THE RESEARCH COOPERATION
FOR
THE PROJECT OF THE SEAWATER DESALINATION TECHNOLOGY
IN THE KINGDOM OF SAUDI ARABIA

FINAL REPORT
(SUMMARY)

FEBRUARY 1995

JAPAN INTERNATIONAL COOPERATION AGENCY

SALINE WATER CONVERSION CORPORATION

PREFACE

In response to the request from the Government of the Kingdom of Saudi Arabia, the Government of Japan decided to implement the technical cooperation project for the seawater desalination technology, and entrusted the project to the Japan International Cooperation Agency (JICA).

JICA sent a team, consisting of researchers from the Water Re-Use Promotion Center, to the Saline Water Conversion Corporation (SWCC) of the Kingdom of Saudi Arabia from January 1992 to February 1995 for the collaborative research activity as the third stage of the extended period.

The team conducted four experimental research themes under close cooperation with researchers from SWCC, and those fruitful achievements are highly competent for the publication in international conferences.

I hope that this report will contribute to the advancement of seawater desalination technology in the Kingdom of Saudi Arabia and to enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Kingdom of Saudi Arabia for their close cooperation extended to the team.

February 1995

Kimio Fujita
President
Japan International Cooperation Agency

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Note.

<Structure of this Report>

In this report, chapter and section will be shown at the front contents and further detailed contents will be shown at the front of the sections and paragraphs.
The page number at the bottom of the page is a serial number of each paragraph, however, header showing section, chapter and paragraph is printed at the top of the page to avoid confusion and make it easy to access the searching pages.

1. Introduction

1. Introduction

This FINAL REPORT covers the results of the cooperative research work conducted for the purpose of facilitating mutual communication between the SALINE WATER CONVERSION CORPORATION in the Kingdom of Saudi Arabia (hereinafter referred to as "SWCC") and the research cooperation team nominated by JAPAN INTERNATIONAL COOPERATION AGENCY (hereinafter referred to as "JICA") for the execution of the research cooperation, schemed in the INCEPTION REPORT of the "RESEARCH COOPERATION FOR THE SEAWATER DESALINATION TECHNOLOGY BETWEEN SALINE WATER CONVERSION CORPORATION AND JAPAN INTERNATIONAL COOPERATION AGENCY" (hereinafter referred to as "INCEPTION REPORT") based on "the DOCUMENT ON THE THIRD EXTENSION OF THE TECHNICAL COOPERATION FOR THE PROJECT OF THE SEAWATER DESALINATION TECHNOLOGY BETWEEN SWCC AND JICA" (hereinafter referred to as "Third Extension R/D") and "the MINUTES OF MEETING ON RESEARCH COOPERATION FOR THE PROJECT OF THE SEAWATER DESALINATION TECHNOLOGY BETWEEN SWCC AND JICA" (hereinafter referred to as "the M/M"), signed between SWCC and JICA on 13 October, 1992.

2. Historical Background

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2. Historical Background

2.1 Outline

In its second five years plan in 1976, guidelines were established for large scale industrialization and the preparation of urban infrastructure in the Kingdom of Saudi Arabia and national construction has been promoted steadily ever since. Consequently, the securing of large quantities of water for industrial use as well as water for domestic purpose became a major problem. The geographical conditions dictate that the major part of the necessary water supplied must be derived from seawater so that the role of seawater desalination plants has become increasingly important in recent years.

In the light of this background, a round of preliminary negotiations between Japan and Saudi Arabia began in November 1975, during a visit to Japan by the Governor of SWCC, with his informal request to the Japanese Government for cooperation on seawater desalination technology.

In January 1982, JICA and SWCC signed a Record of Discussion concerning the implementation of this project (hereinafter referred to as the R/D) and the cooperation has started.

The period of cooperation has been extended to February 1984, re-extended to February 1992, and finally to February 1995. This final report covers the results of the research cooperation project conducted during the period of final extension, from March 1992 to February 1995.

2.2 Chronicle

The outline of the circumstances of the research cooperation project are as follows:

(1) January 1982 : SWCC and JICA signed R/D

(2) October 1987 : The period of cooperation has been extended for three years to February 1989.

(3) December 1990 : The re-extension for another three years has been discussed with the

scheme during the period and mutual understandings has been obtained.

(4) April 1991 : The re-extension up to February 1992 has been signed by both parties which was delayed by the Gulf War. Four research themes on MSF and seven research themes on RO has been conducted during this period.

(5) October 1992 : The M/M for the third extension has been signed by both parties. The period of cooperation was from March 1992 to February 1995 and two research themes on MSF and also two research themes on RO were selected.

2.3 Contents of Research Activities

Due to the consequence of the Gulf War as well as other causes, the pollution of seawater by oil became a crucial issue for seawater desalination at the discussion of the scheme of second and third extension. The SWCC strongly requested to include the study on countermeasures against oil contamination of desalination plant in the cooperative research, and such subjects were covered in the research themes.

The research themes conducted during the second extension period, up to February 1992, were as follows:

<MSF>

(1) M-1 Laboratory experiment on scale prevention
(2) M-2 Corrosion tendency for some kinds of materials
(3) M-3 Study on some materials by corrosion measurement apparatus
(4) M-4 Analysis of oil dispersed in raw seawater at the heat rejection section of MSF plants

<RO>

(5) R-1 Sterilization
(6) R-2 Pretreatment of seawater
(7) R-3 Pollution effect of membrane cleaning discharge
(8) R-4 Selection of membrane

(9) R–5 Chemical cleaning of the fouled membrane
(10) R–6 Selection of membrane for hybrid type RO
(11) R–7 Standardization of the main analytical methods

The research themes conducted during the third extension period, up to February 1995, were those extended from the previous M–1, M–4 R–2 and R–6. Those themes are as follows:

(1) Study on scale control for MSF process
(2) Study on countermeasures against oil contamination of product water in MSF process
(3) Study on selection of RO membrane for hybrid system
(4) Study on countermeasures against oil contamination for RO process

3. Objectives of the Research Cooperation

3. Objectives of the Research Cooperation

The objectives of this research cooperation are to have researchers of both Japan and Saudi Arabia conduct collaborative research activities on the 4 research themes related to seawater desalination technology and to transfer Japanese seawater desalination technology to Saudi Arabia.

4. Basic Policy for Implementation of Research Cooperation

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4. Basic Policy for Implementation of Research Cooperation

This research cooperation consists of two parts, firstly collaborative research activities and secondly supplementary arrangement of equipment and materials, details of which are given in the following chapters.

4.1 Collaborative Research Activities

The following four themes related to Multi-Stage Flash Distillation (MSF) and Reverse Osmosis (RO) have been implemented for collaborative research activities.

- **A. Study on Scale Control of MSF Process (MSF-1)**
- **B. Study on Countermeasure against Oil Contamination of Product Water in MSF Process (MSF-2)**
- **C. Study on Selection of RO Membrane for Hybrid System (RO-1)**
- **D. Study on Countermeasure against Oil Contamination for RO Process (RO-2)**

The expression of the research purpose and contents for these four themes described here is identical to that of M/M. Fig. 1 and Fig. 2 show the completed schedule for MSF and RO research activity, respectively.

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

(1) Purpose

Productivity deterioration of an MSF plant stems mainly from scaling of the heat transfer tubes. Thus, it has been studied how to control the scaling by chemical dosing for MSF plants in Saudi Arabia.

(2) Scope of Work

1) Investigation and Preparative Experiment

The effects of some scale inhibitors were compared by conducting scaling tests in a laboratory, in order to select promising candidates in addition to investigate for the status of productivity deterioration of MSF plants in Saudi Arabia.

2) Test with the Heat Transfer Test Equipment

Based on the preparative experiment, the effects of the selected scale inhibitors were tested under thermal flux using the heat transfer test equipment in order to evaluate the scaling rates under various conditions.

Based on these comprehensive data, the scale inhibitor to be tested with the MSF Test Plant were selected.

3) Tests with the MSF Test Plant

-The confirmation test of the selected scale inhibitor were carried out at the MSF Test

Plant.

–The effects of the scale inhibitor with and without simultaneous use of acid were compared.

4) Evaluation and Report

Data obtained from the test with the MSF Test Plant have been evaluated in order to obtain the followings:

–Data relative to the increase in the fouling factor of heat transfer tubes.

–Data relative to the efficiency of ball cleaning for scale removal and its adequate frequency.

(3) Essential Equipment and Materials

1) Equipment

a. Scale deposition test equipment (above 100℃)

b. Scale deposition test equipment (under 100℃)

–three neck flask with a cooler

c. Heat transfer test equipment

–modification of the equipment owned by SWCC

2) Materials

a. Scale inhibitors

b. Brine

c. Sulphuric acid

d. Anti–foaming agent

e. Acid cleaning agents

f. Sponge balls

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

(1) Purpose

In MSF desalination of oil contaminated seawater, contamination of the product water is expected. This study aims at proposing how to prevent such contamination.

(2) Contents of Study

1) Investigation and Preparative Experiment

Information on the seawater quality in case when contaminated by oil and the vapor-liquid equilibria of hydrocarbon and bromoform, were investigated through literature surveys. The preparative experiment on volatility of bromoform and hydrocarbon contained in oil were also carried out.

2) Measurement of Vapor-liquid Equilibria

The vapor-liquid equilibria of hydrocarbon and bromform under the desalination conditions has been measured.

3) Simulation and Prediction of Contamination

The behaviors of hydrocarbon and bromoform in the MSF Test Plant will be simulated and predicted by the combination of the data obtained in 1) and 2) with the characteristics of the MSF Test Plant.

4) Tests with the MSF Test Plant

The results of the computer simulation were confirmed by the experiment done at the MSF Test Plant.

5) Evaluation and Report

The countermeasures against contamination of product water were proposed by analysis and evaluation of the results obtained in 4).

(3) Essential Equipment and Materials

1) Equipment

a. Preparative experiment equipment

b. Vapor-liquid equilibrium measurement equipment with a cooler

c. Personal computer owned by SWCC

d. **MSF Test Plant**

2) **Materials**

a. **Hydrocarbon, bromoform**
b. **Brine**
c. **Scale inhibitors**
d. **Anti–foaming agent**
e. **Acid cleaning agents**
f. **Sponge balls**

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

(1) Purpose

This study aims at the selection for a hybrid desalination systems of the most practical membrane module with a high permeate flux rate among commercially available RO modules to desalinate the high salinity Arabian Gulf seawater yielding product water of 1,000-1,500mg/l TDS.

(2) Scope of Study

1) Investigation and Preparative Experiment

a. Experiments on the performance and the effect of chemical cleaning of fouled membranes

b. Comparison of performance behaivior of several flat membranes with potentially performance were promising conducted to select membranes of high permeate flux rate. Experiment were carried out with clean seawater in conformity with the conditions of Practical temperatures and pressures (the first screening).

c. Tolerance tests of chlorine and turbidity were carried out selected on the membrane (second screening).

2) Experiment with RO Mini-module (1)

a. Further evaluation of the selected membrane selected from the flat membrane test were made using and RO mini-module test unit.

b. For selected modules, tests of chlorine and tolerance, washing, etc. were carried out.

3) Tests using the RO Test Plant

RO modules applicability to a MSF-RO Hybrid desalination system were confirmed by conducting tests on RO modules using RO Test Plant.

4) Evaluation and Report

The most suitable RO module for a MSF-RO Hybrid process and its usage were selected for practical use from among present modules.

(3) Essential Equipment and Materials

1) Equipment

a. SDI measurement equipment

b. Flat membrane tester owned by SWCC

c. Two flat membrane cells

d. **RO Mini–module tester (1)**

e. **RO Test Plant**

2) **Materials**

a. **Flat membranes**

The fouled membranes used in the SWRO plants were obtained with their operation histories through arrangement made by SWCC.

b. **RO Mini–modules**

c. **RO Modules for practical use**

d. **Chemicals such as ferric chloride and SBS**

e. **Anthracite and sand for laboratory scale sand filter test**

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

(1) Objective

This study is aimed at proposing the best countermeasures against oil contamination of seawater RO feed, containing several tens of mg/l of oil. The main objective is to remove oil from an oil cotaminated seawater RO feed prior to its entry to SWRO membranes.

(2) Contents of Study

1) Investigation and Preparative Experiment

a. Literature survey of analytical data, solubility, analytical method and removal method of soluble and insoluble oil into seawater were carried out.

b. Literature survey of analytical data, solubility, analytical method and removal method of halogen compounds such as trihalomethane were carried out.

c. Literature survey of oil tolerance of RO module were carried out as well as literature survey and experiment on removal of halogen compounds such as trihalomethane.

2) Experimental Oil Removal by Pretreatment

a. Preparative experiment

Laboratory experiment were carried out on removal of soluble and insoluble oil present in seawater by coagulation sedimentation and adsorption methods. The removal effect of coagulation-sand-filtration, adsorption by polymer, active carbon and combination of these methods have been studied.

b. Oil dosing experiment

The preparation of oil contaminated seawater model and the analysis oil content were studied.

c. Oil removal experiment

The removal of soluble and insoluble oil were studied by coagulation-sand-filtration, adsorption by polymer, active carbon method, etc.

d. Regeneration of oil removal equipment

The regeneration conditions of media and equipment used in the coagulation-sand-filtration, adsorption by polymer and active carbon were studied.

3) Oil Tolerance Test using a Flat Membrane Tester

Using a flat membrane test unit, experiment on the effect of oil (especially soluble oil) on membrane performance were carried out, using pretreated seawater as the feed water.

4) Experiment with RO Mini-module (2)

Oil tolerance of RO mini-modules were tested using pretreated feed seawater. Based on the results of 2) and 3) above, combination of pretreatment and oil-tolerant RO mini-module will be tested to design the process against oil contamination.

5) Test with the RO Test Plant

Confirmation of the process efficiency and oil tolerance of RO module was examined using the RO Test Plant with practical commercial modules.

