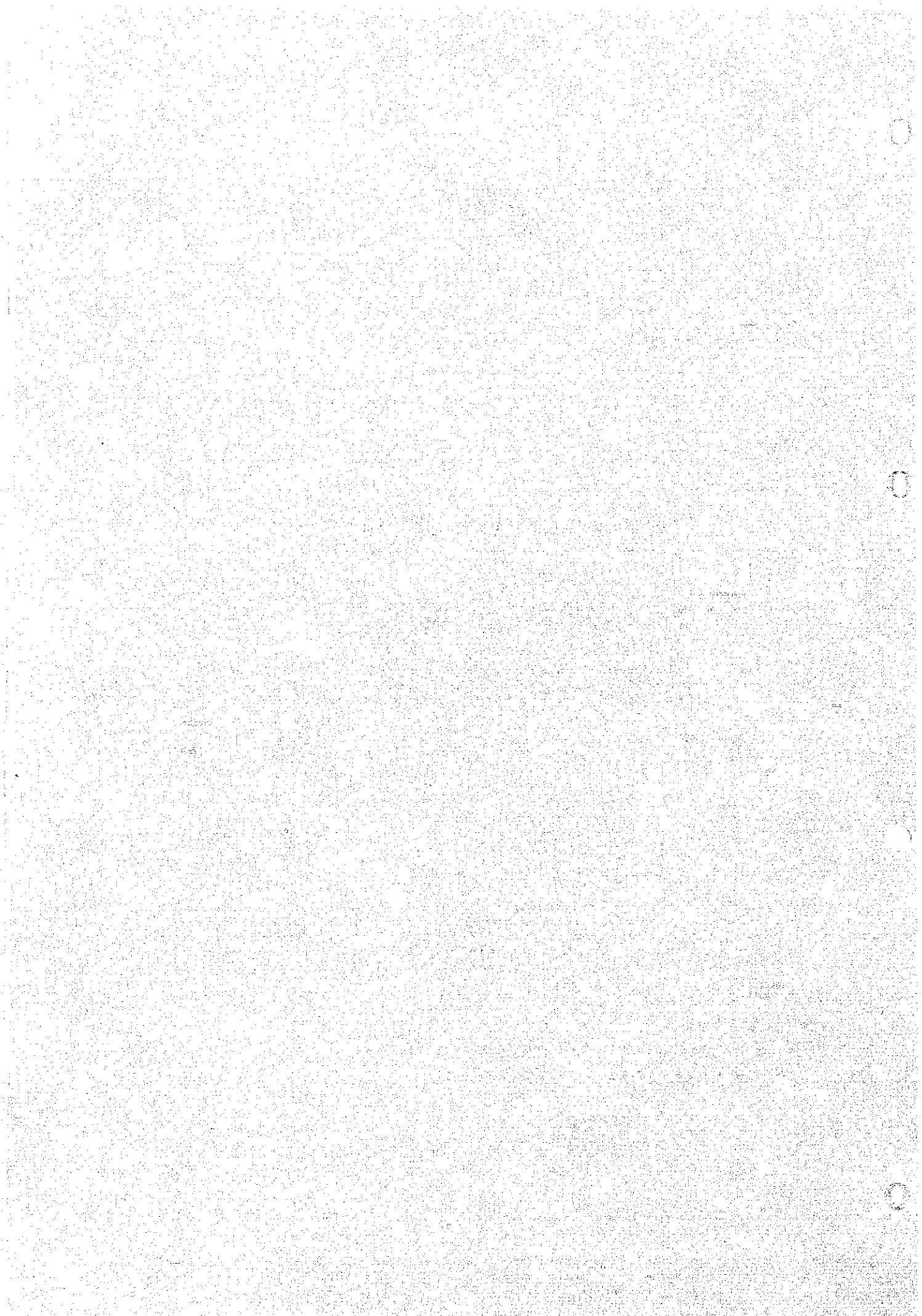
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1. APPENDIX for M1 (Laboratory Experiment on Scale Prevention)

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APPENDIX M1 - 1



APPENDIX M1-1

RESULTS OF LITERATURE SURVEY ON SCALING OF MSF

Published reports concerning scale formation and its prevention in the evaporation-type desalination plant were investigated.

Investigations were carried to search the related reports, refer to ON-LINE DATA BASE "JOIS: FILE OF SCIENCE AND TECHNOLOGY" in The Japan Information Center of Science and Technology, and "DIALOG" in Dialog Information Service, INC. USA.

Key words and logic formulae used for searching, and the hit numbers, are as follows.

JOIS FILE OF SCIENCE AND TECHNOLOGY (1981.01 — 1991.11)

① SEA WATER DESALINATION * FLASH EVAPORATION * (CRUDE OIL + SEA WATER) —	9
② SEA WATER DESALINATION * FLASH EVAPORATION # ① —————	19
③ SEA WATER DESALINATION * EVAPORATION * ADHESION —————	1
④ SEA WATER DESALINATION * FLASH EVAPORATION * ADHESION —————	1
⑤ SEA WATER DESALINATION * EVAPORATION —————	69
⑥ SEA WATER DESALINATION * (SCALE + SCALING) —————	16

JOIS FILE OF SCIENCE AND TECHNOLOGY (1975.01 — 1980.12)

① SEA WATER DESALINATION * FLASH EVAPORATION —————	26
② SEA WATER DESALINATION * EVAPORATION —————	110
③ SEA WATER DESALINATION * (SCALE + SCALING) —————	76

DIALOG

① FILE 44 AQUATIC SCIENCE ABSTRACTS (78-91/AUG)	
SEA WATER DESALINATION * (SCALE + SCALING) —————	49
② FILE 245 WATERNET (71-91/SEP)	
(SEA WATER DESALINATION + SEA WATER * DESALINATION)	
* (SCALE + SCALING) —————	15

③ FILE 8 COMPENDEX	
(SEA WATER DESALINATION + SEA WATER * DESALINATION)	
* (SCALE + SCALING) * (EVAPORATION + DISTILLATION)	26
④ FILE 28 OCEANIC ABSTRACTS (84-91/OCT)	
(SEA WATER DESALINATION + SEA WATER * DESALINATION)	
* (SCALE + SCALING) * (EVAPORATION + DISTILLATION)	23
⑤ FILE 14 ISMEC (73-91/AUG)	
(SEA WATER DESALINATION + SEA WATER * DESALINATION)	
* (SCALE + SCALING) * (EVAPORATION + DISTILLATION)	3

As a next step, judging from the title, abstract, etc. of the above contents, 24 reports were selected, concerning of scale formation and its prevention in Multi-stage Flash Desalination Plant.

About those reports, the following informations introduces the title, volume number, page number, published year, and especially important the abstracts of those reports.

DESALINATION

1. 25 YEARS EXPERIENCE IN THE DEVELOPMENT AND APPLICATION OF SCALE INHIBITORS 30 243-255 (1979)

The demands made on scale inhibitors will continue to be changed by the advances in desalination plant technology. This paper traces the development of scale inhibitors from the early polyphosphate through to the latest high temperature additives. A comparison of acid and additive treatment methods is made together with the plant design factors affecting inhibitor efficiency. The long term suitability of an additive is examined with reference to the ease of plant cleaning and the maintenance of the demister. A test rig permitting the laboratory evaluation of inhibitor formulation under simulated plant conditions is described.

The paper concludes with an attempt to predict future trends in plant

design and the type of inhibitor required for successful long term operation.

2. THE THRESHOLD SCALE INHIBITION PHENOMENON

31 257-266 (1979)

3. ANALYSIS OF THE EFFECT OF BRINE RETENTION TIME ON THE SCALING POTENTIAL

31 267-277 (1979)

The overall view of a potential scaling problem, as encountered in additive treated desalination plants, is considered. The effects of brine circulation characteristics, retention time and supersaturation level, on the degree of scale precipitation, are analyzed by population balance models characterizing mixed flow and plug flow conditions, respectively.

It is shown that mixing effects aggravate the scaling potential.

For identical brine retention times, the degree of bulk precipitation occurring under mixed flow conditions is considerably larger than that occurring under plug flow conditions. Similarly, the induction period in a mixed flow system is shorter than that in a plug flow system.

General trends on the scaling potential predicted by the proposed analysis are illustrated for a modelled desalination unit. The effects of brine retention time and additive concentration are evaluated using estimated values of kinetic coefficients for CaCO_3 retarded precipitation.

4. LABORATORY APPLICATIONS TESTING OF DESALINATION ANTISCALANTS

31 279-288 (1979)

5. CHEMISTRY OF ALKALINE SCALE INHIBITION IN SEAWATER DESALINATION BY FLOCON ANTISCALANT 247

31 289-298 (1979)

6. THE USE OF ACID AND ADDITIVE. PRACTICAL EXPERIENCES IN A MULTISTAGE FLASH PLANT

31 299-307 (1979)

7. A REVIEW OF SCALE CONTROL METHODS

31 309-320 (1979)

For desalination with a multi-stage flash evaporator, scaling constituents of sea water, and the methods of polyphosphate, acid dosing and organic polymers are reviewed. Temperature limitations, scale control performance and plant corrosion are discussed for each method. It is shown that unit water costs reduce with increasing brine temperature and that organic polymers are now competitive with acid dosing. Recent developments in scale control for evaporation of sea water, are discussed, including sulphate ion exchange, fluidized bed evaporators and the use of surfactants.

