5. Study on Scale Control for MSF Process (MSF-1)

CONTENTS

5.1 Investigation and Preparative Experiment

5.1.1.A MSF Plant Survey

(5.1.1.A)

CONTENTS

(5.1.1.A)

List of Tables

List of Figures

1. Introduction

This survey was planned to confirm the accuracy of the computer estimation of the quality of the product water from the MSF test plant when seawater feed is contaminated with oil.

However, the purpose of this survey was changed to that of the water and seawater quality analysis of the MSF actual plants, in order to confirm the information about the characteristics of scale inhibitors which were obtained during this project and to make a plan for the experiment on the hybrid scale inhibitor method, this is, the combination method of the acid dosing method and the scale inhibitor dosing method which is expected to be carried out during the fiscal year 1994.

The sites of the survey were along both coasts of the Kingdom, Arabian Gulf on east coast and Red Sea on west coast.

The analysis of the seawater, the brine and the scale that deposited on the inside of the flash chambers was carried out at SWCC.

This paper makes observation of site survey and reports the results of analysis.

2. The Location and the Schedule of the Plant Survey

The site of the survey were at two points on Arabian Gulf side and at two points on Red Sea side; one plant of SCECO and three plants of SWCC.

SCECO PLANT	**:**	**Qurayyah**	**PLANT (Feb. 2, 1994)**
SWCC PLANT	**:**	**Shoaibah**	**PLANT (Feb. 6, 1994)**
		Shuqaiq	**PLANT (Feb. 7, 1994)**
		Khafji	**PLANT (Feb. 9, 1994)**

3. Results of the Survey

The specification of the plants, the description of the sampled water and the notable information collected at the sites are shown in Table 1. The results of the analysis are shown in Table 2 to Table 6. The chart of X-ray spectrometer is shown in Fig. 1.

4. Summary

Valuable information were obtained by the investigation about the values of M-alkalinity of the recycling brine in case of the hybrid method at Qurayyah plant.

The scaling was found in flashing stages of Shoibah plant's unit. The amount of scale was more in stages of lower temperature. It can be assumed that the effective retention time of scale inhibitors should have an influence on the scaling. It indicates that the characteristics of scale inhibitor, which were confirmed through the selection test of scale inhibitors under beaker scale, were confirmed at the actual plants.

(5.1.1.A)

Table 1 Results of the Site Survey of SCECO/SWCC Desalination Plants (1994)

DATE	SITE	VISITING MSF PLANT	REMARKS
Feb. 2 (Wed.)	QURAYYAH (Eastern)	MSF Plants producing the feed water for Qurayyah Phase-1 Power Plants - Capacity:4.000t/dx3unit - TBT :90, 110℃ - S.Inhi. :H_2SO_4 + BEL.EV (Hybrid system) - User :SCECO - Supplier:MHI	· COLLECT WATER - Raw seawater - Make-up seawater - Recycle brine - Product water · QUALITY IN BRINE - M-Alk :33 $CaCO_3$ ppm - pH :8.26 at 25℃ -
Feb. 6 (Sun.)	SHOAIBAH (Western)	- Capacity:5 MIGDx10 UNIT - TBT :90℃ - S.Inhi. :BEL EV→ALB.A - User :SWCC - Maker :MHI	· COLLECT WATER - Raw seawater - Product water · MAIN TOPIC Scaling in the flash chamber at low temperature. Suggest both chemical dosing rate & injection point.
Feb. 7 (Mon.)	SHUQAIQ (Western)	- Capacity:5 MIGDx4 unit - TBT :90℃ - S.Inhit. :Belgard EV2000 - User :SWCC - Maker :KHIC	· COLLECT WATER - Raw seawater - Product water · MAIN TOPIC Acid cleaning method pH 1 → pH 2
Feb. 9 (Wed.)	KHAFJI (Eastern)	- Capacity:2.5 MIGDx2unit - TBT :90℃ - S.Inhi. :Belgard EV2000 - User :SWCC - Maker :MITSUI	· COLLECT WATER - Raw seawater - Product water · MAIN TOPIC Scale prevention effect DSP≦Belgard EV2000

(NOTE) SCECO : SAUDI CONSOLIDATED ELECTRIC COMPANY

(5.1.1.A)

Table 2 SWCC AL-JUBAIL DESALINATION PLANT

DATE: 25 Nov. '92

No.	Parameter	Unit	Seawater	Brine	Waste
1	pH		8.21	8.68	8.23
2	Color		NIL	NIL	NIL
3	Turbidity		NIL	NIL	NIL
4	Conductivity	μS/cm	58,600	81,800	63,500
5	M-Alkalinity (as $CaCO_3$)	mg/ℓ	130.1	194	143.5
6	Residual Chlorine	mg/ℓ	0.25	0.02	0.12
7	Total Hardness (as $CaCO_3$)	mg/ℓ	6,738	9,488	7,924
8	Total Dissolved Solids (105℃)	mg/ℓ	46,990	69,730	51,776
9	Total Dissolved Solids (180℃)	mg/ℓ	42,288	64,430	47,022
10	Total Organic Carbon	mg/ℓ	2.18	2.08	2.09
11	Chloride	mg/ℓ	23,754	35,454	26,235
12	Sulfate (gravinity; as SO_4)	mg/ℓ	3,265	4,854	3,483
13	Nitrate (as N)	mg/ℓ	0.1	0.85	0.85
14	Sodium (as Na)	mg/ℓ	12,860	17,460	13,780
15	Calcium (as Ca)	mg/ℓ	519	757	605
16	Magnesium (as Mg)	mg/ℓ	1,326	1,845	1,572
17	Chromium	μg/ℓ	0.26	0.11	0.009
18	Total-Copper	μg/ℓ	4.5	4.3	3.3
19	Total-Iron	μg/ℓ	4.9	3.2	3.5
20	Total-Manganese	μg/ℓ	0.45	0.48	0.34
21	Total Nickel	μg/ℓ	1.7	1.2	1

(5.1.1.A)

Table 3 QURAYYAH POWER PLANT PHASE-II DESALINATION PLANT UNIT C

DATE: 19 JULY '93

ITEM		UNIT	TIME				LIMIT
			10:00	11:00	13:30	14:30	
DISTILATE FLOW RATE		kg/s	29.5	29.5	48	48	
TOP BRINE TEMPERATURE		℃	90.5	90.5	106	106	
BRINE RECIRCULATION FLOW RATE		kg/s	330	330	430	420	
MAKE-UP FLOW RATE		kg/s	103	105	161	161	
ACID DOSING RATE AUTO/MAN		kg/s	0.008 ~0.012 AUTO	0.008 ~0.012 AUTO	0.013 ~0.015 AUTO	0.013 ~0.016 AUTO	
ACID DOSING PUMP STROKE A/B		%	A / 36	B / 36	B / 54	A / 54	
ALKALINITY (as $CaCO_3$)	BEFORE ACID INJECTION	mg/ℓ	130	131	129	130	
	DECARBONATOR OUTLET	mg/ℓ	21	28	31	32	20~35
	DEAERATOR OUTLET	mg/ℓ	24	24	27	30	
	RECYCLE BRINE	mg/ℓ	35	32	33	35	24~43
pH	BEFORE ACID INJECTION	(Lab)	8.02	8.0	8.0	7.99	
	CONTROL/LOCAL DECARBONATOR OUTLET AT-506	(Inst)	7.58	7.50	7.46	7.43	6.7~7.0
		(Lab)	7.15	7.43	7.46	7.42	
	CONTROL/LOCAL RECYCLE BRINE AT-507	(Inst)	8.3	8.18	8.26	8.28	7.8~8.3
		(Lab)	8.01	7.85	7.96	7.47	
CHLORIDE	BEFORE ACID INJECTION	mg/ℓ	30,100	30,000	30,000	30,000	
	RECYCLE BRINE	mg/ℓ	38.600	37,800	37,800	37,900	
	BLOW DOWN	mg/ℓ	41,500	42,000	42,200	41,800	
BRINE RECYCLE CONCENTRATION FACTOR		–	1.28	1.26	1.26	1.26	1.2~1.3
BRINE BLOW DOWN CONCENTRATION FACTOR		–	1.38	1.40	1.40	1.39	1.4~1.5
CO_2 CONCENTRATION AT THE DECARBONATOR OUTLET		mg/ℓ as $CaCO_3$	5.7	–	6.6	–	
CO_2 CONCENTRATION AT THE DEAERATOR OUTLET		mg/ℓ as $CaCO_3$	4.4	–	3.96	–	

(5.1.1.A)

Table 4 QURAYYAH POWER PLANT PHASE-I DESALINATION PLANT UNIT B

(1/2)

DATE: 19 MAY '94

ITEM		UNIT	TIME 1,100 H	 1,400 H	 1,600 H	 1,750 H	LIMIT
DISTILATE FLOW RATE		kg/s	30	30	47	47	
TOP BRINE TEMPERATURE		℃	92	92	108	108	
BRINE RECIRCULATION FLOW RATE		kg/s	325	325	420	420	
MAKE-UP FLOW RATE		kg/s	105	105	161	161	
ACID DOSING RATE AUTO/MAN		kg/s	0.0135 ~0.0085 AUTO	0.014 ~0.005 AUTO	0.021 ~0.013 AUTO	0.022 ~0.015 AUTO	
ACID DOSING PUMP STROKE A/B		%	A / 37	B / 37	B / 55	A / 56	
ALKALINITY (as $CaCO_3$)	BEFORE ACID INJECTION	mg/ℓ	130		130		
	DECARBONATOR OUTLET	mg/ℓ	34		41		20~35
	DEAERATOR OUTLET	mg/ℓ	26		33		
	RECYCLE BRINE	mg/ℓ	46		45		24~43
pH	BEFORE ACID INJECTION	(Lab)	8.02		8.03		
	CONTROL/LOCAL DECARBONATOR OUTLET AT-506	(Inst)	7.25	5.8 / 5.72	7.2 / 7.22		6.7~7.0
		(Lab)	7.45		7.25		
	CONTROL/LOCAL RECYCLE BRINE AT-507	(Inst)	7.85	7.9 / 7.91	8.02 / 8.02		7.8~8.3
		(Lab)	–		8.12		
CHLORIDE	BEFORE ACID INJECTION	mg/ℓ	31,018		31,018		
	RECYCLE BRINE	mg/ℓ	41,122		41,122		
	BLOW DOWN	mg/ℓ	45,780		46,440		
BRINE RECYCLE CONCENTRATION FACTOR		–	1.32		1.32		1.2~1.3
BRINE BLOW DOWN CONCENTRATION FACTOR		–	1.47		1.49		1.4~1.5
CO_2 CONCENTRATION AT THE DECARBONATOR OUTLET		mg/ℓ as $CaCO_3$	–	8.0	–	–	5.0
CO_2 CONCENTRATION AT THE DEAERATOR OUTLET		mg/ℓ as $CaCO_3$	–	4.0	–	–	1.0

Note) Concentration of sulfuric acid to be dosed is 80 %.

(5.1.1.A)

Table 4 QURAYYAH POWER PLANT PHASE–I DESALINATION PLANT UNIT B

(2/2) DATE: 19 MAY '94

ITEM		UNIT	TIME				LIMIT
			1,930 H	2,040 H			
DISTILATE FLOW RATE		kg/s	50	50			
TOP BRINE TEMPERATURE		℃	110	110			
BRINE RECIRCULATION FLOW RATE		kg/s	435	435			
MAKE-UP FLOW RATE		kg/s	170	170			
ACID DOSING RATE AUTO/MAN		kg/s	0.022 ~0.015 AUTO	0.022 ~0.015 AUTO			
ACID DOSING PUMP STROKE A/B		%	A 59	B 59			
ALKALINITY (as $CaCO_3$)	BEFORE ACID INJECTION	mg/ℓ	130				
	DECARBONATOR OUTLET	mg/ℓ	28				20~35
	DEAERATOR OUTLET	mg/ℓ	28				
	RECYCLE BRINE	mg/ℓ	32				24~43
pH	BEFORE ACID INJECTION	(Lab)	8.03				
	CONTROL/LOCAL DECARBONATOR OUTLET AT-506	(Inst)	7.25				6.7~7.0
		(Lab)	7.45				
	CONTROL/LOCAL RECYCLE BRINE AT-507	(Inst)	7.20 7.18				7.8~8.3
		(Lab)	7.97				
CHLORIDE	BEFORE ACID INJECTION	mg/ℓ	31,018				
	RECYCLE BRINE	mg/ℓ	37,753				
	BLOW DOWN	mg/ℓ	44,489				
BRINE RECYCLE CONCENTRATION FACTOR		–	1.22				1.2~1.3
BRINE BLOW DOWN CONCENTRATION FACTOR		–	1.43				1.4~1.5
CO_2 CONCENTRATION AT THE DECARBONATOR OUTLET		mg/ℓ as $CaCO_3$	–	4.4			5.0
CO_2 CONCENTRATION AT THE DEAERATOR OUTLET		mg/ℓ as $CaCO_3$	–	1.8			1.0

Note) Concentration of sulfuric acid to be dosed is 80 %.