6) Evaluation and Report

A combination of seawater pretreatment and use of oil-tolerant modules are at presently the best countermeasures against oil-contamination.

(3) Essential Equipment and Materials

1) Equipment

a. Two flat membrane cells
b. Oil dosing preparation equipment
c. Oil adsorption equipment
d. Oil adsorption tower back-washing equipment
e. RO Mini-module testers (2)
f. RO Test Plant

2) Materials

a. Flat membranes
b. Dosing oil for preparation of contaminated seawater
c. RO Mini-modules
d. RO Modules for practical use

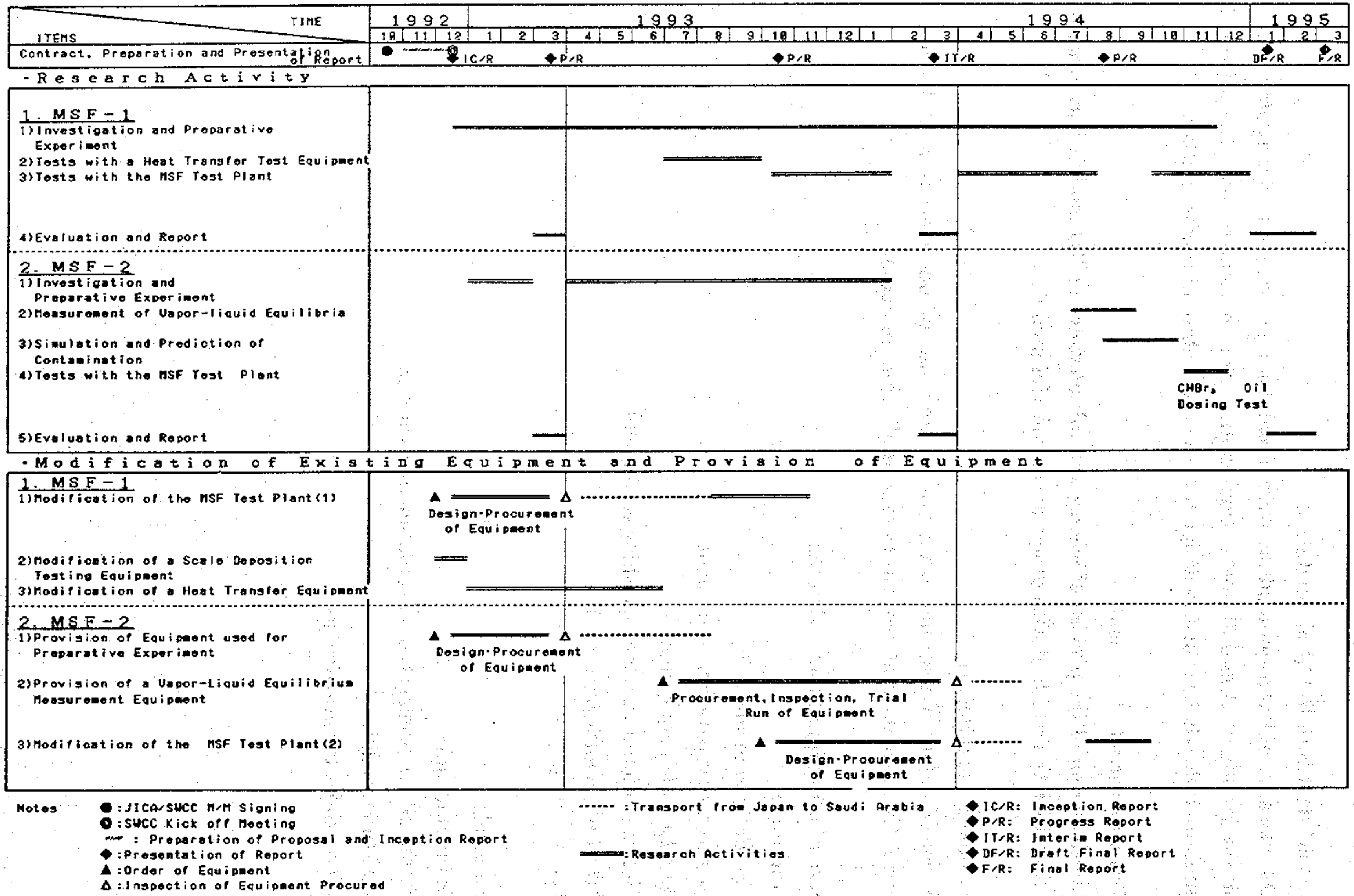

Fig. 1　Time schedule for Laboratory Equipment and MSF Test Plant

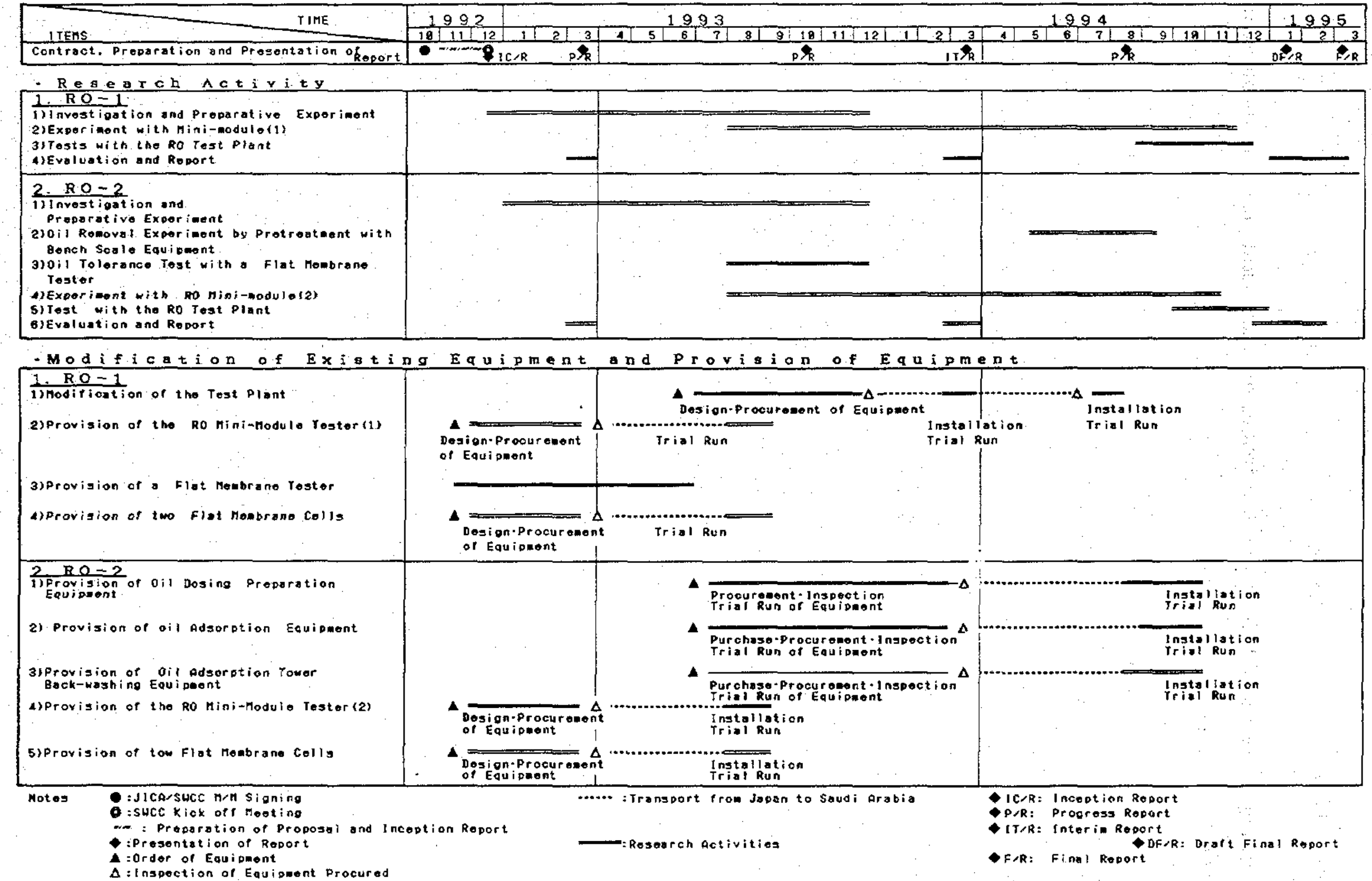

Fig. 2 Time Schedule for Laboratory Equipment and RO Test Plant

4.2 Work Plan

The working schedules and the research activities for each fiscal year are summarized in Fig. 3–Fig. 6.

(4)

Fiscal Year		1992					Remarks
Month		11	12	1	2	3	
	1. Explanation and discussion of the inception report						
	2. Technological discussion with the counterpart						
	3. Transfer of the MSF & RO Test Plants and installation plan						
	4. Implementation of collaborative research						
	1) Investigation and preparative experiment						
MSF-1	① The status of productivity deterioration of MSF plants						
MSF-1	② Selection of scale inhibitors						
MSF-1	③ Modification of the scale deposition test equipment						
MSF-1	2) Tests with the heat transfer test equipment						
MSF-1	① Modification of the heat transfer test equipment						
MSF-1	② Selection of scale inhibitors						
MSF-1	3) Tests with the MSF Test Plant						
MSF-1	① Support for installation						
MSF-1	② Trial runs						
MSF-1	③ Operation tests						
MSF-1	④ Water analysis						
MSF-1	⑤ Evaluation of fouling factor						
MSF-1	4) Evaluation and report					◆P/R	
MSF-2	1) Investigation and preparative experiment						
MSF-2	① Investigation of the Arabian Gulf seawater						
MSF-2	② Preparative experiment						
MSF-2	③ Water analysis						
MSF-2	2) Measurement of vapor-liquid equilibria						
MSF-2	3) Simulation and prediction						
MSF-2	4) Tests with the MSF Test Plan						
MSF-2	① Modification of the plant						
MSF-2	② Operation tests						
MSF-2	③ Water analysis						
MSF-2	④ Evaluation of transferred substance to product water						
MSF-2	5) Evaluation and report					◆P/R	
RO-1	1) Investigation and preparative experiment						
RO-1	① Survey on RO modules for hybrid system						
RO-1	② Performance evaluation of fouled membrane						
RO-1	2) Comparison tests of flat membranes						
RO-1	3) Tolerance tests with flat membrane in chroline and turbidity						
RO-1	4) Experiment with the RO mini-module tester (1)						
RO-1	① Selection of module						
RO-1	② Tolerance tests with flat membrane in chroline and turbidity						
RO-1	5) Experiment with the RO Test Plant						
RO-1	① Support for installation						
RO-1	② Experiment						
RO-1	6) Evaluation and report					◆P/R	
RO-2	1) Investigation and preparativwe experiment						
RO-2	2) Oil removal experiment by pretreatment with bench scale equipment						
RO-2	3) Oil tolerance tests with a flat membrane tester						
RO-2	4) Experiment with the RO mini-module (2)						
RO-2	5) Test with the RO Test Plant						
RO-2	6) Evaluation and Report					◆P/R	

Notes : ——— Implementation by JICA; ——— Implementation by SWCC; ═══ Implementation by JICA/SWCC

Fig. 3 The First Research Activities in Saudi Arabia

	Fiscal Year	1993												Remarks
	Month	4	5	6	7	8	9	10	11	12	1	2	3	
	4. Implementation of collaborative research													
MSF-1	1) Investigation and preparative experiment													
	① The status of productivity deterioration of MSF plants													
	② Selection of scale inhibitors													
	③ Modification of the scale deposition test equipment													
	2) Test with the heat transfer test equipment													
	① Modification of the heat transfer test equipment													
	② Selection of scale inhibitors													
	3) Tests with the MSF Test Plant													
	① Support for installation													
	② Trial runs													
	③ Operation tests													
	④ Water analysis													
	⑤ Evaluation of fouling factor													
	4) Evaluation and report							◆P/R						
MSF-2	1) Investigation and preparative experiment													
	① Investigation of the Arabian Gulf seawater													
	② Preparative experiment													
	③ Water analysis													
	2) Measurement of vapor-liquid equilibria													
	3) Simulation and prediction													
	4) Tests with the MSF Test Plant													
	① Modification of the plant													
	② Operation tests													
	③ Water analysis													
	④ Evaluation of transferred substance to product water													
	5) Evaluation and report							◆P/R						
RO-1	1) Investigation and preparative experiment													
	① Survey on RO module for hybrid system													
	② Performance evaluation of fouled membranes													
	2) Comparison tests of flat membranes													
	3) Tolerance tests with flat membrane in chlorine and turbidity													
	4) Experiment with the RO mini-module tester (1)													
	① Selection of module													
	② Tolerance tests with flat membrane in chlorine and turbidity													
	5) Experiment with the RO Test Plant													
	① Support for installation													
	② Experiment													
	6) Evaluation and report							◆P/R						
RO-2	1) Investigation and preparative experiment													
	2) Oil removal experiment by pretreatment with bench scale equipment													
	3) Oil tolerance tests with a flat membrane tester													
	4) Experiment with the RO mini-module (2)													
	5) Test with the RO Test Plant													
	6) Evaluation and report							◆P/R						

Fig.4-1 The Second Research Activities in Saudi Arabia

Month	4	5	6	7	8	9	10	11	12	1	2	3	Remarks
1. RO-1 : Analysis of fouled membranes													
2. Preparation of the interim rep.												◆IT/R	

Notes: ——— : Implementation by JICA ━━━ : Implementation by SWCC ═══ : Implementation by JICA/SWCC