8. REDUCING AND MONITORING CORROSION IN MSF EVAPORATORS IN THE CHANGE-OVER FROM ACID TREATMENT TO TREATMENT WITH ADDITIVES

39 339-350 (1981)

This paper concerns multi-stage flash plant operating in the Mediterranean area, where seawater acid treatment was replaced by scale control through the use of a proprietary polycarboxylic synthetic polymer. Corrosion effect were monitored in the brine and in the distillate system. The results obtained make manifest the less corrosive conditions on all metals during the additive treatment, and the reduction of corrosion rate resulted in a substantially smoother plant operation with less frequent plant shutdown and consistent economic saving.

9. SCALE CONTROL ADDITIVE-PRACTICAL EXPERIENCES IN MULTISTAGE FLASH PLANTS

54 301-305 (1985)

1 0. ON THE THERMAL STABILITY OF THE HCO_3^- AND THE CO_3^{2-} IONS IN AQUEOUS SOLUTIONS

69 241-249 (1988)

1 1. THE PROBLEM OF ALKALINE SCALE FORMATION FROM A STUDY ON ARABIAN GULF WATER

71 313-324 (1989)

1 2. PRACTICAL EXPERIENCE IN SCALE CONTROL

73 313-325 (1989)

1 3. BELGARD EV-15 YEARS' EXPERIENCE IN SCALE CONTROL

73 341-357 (1989)

This paper reviews the early history of BELGARD EV and subsequent work leading to the introduction of BELGARD EV2000. Up-to date experience with BELGARD products is presented, including use with sponge ball cleaning, optimisation of additive dose levels, advances in dosing techniques, development of analytical methods for polymers, and advances in on-site monitoring.

1 4. INHIBITION EFFICIENCY OF SCALE FORMATION BY CHEMICAL ADDITIVES

74 355-361 (1989)

1 5. ALKALINE SCALE FORMATION RESTRICTION IN DESALINATION PLANTS BY MEANS OF ANTISCALANT ADDITIVES

83 55-63 (1991)

1 6. PERFORMANCE TEST OF A NEW ANTISCALANT "AQUAKREEN KC-550" UNDER HIGH TEMPERATURE CONDITIONS AT THE MSF DESALINATION PLANT IN DUBAI

83 65-75 (1991)

CORROSION

1 7. THE KINETICS AND MECHANISM OF FORMATION OF CALCIUM SULFATE SCALE MINERALS
— THE INFLUENCE OF INHIBITORS

35 304-308 (1979)

I&EC FUNDAMENTALS

1 8. MECHANISM OF CALCIUM SULFATE SCALE DEPOSITION ON HEAT-TRANSFER SURFACES

9 1-10 (1970)

BULLETIN OF THE SOCIETY OF SEA WATER SCIENCE, JAPAN

1 9. THE EFFECT OF VARIOUS ADDITIVES ON THE FORMATION OF ALKALINE SCALE

30 20-25 (1976)

The effect of 13 kinds of additives on the formation of alkaline scale was studied under the conditions of a small evaporator, brine concentration CF 2 and temperature 101 °C. Sodium poly phosphate and sodium poly acrylate were effective in scale prevention, and this effect was brought about by their inhibition of scale forming constituents.

The effect of sodium poly acrylate for preventing alkaline scale was changed by the polymerization grade, and the low polymerization grade such as p.g. 75, 100 was to be most effective.

2 0. STUDIES ON THE SCALE FORMATION AND ITS PREVENTION IN CONCENTRATING
PROCESS OF SEA WATER

32 3-33 (1978)

On the salt-manufacturing process and sea water desalination, scale formation and its prevention are discussed. For scale formation, the following studies were made:

- (1) The relationship between concentrating method of sea water and behavior of scale components of sea water or compositions of adhered scale.
- (2) Rate of dissolution and crystallization of calcium sulfate in the

brine during transition stage. For scale prevention, effect of various additives on the formation of alkaline and calcium sulfate scale were studied.

2 1. SCALE CONTROL IN DESALINATION AND SALT-MANUFACTURE

36 14-21 (1982)

Scale formation and its prevention are the most important problem in sea water industries. This paper shows the development of advanced researches in related field. On desalination, scale formation (alkaline and sulfate scale) and scale prevention (pH control, threshold treatment method, sponge ball method and seeding process) are discussed. The salt manufacturing process, pretreatment of sea water, removal of turbidity, scale formation and its prevention, are illustrated.

2 2. BEHAVIOR OF THE CARBONATES IN RECIRCULATING BRINE IN A MULTI-STAGE FLASH EVAPORATION-TYPE DESALINATION PLANT

39 19-26 (1985)

Material balance of the carbonates in recirculating brine in a plant, on the relation of alkaline scale formation, was calculated.

The calculated values were compared with the experimental data on the pH control method using a 100 m³/d, 10-stage flash evaporator.

Material balance of the carbonates in the brine could be calculated on the basis of the dissociative equilibrium of the carbonates.

In the MSF evaporator, the brine is circulated in the condensers of the evaporating stages, the brine heater and the flash chambers.

In calculating the material balance of the carbonates in the brine, it is sufficient to consider, only scale formation in the heat transfer tube, and, in the flash chamber, both the carbon dioxide dispersion and the scale formation must be considered.

2 3. ALKALINE SCALE FORMATION IN A MULTI-STAGE FLASH EVAPORATION-TYPE DESALINATION PLANT

6 248-254 (1980)

Scale formation on the heat transfer tubes in a multi-stage flash desalination plant was studied by using a 10-stage flash evaporator with a capacity of 100 m³/d. In a 100-hour continuous operation test, sulfate scale did not precipitate, but a large amount of alkaline scales formed on the surface of the tubes in the brine heater and the condensers of the evaporator. The major component of the alkaline scales was calcium carbonate at the low-temperature stages, and magnesium hydroxide at the high-temperature stages. Formation of alkaline scales is related to the dissociation equilibrium of carbonic acid in the brine. In submerged tube-type evaporators, the brine evaporates on the surface of the tubes. On the other hand, in flash evaporators, the brine does not evaporate in the tubes. Therefore the behavior of carbonic acid in the brine in the flash evaporator differs from that in the submerged tube-type evaporator. From the results of calculation of the mass balance of carbonic acid in the flash evaporator using scale deposition rate data, crystallization rate coefficients for calcium carbonate and magnesium hydroxide were obtained as a function of brine temperature.

2 4. SPONGE BALL CLEANING FOR SCALE PREVENTION IN A MULTI-STAGE FLASH EVAPORATION PLANT

9 516-522 (1983)

The scale prevention effect of sponge ball cleaning was investigated in a 100 m³/d-capacity, 10-stage flash evaporation plant. It was found that the scale removal rate by ball friction was inversely proportional to deposit thickness, and that the removal of scale was insufficient because of a high scale deposit rate. Sponge ball cleaning combined with pH

control, in which 50 percent decarbonation of feed sea water, showed good effect in prevention of scaling and corrosion.

As the scale formation and its prevention in desalination plant, recent published reports were investigated, but the report which is described about the effect of scale inhibitor influenced by oil containing in the sea water, could not be found out.

However, fundamental investigation reports are useful for carrying out this experimental research and will be succeed to the reference literature in arranging the experimental results quantitatively.

APPENDIX M1-2



**RESULTS OF CORROSION STUDIES ON MILD STEEL (MS) AND
STAINLESS STEEL, TYPE 316 (SS) IN BRINE WITHOUT
OIL AND WITH 100 PPM OIL AT 50°C & 80°C**

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*Research Development & Training Center
Saline Water Conversion Corporation*

Introduction

The general corrosion rates were determined for the two abovementioned materials, MS and SS under the different conditions given above, i.e., in plain brine, containing no oil and in brine having 100 ppm of oil mixed in it. The experiments were conducted under these conditions at 50°C and 80°C.

Experimental

Electrochemical methods were employed to determine the corrosion rates. The experiments were carried out on EG & G model 342-2 Soft Corr measurement system. The system consists of model 273 potentiostat/galvanostat, model 342 corrosion software and model 30 IBM PS-2. All the experiments were carried out using a corrosion cell with saturated calomel as reference electrode (SCE) and graphite as counter electrode (EG & G model K0047).

The test specimens (of MS & SS) were taken in the form of small circular disks, about 1.5-2 mm thick and 16 mm diameter. They were ground successively with different grades of emery paper down to 600 grit, then washed, rinsed, degreased, rinsed again in distilled water, dried and placed in the sample holder of the model K0047 test cell. The total exposed surface area of the specimen was 1cm². The brine solution was first deaerated by purging with pure nitrogen for 1 hour, then the specimen was placed in solution and allowed to attain steady-state for 2 hours. Thereafter the experiments were run with the softcorr program. The polarization resistance (PR) technique was used for the corrosion rate measurements. Tafel experiments were also run

separately for each experimental conditions to obtain values of anodic and cathodic tafel slopes which are needed for calculating the corrosion rates by the PR technique. Throughout the measurements, the brine solution was kept stirred by a magnetic stirrer.

The experimental set up used is explained in Fig. 1, where the test cell arrangement and other instruments used are shown schematically with the help of sketches and block diagrams.