(5.1.1.A)

Table 5 QURAYYAH POWER PLANT DESALINATION PLANT

DATE: 20 Jun. '94

Item	Expressed as		Water Quality Data				Note
			S−R	S−M	S−C	S−P	
pH	(at 23.3 ℃)		8.14	8.18	8.3	7.3	
Calcium	Ca mg/ℓ		588	−	729	−	
Magnesium	Mg mg/ℓ		2,048	−	2,676	−	
Sodium	Na mg/ℓ		17,262	−	21,696	0.7	
Potasium	K mg/ℓ		≒ 500	−	≒ 600	−	
Total Cations		$CaCO_3$ mg/ℓ	48,063	−	60,767	−	
M-Alkalinity		$CaCO_3$ mg/ℓ	129.5	129	165	−	
Chloride	Cl mg/ℓ		30,961	−	39,460	< 1	
Sulfate	SO_4 mg/ℓ		2,361	−	4,867	−	
Total Anions		$CaCO_3$ mg/ℓ	47,385	−	60,991	−	
SS	mg/ℓ		−	−	6.73	−	
Conductivity	μS/cm		−	−	−	0.863	at 23 ℃

Note) S-R ; Raw seawater, S-M ; Make up water
S-C ; Recycle brine, S-P ; Product water

(5.1.1.A)

Table 6 SWCC DESALINATION PLANTS

DATE: 2, 6, 7 & 9 Feb.'94

Place	Sample	Calcium Ca (mg/ℓ)	Magnesium Mg (mg/ℓ)	Chloride $C\ell$ (mg/ℓ)	M-Alkalinity as $CaCO_3$ (mg/ℓ)	Conductivity (μS/cm)	pH
Qurayyah (Feb. 2)	Product Water	ND	ND	ND	5.0	1.4	6.00
	Raw sea water	575	1,628	31,205	132.4	71,200	7.89
	Make up water	521	1,660	31,205	131.0	71,200	7.89
	Recycle brine	763	2,411	45,212	188.9	96,000	—
Khafji (Feb. 9)	Product Water	ND	ND	ND	4.2	11.4	8.50
	Raw sea water	412	1,163	23,340	137.0	54,200	7.98
Shoibah (Feb. 6)	Product Water	ND	ND	ND	3.2	9.1	6.00
	Raw sea water	400	1,172	23,340	123.5	53,600	7.89
	Scale	22.3 %	4.27 %	—	—	—	—
Shugayg (Feb. 7)	Product Water	ND	ND	ND	3.7	1.7	6.20
	Raw sea water	425	1,200	22,694	125.0	54,100	7.98

(5.1.1.A)

Operator : John G O'Hara
Client : Dr. Nomani
Job : Shoaibah Plant flash chamber scale
Spectrum 3 (28 February 1994 13:51)

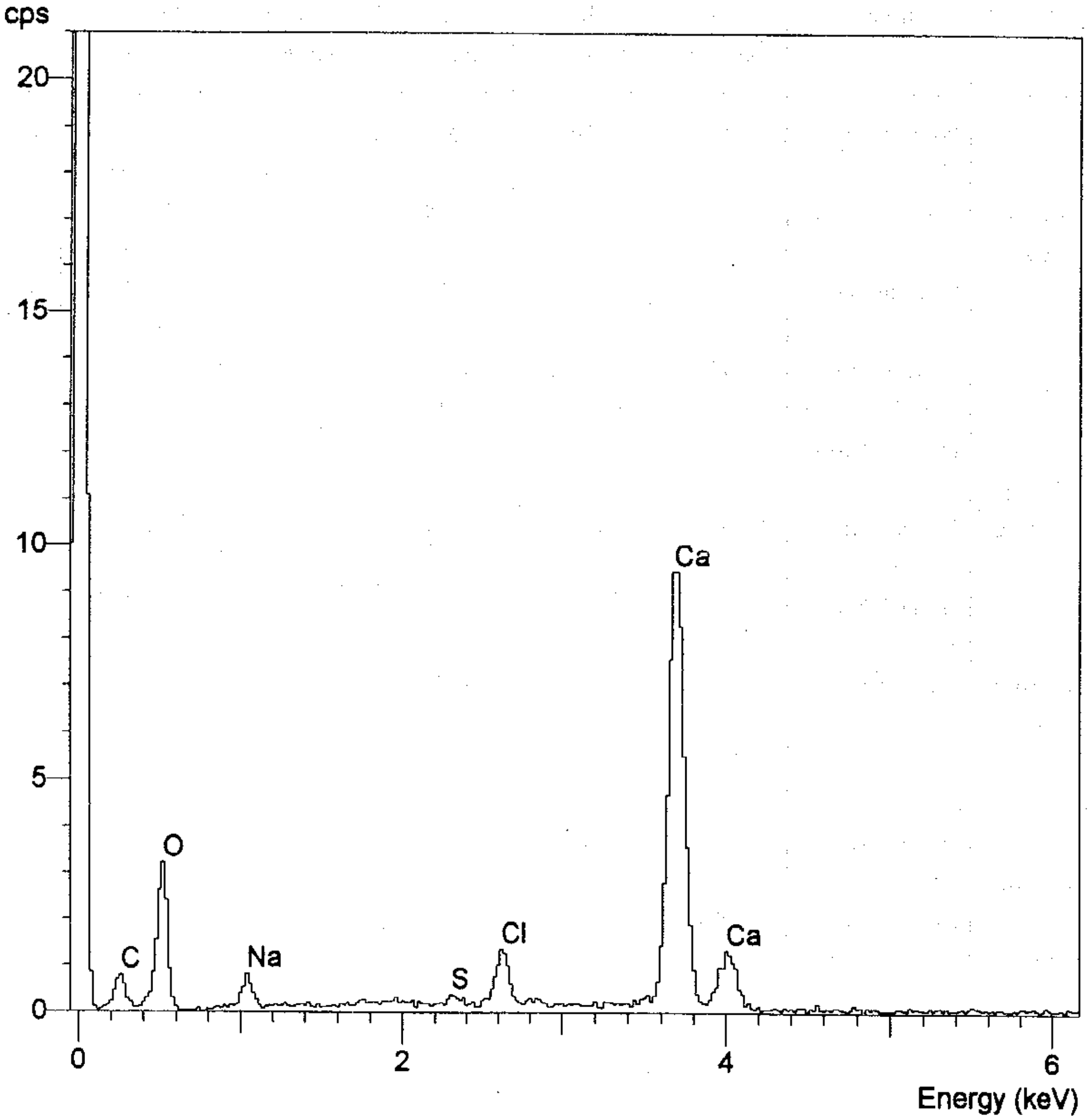


Fig. 1 X-RAY SPECTRUM OF SCLAE

5.1.1.B The Status of MSF Plants

(5.1.1.B)

CONTENTS

(5.1.1.B)

List of Tables

(5.1.1.B)

List of Figures

1. Introduction

SWCC has been operating many Multi-Stage Flash (MSF) desalination plants (MSF plants) for 25 years, since started the operation of the MSF plant phase I at Duba in the Kingdom of Saudi Arabia in 1968. Many research works and discussions were done in order to establish the optimum operation and maintenance since then.

This research was carried out in order to survey literature published by SWCC and to apply the experimental conditions in evaluation of the results under the series of MSF-1 tests.

2. Al-Khobar MSF Plant phase II (AK-II)

MSF plants of SWCC are shown in Fig. 1.

The report on Al-Khobar MSF-II plant was most useful in regard to Top Brine Temperature (TBT), kinds of scale inhibitors and its dosing rate. This plant is on the western coast of the Arabian Gulf. This paper reviewed the operating experience gained during the second decade at this site in general and particularly a full decade on AK-II MSF's with no tube acid cleaning.

2.1 Description of the Plant

Al-Khobar Phase II is a dual purpose plant comprising five extraction and condensing Boiler Turbine Generator (BTG) power sets and ten Multi-Stage Flash evaporators.

AK-II MSF's were designed with a variable TBT. Seasonal variation seawater temperature are within 15 to 35 deg.C from winter to summer and seawater salinity varies due to tidal effects, in very wide range of 47 to 57 g/kg of Total Dissolved Solids (TDS).

AK-II MSF evaporators are designed with fouling factors of 0.2, 0.12 & 0.16 meter square degrees Kelvin per kilo watt (m^2 K/kw) for heat rejection, recovery and input section, i.e. brine heater respectively.

The evaporator design parameters are shown in Table 1.

2.2 Discussion about Operating Conditions

The operating conditions are as follows.

(1) The evaporator operating parameters are shown in Table 2.

(2) Through optimization trials it was found that antiscalant's market could not provide a grade suitable for safe and prolonged operation at TBT of more than 108 degrees centigrade. Consequently, high temperature operation were restricted to the bare

minimum with a TBT limit of 105 degrees centigrade.

(3) The operating conditions during the period between 1984 to 1992 are as follows.

a. distillate production, TBT, antiscalant dosing rate, performance ratio and availability on No.1 are shown in Fig. 2, Table 3 and Table 4.

b. Distillate production, TBT, antiscalant dosing rate, performance ratio and availability on No. 4 are shown in Fig. 3, Table 5 and Table 6.

c. Distillate production, TBT, antiscalant dosing rate, performance ratio and availability on No. 7 are shown in Fig. 4, Table 7 and Table 8.

3. Remarks

Through this literature survey, useful data were obtained for the series of MSF-1 tests. They are as follows.

a. TBT is 90 to 112 degrees centigrade, considering the future operation.

b. Antiscalant dosing rate is less than 2 ppm per make-up.

c. Brine concentration is 1.4 times the sea water in the Arabian Gulf in accordance with the results of Al-Jubail Phase II plants.

4. References

1) Mohammad Abdul-Kareem Al-Sofi et al.; A full decade of operating experience on Al-Khobar-II Multi-Stage Flash (MSF) Evaporators (1982-1992)

2) N. Nada, S. Bakheet; Long term trial and optimization of BEV2000 in Jeddah Phase IV

3) Mohammad Abdul-Kareem Al-Sofi, et al.; Practical experience in scale control

4) Kingdom of Saudi Arabia Saline Water Conversion Corporation: The Guidebook

Existing Desal, Plants Along The Red Sea

HAQL

Process (No. of Units)	Installed Capacity Cu. M/Day	Megawatts	Year of Operation
Phase I (MSF)	(1) 882	–	1979
Phase II (R.O)	6590	–	1989

DUBA

Phase I (MSF)	(1) 230	–	1968
Phase II (MSF)	(1) 550	–	1978
Phase III (R.O)	3788	–	1989

AL WAJH

Phase I (MSF)	(1) 230	–	1968
Phase II (MSF)	(1) 550	–	1978

UMM LAJJ

Phase I (MSF)	(1) 550	–	1974
Phase II (R.O)	3788	–	1986
Two units (REHEAT)	910	–	1981

YANBU

Phase I (MSF)	(5)107954	(5)250	1980
Phase II (MSF&R.O)	227272		*

RABIGH

Phase I (MSF)	(2) 1288	–	1980

JEDDAH

Phase I R.O. Rehab	56800	(2) 50	1989
Phase II (MSF)	(4) 43181	(2) 84	1977
Reverse Osmosis	12120	–	1977
Phase III (MSF)	(10) 87878	(5) 240	1973
Phase IV (MSF)	(10)220075	(5) 600	1980
R.O. II	56800	—	1995

SHOAIBAH

Phase I (MSF)	(10,181818	(5) 320	1988
Phase II MSF	378787	500	*

AL BIRK

Phase I (R.O)	2272	–	1982

ASSIR

Phase I (MSF)	(4)94696	(2)128	1988

FARASAN

Phase I (MSF)	(2) 500	2.3	1978

AL-LEETH

Phase I (Planned)	568	–	–

QUNFUDA

Phase I (Planned)	3788	–	–

Existing desal. Plants Along The Gulf

AL KHAFJI

Phase I (MSF)	(1) 550	–	1972
Phase II (MSF)	(2) 22727	–	1985
Rush Units	(5) 1250	–	1978

AL JUBAIL

Phase I (MSF)	(6) 136363	(5) 360	1980
Phase II (MSF)	(4)958333	(10)1295	1982
R.O.	75757	—	*