Fig.4-2 The Second Research Activities in Japan

	Fiscal Year	1994												Rematks
	Month	4	5	6	7	8	9	10	11	12	1	2	3	
	4. Implementation of collaborative research													
MSF-1	1) Investigation and preparative experiment													
	①The ststus of productivity deterioration of MSF plants													
	②Selection of scale inhibitors													
	③Modification of the scale deposition test equipment													
	2) Tests with the heat transfer test equipment													
	①Modification of the heat transfer equipment													
	②Selection of scale inhibitors													
	3) Tests with the MSF Test Plant													
	①Support for installation													
	②Trial runs													
	③Operation Tests													
	④Water analysis													
	⑤Evaluation of fouling factor													
	4) Evaluation and report				◆P/R									
MSF-2	1) Investigation and preparative experiment													
	①Investigation of the Arabian Gulf seawater													
	②Preparative experiment													
	③Water analysis													
	2) Measurement of vapor-liquid equilibria													
	3) Simulation and prediction													
	4) Tests with the MSF Test Plant													
	①Modification of the plant													
	②Operation test													
	③Water analysis													
	④Evaluation of transferred substance to product water													
	5) Evaluation and report				◆P/R									
RO-1	1) Investigation and preparative experiment													
	①Survey on RO modules for hybrid system													
	②Performance evaluation of fouled membrane													
	2) Comparison tests of flat membrane													
	3) Tolerance tests with flat membrane in chlorine and turbidity													
	4) Experiment with the RO mini-module tester (1)													
	①Selection of module													
	②Tolerance tests with flat membrane in chlorine and turbidity													
	5) Experiment with the RO Test Plant													
	①Support for installation													
	②Experiment													
	6) Evaluation and report				◆P/R									
RO-2	1) Investigation and preparative experiment													
	2) Oil removal experiment by pretreatment with bench scale equipment													
	3) Oil tolerance tests with a flat membrane tester													
	4) Experiment with the RO mini-module (2)													
	5) Test with the RO Test Plant													
	6) Evaluation and report				◆P/R									

Fig.5-1 The Third Research Activities in Saudi Arabia

Fiscal year 1994	4	5	6	7	8	9	10	11	12	1	2	3	備 考
4. Preparation of the draft final report													

Notes: ——— : Implementation by JICA ━━━━ : Implementation by SWCC ═════ : Implementation by JICA/SWCC

Fig.5-2 The Third Research Activities in Japan

(4)

Fiscal Year	1994												Remarks
Month	4	5	6	7	8	9	10	11	12	1	2	3	
5. Explanation of the draft final report											◆DF/R		

Fig.6-1 The Fourth Research Activities in Saudi Arabia

Fiscal Year	1994												Remarks
Month	4	5	6	7	8	9	10	11	12	1	2	3	
5. Preparation of the final rep.											——	——	
6. Sending the final rep. to SWCC												—	

Notes: ——— :Implementation by JICA ———— :Implementation by SWCC ════ : Implementation by JICA/SWCC

Fig.6-2 The Fourth Research Activities in Japan

4.2.1 The First Research Activities in Saudi Arabia (January–March, 1993)

(1) **Explanation and discussion of the Inception Report**
In January, 1993, JICA team explained the Inception Report at SWCC head office in Riyadh and confirmed the division of responsibility for the work between JICA and SWCC.

(2) **Technical meeting between SWCC and JICA**
Based on the Inception Report, SWCC and JICA discussed the technical aspects of the research themes in detail at SWCC's R&D Center. On this occasion, it was agreed that if there were a request to change the plan, appropriate modification could be made within the M/M limitation.

(3) **Plans for the transportation of MSF and RO Test Plant**
The MSF and RO Test Plants had been stored at Yanbu, but in January–February 1993 they were moved to Al Jubail.

(4) **Implementation of collaborative research**
Collaborative research activities were undertaken in the R&D Research Center according to the scheme mentioned in 4.1.

(5) **Preparation of progress report**
The progress report covering the results of the literature survey and the preparative experiments mentioned above have been published, March, 1993.

4.2.2 The second Research Activities in Saudi Arabia (April 1993 – March 1994)

(1) Supplementary chemical analysis equipment arranged in this period were as follows:

A : X–ray diffractometer,
B : Ion chromatography,

Concerning A, the equipment, including a supply of parts, has been assembled, inspected and operated and technical guidance has been given on its operation and maintenance as well as guidance on application technology.
Concerning B, assembly and installation were completed in the previous period. In this

period, training has been given on analytical operations to promote proficiency in the operation of the equipment and, at the same time, guidance has been given in care and maintenance technology and application technology so that those involved will be fully informed.

(2) Implementation of collaborative research
Collaborative research activities were undertaken in the R&D Research Center according to the scheme mentioned in 4.1.

(3) Preparation of progress report
The progress report on the research work during this period have been published on October, 1993.

4.2.3 The Second Research Activities in Japan

(1) Publication of Interim Report
The interim report on the results of the research work during the first and the second research activities periods have been published on February, 1994.

(2) Explanation and discussion of the Interim Report
In March, 1994, JICA team discussed the Interim Report at SWCC.

(3) Analysis of fouled membrane
The analysis of the collected fouled membranes have been conducted both at Saudi Arabia and Japan as part of the RO–1 project.

4.2.4 The Third Research Activities in Saudi Arabia (April 1994 – Feb. 1995)

(1) Implementation of collaborative research
Collaborative research activities were undertaken in the R&D Research Center according to the scheme mentioned in 4.1.

4.2.5 The Third Research Activities in Japan (April 1994– Feb. 1995)

(1) Preparation of draft final report
The collaborative research was completed at the end of December 1994, after which the JICA team returned to Japan, taking with them the data required for the preparation of the draft for the final report to be completed in Japan. This report summarizes the results of the collaborative research which has been made up to that

time, at all times in collaboration with SWCC.

(2) Explanation to SWCC
For a period of nine days in February 1995, JICA team explained the draft for final report for the benefit of SWCC and its contents were discussed.

4.2.6 Preparation of Final Report

The final report was prepared jointly by SWCC/JICA researchers within the last one month.

4.3 Undertaking of JICA and SWCC

(1) Undertaking of JICA and SWCC has been established for the following items.

1) Laboratory equipment
2) Materials
3) Test Plant
4) Personnel required
5) Others

(2) JICA has provided the following experimental equipments and SWCC has provided the utilities for them and also provided necessary manpower for the installation and commissioning:

1) Mini-Module Tester (1)
2) Mini-Module Tester (2)
3) Cooling Water Cycling Equipment for SWCC's Flat Membrane Tester
4) Cooling Water Cycling Equipment for Mini-Module Tester (1)

(3) JICA and SWCC have made an agreement as relate to the responsibility undertakings for the main equipment used for this research activities.

(4) SWCC provided the following:

1) Six separate office spaces and one meeting room for the members of JICA team
2) A fully furnished accommodation for the members of JICA team according to SWCC's standard during their stay in the Kingdom of Saudi Arabia
3) Vehicles with drivers for the JICA team during working hours including commutation
4) Expenses and necessary duties on the internal business trip in the Kingdom of Saudi Arabia for the members of JICA team
5) Customs formalities and their necessary charges, if any, as may be imposed upon the equipment and/or materials to be provided by JICA to SWCC
6) Expenses and necessary duties on the domestic transportation for the equipment and/or materials to be provided by JICA to SWCC
7) Expenses on the telephone and fax from SWCC Research Center to the offices in Japan for the JICA team to send important information with permission of the coordinator of SWCC Research Center
8) Chemical and physical analysis
9) Pretreated seawater feed

(4)

4.4 Organization

The organization and division of responsibilities are shown in Fig.7 and Table 1.

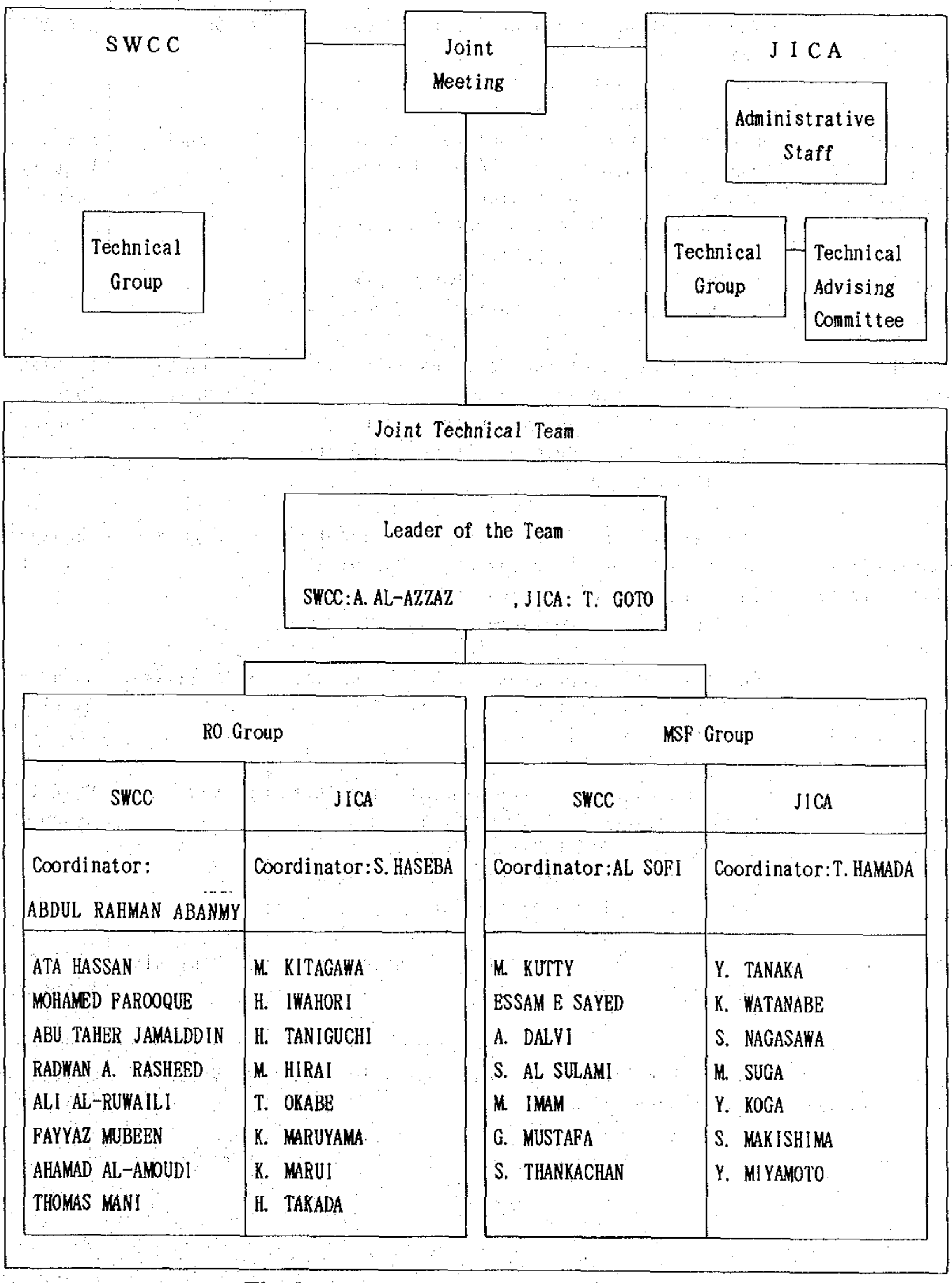

Fig. 7 Organization Chart of the Project

Table 1-1 Division of Responsibilities

Responsibilities	Contents of Work	Name	
		JICA	SWCC
General Management	・Management and planning for research activity ・Negotiation with counterpart	T. Goto	A.A.Al-Azzaz
MSF-1, MSF-2 (Research and Coordination)	Implementation of experimenntal research in Saudi Arabia and evaluation of the results ・Scale inhibitor selection ・Characteristics of the test plant for simulation of oil behavior ・Evaluation of chemistry related data ・Evaluation of heat transfer related data	T. Hamada	A.K.Al-Sofi M.Kutty Essam
MSF-1, MSF-2 (Analysis)	・Implementation of chemical analysis for seawater, brine and scale ・Evaluation of chemical analysis data ・Assistance for implementation of experimental research	Y. Tanaka M. Suga	S.Sulami Imam Thankachan
MSF-2 (Vapor-Liquid Equilibrium-1)	・Implementation of bench-scale preparative experiment for oil behavior in MSF plant ・Investigation of physical properties for analysis of oil contaminants behavior	K. Watanabe	Thankachan A.G.Dalvi
MSF-2 (Vapor-Liquid Equilibrium-2)	・Obtaining of Vapor-Liquid equilibrium data ・Determination of given condition for computer simulation programs	S. Nagasawa	M.Kutty Dalvi Thankachan
MSF-2 (Computer Analysis)	・Preparation of computer simulation program Hard Ware: NEC PC98 & IBM-PS/2 Soft Ware: BASIC, FORTRAN & C or C^{++} ・Amendment of computer simulation programs based on experimental results	Y. Koga	M.Kutty Essam
MSF Test Plant (1)	・Supervision for the test plant assembly and installation	S. Makishima	Al-Sofi, M.Kutty, Essam
MSF Test Plant (2)	・Supervision for trial runs, operation and maintenance of the test	Y. Miyamoto	Al-Sofi, M.Kutty, Essam

(4)

Table 1-2 Division of Responsibilities

Responsibilities	Contents of Work	Name	
		JICA	SWCC
RO-1, RO-2 (Research and Coordination)	Implementation of experimental research in Saudi Arabia and evaluation of the results ・Prior investigation for RO-1 ・Evaluation of preparative experiment results for RO-2 ・Evaluation of mini-module test results for RO-1 & RO-2 ・Evaluation of the test plant results	S. Haseba	A. Abanmy A. Hassan
RO-1, RO-2 (Analysis-1)	・Water quality analysis needed for flat membrane tests, mini-module tests and the test plant tests ・Mini-module tests for membrane selection in hybrid system ・Tolerance tests with mini-modules in chlorine and turbidity ・Support for information retrieval from Japan	M. Kitagawa Y. Taniguchi	M. Farooque A. Jammaldin A. R. Ali M. Fayyaz
RO-1, RO-2 (Analysis-2)	・Investigation of fouling for used RO membrane and study of cleaning method ・Implementation of RO system performance analysis and hybrid system simulation calculation ・Evaluation and selection of membrane for hybrid system	H. Iwahori K. Marui	Nomani Ata Hassan A. Jammaldin A. R. Ali M. Fayyaz
RO-1, RO-2 (Membrane Evaluation-1)	・Comparison tests with flat membrane tester to select membranes for hybrid system ・Tolerance tests with flat membrane tester in chlorine ・Operation of the test plant for RO-1 and evaluation of the results ・Assistance for implementation of experimental research	M. Hirai	Nomani Ata Hassan M. Farooque A. R. Ali M. Fayyaz
RO-1, RO-2 (Membrane Evaluation-2)	・Comparison tests with mini-module tester to select membranes for hybrid system ・Tolerance tests with flat membrane tester in turbidity ・Operation of the test plant for RO-2 and evaluation of the results	T. Okabe	Ata Hassan M. Farooque A. Jammaldin A. R. Ali M. Fayyaz
RO-2 (Pretreatment)	・Removal tests of oil from seawater by coagulation & filtration and adsorption ・Studies and tests on preparation artificially oil contaminated seawater ・Literature survey on analytical methods oils and organic halogen compounds such as trihalomethane in seawater ・Literature survey on tolerance tests with RO modules in oils and separation capacity of membrane for organic halogen compounds ・Experiments for oil removal by pretreatment	K. Maruyama	Ata Hassan M. Fayyaz M. Farooque A. Jamalddin A. R. Ali
R O Test Plant	・Supervision for the test plant assembly, installation, trial runs, operation and maintenance	H. Takada T. Yago	A. Hassan A. Abanmy

4.5 Supplementary Arrangement of Equipment

The work of setting up common materials (research instruments, the MSF Test Plant, and the RO Test Plant) in the assigned locations and making adjustments was carried out and the plan for the preparation of common materials was implemented. Within this period supplementary parts for the installation/ modification of MSF and RO test plants and supplementary laboratory equipment for the preparative experiments were supplied.