Results and Discussion

As already stated, the corrosion rates were determined using polarization resistance (PR) technique. Figs. 2 & 3 show the polarization resistance plots obtained for mild steel at 80°C in brine containing no oil and 100 ppm oil respectively. Similar plots were obtained for all the other experimental conditions and corrosion rates were determined from each of them. The corrosion rates obtained for both MS and SS under all the experimental conditions are presented in table 1 below :

Table 1

Experimental Conditions	Corrosion rates, mpy	
	Mild Steel	SS 316
Plain brine, 80°C	12.81	0.2065
Brine + 100 ppm oil, 80°C	10.43	0.135
Plain brine, 50°C	16.82	0.2797
Brine + 100 ppm oil, 50°C	6.68	0.1498

The most noteworthy feature brought out by the experimental results is that mixing of 100 ppm of oil to the brine brings down the corrosion rates from those obtained in plain brine without oil addition. This is true for both MS and SS at both the experimental temperatures. This observation indicates that the oil might form some kind of film on the metal surfaces that causes

a reduction in the corrosion rates. The reduction in corrosion rates, however, is more pronounced at 50°C compared to that at 80°C, particularly for mild steel. Also, the corrosion rates at 80°C are lower than those at 50°C in plain brine for both MS and SS. These observations may suggest that there is perhaps more effective deaeration at 80°C as compared to the deaeration at 50°C, which in turn will lead to a lower oxygen reduction at the higher temperature. The net effect is that the corrosion rate is lower at the higher temperature. There is yet another possibility that the adsorption characteristic of the oil film on metal surface may be significantly affected by the temperature, such that at the lower temperature (50°C) the oil film is forming a more effective barrier than at the higher temperature (80°C). Thus there is a greater reduction in corrosion rate at 50°C than at 80°C between plain brine and oil mixed brine.

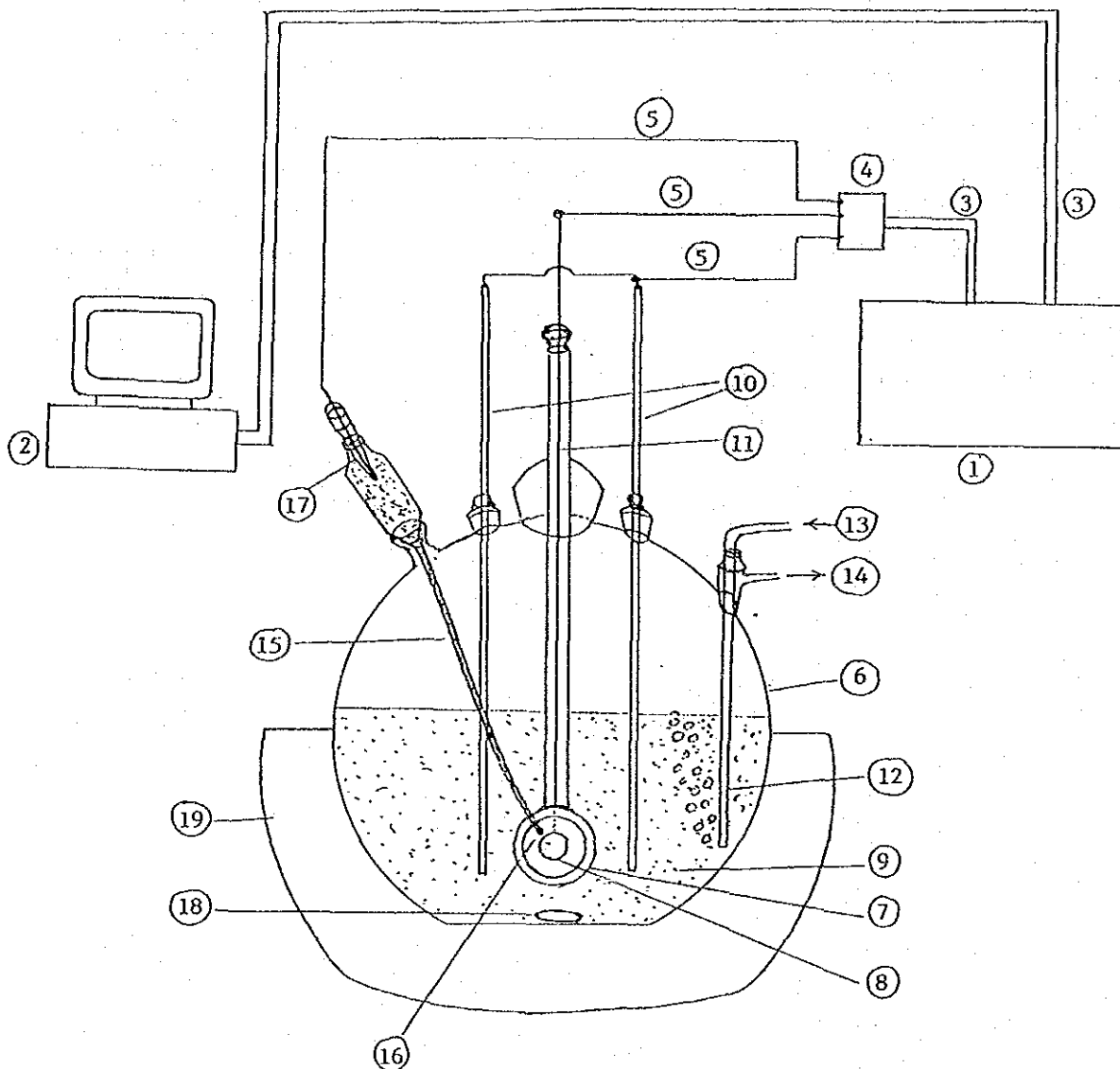


Fig. 1 Schematic presentation of experimental set up shown with the help of sketches and block diagrams (not drawn proportionately).

Legends :

- (1) Potentiostat, EG & G model 273, (2) Computer, IBM Model 30 PS-2, (3) Cables connecting Potentiostat to differential electrometer & computer, (4) Differential electrometer, (5) Electrical leads from different electrodes to differential electrometer, (6) Test cell (EG & G model K0047), (7) Specimen holder (Teflon), (8) Specimen (exposed area = 1 cm²), (9) Test solution (brine), (10) Counter electrodes (graphite), (11) Electrical contact between specimen & electrical lead, (12) Gas-purging tube, (13) Purified nitrogen IN, (14) Nitrogen OUT, (15) Salt bridge capillary, (16) Membrane tip, (17) Reference electrode (saturated calomel), (18) Magnetic stirring bit, (19) Heating bath with magnetic stirrer & temperature controller.

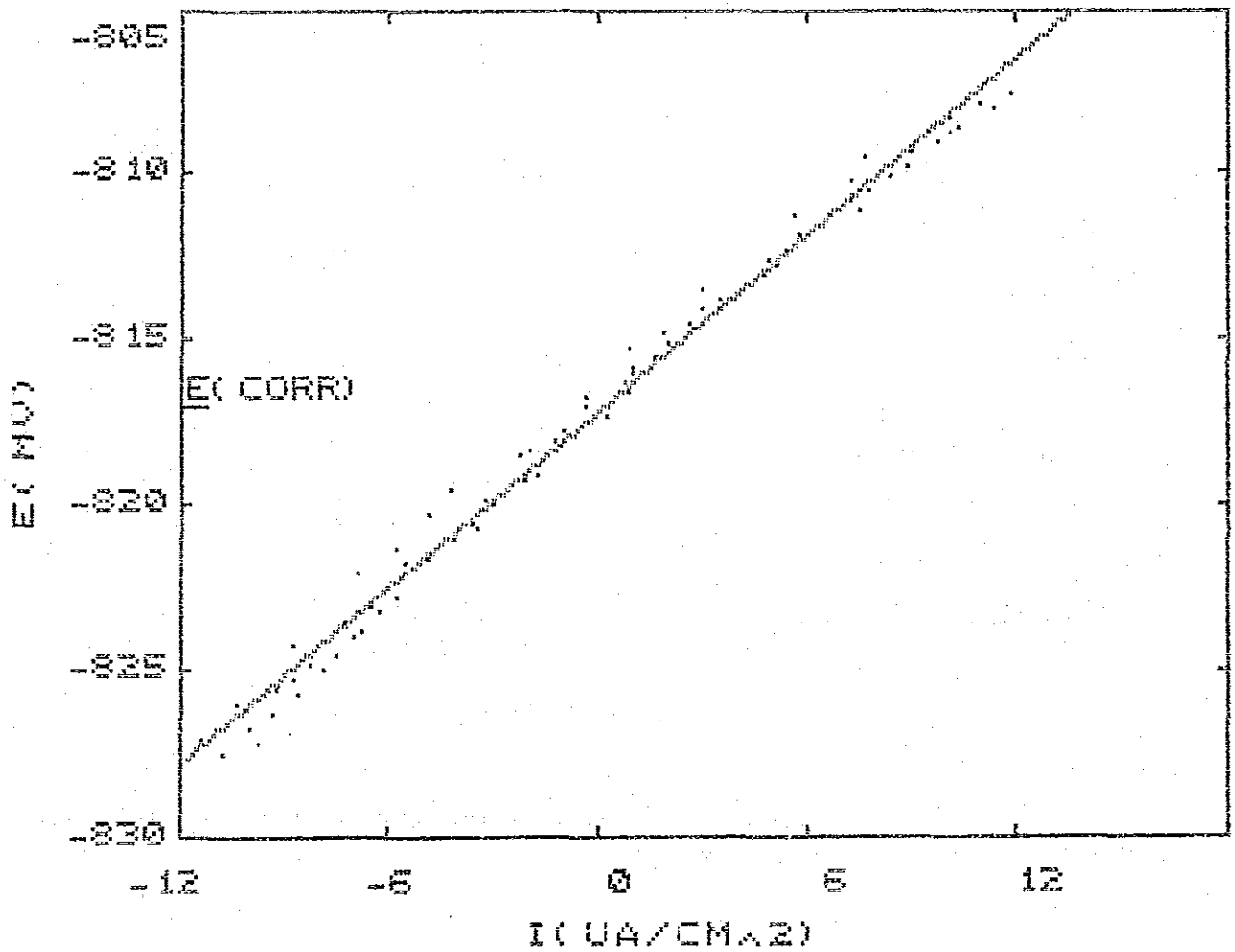


Fig. 2 Polarization-resistance plot for mild steel at 80°C in plain brine containing no oil.