AL KHOBAR

Phase II (MSF)	(10)195075	(5) 750	1982
Phase III MSF	227272	468	*

Existing Plants	△
Planned Plants	□
Existing Pipelines	————
Planned Pipelines	– – – –

MSF - Multistage Flash
R.O. - Reverse Osmosis

* Under construction

المملكة العربيـــة الســعودية
المؤسسة العامة لتحلية المياه المالحة
KINGDOM OF SAUDI ARABIA
SALINE WATER CONVERSION CORPORATION

Fig. 1 MSF Plants of SWCC

Table 1 Evaporator Design Parameters

Parameters	
Brine Velocity (normal) m/sec.	1.8
Surface area in Heat Recovery sq.m.	52,873
Surface area in Heat Rejection sq.m.	10,809
Surface area in Brine Heater sq.m.	3,586
Design Heat Transfer Coefficient (clean) W/sq.m.K	
A. Heat Recovery	4,374
B. Heat Rejection	3,437
C. Brine Heater	4,359
Design Heat Transfer Coefficient (dirty) W/sq.m.K	
A. Heat Recovery	2,868
B. Heat Rejection	2,037
C. Brine Heater	2,568
Design Fouling Factor Sq.cm. K/W	
A. Heat Recovery	1.2
B. Heat Rejection	2.0
C. Brine Heater	1.6

(5.1.1.B)

Table 2 Evaporator Operating Parameters

Variables	LTO		HTO			
	Design	Actual	Design 120%	Design 134%	Actual 120%	Actual 134%
Seawater Temp.(SWT) deg.C	35	35	35	35	35	35
T.B.T. Deg.C	90	90	106	115	103	112
Flash range Deg.C	48	48	63	72	61	70
Recycle Flow cu.m./hr.	12,257	12,000	11,100	11,100	11,000	11,000
Make-up Flow cu.m./hr.	5,000	4,500 to 5,500	5,000	5,000	4,500 to 6,000	4,500 to 6,000
Recycle Brine TDS, ppm	63,000	63,000 to 65,000	63,000	63,000	64,000	64,000
Condensate Flow cu.m./hr.	144	135 to 145	167	192	160	190
Product Water flow cu.m./hr.	895	920	1,075	1,210	1,100	1,220
Performance Ratio kg/2326 kj	6.5		6.88	6.9	6.9	7.0

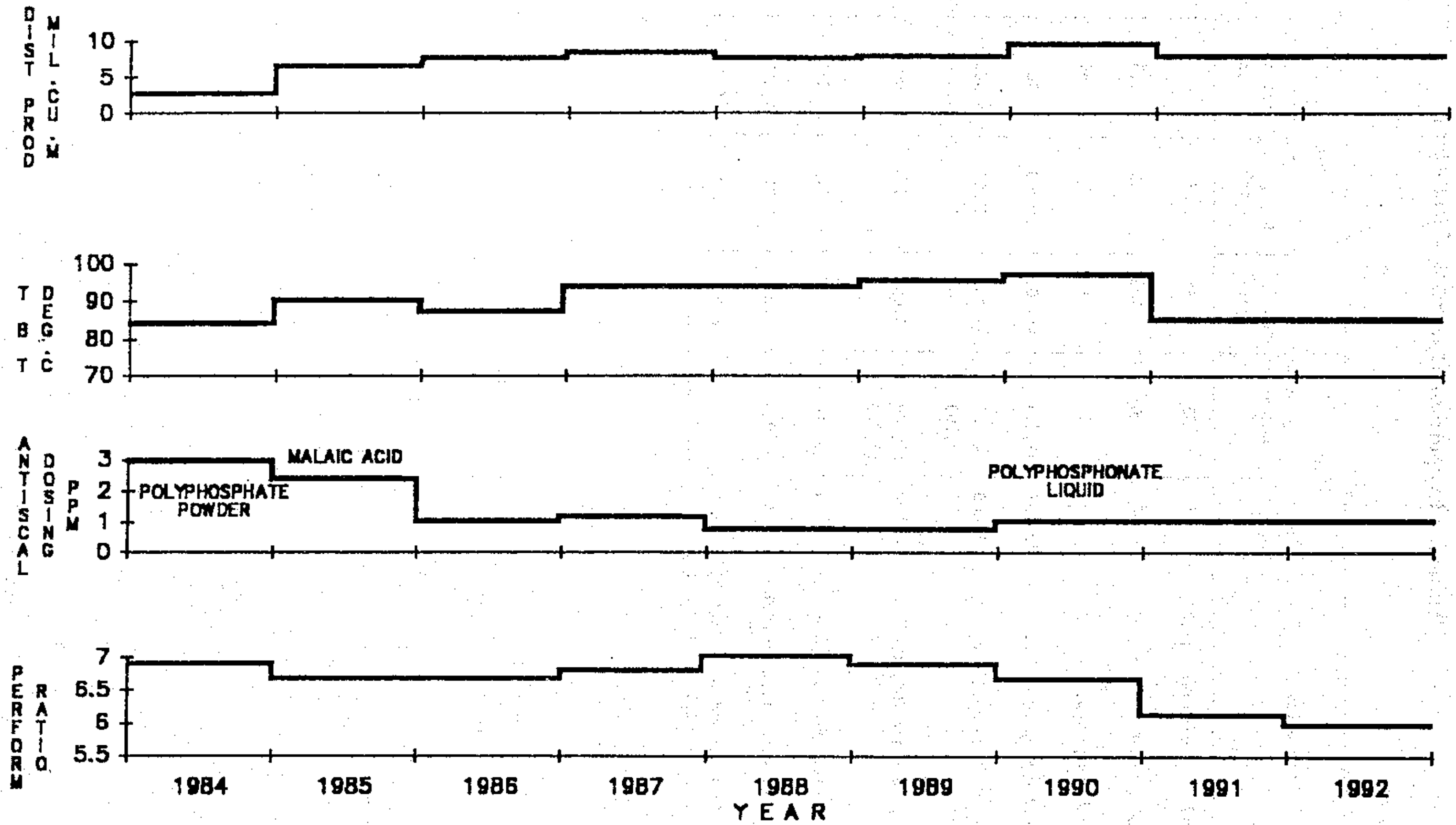


Fig. 2 Graphical Presentation of Unit One Prime Operating Condition

Table 3 Unit One Production & Availability

YEAR	DISTILLATE PRODUCTION CU.M.	AVAILABILITY %
1984	2,684,023	33 -
1985	6,619,930	81
1986	7,449,443	91
1987	8,377,911	100 +
1988	7,618,703	93
1989	7,873,506	96
1990	9,492,022	100 +
1991	7,961,674	97
1992	7,814,620	95

Table 4 Unit One Prime Operating Parameters

YEAR	AVERAGE TBT DEG.C *	ANTISCAL DOSE RATE PPM	PERFORMANCE RATIO
1984	84	3	6.9
1985	90	2.4	6.7
1986	87	1	6.7
1987	94	1.1	6.81
1988	94	0.75	7.01
1989	95	0.74	6.93
1990	97	1.02	6.68
1991	85	1	6.17
1992	85	1	6.01

* TBT range of 82 - 106 deg.C

\+ Availability higher than the 85% design are due to shorter shutdowns and/or wider flash range by either bottom or top brine temperature operation.

\- Availability lower than the 85% design are primarily due to extended shutdowns especially for rectifications.

(5.1.1.B)

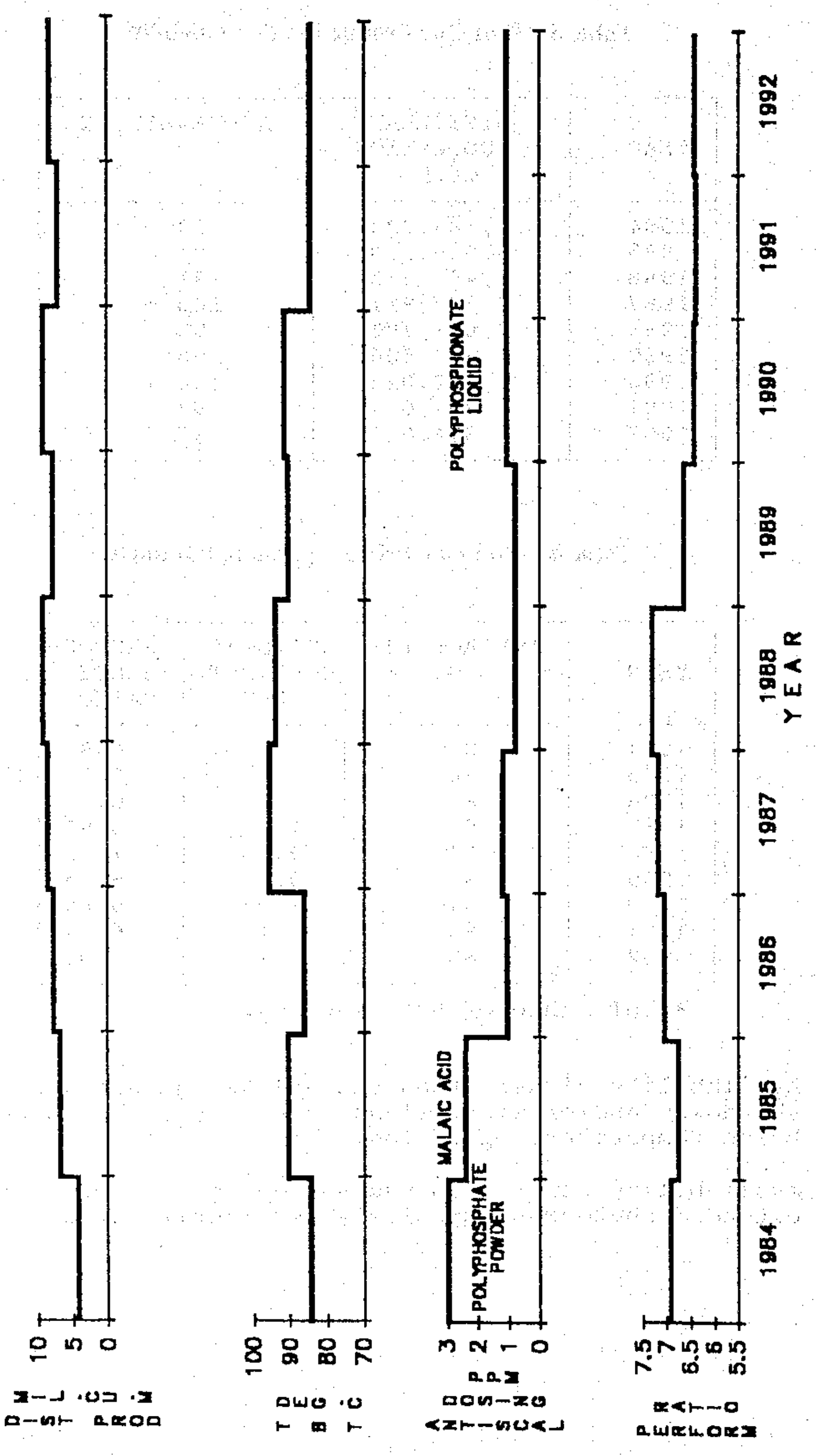


Fig. 3 Graphical Presentation of Unit Four Prime Operating Condition

(5.1.1.B)