4.5.1 Supplementary Arrangement of Chemical Analysis Equipment

Within this project period, dispatching engineers to take charge of the following items (Table 2), the supplement to the common materials plan was implemented and guidance on operation and maintenance technologies were made.

(1) Chemical Analysis Device A
- Implementation of assembly, installation and inspection
- Guidance on operation and maintenance technology for electron probe micro-analyzer.
- Implementation:from October 1994 to November 1994

(2) Chemical Analysis Device B
- Implementation of assembly, installation and inspection
- Guidance on operation and maintenance technology for ICP emission spectrometer, infra-red spectrometer and spectrophotometer.
- Implementation:from October 1994 to November 1994

(3) Chemical Analysis Device C
- Implementation of assembly, installation and inspection
- Guidance on operation and maintenance technology for X-ray diffractometer.
- Implementation:in January, 1992

(4) Chemical Analysis Device D
- Guidance on operation and maintenance technology for the ionchromatograph
- Implementation:in April, 1992 and September, 1993

English version of operation manual for ion chromatograph IC-500PS was prepared and submitted.

(4)

4.5.2 Supplementary Supplied Parts and Laboratory Equipment

Supplementary supplied parts for the installation of the Test Plants and equipment for the preparative experiment are listed in Table 3.

Details of the installations work are described in the following sections.

a.	Installation of the MSF Test Plant	:5.3.1
b.	Modification work of the MSF Test Plant	:6.4.1
c.	Installation of the RO Test Plant	:7.3.1
d.	Installation of Pretreatment of Oil Removal Experiment	:8.2.1
e.	Installation of the Mini-module Tester	:7.2.1

(4)

Table 2 Division of Responsibilities for Chemical Analysis Equipment

Responsibility	Contents of Work	Name	
		JICA	SWCC
Chemical Analysis Equipment A	• Implementation of assembly, installation and inspection • Guidance on operation and maintenance technology for Electron Probe Microanalyzer	Y. Tanehata	Nausha Asrar T. Prakash John O'hara Ismail Andijani Mohd Ismail Noor Ahmed
Chemical Analysis Equipment B	• Implementation of assembly, installation and inspection • Guidance on operation and maintenance technology for ICP Emission Spectrometer, Infrared Spectrometer and Spectrophotometer	M. Inoue	S. Sulami A. G. Dalvi M. A. Javeed Radwan Rasheed
Chemical Analysis Equipment C	• Implementation of assembly, installation and inspection • Guidance on operation and maintenance technology for X-ray diffractometer	S. Sakano	Andijani Al-Fozan Shahreer
Chemical Analysis Equipment D	• Implementation of assembly, installation and inspection • Guidance on operation and maintenance technology for Ionchromatograph • Preparation of English Version of Operation Manual	N. Kawashima H. Ohtsuka	S. Sulami A. G. Dalvi Azhar A. Nomani Radwan Sulaiman

Table 3 Parts and Equipment Supplied by JICA

No.	Description
1.	Additional Parts for MSF test Plant
1.1	Pumps & Motor for Distilate Sampling
1.2	Prefab Piping for Distilate
1.3	Pump & Motor for Brine Samoling
1.4	Prefab Piping for Brine Sampling
1.5	Boss for Probe Sampling
1.6	Oil Tank(100 liter)
1.7	Pump & Motor for Oil Feed
1.8	Oily water Sepatrator
1.9	Piping Materials for Oil Feed and Oily Water Separator
1.10	Pump Suporter
1.11	Resistance Bulb
1.12	Hybrid Recorder
1.13	Control Panel
1.14	Cable (CVV-5),Cable(CV600V)
1.15	Glove Valve etc.
2.	Vapor/Liquid Equilibrium,Main Equuipment and Mounting Suport Frame
3.	Mini-module Test Equipment(1)
4.	Mini-module Test Equipment(2)
5.	Full Automatic Water Chilling Unit
6.	Equipment for Preparative RO Experiment(1)
6.1	Disperger
6.2	Coagulation Tank
6.3	Stirrer
6.4	Ultra High Purity Water System
6.5	Gas Chromatograph Column
6.6	Laboratory Stand
6.7	Column Holder
6.8	Boiling Stone
6.9	Attachments for TOC
6.10	Sand Filter Column
7.	Equipment for Preparative RO Experiment(1)
7.1	Ultrasonic Homogenizer
7.2	Quartz Cell for Oil Measuring Equipment
7.3	Roller Pump
8.	Parts for EPMA
9.	Parts for Infrared Spectrophotometer
10.	Accessories for 2pen Recorder
11.	Parts for X-ray Diffractometer D/MAX
12.	PR Gas (Proportional Gas)

Table 3 Parts and Equipment Supplied by JICA

No.	Description
13.	Additional Parts for RO test Plant
13.1	Pumps for RO Test Plant
13.2	Belt Cover of High Pressure Pump
13.3	Terminal Box
13.4	UV Sterilizer
13.5	Victaulic Joint
13.6	Junction Box Case
13.7	Conduit Pipe
13.8	Ragging Materials
13.9	Tightening Bolts for M10-01
13.10	Tightening Bolts for HE-201
13 11	Pressure Gauge
13.12	Pneumatic Operated Butterfly Valve
13.13	Manual Valve
13.14	Piping Materials
13.15	Spare Parts for Pumps, Electric Equipment
13.16	Analytical Equipment
14	Pretreatment Equipment of Oil Contaminated Seawater
14.1	Oil Addition Adjusting Equipment
14.2	Adsored Oil Removing Equipment
14.3	Adsorbed Oil Recovery Equipment

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

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

Prevention of scaling in heat exchanger tubes is a continuing problem for MSF plant operations. The performance of MSF plant will be significantly deteriorated when the fouling factor of the tubes increases by scaling and results in increase of the water production cost. Consequently, many kinds of scale prevention method have been tested. Recently, however, the chemical dosing is the main method for the scale prevention.

The mechanism of scaling is highly complicated and it is not able to clarify the mechanism even by the present advanced science. Thus, in case of the selection for the scale inhibitor, *empirical approach is adopted instead of theoretical approach.* However, *it is not practical* to use a commercial plant for the test of the scale inhibitors, since they should be tested under various conditions for a long time period.

This research was aimed for the systematic investigation on the scale prevention by chemical dosing method, starting from the fundamental experiments in laboratory and proceeding to the tests using the MSF Test Plant. Those results obtained from this research are in good agreement with the understandings and knowledge which had been attained from actual plant operations. We believe that this research made considerable contribution to the knowledge on scale prevention of the MSF plant.

5.1 Investigation and Preparative Experiments

5.1.1.A. MSF Plant Survey

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)**

5.1.1.B. The Status of MSF Plants

1. Introduction

SWCC has been operating many Multi-Stage Flash (MSF) desalination plants (MSF plants) for over 25 years, starting from the operation of the MSF plant phase I at Duba in Kingdom of Saudi Arabia in 1968. Many researchers and discussion 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 them experimental conditions and evaluation of the results under the series of MSF-1 tests.

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

2.1 Abstract 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.

2.2 Discussion about Operating Conditions

The operating conditions by the paper* are as follows.

(1) The evaporator operating parameters are shown in Table 1.
(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 operations were restricted to the bare minimum with a TBT limit of 105 degrees centigrade.

3. Remarks

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

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* Mohammed Abdul-Kareem Al-Sofi et al; A full decade of operating experience on Al-Kohbar-II Multi-Stage Flash (MSF) Evaporators (1982-1992)

3. 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 bench scale, were confirmed at the actual plants.

a. **TBT is from 90 to 112 degrees centigrade, considering the future operation**
b. **Antiscalant dosing rate is less than 2 ppm**
c. **Brine concentration is 1.4 times the sea water in the Arabian Gulf which conforms to the case of Al-Jubail Phase II plants.**

Table 1 Evaporator Operating Parameters of Al-Khobar-II

Variables		LTO		HTO			
		Design	Actual	Design 120%	Actual 134%	Design 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	m^3/h	12,257	12,000	11,100	11,100	11,000	11,000
Make-up Flow	m^3/h	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	m^3/h	144	135 to 145	167	192	160	190
Product Water Flow	m^3/h	895	920	1,075	1,210	1,100	1,220
Performance Ratio	kg/2326kj	6.5		6.88	6.9	6.9	7.0

5.1.2 Experiment for Selection of Scale Inhibitor

1. Introduction

There are many types of scale inhibitors on the market. It is difficult to discriminate among them, and it is not easy to make a selection for use in an actual plant by checking the properties of each scale inhibitor. 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 the initiation of scale formation, that is, the threshold effect, and the second is to confirm the effectiveness of the scale inhibitor 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.

2. Purpose

This study was conducted in order to confirm the threshold effect of each antiscalant by knowing the changes of M-alkalinity versus retention time. Retention time versus scale inhibitor dose rate in 500 ml of artificial brine of 1.4 times the normal sea water 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.

The assumption 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.

3. Experimental Method

3.1 Materials

Scale Inhibitors

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

3.2 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.

(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.

Table 2 Properties of Scale Inhibitors for Screening Test

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

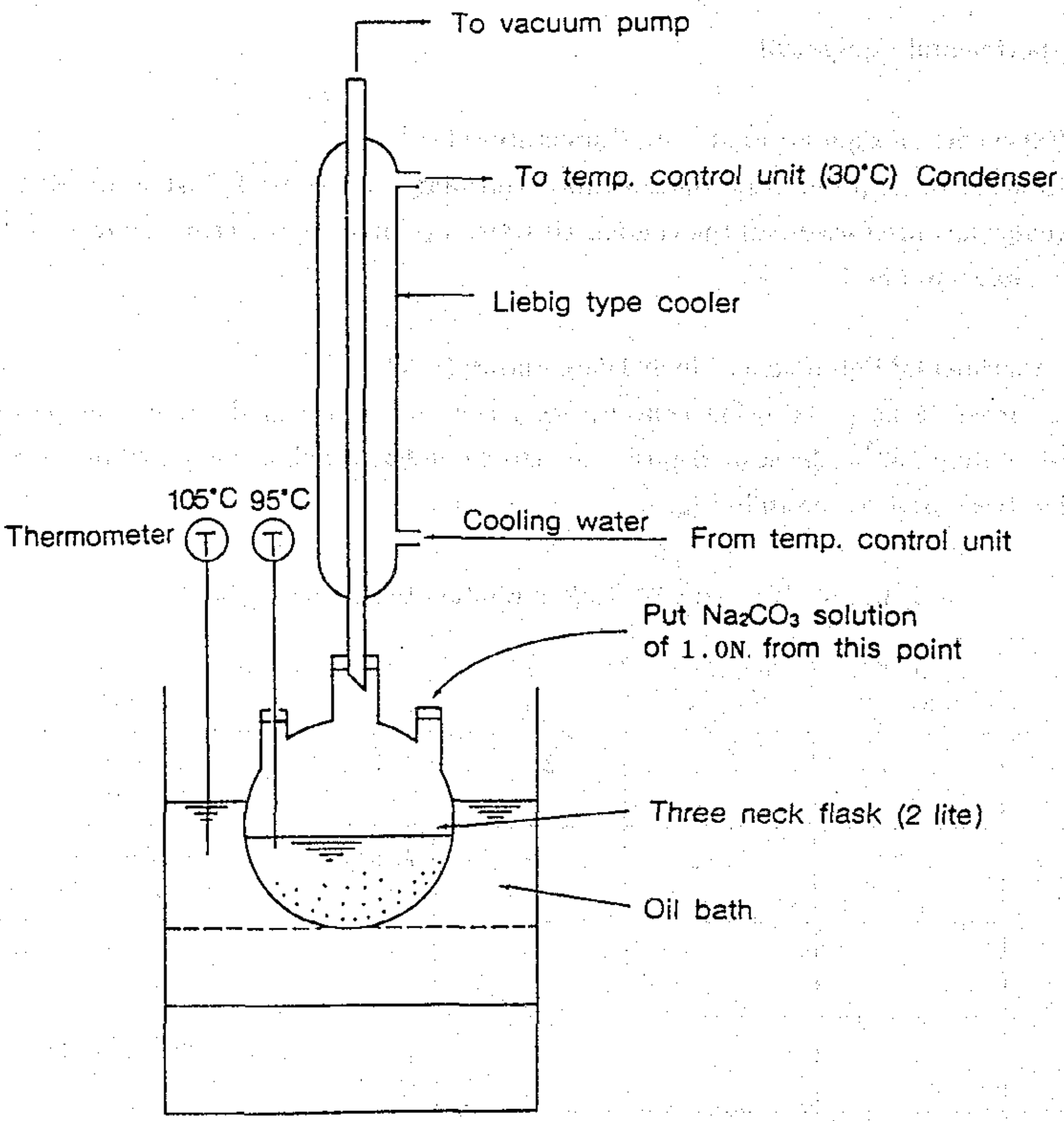


Fig. 1 Test Equipment for Low Temperature (95℃)