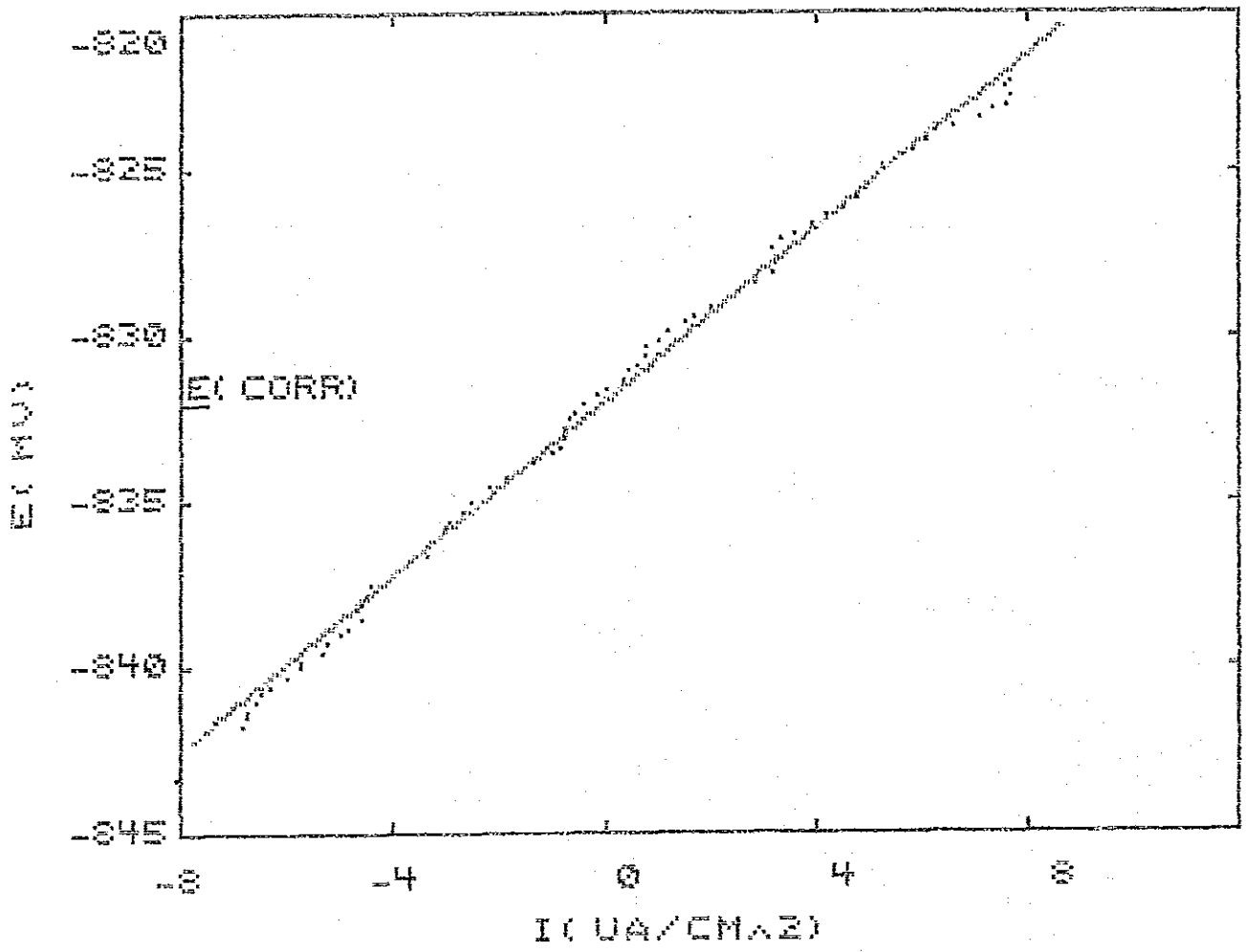


Fig. 3 Polarization resistance plot for mild steel at 80°C in brine mixed with 100 ppm oil.

APPENDIX M 1 - 3

APPENDIX M1-3-1 : DETAILED SCHEDULE ON RESEARCH THEMES (M-1)

APPENDIX M1-3-2 : TEST PROCEDURE FOR M-1

APPENDIX M1-3-3 : RECORDING SHEET FOR TEST(1) OF M-1 EXPERIMENT

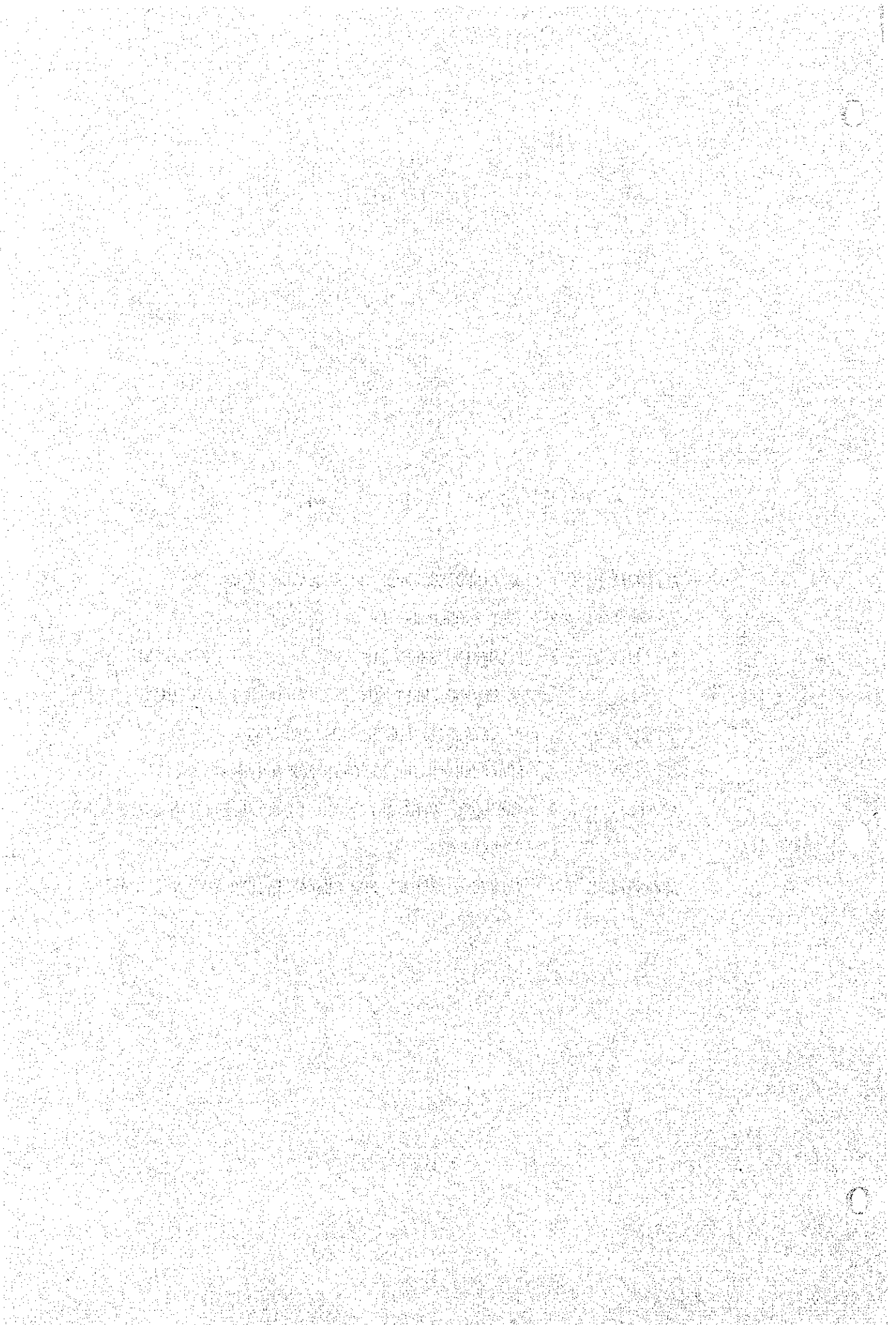
RECORDING SHEET FOR TEST(2) OF M-1 EXPERIMENT

APPENDIX M1-3-4 : MATERIALS(1) FOR M-GROUP MEETING

APPENDIX M1-3-5 : SCHEDULE ON THE REPORTS FOR M-1, M-4

APPENDIX M1-3-6 : THE MOST IMPORTANT POINT TO BE REFERED IN PLANNING
EXPERIMENTS

APPENDIX M1-3-7 : RESUME OF REPORT FOR RESEARCH THEMES (M-1 & M-4)



APPENDIX M1-3-1

DETAILED SCHEDULE ON RESEARCH THEMES(M-1)

ITEM	NOVEMBER			DECEMBER		
	1	10	20	30	10	20
1 Meeting *1) with Dr. El-Sayed	△ ²					
2 Planning*2) ①Test condition ②Test Procedure ③Analysis Method	2 — 3					
3 Preparation *3) ①Experiment 1)Instrument • Assembling • Trial 2)Conc. sea water sample ②Analysis*4) 1)Apparatus 2)Reagents 3)Calibration	4 — 13 4 — 10 5 — 10 △ ¹¹					
4 Implementation*5)		16 — 4				
5 To prepare SEM- photograph				7 — 10		
6 Preliminary Report*1)				7 — 18		
7 Collecting/Reading information *1)						
						(To do at January 1992)

(NOTE)

- Dr. El-Sayed will participate in the conference during 25-27 November.
- Mr. Monazir Imam will go back own country during 7-30 November.