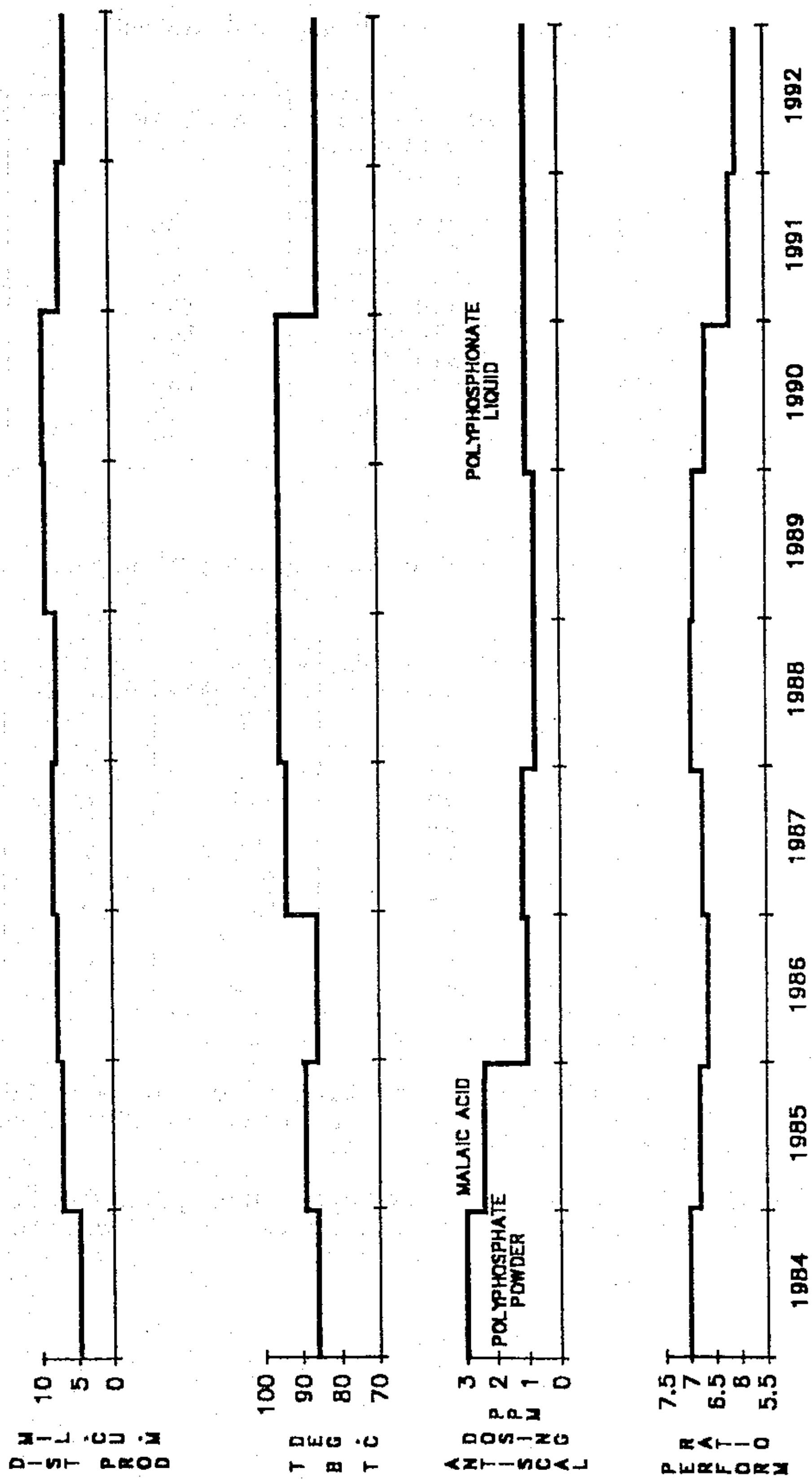


Fig. 4 Graphical Presentation of Unit Seven Prime Operating Condition

Table 5 Unit Four Production & Availability

YEAR	DISTILLATE PRODUCTION CU.M.	AVAILABILITY %
1984	4,089,593	50 -
1985	6,666,505	81
1986	7,894,407	96
1987	8,482,913	100 +
1988	8,670,000	100 +
1989	7,810,577	95
1990	9,073,790	100 +
1991	7,140,308	87
1992	8,179,357	99 +

Table 6 Unit Four Prime Operating Parameters

YEAR	AVERAGE TBT DEG.C *	ANTISCAL DOSE RATE PPM	PERFORMANCE RATIO
1984	85	3	6.89
1985	90	2.4	6.76
1986	86	1	7.06
1987	95	1.1	7.15
1988	94	0.75	7.26
1989	90	0.74	6.6
1990	91	1.02	6.37
1991	84	1	6.36
1992	84	1	6.37

* TBT range of 82 - 106 deg.C

+ Availability higher than the 85% design are due to shorter shutdowns and/or wider flash range by either bottom or top brine temperature operation.

- Availability lower than the 85% design are primarily due to extended shutdowns especially for rectifications.

Table 7 Unit Seven Production & Availability

YEAR	DISTILLATE PRODUCTION CU.M.	AVAILABILITY %
1984	4,470,019	55 -
1985	6,827,525	83
1986	7,543,906	92
1987	8,076,020	98
1988	7,600,244	93
1989	9,112,113	100 +
1990	9,189,115	100 +
1991	7,271,747	89
1992	6,037,502	73

Table 8 Unit Seven Prime Operating Parameters

YEAR	AVERAGE TBT DEG.C *	ANTISCAL DOSE RATE PPM	PERFOR-MANCE RATIO
1984	86	3	7
1985	89	2.4	6.76
1986	86	1	6.61
1987	94	1.1	6.75
1988	95	0.75	6.94
1989	95	0.74	6.88
1990	95	1.02	6.64
1991	85	1	6.18
1992	85	1	6.06

* TBT range of 82 - 106 deg.C

\+ Availability higher than the 85% design are due to shorter shutdowns and/or wider flash range by either bottom or top brine temperature operation.

\- Availability lower than the 85% design are primarily due to extended shutdowns especially for rectifications.

5.1.2 Experiment for Selection of Scale Inhibitor

(5.1.2)

CONTENTS

List of Tables

List of Figures

1. Introduction

On MSF seawater desalination plants, scaling is one of the factors decreasing the heat transfer efficiency. Scaling is the soluble constituents in seawater which deposit and adhere to the internal faces of heat transfer tubes, and subsequently causes decreasing of the heat transfer efficiency.

To suppress both the deposition and the adhesion of scale, tow methods are currently employed; the acid dosing method and the chemical dosing method.
Because there is no scale deposition, the acid dosing method has certain merits in that the MSF plant remains compact and therefore its operation costs are kept down. On the other hand, this dosing method has many drawbacks in that it requires very closely monitored operation.

In the chemical dosing method, a scale inhibitor is dosed to brine in order to slow down the rate of the deposition of scale, at the same time to suppress the adhering properties of the scale. Because of overcoming the drawbacks of the acid dosing method, the chemical dosing method employed together with a scale removal by ball cleaning has currently become the main-stream method of the scale prevention. In the Middle East, this method has almost been adopted exclusively.

There are many types of scale inhibitors on the market. It is difficult to discriminate between them, and it is not easy to make a selection by checking the properties of each scale inhibitor in an actual plant. Also, it is not easy to check the properties of every scale inhibitor with demonstration tests and equipment. Therefore, standards for the selection of scale inhibitors through laboratory experiments should be established. It is established in two steps: the first is to confirm the effectiveness of scale inhibitor in preventing of the initiation of scale formation, that is, the threshold effect, and the second is to confirm the effectiveness of the scale to reduce the adhering properties, that is, the crystal distortion effect. It is said that the crystal distortion effect is to change the crystal structure of deposits into the different crystal structure like ball, and to suppress the adhering properties because of its structure.

The method of confirming the threshold effect has already been established. It was proved in the first report (the SWCC/JICA final report of fiscal year 1991) that a scale inhibitor has the ability to prevent the deposition of scale when it contacts brine in a supersaturated condition. but its ability decreases with the increase of retention time, that is, reaction time.

In a subsequent report (the progress report in March of half fiscal year 1993), it has been established that polyphosphonate anti-scalant (PPN) has the highest threshold effect among the three types of anti-scalants studied; PPN, polymeric acid (PMA) and polycarboxylic acid (PCA) at conditions of 95℃, dose rate of 2 ppm and retention time around 10 minutes.

For the purpose of selecting some anti-scalants which are to be used in the tests to confirm the crystal distortion effect with the heat transfer test equipment, this study was reported on the threshold effect of seven kinds of anti-scalants which include the above mentioned anti-scalants at conditions of both 95 and 110℃.

2. Background of Scale Inhibitors

Total dissolved salts and high temperature of seawater cause deposition. There are two types of scale which are alkaline scale (soft scale) of calcium carbonate and magnesium hydroxide, and hard scale of calcium sulfate. It is very difficult to remove hard scale by acid cleaning or by any other measures. The optimum top brine temperature and concentration are, therefore, fixed in order to prevent the deposition of hard scale. On the other hand, soft scale can be removed easily.

It is generally known that by dosing of 1 – 3 mg/L of scale inhibitor into the make up sea water, brine has both the threshold effect and the crystal distortion effect. In the initial stage, anti-scalant of polyphosphate were much used. It is said that these anti-scalants change calcium ions and magnesium ions of sea water into soluble complex salt selectively, and prevent or delay their reaction with carbonic acid ions and their consequent deposition. It is a matter of common knowledge that the highest top brine temperature, at which scale can be barely controlled with these scale inhibitors, is 90℃. At more than 90℃, these anti-scalants change to ortho-phosphate by the reaction of hydrolysis and lose their effects.

To overcome this temperature limits, anti-scalants of polymeric carboxylic acid type were developed during the 1970's. These scale inhibitors made the operation at temperature of up to 118℃ possible. Many scale inhibitors of polymeric carboxylic acid type are on the market at present and are mainly used in MSF plants.

It is also regarded that anti-scalants of polymeric carboxylic acid type keep supersaturation at high temperature by changing calcium ions and magnesium ions into soluble complex salt and prevent or delay their reaction with carbonic acid ions and their consequent deposition.

When the concentration and the temperature of the brine rise, magnesium ions contained in the brine deposit as hydroxide, and calcium ions as calcium carbonate, That is indicated by following equations:

$$Mg^{2+} + 2OH^{-} \rightarrow Mg(OH)_2 \quad pK = 15.35(60℃),\ 14.59(100℃) \qquad (1)$$
$$Ca^{2+} + CO_3{}^{2-} \rightarrow CaCO_3 \quad pK = 3.00(60℃),\ 2.60(100℃) \qquad (2)$$

On the other hand, carbonic acid ions of the brine change to carbon dioxide or bicarbonate ions depending on pH of the brine, and exit in their respective abundance ratio :

$$2CO_2+2H_2O=2H^{+}+2HCO_3{}^{-}=4H^{+}+2CO_3{}^{2-}=2H^{+}+CO_2+CO_3{}^{2-}+H_2O \qquad (3)$$

The total amounts of the above soluble substances can be determined by measuring the consumed amount of acid (M-alkalinity), and can be indicated in the calcium carbonate amount (mg/L).

When magnesium hydroxide scale and calcium carbonate scale precipitate in the brine, by removing them from the brine through filtration, the M-alkalinity of the brine is decreased to the equivalent of the scale deposition. The amount of the deposited scale is, therefore, obtained by subtracting the M-alkalinity of the filtrate, from the initial M-alkalinity of the brine. This is a titration method, and can be carried out more easily than the gravimetric method. The threshold effect of scale inhibitors is thus checked by measuring difference in M-alkalinity before and after the test.

3. Purpose

This study was conducted in order to confirm the threshold effect of each antiscalant by knowing the changes of retention time versus M-alkalinity. Retention time versus scale inhibitor dose rate in 500 ml of artificial brine of 1.4 times the normal seawater in the Arabian Gulf (in accordance with the results of Al-Jubail Phase II plants) were studied, by dosing 10 ml of 1 normal sodium carbonate solution at 95℃ and 110℃. Considering the amount of deposition of calcium carbonate and magnesium hydroxide as the decrease of threshold effect in accordance with retention time, its confirmation was carried out by measuring the soluble M-alkalinity of each brine.

A decision that scale inhibitors with a high value of residual M-alkalinity while retaining their values for a long time have a superior threshold effect, was adopted as the standard of selection of antiscalant to be used for the test with the heat transfer test equipment which is expected to confirm the crystal distortion effect.

4. Experimental Method

4.1 Materials

(1) Brine

The brine used was prepared artificially at a concentration of 1.4 times the normal seawater in the Arabian Gulf in accordance with the results of Al-Jubail Phase II plants. Artificial seawater is generally composed of chemical A and chemical B. The chemical constituents of each solution when dissolved, both 22 g of chemical A and 16 g of chemical B for artificial seawater, and both 41.25 g of chemical A and 30 g of chemical B for artificial brine(1), are shown in Table 1. Artificial brine(2) is composed of seawater and chemical B, and its constituents of solution is also shown in Table 1. Artificial brine(2) was used for this study.

(2) Scale Inhibitors

The main physical properties and composition of scale inhibitors which are examined in this study, are shown in Table 2.