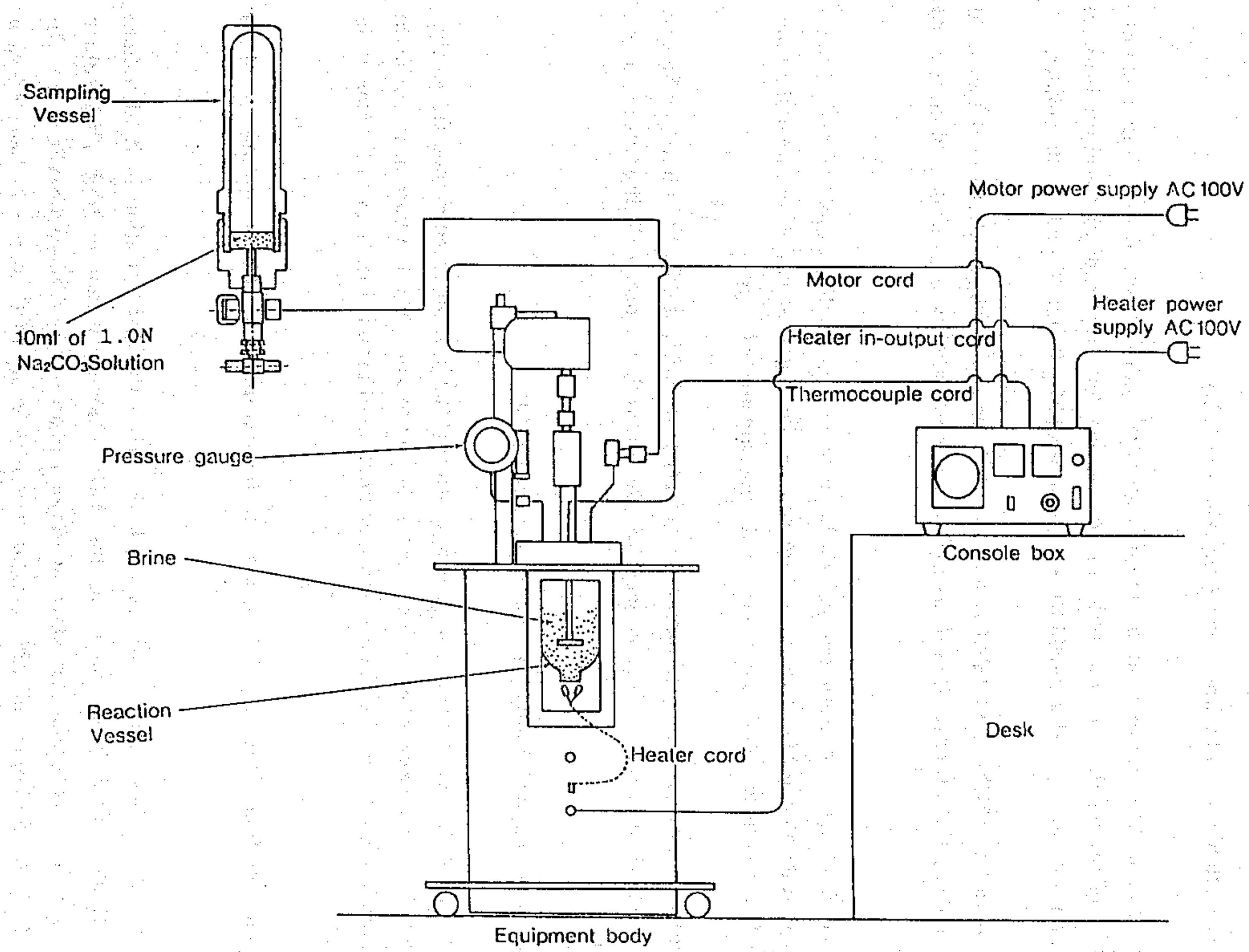


Fig. 2 Test Equipment for High Temperature (110℃)

4. Discussion

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

As the result of the experiment at low temperature (95℃), 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), PPN(M) had the lowest value of M-alkalinity and the shortest holding time at dosing rate of 0.5 ppm, though, had no typical relationship between dosing rate above 0.7 ppm.

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.

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

As the result of the experiment at high temperature (110℃), 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 as a candidate for the next test with the heat transfer test equipment.

5. 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 equipment.

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

(2) PPN(M) and PPN(A) have the highest threshold effect at the 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 test equipment.

(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 equipment.

5.2 Test with the Heat Transfer Test Equipment

1. Introduction

It is well known that scale inhibitors have an effect which prevents adhesion between the individual precipitated particles or between the particles and solid (metal) surfaces with which they are in contact. This occurs because the scale inhibitor completely distorts the soft scale composed of normal regular crystals.

It is generally pointed out that the scale distorted by a scale inhibitor is easier to disperse, and that the normal flow of water in the distillation plant is sufficient to keep the small particles on the move until they are removed from the plant during normal blow-down as an effluent brine. For this reason scaling does not easily occur.

Crystal distortion effect of a scale inhibitor can be confirmed at an actual plant by means of measuring the decrease in heat transfer efficiency, that is, the increase of the fouling factor of the heat transfer tubes in this study.

2. Purpose

This study, which is meant to be the second step of the selection test using the heat transfer test equipment, has been carried out in order to confirm the crystal distortion effect of PPN(M) by determining the fouling factors at 90℃ and 102℃.

The heat transfer test equipment, which is constructed as a recirculation system so as to operate continuously, has a capacity of heat load of 4–8kW/m^2 at a velocity of brine in the heat transfer tube of 1.8–2m/s. The brine to be used has almost the same water quality as the actual plant.

Through the above process, experimental and evaluation method will be established.

3. Experimental method

3.1 Materials

Scale inhibitor

Name, physical properties, composition and results of the experiment on threshold effect, which were to be used for this test, are shown in Table 3.

3.2 Experimental Equipment

A flow sheet for the heat transfer test equipment is shown in Fig. 3.

Table 3 Properties of Scale Inhibitors for Heat Transfer Test

Name	Specific Gravity	pH	Major Constituent	Results of Test on Threshold Effect
PPN(M)	1.37	11.0	Polyphosphonate	Best Quality at 95°C & 110°C

3.3 Experimental Conditions

(1) Brine temperature

a. Experiment at normal temperature

Since the outlet temperature of the brine heater during normal operation is 90.56℃ in Al–Jubail Phase–II Plant, it was decided that the experiment should be conducted at 90℃.

b. Experiment at high temperature

The temperature condition, which was above 90℃, was set at 102℃.

(2) Dose rate of scale inhibitor

It was confirmed in the previous study of threshold effect that the optimum dose rate of scale inhibitors is 2ppm, and also that the retention time at which threshold effect was lost is about 20 minutes.

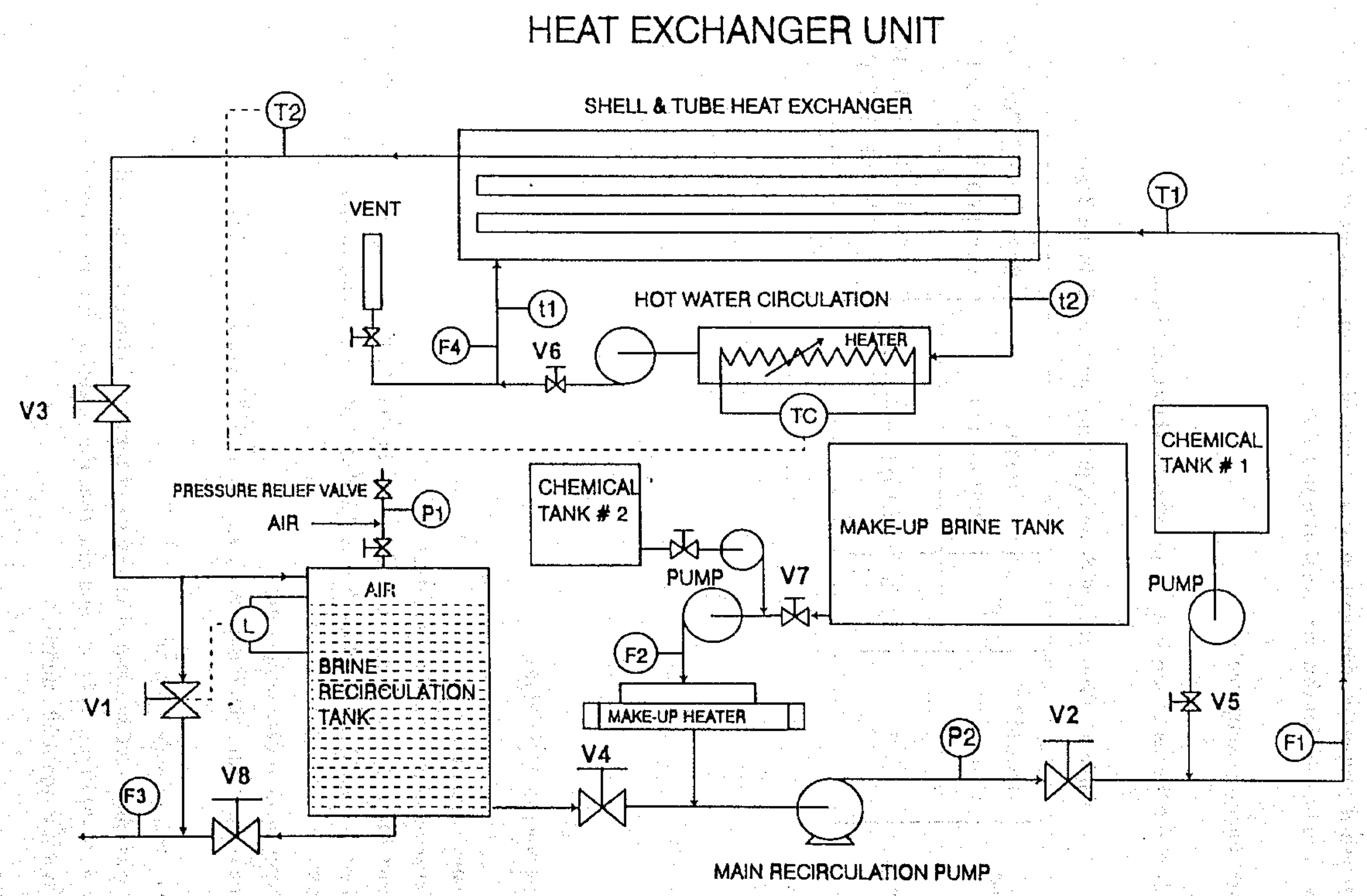


Fig. 3 Flow Sheet for the Heat Transfer Test Equipment

4. Results and Discussion

Figure 4 show that values of fouling factor are at about zero at the beginning of both runs, at 90℃ and 102℃. Fouling factor then increases with time at slow linear rates where its values reach about 0.07 and 0.08m^2K/kW at 90℃ and 102℃ respectively.

Comparisons of heat transfer behaviors in blank tests to those of additive tests show that effectiveness of the scale inhibitor is quite significant. Also a comparison between the heat transfer behavior in the additive tests show that the rate of fouling at 102℃ is slightly higher than that at 90℃. This is expected since the process of scale formation and deposition is temperature dependent.

The clean value of heat transfer coefficient taken as the reference for calculating fouling factors as fixed for all runs at 1.58kW/m^2K. One may notice that values of heat transfer coefficient at the start of blank tests are slightly lower than those of additive tests which have resulted in slightly higher values for fouling factors at the start of blank tests as compared to additive tests. This can be explained by the fact that the heat exchanger tube was replaced when leakage was observed after completion of blank tests and a new tube was installed for the additive tests.

5. Conclusion:

1. Experiments were carried out using a laboratory scale heat exchange test equipment which facilitates heat transfer measurements under conditions that resemble those in the brine heater of MSF plants.
2. Results obtained from the experiments, though they are very limited, show that this technique where heat transfer measurements are used in determining the effectiveness of a given scale inhibitor can be successfully used.
3. Further tests where scale inhibitors can be tested for longer durations (1000–2000 hours) are requested. Such tests will make available a body of data and results which can be reliably used in validating the present technique and in determining its effectiveness.