AGENDA ON NOV. 2

(M-1)

- *1) ① Instrument apparatus and reagents needed for experiment
To use your Research Center equipment if necessary except specific instruments
- ② Collection of information and reading
More emphasis on collection of materials for your practice or its own accumulated so far
- ③ Preparation for preliminary report
To recommend that you are to prepare a preliminary report in reference to the inception report
- *2) ① To discuss phenomena concerning precipitation & prevention of alkaline scale from the sea water in dynamic/static field
- ② Reconfirmation of test condition and analysis method for m-Alkalinity, pH etc.
- *3) Apparatus transported from YANBU
Rotary evaporator etc.
- *4) Analytical item: EC, m-Alk, pH, Cl, Ca, Mg in the brine
- *5) Test condition

Temperature(°C)	95		80	50
Additives dosing rate(ppm)	0	5	5	5
Oil concentration(ppm)	0	0, 1, 10, 100	0, 1, 10, 100	1, 10, 100

(Total 12 condition)

APPENDIX M1-3-2

TEST PROCEDURE FOR ITEM M-1

1. Preparation of brine

- ① Put 800ml of the raw sea water into the rotary evaporator(S_R).
- ② Concentrated*¹⁾ it up to 571ml, evaporating by flashing under less than 60°C(S_{RB}).
- ③ Prepare 11l of the brine in total and keep it in the polyethylene bottle with faucet.

2. Preparation of Na_2CO_3 solution for m-alkalinity control.

Prepare 1/2N Na_2CO_3 solution (Dissolve 25.15g of Na_2CO_3 with pure water and make its volume to 1 liter)

3. Precipitation test

3.1 Test conditions (12 conditions)

Test NO.	Sb* ²	S1-1~S1-4	S2-1~S2-4	S3-2~S3-4
Temperature(°C)		95	80	50
Additives dosing rate(ppm)	0	5	5	5
Oil concentration(ppm)	0	0, 1, 10, 100	0, 1, 10, 100	1, 10, 100

3.2 Apparatus

Refer to Fig 3.1 (hereinafter referred to as "FLASK").

3.3 Procedure

3.3.1 Blank test

- ① Put 800ml of the test sample into the FLASK.
- ② Raise the temperature of the test sample up to 95°C in the oil bath heated in advance.
- ③ Keep refluxing for 30 min and observe if some precipitation occurs.

*1) Concentration factor= $S_R/S_{RB}=1.4$

*2) Blank test

- ④ If not, add the specified amount*¹ of Na₂CO₃ solution and keep refluxing for 1 hour.
- ⑤ Immediately*², filter it with filtering paper (No. 5C), then take the filtrate and the precipitate (B_L, S_L).

3.3.2 Main test

(1) S1-1, S2-1

- ① Put 800ml of the test sample with 4mg of additives into the FLASK for each condition of temperature and stir.
- ② Raise the temperature of the test sample up to 95 and 80°C respectively in the oil bath heated in advance.
- ③ Keep refluxing for 30 min, and observe if some precipitation occurs.
- ④ If not, add the specified amount*¹ of Na₂CO₃ solution and keep refluxing for 1 hour.
- ⑤ Immediately*², filter it with filtering paper (No. 5C), then take the filtrate and the precipitate (B₁₁, B₂₁, S₁₁, S₂₁).

(2) S1-2~4, S2-2~4, S3-2~4

- ① Add 0.8, 8, and 80mg of oil with 4mg of additives to 800ml of the test sample for each condition of temperature.
- ② Stir each test sample for 20sec with a mixer and put it into the FLASK.
- ③ Raise the temperature of the test sample up to 95, 80 & 50°C respectively in the oil bath before hand, and observe if some precipitation occurs.
- ④ If not, add the specified amount*¹ of Na₂CO₃ solution and keep refluxing for 1 hour.
- ⑤ Immediately*², filter it with filtering paper (No. 5C), then take the filtrate and the precipitate (B₁₂, B₁₃, B₁₄, S₁₂, S₁₃, S₁₄, B₂₂, B₂₃, B₂₄, S₂₂, S₂₃, S₂₄, B₃₂, B₃₃, B₃₄, S₃₂, S₃₃, S₃₄).

*1 : CASE 1 (C_{Cl} in S_{RB}/C_{Cl} in S_R) = 1.4 > C_{Alk} in S_{RB}/C_{Alk} in S_R

$$V_{R-CAC03} = (1.4 C_{Alk} \text{ in } S_R - C_{Alk} \text{ in } S_{RB}) 0.8 / (25.15 \times 10^3)$$

Where, $V_{R-CAC03}$: Minimum volume of 1/2N Na₂CO₃ Solution (l)

C_{Cl} : Concentration of chlorine ion (mg/l)

C_{Alk} : Concentration of m-Alkarity (CaCO₃ mg/l)

0.8 : Sampling volume of S_{RB} (l)

25.15*10³ : Concentration of Na₂CO₃ solution (CaCO₃ mg/l)

CASE 2 (C_{Cl} in S_{RB}/C_{Cl} in S_R) = 1.4 = C_{Alk} in S_{RB}/C_{Alk} in S_R

THIS WILL BE PRESENTED LATER.

*2 : Before temperature drops to the limits where the precipitate redissolve again

3.4 Measurement

3.4.1 Temperature

- Cooling water inlet (T_{CW-IN}) ($^{\circ}C$)
- Cooling water outlet (T_{CW-OUT}) ($^{\circ}C$)
- Oil bath (T_O) ($^{\circ}C$)
- Test sample in the FLASK (T_B) ($^{\circ}C$)
- Temperature difference ($\Delta T = T_O - T_B$) ($^{\circ}C$)

3.4.2 Volume and weight

- B_b (l)
- B_{11}, B_{21} (l)
- $B_{12}, B_{13}, B_{14}, B_{22}, B_{23}, B_{24}, B_{32}, B_{33}, B_{34}$ (l)
- S_b (g)
- S_{11}, S_{21} (g)
- $S_{12}, S_{13}, S_{14}, S_{22}, S_{23}, S_{24}, S_{32}, S_{33}, S_{34}$ (g)

3.4.2 Analysis of constituents

- Sample B = pH(25 $^{\circ}C$), m-Alk, Cl, Ca, Mg (mg/l)
- Sample S = Cl as NaCl (mg/g)
- Ca as $CaCO_3$ (mg/g)
- Mg as $Mg(OH)_2$ (mg/g)

4. Microscopic observation of precipitate

Select the most appropriate specimen among sample S for examination with SEM to be done at the Research Institute of the University of Petroleum and Minerals.

5. Evaluation of results

THIS WILL BE PRESENTED LATER.

RECORDING SHEET FOR TEST(1) OF M-1 EXPERIMENT Date: , , 1991

Tests No	S -	Temp.	°C	Additives Conc.	mg/l μ l/l	Oil Conc.	mg/l μ l/l	* Note
No	Subjects	Sym.	Measuring items	Unit	Results			
1	Formation of p. p. t	pH _S	pH before heating	25°C*				change into 25 °C as CaCO ₃ as CaCO ₃ as CaCO ₃
2		pH _F	pH of filtrate	25°C*				
3		Ak _S	m-Alk before heating	mg/l*				
4		Ak _A	m-Alk added	mg/l*				
5		Ak _F	m-Alk of filtrate	mg/l*				
6		t _o	Oil bath temperature	°C				-t _o - t _B
7		t _B	Brine temperature	°C				
8		Δt	Temp. difference	°C				
9		T _S	Starting time	hr	°	'	t=t _B	
10		T _M	Time after X min.	hr	°	'	X= min	
11		T _F	Time after Y min.	hr	°	'	Y= min	
12		V _{NA}	V. of Na ₂ CO ₃ sol. added	l				
13		V _B	V. of filtrate	l				
14		W _{lS}	W. of ppt. after dry'g	g				
15		Results of observa- tion by eyes				Sharp	Round	

(NOTE) • Ak_A=(53)(0.94)(10³)V_{NA}/0.8 [mg/l as CaCO₃]
 • Cocentration of Na₂CO₃ solution:1N
 • To dry at 105°C