(3) Instruments for Analysis and Measuring, and Method

- pH	; pH meter (Fisher 825MP)
- M-alkalinity	; Automatic titrater (Fisher Model 465)
- Calcium ion	; Atomic absorption photometer (VARIAN AA-975)
- Magnesium ion	; Atomic absorption photometer (VARIAN AA-975)
- Concentration factor	; Salinometer

Table 1 Chemical Composition of Artificial Seawater/Brine

Constituents	Artificial S.W (1)	Artificial Brine (2)	Artificial Brine (1)
pH (at 25℃)	9.2	*	9.2
M-Alkalinity ($CaCO_3$ ppm)	115.8	183	180
Na (ppm)	12,460	*	18,690
Ca (ppm)	408	482	649
Mg (ppm)	1,030	1,437	1,545

* Same as in Gulf Seawater

Table 2 Properties of Scale Inhibitors

Name	Specific gravity	Density (kg/l)	pH	Appearance	Major Constituent
PCE	1.22	1.22	1.2～2.0	Amber Liquid	Polymeric carboxylic acid
PCS (PCA)	1.22	1.22	1.2～2.0	Amber Liquid	Polymeric carboxylic acid
PMA	—	—	—	—	Polymeric maleic acid
PPN	—	—	—	—	Polyphosphonate
PPN(M)	1.4	—	11.0	Pale Yellow Liquid	Polyphosphonate
PPN(A)	1.4	—	10	Pale Yellow Liquid	Polyphosphonate

4.2 Experimental Equipment

(1) Experimental Equipment at Low Temperature (95℃)

In order to keep the brine concentration constant, a three-neck flask attached to the cooler has been used and the condensed water has been totally returned to this flask, as shown in Fig. 1.

An oil bath and a vacuum pump have been used for raising temperature and for keeping it constant.

(2) Experimental Equipment at high Temperature (110℃)

In order to keep the brine concentration constant and also the brine temperature more than 100℃, the scale deposition test equipment which is composed of autoclave has been used, as shown in Fig. 2.

4.3 Experimental Condition

(1) Brine Temperature

a. Low temperature

Since the outlet temperature of the brine heater during normal operation is 90.56℃ in Al-Jubail Phase-II Plant, it has been decided to conduct the experiment at 95℃.

b. High temperature

Since the maximum usable temperature of scale inhibitors is 115℃, it has been decided to conduct the temperature at 110℃.

(2) Brine concentration

The concentration of brine has been determined to be 1.4 times the normal seawater in accordance with the operating condition in Al-Jubail Phase-II plants.

(3) Concentration of scale inhibitor to be dosed

It has been decided to conduct the concentration of each inhibitor at less than 2 ppm.

(4) Retention time of scale inhibitor

It has been decided to use a retention time of up to 40 minutes.

Table. 3 shows the combination of those various factors which allow us to achieve the most effective results.

4.4 Experimental method

Experiments on the deposition of precipitation have been conducted according to the following procedures.

(1) **Charging of brine**

Specified quantities of a scale inhibitor whose concentration is 1,000 ppm, was dosed in 500 ml of artificial brine and stirred with a blender for 20 seconds. The prepared brine was charged immediately into the concerned reactor.

(2) **Heating of brine**

During the low temperature test, the temperature is kept at a constant 95℃ while returning the condensed water, and during the high temperature test, it is kept at a constant 110℃, each test for 15 minutes. To start the test, it must first be confirmed that there is no occurrence of precipitation. It will be noticed that the internal pressure of the reactor at 110℃ naturally remains at 0.143 MPa.

(3) **Reaction time**

To dose 1 normal sodium carbonate of 10 ml to brine in this state and to stir quickly, this time was decided to be the time of the beginning of the reaction. When starting to dose 1 normal sodium carbonate, M–alkalinity begins to decrease with the formation of precipitation. When dosing 1 normal sodium carbonate further, there is a point where M–alkalinity begins to increase. This point is the breaking point of a supersaturated state.

(4) **Sampling of specimens and measuring**

After dosing sodium carbonate to brine, 25 ml sample portions were collected at specific times; i.e. 5, 10, 15, 20, 30 and 40 minutes. All samples were filtered through 0.45 um filter paper, and filtrates were measured for Ca, Mg and M–alkalinity.

The M–alkalinity of brine at each specific time can be determined by the following equation.

$$\text{Assumed M-alkalinity after having dosed 1N } Na_2CO_3 = (50)(10^3)V_{NA}/V_S + ALK_S \quad (4)$$

$$[\text{ppm as } CaCO_3]$$

(5.1.2)

where

$(50)(10^3)$: M-alkalinity of 1N Na_2CO_3 solution [ppm as $CaCO_3$]

V_{NA}: Amount of 1N Na_2CO_3 solution to be dosed [L]

V_S: Amount of brine to be dosed[L]

AlK_S: M-alkalinity of brine before being dosed [ppm as $CaCO_3$]

5. Results

(1) Table 4 shows the results of the residual M-alkalinity of each filtrate which were measured according to the experimental conditions shown in Table 3.

(2) Table 5 shows the results of the residual M-alkalinity under various dosing rate of a scale inhibitor PPN(M) at 95℃.

(3) Table 6 shows the results of calcium and magnesium concentrations of each filtrate.

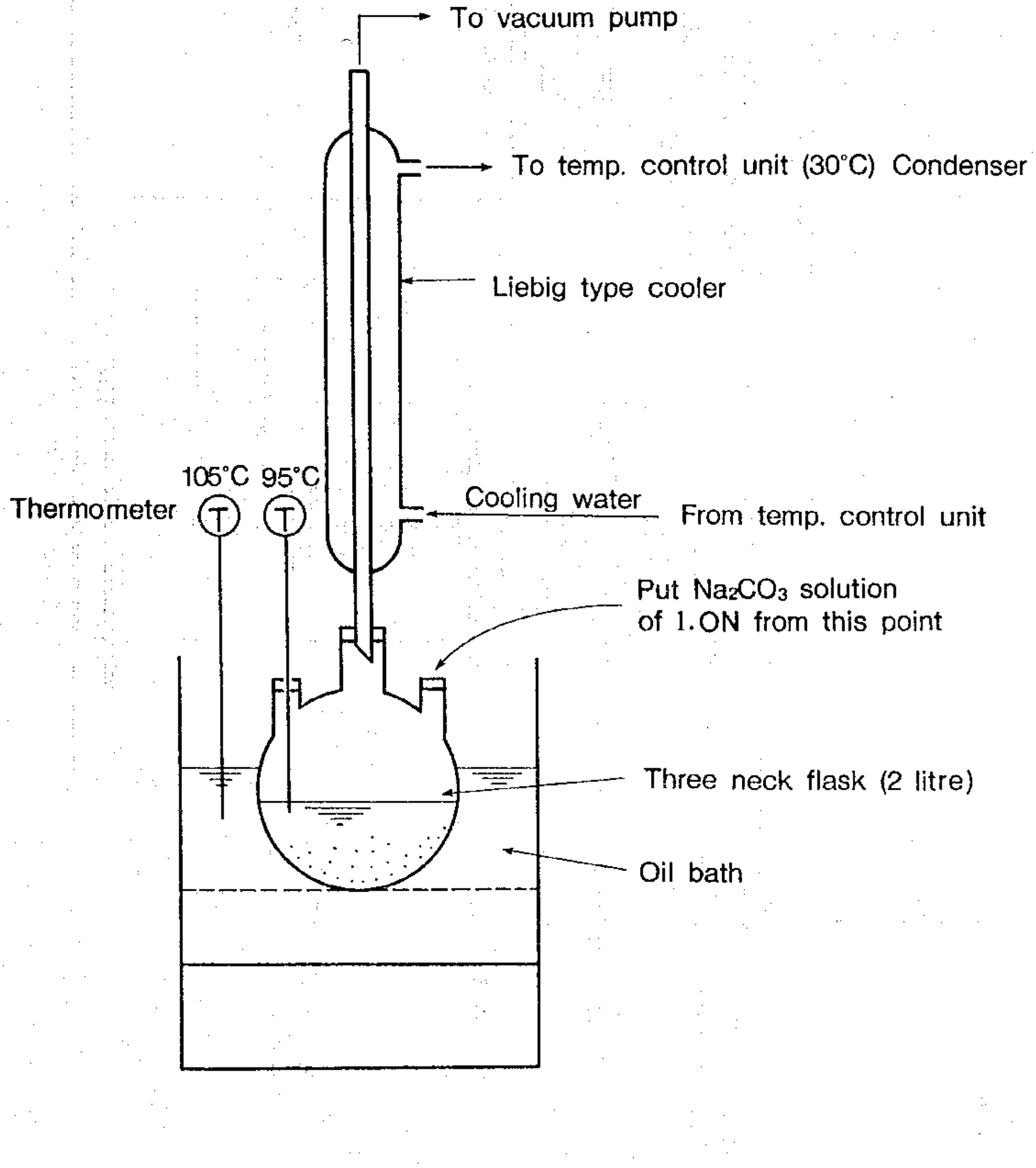


Fig. 1 Equipment using for Deposition of Precipitation at 95 ℃

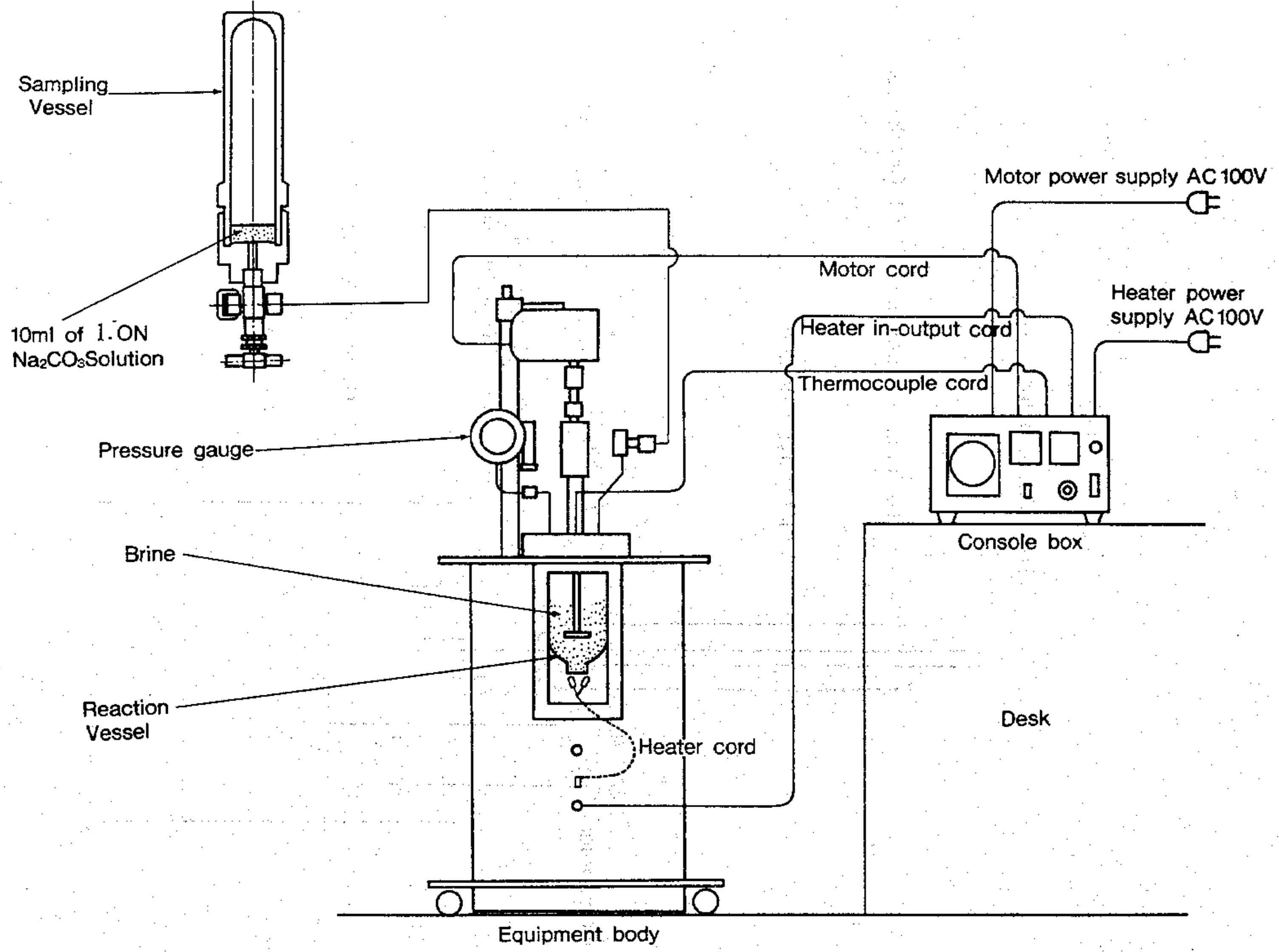


Fig. 2 Equipment using for Deposition of Precipitation at 110 ℃

Table 3 Experimental Conditions (1/2)