(5)

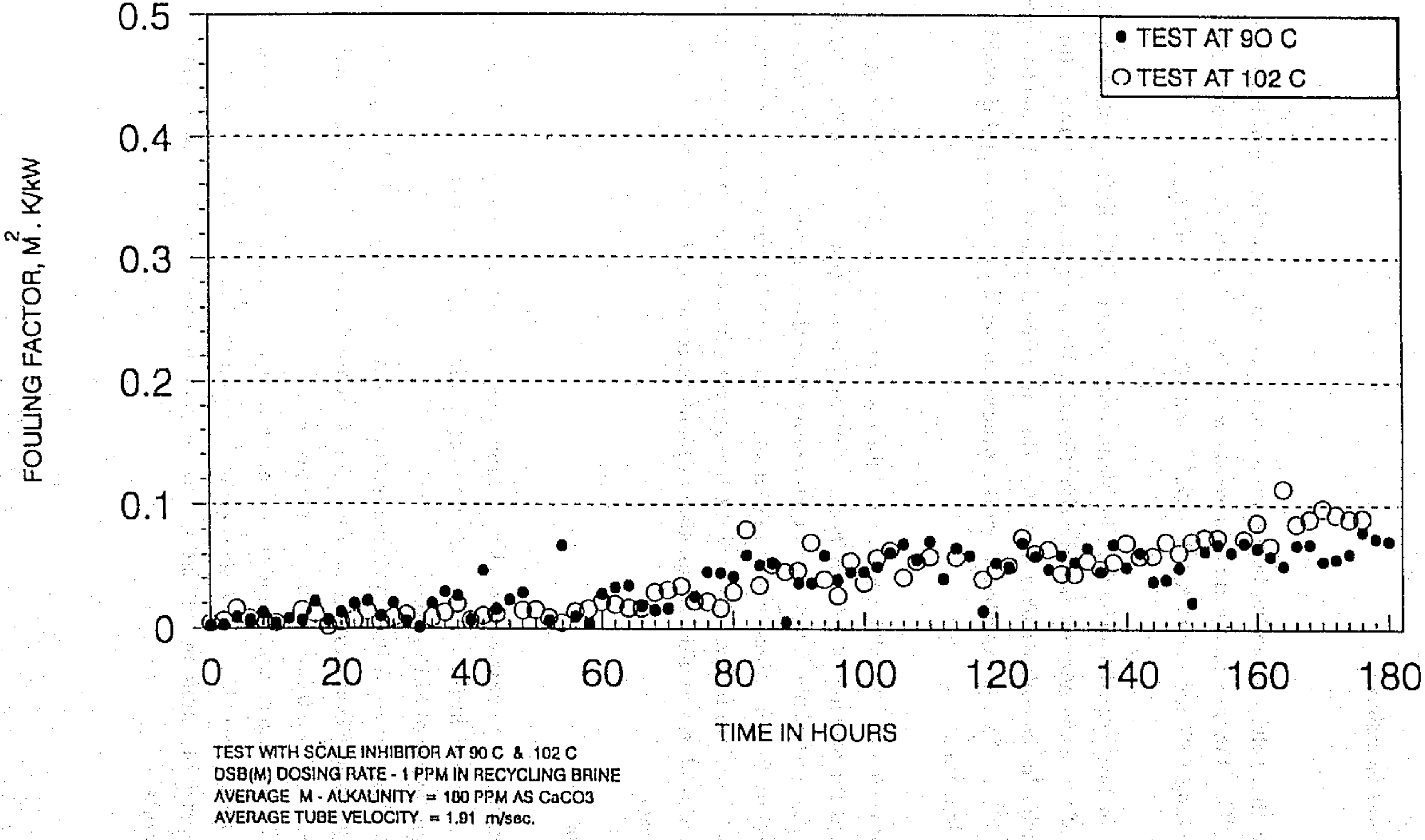


Fig. 4 Time Dependency of Fouling Factor in Test 3 and 4

5.3 Tests with the MSF Test Plant

5.3.1 Installation of the MSF Test Plant

1. Introduction

The installation work for the MSF Test Plant has progressed as scheduled. The boiler fuel oil for trial run and performance tests was prepared by mixing heavy oil (Bunker C) and light diesel oil at a predetermined ratio.

P&I Diagram of 20t/d MSF Test Plant is illustrated in Fig. 5.

2. Installation and Commissioning

The installation and commissioning of the MSF Test Plant began on July 31, 1993 and finished on November 1, 1993.

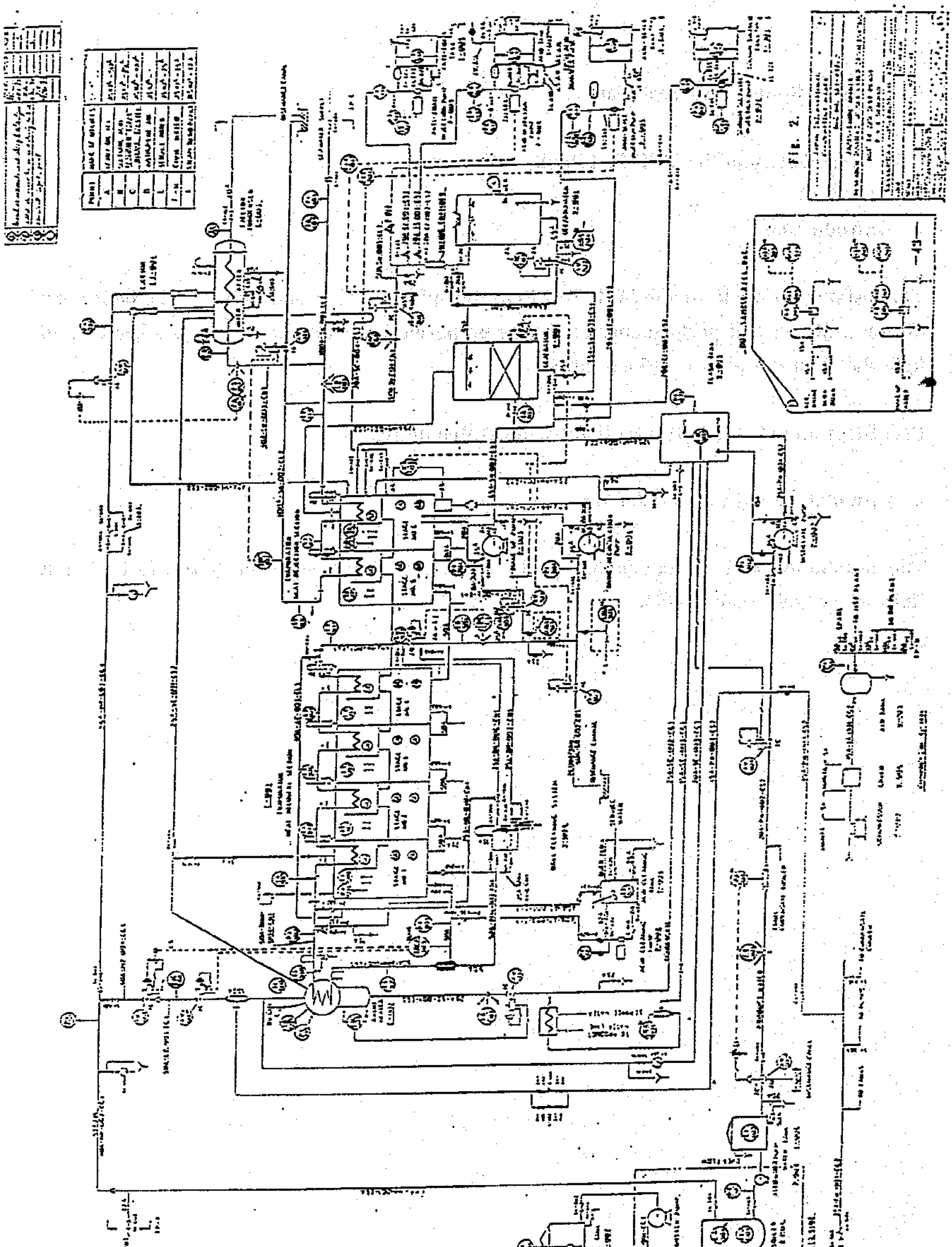


Fig. 5 P&I Diagram of 20t/d MSF Test Plant

5.3.2 Results of Trial Run and Performance Test

1. Introduction

After all installation works of the MSF test plant have been completed, the plant was ready to undergo a series of tests to confirm its performance.

In this section, the results of the performance tests and the trial run are reported.

2. Results of performance Test of MSF Test Plant

Table 4 shows the results of the heat balance check which was conducted during the performance test.

The amount of water produced at a top brine temperature of 112℃ was 0.80t/h, which was about 1.07 times as the design value of 0.75t/h. Thus, it was proved that the design value was satisfied sufficiently.

Following this, the overall coefficient of heat transfer in brine heater and heat recovery and rejection stages were measured as a part of the performance test. The result of this measurement is shown in Table 5. According to these results, variations in the values of the overall heat transfer coefficients (U–value) are recognized at each evaporation stage.

It is considered, however, that this problem can be solved by the adjustment of the venting system. These overall heat transfer coefficient are a reference on which the calculation of the fouling factor is based. Thus, it is the most important value in the test of MSF–1. Therefore, it was decided that a re–adjustment would be made when this test is resumed.

Table 4 Heat Balance of MSF Test Plant Obtained in the Performance Test

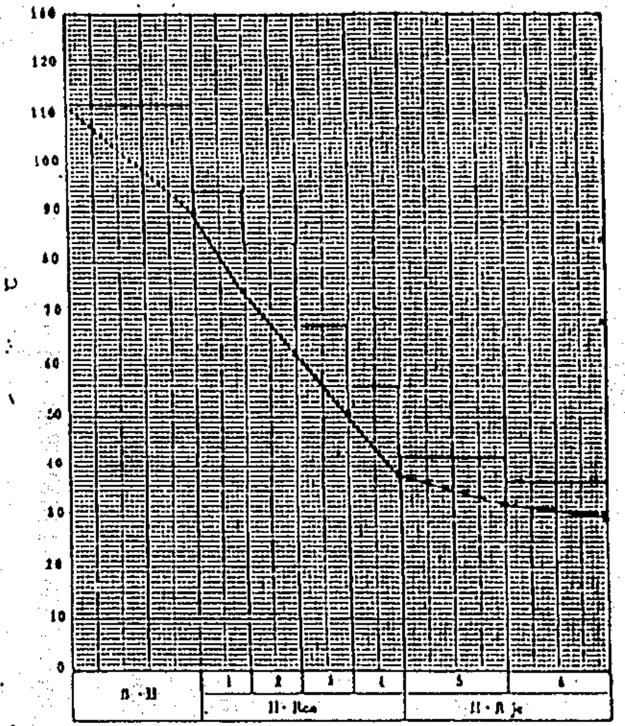
Run No.	–	Measuring Date	29-OCT-'93	14° 45'	Total Ope. Time	hrs
Flow Rate (t/h)		Feed SW (FR201)	Recir. B. (FR301)	Product W(FR401)	Condens. (FRG01)	HRje SW (FR101)
		3.25	6.53	1060-260=800	260	17
Pressure		Supply S. (PI605)	BH Shell (PI603)	Eject. S. (PI604)	BH Out B. (PI303)	Deaerator (PI)
		8.2 kg/cm²G	0.6 kg/cm²G	8 kg/cm²G	1.0 kg/cm²G	torr
Concentration		Feed SW ( )	Recir. B. ( )	Product (CRA401)	Condens. (CRG01)	
		ppm	ppm			
Efficiency		Performance R.	Concentration R.			
		3.08 (2.4)				

Temperature	Position		Brine HTR	Heat Recovery Section 1S	2S	3S	4S		Heat Rejection Section 5S		6S
	In Tube	TI	309	308	307	306	305	304	106	105	104
		℃	112	90	74	62	51	37	38	32	30
	F. Chamb. G. Phase	TI	TR-602	501	502	503	504		505		506
		℃	114	94	84	68	56		42		37
	F. Chamb. L. Phase	TI									
		℃									
	Steam	TI	Heating Steam 601		Condensate				Product Water		
		℃	120								

Condition of Ball Cleaning		
	Starting Time of Cleaning	
	Finishing Time of Cleaning	
	Cleaning Time per an Inning	
	Numbers of Inning	
	Total Cleanig Time	
	Numbers of Ball Thrown	
	Numbers of Ball Recovered	

<MEMORANDUM>

HEAT CYCLE



Atomospheric Phenomena	Temperature	Pressure

SIGNATURE

Table 5 Overall Heat Transfer Coefficient

Operation Date. Time	Calculation Item			Brine Heater	No. 1 Stage	No. 2 Stage	No. 3 Stage	No. 4 Stage	No. 5 Stage	RUN No. No. 6 Stage	– NOTE
Date	Flow Rate	W	kg/h	6530	6530	6530	6530	6530	12000	12000	
29. OCT '93	Specific heat	Cp	kJ/(kg K)	3.966	3.943	3.929	3.977	3.905	3.896	3.893	
Time	H. E. Outlet Temp.	T_2	℃	112	90	74	62	51	38	32	
14'45	H. E. Inlet Temp.	T_1	℃	90	72	62	51	37	32	30	
Total	Rising Temp.	ΔT	℃	22	16	12	11	14	6	2	
Ope. Time	H. Trans. Rate	Q	kJ/s	158.265	128.74	85.521	78.155	99.165	110.387	36.761	
	H. Trans. Area	S	m²	4.6723	4.937	4.937	4.937	4.937	4.9556	4.9556	
	F. Chamb. Temp.	t	℃	114	94	84	68	56	42	37	
B. Cleaning	L. M. T. D	ΔT_m	K	8.8535	10.559	15.22	10.562	10.481	6.548	5.944	
Frequency	U Value	U	kW/(m² K)	3.8995	4.2712	2.8974	3.818	4.8773	3.400	1.2475	
	Clean-U Value	U_c	kW/(m² K)								
	Fouling Factor	f_s	(m² K)/kW								

MEMORANDUM : $1J = 2.38889 \times 10^{-4} kcal = 2.77778 \times 10^{-7} kW \cdot h = 0.101972 kgf \cdot m$
$1kW = 860 kcal/h = 3.600 kJ/h$

Calculation Formula	$\Delta T = T_2 - T_1$ $\Delta t_1 = t - T_1$ $\Delta t_2 = t - T_2$ $\Delta T_m = \Delta T / \ln(\Delta t_1 / \Delta t_2)$ $Q = WCp\Delta T$ $U = Q/(S\Delta T_m)$ $f_s = (1/U) - (1/U_c)$

5.3.3 Test with Single Scale Inhibitor

1. Introduction

Based on the results explained in the previous sections, PPN (M) has been selected as the scale inhibitor to be further tested by the MSF Test Plant under the condition of single inhibitor dosing.