COMMENTS	
	Signature

RECORDING SHEET FOR TEST(2) OF M-1 EXPERIMENT

Date: , , 1991

Tests No	S	Temp.	°C	Additives Conc.	mg/l μ l/l	Oil Conc.	mg/l μ l/l	* Note
No.	Subjects	Sym.	Measuring items	Unit	Results			
1		V _B	V. of filtrate	l				change into 25 °C as CaCO ₃
2		pH _F	pH of filtrate	25°C*				
3		AK _F	m-Alk of filtrate	mg/l*				
4		Cl _F	Cl ion in filtrate	mg/l				
5	Quantity of Ca ²⁺ Mg ²⁺ in filtrate	Ca _s	Ca ion before heat'g	mg/l				CaCO ₃
6		Ca _F	Ca ion in filtrate	mg/l				
7		Ca _{P1}	Ca _s -Ca _F	mg/l				
8		W _{1Ca}	2.5(Ca _{P1})(V _B)	mg *				
9		Mg _s	Mg ion before heat'g	mg/l				
10		Mg _F	Mg ion of filtrate	mg/l				
11		Mg _{P1}	Mg _s -Mg _F	mg/l				
12		W _{1Mg}	2.4(Mg _{P1})(V _B)	mg *				
13	Quantity of CaCO ₃ & Mg(OH) ₂ in ppt	W _{1s}	W. of ppt. after dry'g	mg				W _{1s} W _{1NC}
14		W _{1c1}	W. of Cl after dry'g	mg				
15		W _{1NC}	W. of NaCl	mg				
16		W _{2s}	W. of actual ppt	mg *				
17			W. of Ca	mg				
18		W _{2Ca}	W. of CaCO ₃	mg				
19			W. of Mg	mg				
20		W _{2Mg}	W. of Mg(OH) ₂	mg				

THE SUMMARY OF TEST RESULTS FOR RESEARCH THEMES:M-1

1. Viewpoint of the M-1 test

- The degree(ΔALK_F) of decrease in supersaturated m-Alkalinity

2. Test results

TEST No.	TEMP.	CONC. OF ADDITIVES	CONC. OF OIL	M-ALKALINITY			NOTE
				*1	*2	*3	
	°C	ppm	ppm	ppm as CaCO ₃			
				ALK _S	ALK _F	ΔALK_F	
S1-b	95	0	0	154.1	112.7	0	
S1-1	95	5	0	154.1	98.9	-13.8	
S1-2	95	5	1	154.1	108.1	-4.6	
S1-4	95	5	100	154.1			
S1-5	95	10	100	154.1			● *5
S1-6	95	5	0	154.1			● *6
S2-b	80	0	0	154.1	108.1	0	
S2-1	80	5	0	154.1	210.5	102.4	
S2-2	80	5	1	154.1	151.8	43.7?	*4)
S2-4	80	5	100	154.1	211.6	103.5?	*4)
S2-5	80	3	0	154.1			● *5
S2-3	80	5	10	154.1			● *5
S3-b	50	0	0	154.1	197.8	0	
S3-1	50	5	0	154.1	218.5	20.7	
S3-2	50	5	1	154.1	207.0	9.2	
S3-4	50	5	100	154.1			

- NOTE *1) ALK_S:m-Alkalinity of brine before heating
 *2) ALK_F:m-Alkalinity in filtrate of samples obtained by adding
 1N NaCO₃ solution for break of supersaturated condition.
 *3) $\Delta\text{ALK}_F = (\text{ALK}_F \text{ of S-1} \sim \text{S-6}) - (\text{ALK}_F \text{ of S-b})$
 *4) Marks ? indicate the re-experiment conditions
 *5) Marks ● indicate the experiment conditions supplemented
 *6) Reaction time(Y)= min.

3. Evaluation of test results until now

1) At 95°C, while concentration of ADDITIVES is 5ppm, no threshold effect is found.

2) At 80°C, a remarkable threshold effect is found in case where concentration of ADDITIVES is 5 ppm. However, in existence of 1ppm of oil, the threshold effect may be considerably reduced.

If this is the fact, it would be worthy of the greatest result for M-1. At present, there are contradiction in two data obtained. A careful retest will be needed to make it clear.

3) At 50°C, supersaturation state of sea water can be kept and even in existence of oil, there are no changes in the threshold effect by ADDITIVES.

THE SUMMARY OF TEST RESULTS FOR RESEARCH THEMES:M-1
(INCLUDED THE ADDITIONAL TEST CONDITION)

4 DEC. 91
12 DEC. 91

TEST NUMBER	REACTION TIME		TEMP. °C	CONC. OF ADDITIVES ppm	CONC OF OIL ppm	M-ALKALINITY			BLNK
	min					ALK _S	ALK _F	ΔALK _F	
						ppm as CaCO ₃			
S1b1	60		95	0	0	154.1	112.7	0	
S1b2	5		95	0	0	181.7	455.4	0	
S1b3	5		95	0	100	181.7			
S101	60		95	5	0	154.1	98.9	-013.8	S1b1
S102	60		95	5	1	154.1	108.1	-004.6	S1b1
S104	60		95	5	100	154.1	94.3	-018.4	S1b1
S105	60		95	10	100	154.1	140.0	27.3	S1b1
S106	5		95	5	0	154.1	515.0	59.6	S1b2
S107	5		95	5	1	181.7	388.7	-066.7	S1b2
S108	5		95	5	100	181.7	213.9	-241.5	S1b2
S1b4	17		95	0	0	181.7		0	
S109	17		95	5	0	181.7	218.5		S1b3
S110	17		95	5	1	181.7	174.8		S1b3
S111	17		95	5	100	181.7	186.3		S1b3
S112	60		95	3	100	181.7			
S113	5		95	10	100	181.7			
S2b1	60		80	0	0	154.1	108.1	0	
S201	60		80	5	0	154.1	210.5	102.4	S2b1
S202	60		80	5	1	154.1	131.1	23.1	S2b1
S202	60		80	5	1	154.1	151.8	43.7	S2b1
S204	60		80	5	100	154.1	211.6	103.5	S2b1
S204	60		80	5	100	154.1	193.2	85.1	S2b1
S205	60		80	3	0	154.1	89.9	-018.2	S2b1
S203	60		80	5	10	154.1	138.0		S2b1
S206	5		80	5	0	181.7	246.1		S2b1
S207	5		80	5	1	181.7	262.2		S2b1
S208	5		80	5	100	181.7	446.2		S2b1
S3b1	60		50	0	0	154.1	197.8	0	
S301	60		50	5	0	154.1	218.5	20.7	S3b1
S302	60		50	5	1	154.1	207.0	9.2	S3b1
S304	60		50	5	100	154.1	174.8	-23.0	S3b1

THE SUMMARY OF TEST RESULTS FOR RESEARCH THEMES:M-1
(INCLUDED THE ADDITIONAL TEST CONDITION)

IMPORTANT POINTS

The higher residual m-alkalinity, the less precipitate.
This leads to scale prevention.

- (Note) • ALK_S :m-Alk before heating (No precipitation occur.)
• ALK_F :m-Alk of filtrate = Residual alkalinity
• ΔALK_F : ALK_F - (ALK_F obtained by tests indicated in column:BLNK)
• BLNK :Test number selected for a comparison
• Calculated alkalinity in case of adding 1N Na_2CO_3 solution is as shown below.

$$\{(50)(10^3)V_{NA}/V_S\} ALK_S \text{ ppm as } CaCO_3.$$

Where, $(50)(10^3)$:Alkalinity of 1N Na_2CO_3 solution [ppm as $CaCO_3$]

V_{NA} :Amount of 1N Na_2CO_3 added [l]

V_S :Amount of brine before heating [l]

1. Effect of temperature

TEST NUMBER	REACTION TIME		CONC. OF ADDITIVES	CONC OF OIL	M-ALKALINITY			BLNK
	min	TEMP. °C			ALK _S	ALK _F	ΔALK _F	
					ppm as CaCO ₃			
S1b1	60	95	0	0	154.1	112.7	0	
S101	60	95	5	0	154.1	98.9	0	
S102	60	95	5	1	154.1	108.1	0	
S104	60	95	5	100	154.1	94.3	0	
S2b1	60	80	0	0	154.1	108.1	4.6	S1b1
S201	60	80	5	0	154.1	210.5	111.6	S101
S202	60	80	5	1	154.1	131.1	23.0	S102
S202	60	80	5	1	154.1	151.8	43.7	S102
S204	60	80	5	100	154.1	211.6	117.3	S104
S204	60	80	5	100	154.1	193.2	98.9	S104
S3b1	60	50	0	0	154.1	197.8	85.1	S1b1
S301	60	50	5	0	154.1	218.5	119.6	S101
S302	60	50	5	1	154.1	207.0	98.9	S102
S304	60	50	5	100	154.1	174.8	80.5	S104

2. Effect of reaction time

TEST	REACTION		TEMP.	CONC. OF ADDITIVES	CONC OF OIL	M-ALKALINITY			BLNK
	NUMBER	TIME				min	°C	ppm	
S1b2	5	95	0	0	181.7	455.4	0		
S106	5	95	5	0	154.1	515.0	0		
S107	5	95	5	1	181.7	388.7	0		
S108	5	95	5	100	181.7	213.9	0		
S1b4	17	95	0	0	181.7	131.1	-324.3	S1b2	
S109	17	95	5	0	181.7	218.5	-296.5	S106	
S110	17	95	5	1	181.7	174.8	-213.9	S107	
S111	17	95	5	100	181.7	186.3	-27.6	S108	
S1b1	60	95	0	0	154.1	112.7	-342.7	S1b2	
S101	60	95	5	0	154.1	98.9	-417.6	S106	
S102	60	95	5	1	154.1	108.1	-280.6	S107	
S104	60	95	5	100	154.1	94.3	-119.6	S108	