Name of Scale inhibitor & Test No.		Concentration of Scale inhibitor	Temperature	Retention Time	(NOTE)
		ppm	℃	minutes	
1	Blank	0	95	5	
		0	95	10	
		0	95	15	
		0	95	20	
		0	95	30	
		0	95	40	
2	PPN	2	95	5	
		2	95	10	
		2	95	15	
		2	95	20	
		2	95	30	
		2	95	40	
3	PPN(A)	2	95	5	
		2	95	10	
		2	95	15	
		2	95	20	
		2	95	30	
		2	95	40	
4	PPN(M)	2	95	5	
		2	95	10	
		2	95	15	
		2	95	20	
		2	95	30	
		2	95	40	
5	PCS	2	95	5	
		2	95	10	
		2	95	15	
		2	95	20	
		2	95	30	
		2	95	40	
6	PCE	2	95	5	
		2	95	10	
		2	95	15	
		2	95	20	
		2	95	30	
		2	95	40	
7	PMA	2	95	5	
		2	95	10	
		2	95	15	
		2	95	20	
		2	95	30	
		2	95	40	
8	EV	2	95	5	
		2	95	10	
		2	95	15	
		2	95	20	
		2	95	30	
		2	95	40	

Table 3 Experimental Conditions (2/2)

Name of Scale inhibitor & Test No.		Concentration of Scale inhibitor	Temperature	Retention Time	(NOTE)
		ppm	℃	minutes	
9	EVN	2	95	5	
		2	95	10	
		2	95	15	
		2	95	20	
		2	95	30	
		2	95	40	
10	Blank	0	110	5	
		0	110	10	
		0	110	15	
		0	110	20	
		0	110	30	
		0	110	40	
11	PPN	2	110	5	
		2	110	10	
		2	110	15	
		2	110	20	
		2	110	30	
		2	110	40	
12	PPN(A)	2	110	5	
		2	110	10	
		2	110	15	
		2	110	20	
		2	110	30	
		2	110	40	
13	PPN(M)	2	110	5	
		2	110	10	
		2	110	15	
		2	110	20	
		2	110	30	
		2	110	40	
14	PCS	2	110	5	
		2	110	10	
		2	110	15	
		2	110	20	
		2	110	30	
		2	110	40	
15	PCE	2	110	5	
		2	110	10	
		2	110	15	
		2	110	20	
		2	110	30	
		2	110	40	
16	PMA	2	110	5	
		2	110	10	
		2	110	15	
		2	110	20	
		2	110	30	
		2	110	40	

Table 4 Results on the Residual M-alkalinity of Each Filtrate (1/4)

No	Scale Inhibitor	Conc. of SI	Temp.	Pressure	Retention Time	Residual Alkalinity
	(SI)	(ppm)	(℃)	(MPa)	(Min)	(ppm)
1	Blank	0	95	0.085	5	308
					10	144
					15	111
					20	106
					30	102
					40	102
2	PPN	2	95	0.085	5	396
					10	391
					15	377
					20	229
					30	134
					40	130
3	PPN(A)	1.2	95	0.085	5	382
					10	389
					15	377
					20	377
					30	132
					40	118
4	PPN(M)	2	95	0.085	5	377
					10	382
					15	387
					20	384
					30	123
					40	104
5	PCS	2	95	0.085	5	380
					10	373
					15	347
					20	236
					30	127
					40	120

Table 4 Results on the Residual M-alkalinity of Each Filtrate (2/4)

No.	Scale Inhibitor (SI)	Conc. of SI (ppm)	Temp. (℃)	Pressure (MPa)	Retention Time (Min)	Residual Alkalinity (ppm)
6	PCE	0	95	0.085	5	391
					10	394
					15	380
					20	313
					30	148
					40	120
7	PMA	2	95	0.085	5	398
					10	380
					15	380
					20	338
					30	134
					40	111
8	EV	1.2	95	0.085	5	396
					10	380
					15	377
					20	319
					30	125
					40	116
9	EVN	2	95	0.085	5	410
					10	384
					15	361
					20	336
					30	111
					40	100

(5.1.2)

Table 4 Results on the Residual M-alkalinity of Each Filtrate (3/4)

No.	Scale Inhibitor (SI)	Conc. of SI (ppm)	Temp. (℃)	Pressure (MPa)	Retention Time (Min)	Residual Alkalinity (ppm)
10	Blank	0	110	0.143	5	153
					10	104
					15	93
					20	86
					30	86
					40	86
11	PPN	2	110	0.143	5	370
					10	169
					15	104
					20	100
					30	93
					40	93
12	PPN(A)	1.2	110	0.143	5	407
					10	199
					15	111
					20	111
					30	102
					40	97
13	PPN(M)	2	110	0.143	5	421
					10	310
					15	125
					20	111
					30	109
					40	100
14	PCS	2	110	0.143	5	403
					10	183
					15	109
					20	102
					30	93
					40	83

Table 4 Results on the Residual M-alkalinity of Each Filtrate (4/4)

No	Scale Inhibitor (SI)	Conc. of SI (ppm)	Temp. (℃)	Pressure (MPa)	Retention Time (Min)	Residual Alkalinity (ppm)
15	PCE	0	110	0.143	5	405
					10	211
					15	118
					20	102
					30	100
					40	90
16	PMA	2	110	0.143	5	442
					10	287
					15	120
					20	104
					30	106
					40	102

(5.1.2)

Table 5 Results on the Residual M–alkalinity of PPN(M)

No	Scale Inhibitor (SI)	Conc. of SI (ppm)	Temp. (℃)	Pressure (MPa)	Retention Time (Min)	Residual Alkalinity (ppm)
1	PPN(M)	0.5	95	0.085	5	375
					10	359
					15	350
					20	292
					30	111
					40	109
2	PPN(M)	0.7	95	0.085	5	410
					10	405
					15	396
					20	375
					30	160
					40	139
3	PPN(M)	0.9	95	0.085	5	400
					10	398
					15	398
					20	384
					30	162
					40	144
4	PPN(M)	1.1	95	0.085	5	409
					10	403
					15	403
					20	336
					30	146
					40	132
5	PPN(M)	1.3	95	0.085	5	428
					10	394
					15	394
					20	361
					30	167
					40	148
6	PPN(M)	1.5	95	0.085	5	400
					10	412
					15	396
					20	338
					30	157
					40	139

Table 6　Results on Ca and Mg Concentration of Each Filtrate (1/3)

No	Scale Inhibitor (SI)	Conc. of SI (ppm)	Temp. (℃)	Pressure (MPa)	Retention Time (Min)	Conc. in Filtrate	
						Ca (ppm)	Mg (ppm)
1	PCE	2	95	0.085	2	388	939
					5	398	880
					10	365	909
					15	405	909
					20	316	969
					45	134	822
					60	137	822
2	PMA	1.2	95	0.085	2	486	909
					5	467	880
					10	483	1,023
					15	467	939
					20	350	851
					45	159	880
					60	152	909
3	PMA*	2	95	0.085	2	543	1,501
					5	427	1,501
					10	419	1,518
					15	—	—
					20	400	1,456
					45	—	—
					60	326	1,499
4	PPN*	2	95	0.085	2	640	1,518
					5	588	1,518
					10	543	1,499
					15	—	—
					20	369	1,481
					45	—	—
					60	368	1,412
5	PPN(M)	1.2	95	0.085	2	410	794
					5	398	794
					10	402	794
					15	412	850
					20	390	879
					45	166	850
					60	157	850

Note; * Values were obtained during the fiscal year 1993.

Table 6 Results on Ca and Mg Concentration of Each Filtrate (2/3)

No.	Scale Inhibitor (SI)	Conc. of SI (ppm)	Temp. (℃)	Pressure (MPa)	Retention Time (Min)	Conc. in Filtrate	
						Ca (ppm)	Mg (ppm)
6	PPN(M)	2	95	0.085	2	362	1,274
					5	337	1,350
					10	325	1,300
					15	300	1,350
					20	275	1,325
					45	—	—
					60	138	1,325
7	PPN(A)	2	95	0.085	2	412	1,249
					5	435	1,325
					10	325	1,274
					15	312	1,325
					20	138	1,300
					45	—	—
					60	112	1,300
8	PCE	2	110	0.143	2	386	1,186
					5	359	1,152
					10	266	1,220
					15	234	1,186
					20	231	1,186
					45	210	1,101
					60	217	1,186
9	PCS	2	110	0.143	2	427	1,220
					5	420	1,254
					10	303	1,237
					15	280	1,254
					20	262	1,254
					45	252	1,237
					60	245	1,271
10	PMA	2	110	0.143	2	376	1,271
					5	321	1,237
					10	241	1,237
					15	231	1,254
					20	224	1,254
					45	224	1,254
					60	217	1,220

Note; * Values were obtained during the fiscal year 1993.

Table 6 Results on Ca and Mg Concentration of Each Filtrate (3/3)

No	Scale Inhibitor (SI)	Conc. of SI (ppm)	Temp. (℃)	Pressure (MPa)	Retention Time (Min)	Conc. in Filtrate	
						Ca (ppm)	Mg (ppm)
11	PPN	2	110	0.143	2	359	1,169
					5	359	1,169
					10	317	1,207
					15	290	1,207
					20	276	1,207
					45	300	1,188
					60	262	1,246
12	PPN(A)	2	110	0.143	2	426	1,304
					5	331	1,304
					10	303	1,246
					15	303	1,265
					20	290	1,265
					45	303	1,285
					60	276	1,246
13	PPN(M)	2	110	0.143	2	426	1,285
					5	359	1,285
					10	290	1,304
					15	248	1,304
					20	248	1,285
					45	234	1,324
					60	234	1,265

Note; * Values were obtained during the fiscal year 1993.

6. Discussion

Based upon the results shown in Table 4.

- The result on M–alkalinity at low temperature (95℃) is shown in Fig. 3.
- The result on M–alkalinity at high temperature (110°) is shown in Fig. 4.
- The changes of retention time with the values of ratio of final calcium concentration Ca(f) to initial one Ca(i) at high temperature (110℃) is shown in Fig. 5.
- The changes of retention time with the values of ratio of final magnesium concentration Mg(f) to initial one Mg(i) at high temperature (110℃) is shown in Fig. 6.
- The relationship between M–alkalinity and Ca & Mg concentration is shown in Fig. 7.
- The optimum concentration of PPN(M) is shown in Fig. 8.

6.1 Selection of scale inhibitor at low temperature (95℃)

As the result of the experiment at low temperature (95℃) shown in Fig. 3, it has been demonstrated that M–alkalinity of the blank (No scale inhibitor was dosed) decreased radically and the brine in which scale inhibitor was dosed held the initial value of M–alkalinity for 15 – 20 minutes.

Scale inhibitor PPN(M) and PPN(A) had the high values of M–alkalinity and had a 20 minute holding time, though, they decreased to the same value as other scale inhibitors at 40 minutes.

As the result of the relationship between dosing rate and M–alkalinity on PPN(M) shown in Fig. 8, PPN(M) had the lowest value of M–alkalinity and the shortest holding time at dosing rate of 0.5 ppm. Effect of dosing rate above 0.7 mg/L is not very significant, however, this needs further investigation.

As mentioned above, it is pointed out in the 95℃, that PPN(M) and PPN(A) have the highest threshold effect compared with other scale inhibitors and their suitable dosing rate are above 0.7 ppm.

6.2 Selection of scale inhibitor at high temperature (110℃)

As the result of the experiment at high temperature (110℃) shown in Fig. 4, it has been demonstrated that M–alkalinity of the blank already decreased at 5 minutes, and M–alkalinity of the brine in which scale inhibitor was dosed decreased gradually and attained the constant value at 15 minutes.

It is pointed out that PPN(M) and PMA have the highest threshold effect at dosing rate of 2.0 ppm.

According to the above-mentioned results, PCE was in the third position in its threshold effect. Though, PCE is adequate for the MSF plant operation at high temperature compared with the phosphonates, since its major constituent is poly-carboxylic acid. On the point of the difference of scale crystal structure view, PCE should be selected for the next test with the heat transfer test unit.

6.3 Changes of retention time with values of ratio of final calcium concentration Ca(f) to initial one Ca(i) and with values of final magnesium concentration Mg(f) to initial one Mg(i)

As the result of changes of retention time with Ca(f)/Ca(i) shown in Fig. 5, calcium concentration keep constant until 20 minutes.

On the other hand, as the result of changes of retention time with Mg(f)/Mg(i) shown in Fig. 6, 10 through 20% of magnesium ions decrease within 2 minutes. However, little change is recognized in the subsequent magnesium concentration.

This means that the addition of Na_2CO_3 will increase the pH of the liquid and magnesium irons will deposit as magnesium hydroxide, but after a concentration which satisfies the solubility has been reached, magnesium hydroxide will no longer deposit even if the retention time is longer (i.e., even if the M-alkalinity decreases).
By the way, the solubility product (pK) of magnesium hydroxide is 15.35 (69℃) and that of magnesium carbonate is 11.02(60℃). Fig. 7 is a more clear illustration of the above results. It is clear from this figure that by measuring changes in the M-alkalinity, the deposition of calcium carbonate can be estimated without fail, although it is not possible to evaluate the deposition of magnesium hydroxide.