This section reports the results of tests with the MSF Test Plant.

2. Test Plan

2.1 Basic concept of the test

The heat transfer fouling factor, which directly relates to the increase of heat transfer resistance by scaling, had been measured to evaluate the effect of a single inhibitor dosing. The time dependency of the fouling factor of the heat transfer tube has been traced with PPN(M) dosing.

2.2 Method of calculation of fouling factor

The fouling factor is defined by the following equations.

$$\Delta T = T_2 - T_1 \qquad (2.1)$$
$$\Delta T_1 = T - T_1 \qquad (2.2)$$
$$\Delta T_2 = T - T_2 \qquad (2.3)$$

Using the equations 2.1, 2.2 and 2.3,

$$\Delta Tm = (\Delta T_2 - \Delta T_1)/\ln(\Delta T_2/\Delta T_1) \qquad (2.4)$$

On the other hand,

$$Q = WCp\ \Delta T \qquad (2.5)$$

Using the equations 2.4 and 2.5

$$U = Q/(S\ \Delta Tm) \qquad (2.6)$$

The fouling factor F_o is defined as

$$F_o = (1/U - 1/U_c) \quad (2.7)$$

Where

T_1	:	Temperature of seawater/brine at the inlet of the heat-transfer tube	℃
T_2	:	Temperature of seawater/brine at the outlet of the heat-transfer tube	℃
T	:	Steam/vapor temperature outside the heat-transfer tube	℃
ΔT_m	:	Logarithmic mean temperature difference (LMTD)	K
W	:	Flow rate of seawater/brine	kg/h
S	:	Area of heat-transfer surface	m^2
Cp	:	Specific heat of seawater/brine	kJ/(kg K)
Q	:	Quantity of heat transfer across the tubes	kJ/h
U	:	Overall heat transfer coefficient	kW/(m^2 K)
Uc	:	Overall heat transfer coefficient at the initial condition	kW/(m^2 K)
Fo	:	Fouling factor	(m^2 K)/kW

2.3 Test conditions

The operation conditions planned in May, 1994 and conducted are shown in Table 6. The details of the test plant operation progress are shown in Fig. 6.

3. Experimental Method

The flow diagram of the MSF test plant, capacity of 20ton/day, is shown in Fig. 5.

4. Results

4.1 Results of U-value measurement

Time dependency of the fouling factor during RUN 3, 4 and 8 are shown in Figs. 8, 9 and 10. The fouling factors are kept between 0.2–0.3m^2K/kW during 300 hours test period when the concentration factor was less than 1.2.

In case when the concentration factor is raised to 1.4, U-value tends to decrease due to

scaling, and the increase of vapor consumption, thus decrease in performance ratio, has been observed as the outlet temperature of brine at brine heater was kept at 112℃. Also, the effect of ball cleaning was clearly observed in the condition.

Table. 6 Operation Conditions of MSF Test Plant for MSF-1 and MSF-2

ITEMS / RUN NO	UNIT	1	2	3	4	5		6		7	8	9	REMARKS
						5 — 1	5 — 2	6 — 1	6 — 2				
1. Objective	----	MSF-1	MSF-1	MSF-1	MSF-1	MSF-1	MSF-1	MSF-2	MSF-2	MSF-2	MSF-1	MSF-2	
2. Operation period (from)		Feb. 03	July10	July25	Sep. 24	Oct. 15	Oct. 24	Oct. 30	Nov. 06	Nov. 14	Nov. 16	Dec. 06	
(to)		Feb. 17	July18	Aug. 13	Oct. 07	Oct. 23	Nov. 07	Nov. 05	Nov. 12	Nov. 15	Dec. 06	Dec. 07	
3. Operation time	hour	324	180	456	320	143	230	114	142	30	472	24	
4. Scale control method *1		Chemi.	Chemi.	Chemi.	Chemi.	Hybrid	Hybrid	Hybrid	Chemi.	Chemi.	Chemi.	Chemi.	
5. Operation mode		Recir.	Recir.	Recir.	Recir.	Recir.	Recir.	Recir.	Recir.	Once	Recir.	Once	
6. Ball cleaning		Once/ 8hours	Once/ 8hours	Once/ 8hours	None*2	None*2	As needed *3	As needed *3	As needed *3	None	As needed *3	None	
7. Top brine temperature	°C	100-112	100-112	112	112	112	112	112	112	112	112	112	
8. Flow rate													
-Make up seawater	m^3/h	3.6	3.6	3.6	3.75	3.25	2.45	2.45	2.3	6.40	2.42	6.40	
-Recirculation brine	m^3/h	5-6.5	5.9-6.5	6.5	6.5	6.5	6.5	6.5	6.5	—	6.5	—	
-Product water	m^3/h		0.55	0.70	0.76	0.79	0.79	0.81	0.86	0.9	0.9	0.9	
-Blow down brine	m^3/h		3.1	2.9	2.99	2.46	1.66	1.64	1.44	5.55	1.52	5.5	
9. Chemical consituents of brine													
-pH at 25°C	-	—	—	8.43	8.52	8.01	8.12	8.0	8.52	8.24	8.52	8.25	
-M-Alkalinity as $CaCO_3$	mg/L	—	—	144	143	45-50	55-60	55-60	180	128	180	128	
-Chloride ion	mg/L	—	—	25,600	26,770	28,290	32,720	32,730	33,320	23,360	33,100	23,350	
-Concentration factor as Cl^-	-	—	—	1.12	1.15	1.22	1.39	1.40	1.40	1.00	1.40	1.0	
10. Dosing rate of chemicals													
-Scale inhibitor = PPN(M)	mg/L	2	2	2	2	1	1	1	2	2	2	1	
-Acid = 98% H_2SO_4	mg/L	None	None	None	None	72	72	72	None	None	None	None	
-Trihalomethane = $CHBr_3$	mg/L	—	—	—	—	—	—	0.5	2.75	—	—	—	
-Oil = Light Diesel Oil #2	mg/L	—	—	—	—	—	—	—	—	10	—	2.5	B.H:
11. Injection point of chemicals		—	—	—	—	—	—	After B.H	Brfore Dea.	After B.H	—	After B.H	Brine Heater

(Note) *1:Chemicals = PPN(M). Hybrid = PPN(M) + H_2SO_4
*2:Be carried out only at start.
*3:Be carried out only in the case of arriving at fouling factor in the brine heater of 0.34-0.36 m^2K/kW

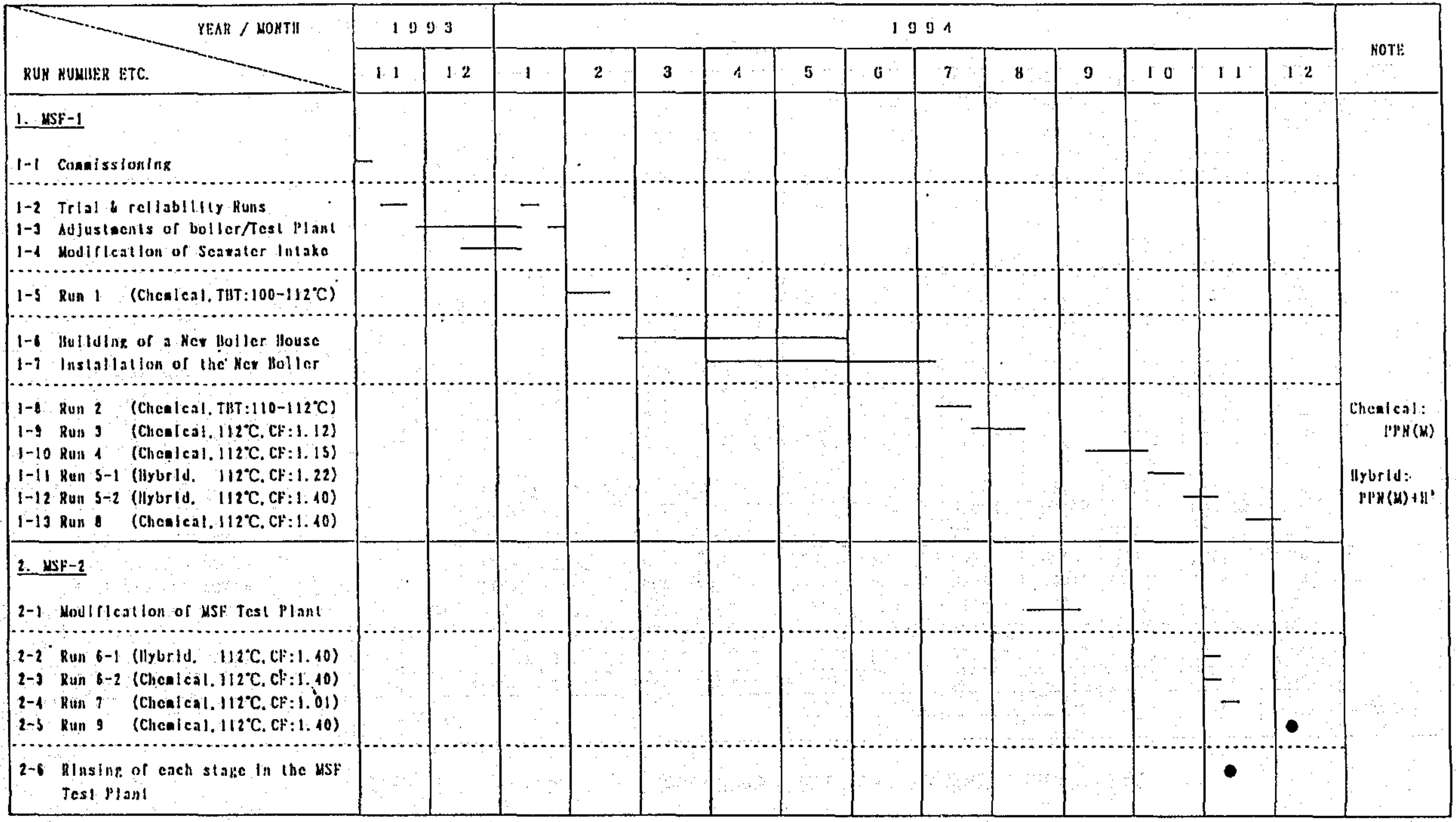


Fig. 6 Operation Progress of Test Plant for MSF–1, MSF–2

(5)

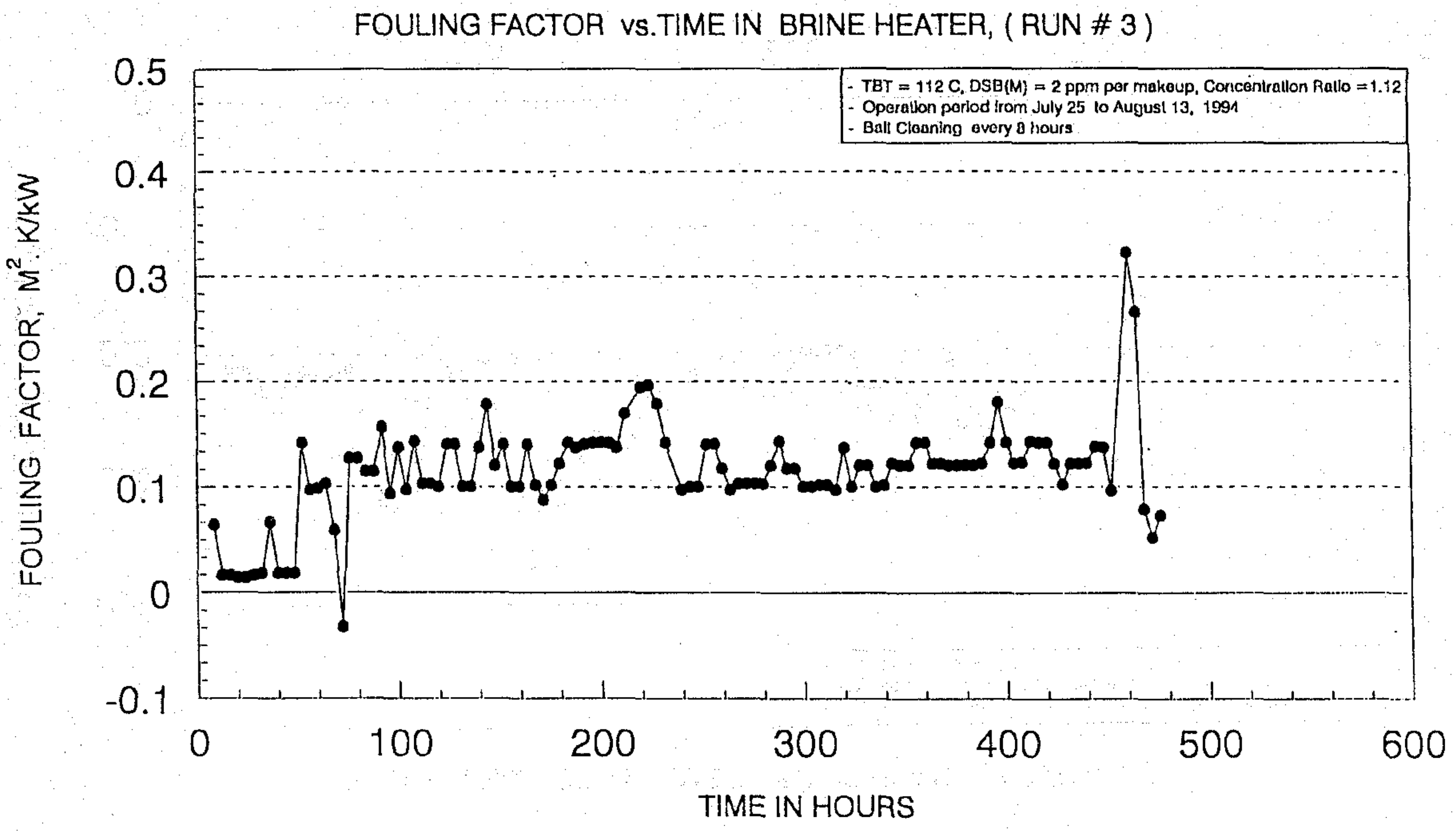


Fig. 7 Time Dependency of Fouling Factor of Brine Heater in RUN–3

(5)