3. Effect of Additives concentration

TEST	REACTION		TEMP.	CONC. OF ADDITIVES	CONC OF OIL	M-ALKALINITY			BLNK
	NUMBER	TIME				min	°C	ppm	
S1b3	5	95	0	100	181.7	179.4	0		
S112	5	95	3	100	181.7	216.2	36.8	S1b3	
S108	5	95	5	100	181.7	213.9	34.5	S1b3	
S113	5	95	10	100	181.7	216.2	36.8	S1b3	

(ALK_F in 60min., 80°C, 3ppm Additives and non-oil of Test No: S205 is 89.9 ppm as CaCO₃)

4. Effect of oil concentration

TEST	REACTION		TEMP.	CONC. OF ADDITIVES	CONC OF OIL	M-ALKALINITY			BLNK
	NUMBER	TIME				min	°C	ppm	
						ALK _s	ALK _F	Δ ALK _F	
S106		5	95	5	0	154.1	515.0	0	
S109		17	95	5	0	181.7	218.5	0	
S101		60	95	5	0	154.1	98.9	0	
S107		5	95	5	1	181.7	388.7	-126.3	S106
S110		17	95	5	1	181.7	174.8	-43.7	S109
S102		60	95	5	1	154.1	108.1	9.2	S101
S108		5	95	5	100	181.7	213.9	-301.1	S106
S111		17	95	5	100	181.7	186.3	-32.2	S109
S104		60	95	5	100	154.1	94.3	-4.6	S101
S101		60	95	5	0	154.1	98.9	0	
S201		60	80	5	0	154.1	210.5	0	
S301		60	50	5	0	154.1	218.5	0	
S102		60	95	5	1	154.1	108.1	9.2	S101
S202		60	80	5	1	154.1	131.1	-79.4	S201
S202		60	80	5	1	154.1	151.8	-58.7	S201
S302		60	50	5	1	154.1	207.0	11.5	S301
S203		60	80	5	10	154.1	138.0		
S104		60	95	5	100	154.1	94.3	-4.6	S101
S204		60	80	5	100	154.1	*211.6	1.1	S201
S204		60	80	5	100	154.1	*193.2	-17.3	S201
S304		60	50	5	100	154.1	174.8	-32.2	S301
S206		5	80	5	0	181.7	246.1	0	
S207		5	80	5	1	181.7	262.2	16.1	S206
S208		5	80	5	100	181.7	446.2	200.1	S206
S106		5	95	5	0	154.1	515.0	0	
S107		5	95	5	1	181.7	388.7	-126.3	S106
S108		5	95	5	100	181.7	213.9	-301.1	S106

SCHEDULE ON MAKING THE REPORTS FOR M-1, M-4

(REV-02)

DATE	MON.	YEAR	Dr. Essam	Dr. Nomani	Hamada	Hamao	Saad
16	DEC.	1991	Discuss contents of report with Hamada (Goto EGYPT)		Discuss contents of report with Dr. Essam	Check report	Test for brushing up of report
17	DEC.	1991		(Goto INDIA)			
18	DEC.	1991					
19	DEC.	1991			(Holiday)	(Holiday)	(Holiday)
20	DEC.	1991	Make report *Introduction		(Holiday)	(Holiday)	(Holiday)
21	DEC.	1991	*Theory	Brush up report	Check report of M-4 and discuss contents of M-1 report with Saad	Check report	Make report *Planning
22	DEC.	1991	*Discussion			Preparation of transportation	*Exp. method
23	DEC.	1991	*Conclusion *Reference *Acknowledge.				*Exp. result
24	DEC.	1991					
25	DEC.	1991					
26	DEC.	1991			(Holiday)	(Holiday)	(Holiday)
27	DEC.	1991			(Holiday)	(Goto YANBU)	(Holiday)
28	DEC.	1991					
29	DEC.	1991				SWCC YANBU FACILITY	
30	DEC.	1991					
31	DEC.	1991			Receive report from Dr. Basu		
1	JAN.	1992			(Holiday)	(Go back to JUBAIL)	(Holiday)
2	JAN.	1992			(Holiday)	(Holiday)	(Holiday)
3	JAN.	1992			(Holiday)	(Holiday)	(Holiday)
4	JAN.	1992	(Go back to SWCC)		Brush up report with Dr. Essam and Dr. Basu	Check report	
5	JAN.	1992	Brush up report with Hamada				
6	JAN.	1992					
7	JAN.	1992					
8	JAN.	1992		(Go back to SWCC)			
9	JAN.	1992	(Holiday)	(Holiday)	(Holiday)	(Holiday)	(Holiday)
10	JAN.	1992	(Holiday)	(Holiday)	(Holiday)	(Holiday)	(Holiday)
11	JAN.	1992		Brush up report with Hamada and Hamao	Check corrosion research instrument	Brush up report with Dr. Nomani and Hamada	
12	JAN.	1992					
13	JAN.	1992	Complete the tentative report:M-1	Complete the tentative report:M-4			
14	JAN.	1992			Receive the tentative report:M-1	Receive the tentative report:M-4	
15	JAN.	1992					
16	JAN.	1992			(Goto JAPAN)		

実験のPlanningにおいて記載する最大のPoint

Alhammadh's idea

- Additives の効果が油の存在によって、どの様に阻害されるかを定量的に把握することである。
 - Additives の効果には Threshold effect と Crystal distortion とがあるが、前者は換言すると、化学量論的にPrecipitation が起こるべき状態をそれが起こらない状態に保つ効果、即ち過飽和状態を保つ効果であり、後者は例えPrecipitation が起きて、その結晶の形状を伝熱面に付着しない様に変形させる効果である。
 - 後者については、PrecipitateのSEMによる写真観察により行う。
 - 前者については、次の手順でAdditives のThreshold effectを明らかにする。
- 1) Concentration Factor 1.4 (Actual plants におけるそれと同じ値) でもPrecipitation が発生しない温度 (60°C) でRaw Sea Water を1.4 倍に濃縮する。

この状態でBrine は過飽和状態で安定である。(Stability Index=)

- 2) この状態のBrine に Na_2CO_3 を添加してm-Alkalinityを最低値まで減少させる。

この状態でBrine は飽和状態となる。

- 3) この状態のBrine にさらに Na_2CO_3 を添加していくと、それは全て CaCO_3 のPrecipitationの生成に消費されることになる。そして CaCO_3 の溶解度積に従い、m-Alkalinityは上昇する。
- 4) しかしm-Alkalinityの上昇程度はAdditives の存在及びその滞留時間(反応時間)によって、また油の存在の有無によって大きく異なる。

これらの関係を明らかにすることが本実験の最大のPoint である。

THE MOST IMPORTANT POINT TO BE REFERED IN PLANNING FOR EXPERIMENTS

Alhammadh's idea

- To grasp quantitatively how effect of Additives is retarded due to existence of oil.
 - Effect of Additives involves the threshold effect and the crystal distortion. The former represents an effect which prevents precipitation being broken up stoichiometrically, that is to keep supersaturation. The latter represents an effect which distorts configuration of crystals so that adherence to heat transfer tube wall may not break up even if precipitation occurs.
 - To evaluate the latter based on SEM examination for precipitate.
 - To make threshold effect of Additives clear according to the following procedure.
- (1) To concentrate 1.4 times raw sea water at the temperature (60°C) where no precipitation occurs in case of concentration factor 1.4 simulated to actual plants.

In this state, brine is kept stable in supersaturation. (Stability Index=)

- (2) To decrease m-alkalinity at minimum by adding Na_2CO_3 to the above brine.

In this state, the brine is in saturated condition.

- (3) All amount of Na_2CO_3 further added to the above brine may be consumed for formation of CaCO_3 precipitates. According to solubility product of CaCO_3 , m-alkalinity increase.
- (4) However, the extent of m-alkalinity increase varies too much due to existence of Additives or oil, retention time (reaction time) and temperature.

Intercorrelation between different parameters (Temp., Time, Additives concentration, Oil concentration and m-Alkalinity) is the most important point in this study.