Based on this, it may be said that the evaluation method with scale inhibitors, which is adopted here, will provide information which is effective for preventing the deposition of calcium carbonate.

(5.1.2)

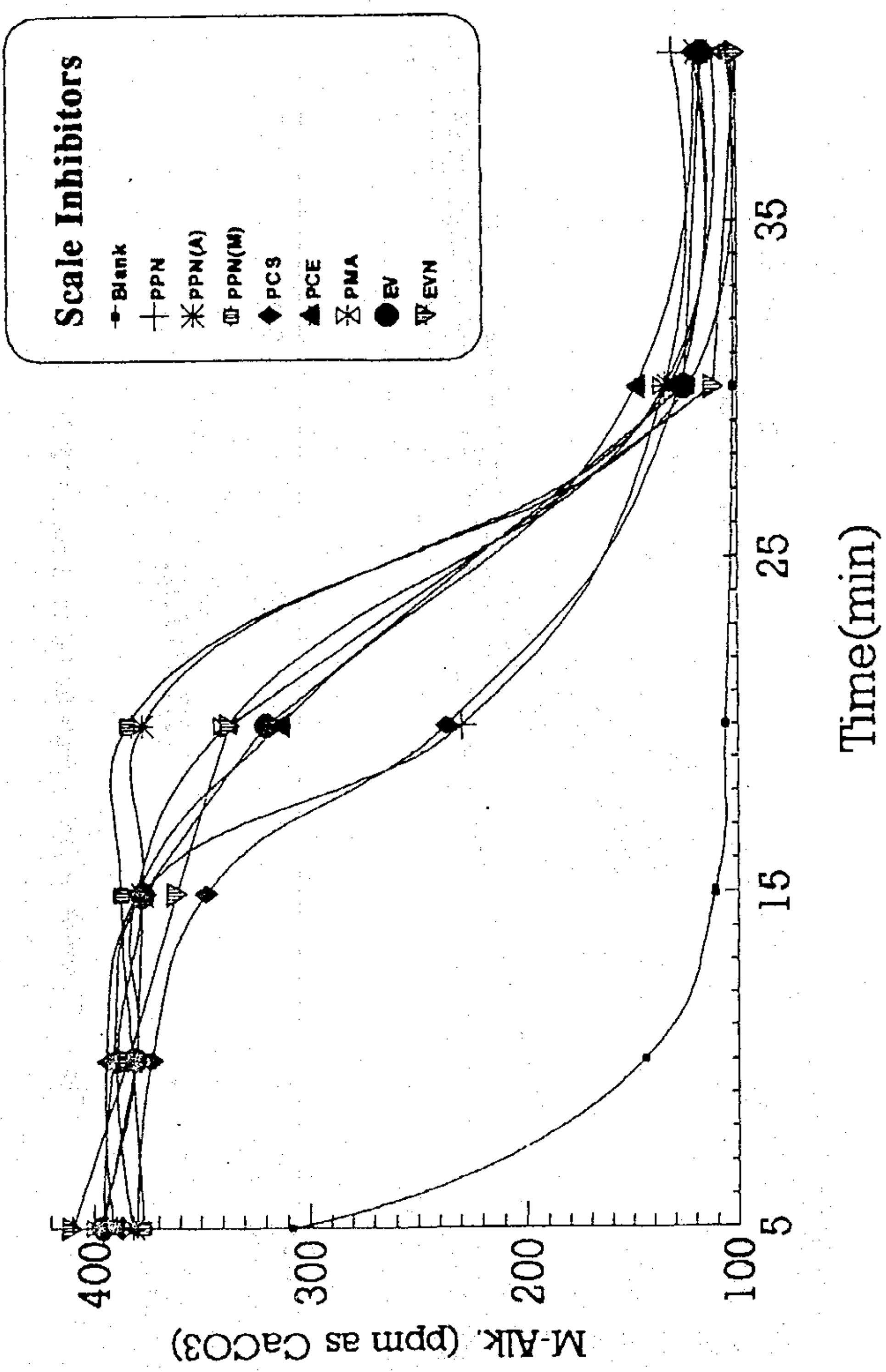


Fig. 3 Threshold Effect of Scale Inhibitor (2 ppm, 95°C)

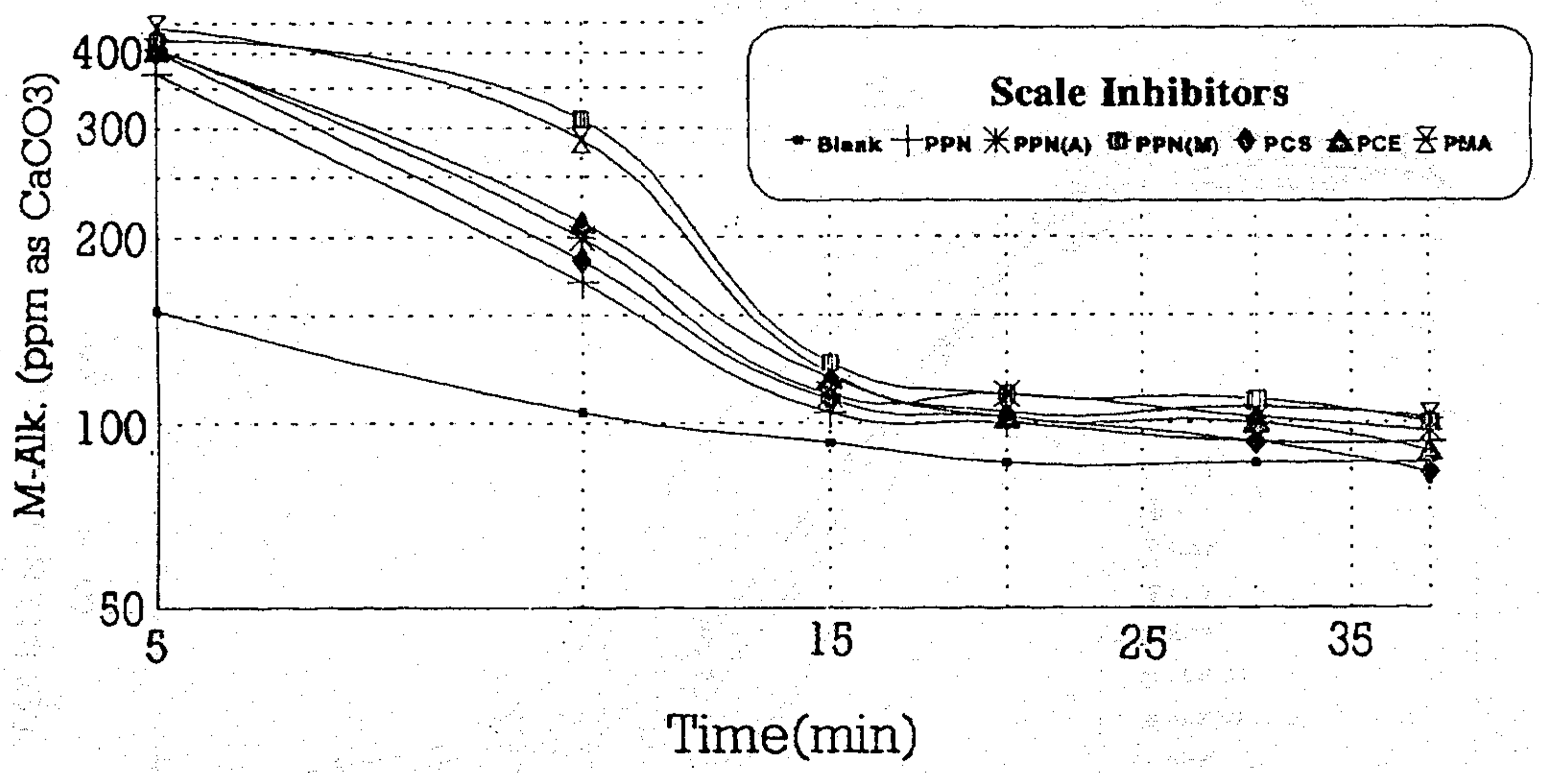


Fig. 4 Threshold Effect of Scale Inhibitor (2 ppm, 110℃)

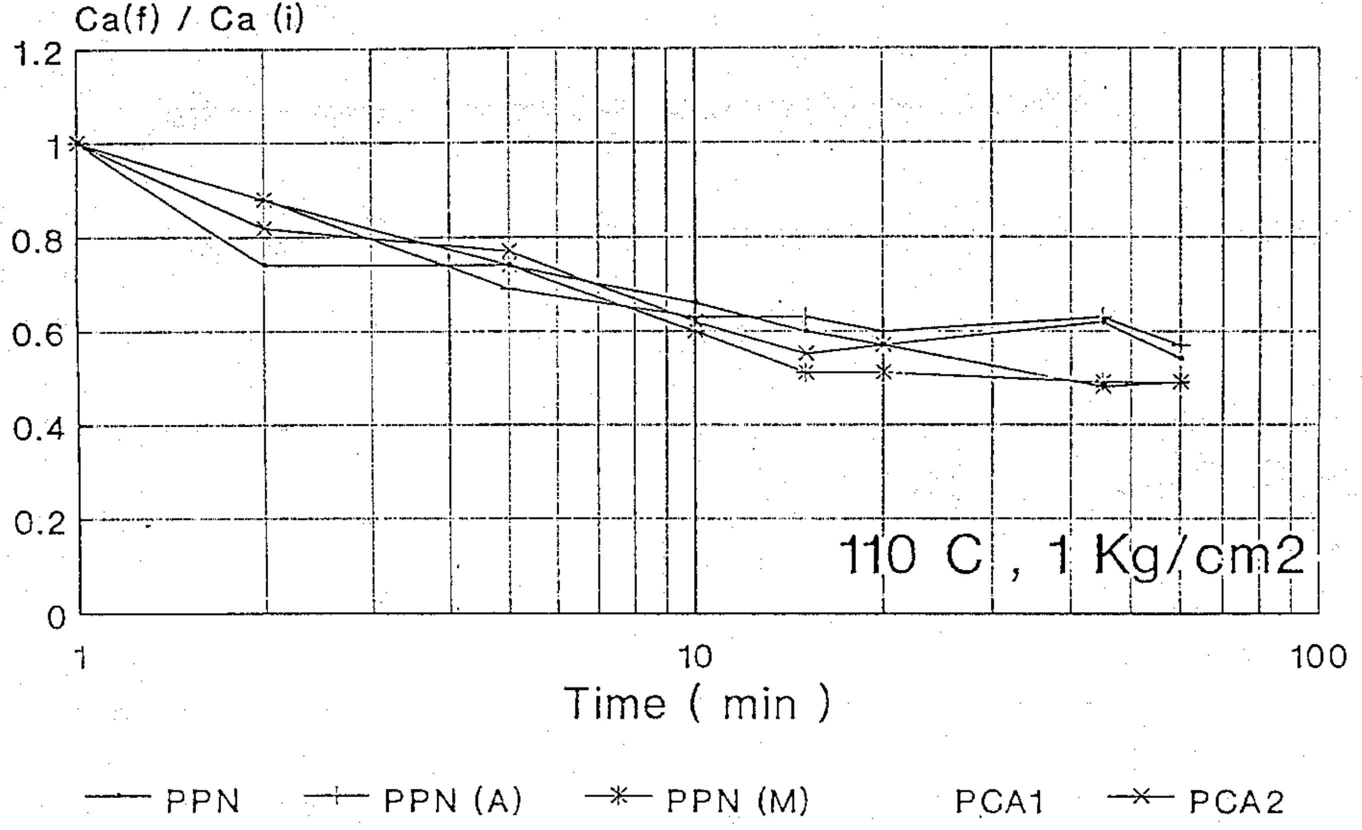


Fig. 5 Changes of Retention Time with Threshold Effect Ca(f)/Ca(i)

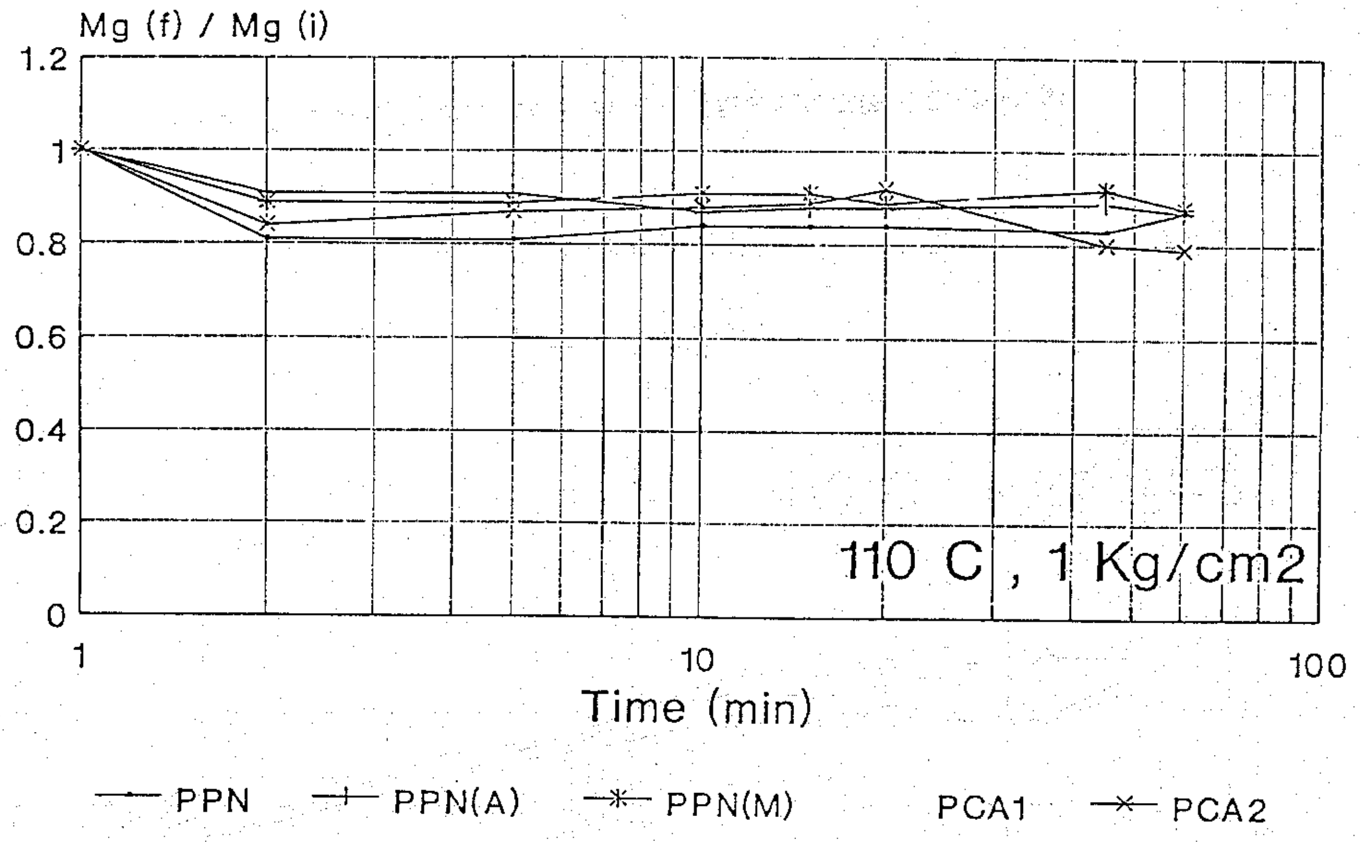
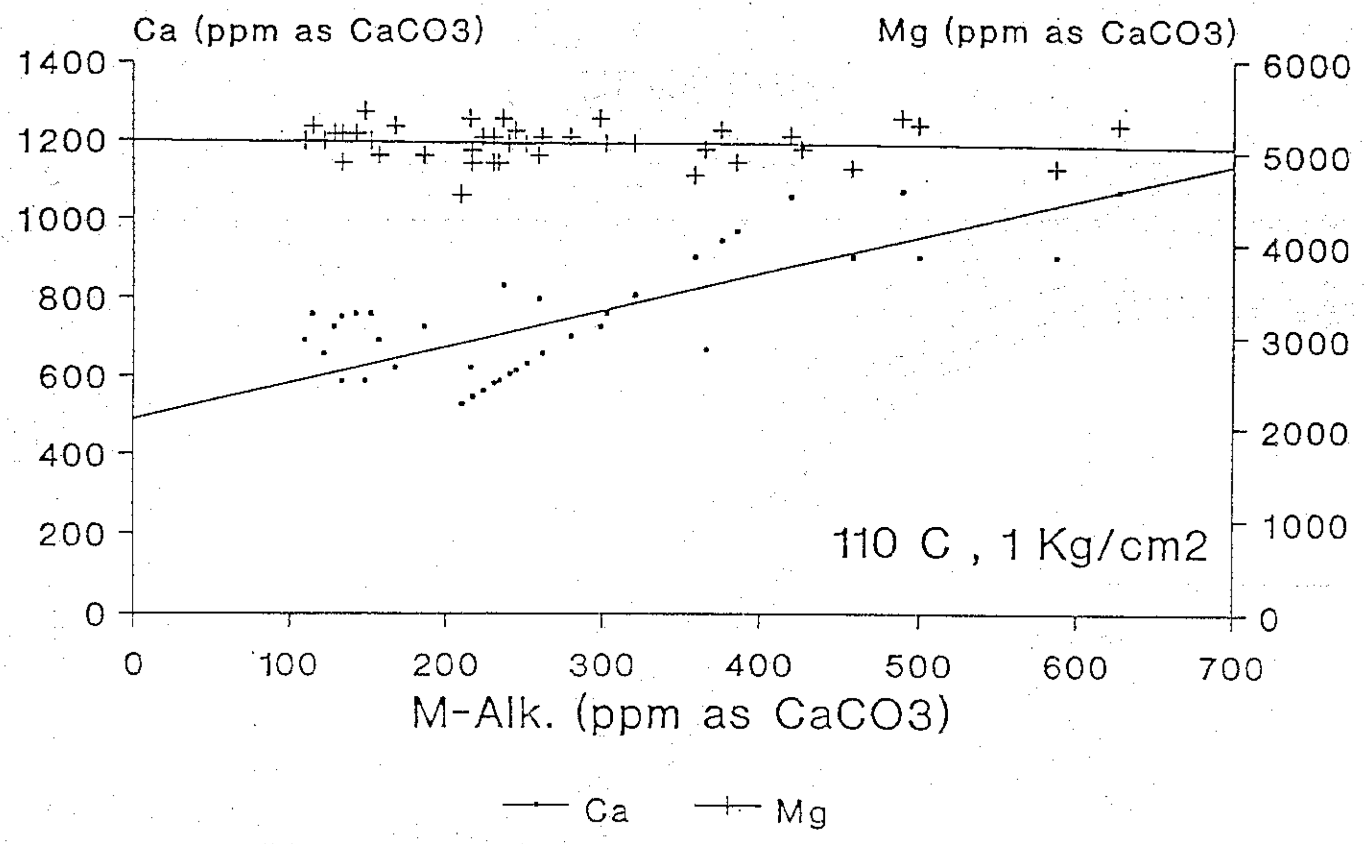


Fig. 6 Changes of Retention Time with Threshold Effect Mg(f)/Mg(I)



PPN,PPN(A),PPN(M),PCS,PCE,PMA @ 2 ppm

Fig. 7 Relationship between M-alkalinity and Ca & Mg Concentrations

(5.1.2)

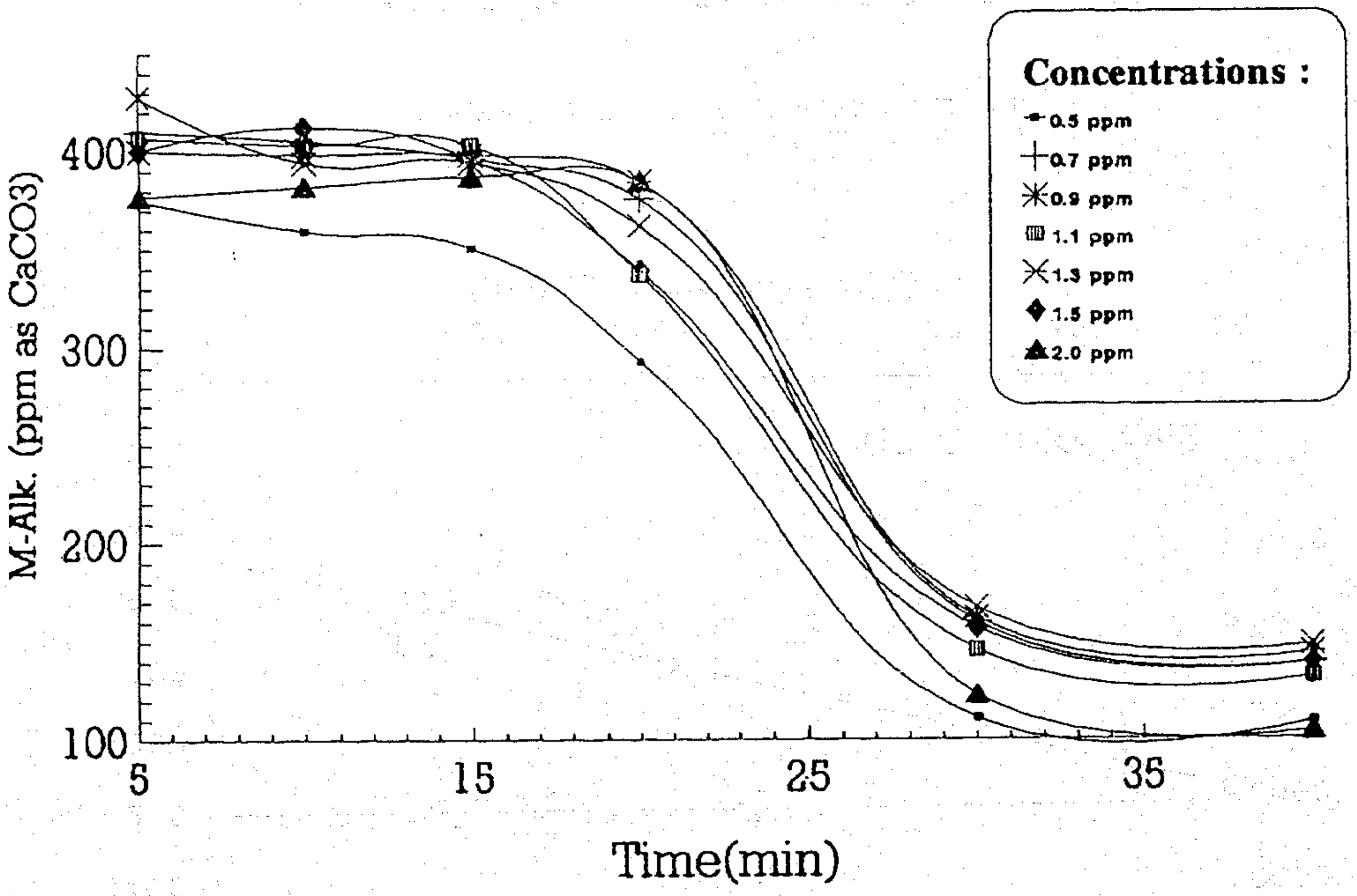


Fig. 8 Optimization the Concentration of PPN(M)

7. Conclusion

As the result of the experiment on the threshold effect of scale inhibitors, the following results were obtained in connection with the scale inhibitors to be used in the test which will be conducted at the next stage with the use of the heat transfer test unit.

(1) As for the scale inhibitor to be used in the test with the heat transfer test unit, three kinds were selected; PPN(M), PMA, and PCE.

(2) PPN(M) and PPN(A) have the highest threshold effect at 95℃ and their suitable dosing rate is above 0.7 ppm.

(3) PPN(M) and PMA have the highest threshold effect at the conditions of 2.0 ppm dosing rate and 110℃. In addition, from the viewpoint of confirming the differences between the scales produced, the third scale inhibitor, PCE, is also planned to be used in the next experiment which will use the heat-transfer pipe test unit.

(4) All scale inhibitors lose the threshold effect within 20 minutes at 90℃, and calcium ions deposit as calcium carbonate.

(5) All scale inhibitors lose the threshold effect within much shorter time (10 mins.) at 110℃.

(6) The adopted evaluation method with scale inhibitor is extremely effective for detection of calcium carbonate scaling.

The most suitable scale inhibitor will be selected through the test with the heat transfer test unit.

8. Reference

1) SWCC (Saline Water Conversion Corporation) / JICA (Japan International Agency); Research Cooperation for the project of the sea water desalination technology, Final report (1992)

2) SWCC (Saline Water Conversion Corporation) / JICA (Japan International Agency); Research cooperation for the project of the sea water desalination technology, Progress report (1993)