APPENDIX M1-3-7

RESUME OF REPORT FOR RESEARCH THEMES:M-1 & M-4
(contents) (JICA Team's Idea)

No.	M-1	M-4
I	Main title	
	Scale prevention for MSF plant supplied with oil-contaminated sea water	Quality of product water in MSF plant supplied with oil-contaminated sea water
II	Sub-title (from Inception Report)	
	Laboratory experiments on scale prevention	Analysis of oil dispersed in raw sea water at the heat rejection section of MSF plant
III	Author	
	<ul style="list-style-type: none"> • Dr. Essam E. F. El-Sayed • Saad Al Sulami • Tadatsugu Hamada 	<ul style="list-style-type: none"> • Dr. A. A. Nomani • Yoshio Hamao • Tadatsugu Hamada
1.	Introduction	
	<ul style="list-style-type: none"> • On basis of outline of Introduction in inception report • In addition to above, refer to it that scale prevention has something close to do with decision for plants size in design. 	<ul style="list-style-type: none"> • On basis of outline of Introduction in inception report • In addition to above, refer to application of suitable method for oil analysis.
2.	Theory(This title could be changed to more appropriate one. Result of literature survey shall be included.)	
	<ul style="list-style-type: none"> • Technological explanation concerning acid & chemical dosing methods (To emphasise importance of alkalinity for water conditioning. To explain threshold effect and crystal distortion in chemical dosing method) • Fouling factor peculiar to methods above. (On basis of measurement in operating MSF plant in Saudi-Arabia) 	<ul style="list-style-type: none"> • Behavior of volatile components MSF process(To explain that it is possible to analyse this on basis of the same way as steam-distillation. To present results of simulated calculation on given conditions) • To present analytical methods for oil in water. To explain advantage or disadvantage for each. To suggest effectiveness of GC/MS.
3.	Planning and procedure of experiments	
	<ul style="list-style-type: none"> • Experiment conditions • Measurement items • Experiment apparatus (e. g. configuration) • Experimental procedure 	
4.	Results	
	<div style="border: 1px solid black; padding: 5px; display: inline-block;">INCOMPLETION</div>	

3. EXPERIMENT PROCEDURES

3.1 PLANNING

(Already explained)

3.2 EXPERIMENT CONDITIONS

(Prepare Tables for experiment conditions)

3.3 EXPERIMENT PROCEDURES

(To explain the following contents)

- Sampling location and quality of raw sea water —(Map or Figure & Table)
- To prepare 1.4 times of raw sea water as TDS (brine), where no ppt occur at 60°C
- Intercorrelation between m-alkalinity and 1N Na₂CO₃ addition in the above brine
- To make it sure that no ppt was broken out even if the brine was kept for 30 min. at the temperature specified in the experiment conditions
- To break out ppt by 1N Na₂CO₃ addition and then kept the temperature and the duration, specified in the experiment conditions
- Separation method of ppt
- To divide ppt for composition analysis and SEM examination
- To search for correlation between composition of ppt and existence of oil, together with mass balance check from analytical data for filtrate and ppts

4. EXPERIMENT RESULTS

(Prepare the following tables and figures)

<TABLE>

- Quality of the brine before and after tests
- Table for evaluation of effect of temperature
- Table for evaluation of effect of reaction time
- Table for evaluation of effect of Additives concentration
- Table for evaluation of effect of oil concentration
- Analytical data of ppt

<FIGURE>

- Correlation between 1N Na₂CO₃ addition and m-alkalinity
- Correlation between residual m-alkalinity and temperature
- Correlation between residual m-alkalinity and reaction time
- Correlation between residual m-alkalinity and Additives concentration
- Correlation between residual m-alkalinity and oil concentration
- Correlation between ppt occurrence and residual m-alkalinity
- Correlation between composition of ppt and oil concentration
- Others

5. DISCUSSION

5.1 Evaluation on Effect of Additives

The aims of this experimental research are to examine and compare by carrying out laboratory experiments, the properties of the additives currently used to prevent scaling, when oil is present in the sea water.

Here, at first, authors wish to review the evaluation on effect of Additives used in this experiment. As stated in chapter 2, Additives have two effects i.e. ① threshold effect ② crystal distortion. In other words, ① represents to easily keep super-saturated state and ② represents to inhibit scaling to tube wall by changing crystalline configurations.

It is unlikely possible to identify for ② in this experiment. This will be discussed afterward, based upon the results of SEM examination. ① can be made sure by analysis for water quality, namely, in case where threshold effect come into force more M-Alkalinity than critical concentration for CaCO_3 ppt, which is stoichiometrically calculated. It is difficult to estimate the amount of CaCO_3 ppt from m-alkalinity change especially from data which are obtained in a test unit where fluid continuously flow in and out, but in case of a batch test like this experiment where the amount of precipitation for m-alkalinity is known.

5.2 Evaluation of precipitation by residual m-alkalinity

From the above point of view, regarding the amount of ppt as value obtained by subtraction of residual m-alkalinity from ones in the initial state. An analysis results for influence of each factors on residual m-alkalinity (ALK_F) are shown in Fig. 5***-5***

5.2.1 Effect of Retention Time on m-alkalinity (ALK_F)

The plot in Fig. 5*** show the correlation between ALK_F and retention time i.e. 5min, 17min, and 60min, after the moment when ppt is forced to occur by addition of 1N Na_2CO_3 into brine prepared in advance to be 5ppm of additives (initial alkalinity is 1,000+181.7ppm as CaCO_3).

First, in 5min test, comparing blank value (•) to 5ppm (+) for additives the bigger ALK_F in the latter represents that additives is retarding the growth of ppt. But in the presence of oil, ppt is likely to easily grow (m-alkalinity to reduce), especially in case of 100ppm oil, reduction rate of m-alkalinity reaches to 3 times of no oil.

On the other hand, as retention time longer, the above difference in m-alkalinity reduces gradually. In 60min. test, m-alkalinity at every condition converges in around 100ppm as CaCO_3 .

It suggests that both additives and oil have something little to do with ppt stoichiometrically. This, especially for additives, supports the established theory. And also it would be identified for oil, being no affinity with water, as easily anticipated.

As far as 60min's concerned, the presence of oil has nothing to do with occurrence of ppt, and effect of additives will be limited to crystal distortion.

Actually, there can not be such a state as the above. The retention time of brine in the actual plants (20,000t/d class) is considered to be 2 or 3min. The most important data would be for 5min test.

Of course the occurrence of ppt cannot directly connect with increase of fouling factor. No matter how much ppt may occur, if additives effectively work on crystal distortion, scaling rate to heat transfer tubes will be retarded. However, it is sure that occurrence of ppt is the primary factor to increase fouling factor. Such viewpoint as possibility on initiation of precipitation by oil is important.

Evaluating 5 min. data from the above point of view, it could be stated that the presence of oil becomes the cause of promotion of precipitation and the higher oil concentration the much ppt.

Cases where taking retention time of brine into account are of S. Steinberg et al other than this experiment.

[WILL BE EXPLAIN BY DR. ESSAM ABOUT
RESULT OF THE DATA-ANALYSIS WHICH
BE CARRIED OUT BY S. STEINBERG ET AL]

Fig.5.1 Effect of retention time
on quantity of scale precipi-
tated

Fig.5.1 shows correlation between retention time and quantity of scale precipitated. In Fig. 5.1, it is clear that there is a close relation between precipitation rate and retention time at the presence of additives.

This trend is similar to this experiment.

And, it is easily anticipated that the extend of increase in precipitation rate with progress of retention time varies due to the kind of additives.

Keen competitions on sale of many kind of additives have been extended in SADI-ARABIA, where there are the biggest demands in the world, and in Japan who has biggest products for MSF plant in the world.

The present circumstances make author perplexed to choose a more suitable ones. Taking it into consideration, it is thought that evaluation in this experiment is an effective way being its simplicity and low-price. It is needed to make its effectiveness sure by systematic tests in future.

5.2.2 Effect of Additives Concentration on Alkalinity

With plots, correlation between residual m-Alkalinity after 5 min. while additives contact with ppt, and concentration of additives at 95°C and 100ppm of oil is shown in Fig.5.***. From the results, it is clear that more than 3ppm of additives are no use to prevent ppt. This is well coincident with the practice of 3 or 4 ppm additives at Al-Jubail Phase-2 plants. It proves by chance that scaling prevention at this plant has been effectively and economically controlled. And also it leads to prove propriety of this evaluation.

5.2.3 Effect of Temperature on Alkalinity

Fig.5*** shows correlation between residual m-alkalinity after 60min while additives contact with ppt, and temperatures at 5ppm of additives, 1 and 100ppm at oil together with a plot of blank value. These data were obtained by 60min test which has been done on a hypothesis that contacting time of additives with ppt, would not have so much influence on m-alkalinity. Strictly speaking, 5min test should be done.

However, high temperature stage has an importance effect of temperature on scaling. Now that those data have already obtained as stated in 5.2.1 and it takes much time to prepare brine, an experiment was suspended this time. The following can be concluded from the above data.

- 1) Oil has not so much effect on m-alkalinity at 50°C and 60min. of retention time. the higher concentration of oil, the lower residual m-alkalinity. Oil promotes growth of ppt to some extent.
- 2) At, 80°C and 60°C of retention time, while almost the same extent of decrease for m-alkalinity as 50°C, was found under free of oil, the higher oil concentration, the more m-alkalinity decrease compared to 50°C.
- 3) At 95°C and 60min. of retention time, each m-alkalinity decrease to a certain level, independent of presence of additives and oil concentration.

5.2.4 Effect of Oil Concentration on m-alkalinity

Fig.5*** shows correlation between residual m-alkalinity and oil concentration at 5min. and 60min. of retention time with parameter of temperature. Evaluation on this is made in 5.2.1 to 5.2.3.

Reference to the fact that particle size of ppt becomes very small under 100ppm of oil should be made. Some of ppt have passed through No.5C filter paper in the case where experimental condition is 100ppm of oil concentration, 80°C and 60min. of retention time. That is the reason why filtrate indicate an abnormal value in m-alkalinity under S204 of experimental condition. 0.45 micron filter was used in the case where S104 of experimental condition is 95°C, 100ppm of oil and 60min. of retention time.

Therefore, such a plot is neglected when drawing correlation curves.

5.3 Evaluation on Crystal Distortion by SEM examination.

5.4 Evaluation on Fouling Factor in the case where sea water is contaminated by oil

6 Conclusion

7 Recommendation for future work

8 References

9 Acknowledgements