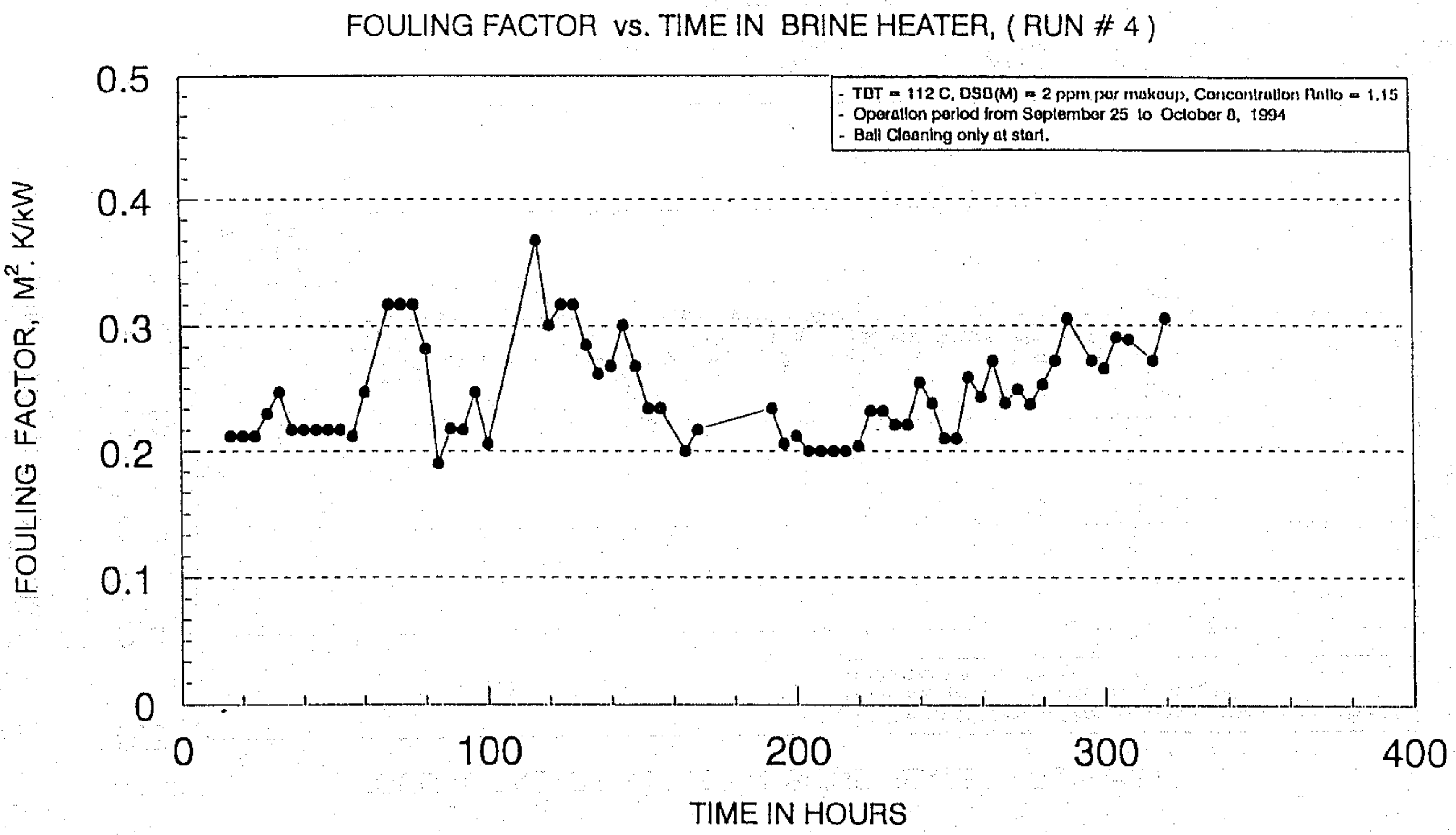


Fig. 8 Time Dependency of Fouling of Brine Heater Factor in RUN–4

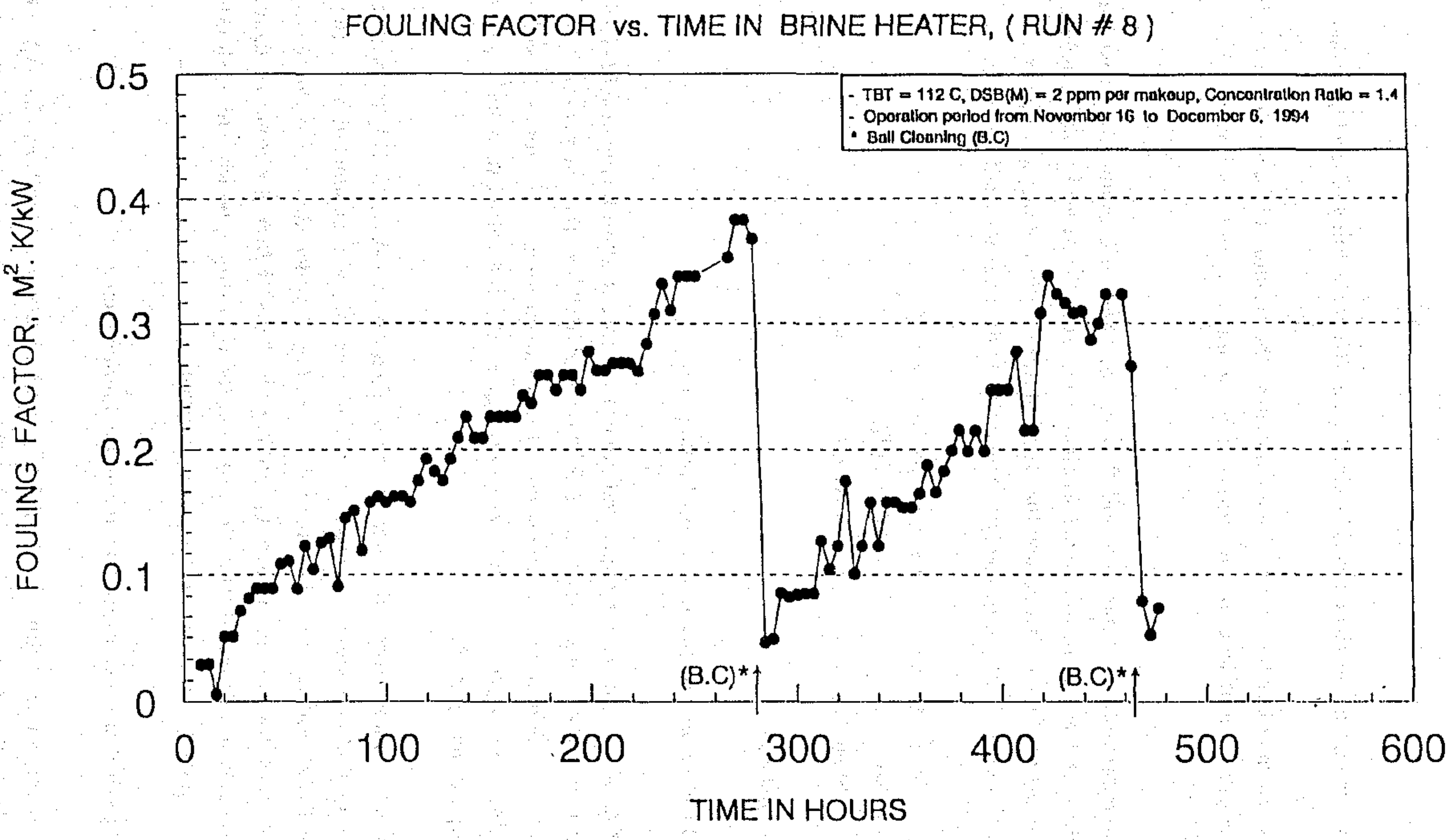


Fig. 9 Time Dependency of Fouling Factor of Brine Heater in RUN–8

4.2 Determination of Heat Transfer Coefficient (U) at the Start of the Operation

In order to calculate the fouling Factor based on the formula (2.7), a reference value for the heat transfer coefficient at the initial stage known as the clean value (Uc) should be determined.

Experimental data of Runs 1–5 and 8 were reviewed to examine the consistency of the theoretical and experimental values as clean values for the overall heat transfer coefficient. It was concluded from this review that the following values obtained experimentally during commissioning tests are to be used as clean overall heat transfer coefficient Uc:

Brine Heater	: 3.70 kW/m^2K
Stage #1	: 6.29 kW/m^2K
Stage #2, 3 & 4	: 4.88 kW/m^2K

5. Discussions

5.1 The effect of ball cleaning on the fouling factor

The effect of the ball cleaning operated under the concentration factor of 1.12–1.15 has been examined by comparing the data of RUN–3 and RUN–4, the former applying the ball cleaning every eight hours and the latter without ball cleaning. The fouling factor of RUN 3 was stable around 0.1–0.15m^2K/kW, while that of RUN–4 raised to 0.3m^2K/kW since ball cleaning was not applied.

On the other hand, when the concentration factor was raised to 1.4, RUN 8, the linear increase of fouling factor was observed. Ball cleaning was conducted when the U–value became 3.70kW/m^2K. The effects are shown in Fig. 9, which shows that the recovery of U–value is incomplete and remaining fouling is 0.05m^2K/kW by fouling factor. This characteristics are different from the results of hybrid method, which will be shown in 5.3.4. In hybrid system, complete recovery was observed.

5.2 The effect of concentration factor on the fouling factor

In case of the concentration factor of 1.15 (M–alkalinity = 140mg/L as $CaCO_3$), RUN 4, no increase in fouling factor was observed. However, when the concentration factor has been raised to 1.4 (M-alkalinity = 180mg/L as $CaCO_3$), RUN 8, the fouling factor showed apparent increase.

Despite the decrease in the M-alkalinity to 45-60mg/L, the fouling factor increases as the concentration factor increases, as shown in RUN-5.

5.3 Time dependency of the fouling factor

Time dependency of the fouling factor can be formulated as follows according to the data obtained from RUN 8, which concentration factor was 1.4 and M-alkalinity was 180mg/L as $CaCO_3$.

RUN No.	M-alkalinity	Initial Stage	After 1st B.C.	Recovery by B.C.
8	180mg/L as $CaCO_3$	$Fo=1.31*10^{-3}t$	$Fo=1.80*10^{-3}t$	85.7%

Where, BC : Ball cleaning
Fo : Fouling factor after t hours (m^2 K/kW)
t : Time (>30h) (h)

After initial transient region of 30 hours, fouling factor increases linearly, but the increasing rate after ball cleaning is higher than at the start of operation. The recovery ratio of fouling factor by ball cleaning is 85.7% of the initial value.

Consequently, ball cleaning should be applied before significant fouling has occurred. Ball cleaning applying every eight hours like this test would be appropriate.

6. Conclusions

For the purpose of the evaluation of the scale inhibitor, PPN(M), in case of top brine temperature of 112℃, the MSF test plant has been operated for total 2350 hrs and following results has been obtained.

(1) The scaling is low when the concentration factor is about 1.2, but scaling becomes apparent when concentration factor is increased to 1.4.
(2) The increase in fouling factor of the brine heater in case of concentration factor of 1.4

is 1.31x10^{-3}m^{2}K/kW/hr. However, the fouling factor decreases to 0.05m^{2}K/kW when ball cleaning is conducted.

(3) Ball cleaning does not remove scale completely, and the increase of fouling factor after ball cleaning is observed as the operation time increases.

(4) Ball cleaning should be applied before obvious increase of fouling factor is observed. This conclusion is in good agreement with the experience of the actual plant operation.

5.3.4 Test with the Simultaneous Use of Single Scale Inhibitor and Acid

1. Introduction

Following the single dosing test, the effect of combined dosing of scale inhibitor and acid, so called hybrid method, on fouling factor has been investigated from October 15 to 30, 1994.

This section reports the results of the hybrid method test.

2. Preparative survey on the Hybrid Method

The operation record of the MSF plant of Qurayyah Power Plant, 4,000x3ton/day, Saudi Consolidated Electric Company (SCECO), which has the experience in actual hybrid operation, has been surveyed for the information on the M-alkalinity.

In this plant, the brine quality during the hybrid operation is controlled as follows.

- pH of brine : 7.8 – 8.3(25℃)
- M-Alkalinity as CaCo3 : 24 – 43ppm
- Concentration factor(as Cl^-) : 1.2 – 1.3

3. Results

The operation of the MSF Test Plant for the hybrid method had been conducted with CF = 1.2.2 and 1.4.

The M-alkalinity of the circulating brine for both tests had been reduced to 1/3 of the single inhibitor dosing tests. The pH of the circulating brine had been controlled above 8. The ball cleaning had been applied only when the fouling factor of the heat transfer tube exceeded 0.34–0.36m^2 K/kW. The deference between RUN 5-1 and the RUN 5-2 is the concentration factor, which was controlled by the amount of the make up feed seawater.

The time dependency of the U-value of each RUN are shown in Figs.10 and 11.

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1) Chemical Engineering Hand Book : p 422 (Fifth Edition)

(5)

As is shown in the RUN 5-1, the fouling factor of brine heater was $0.2m^2K/kW$ under concentration factor of 1.22 up to 143hrs.

In the case where the concentration factor has been raised to 1.4, RUN 5-2, the U-value showed decrease due to the scaling. Consequently, the increase of steam consumption, and thus reduction in performance ratio occurred in order to hold the outlet temperature of brine at the brine heater outlet at 112℃.

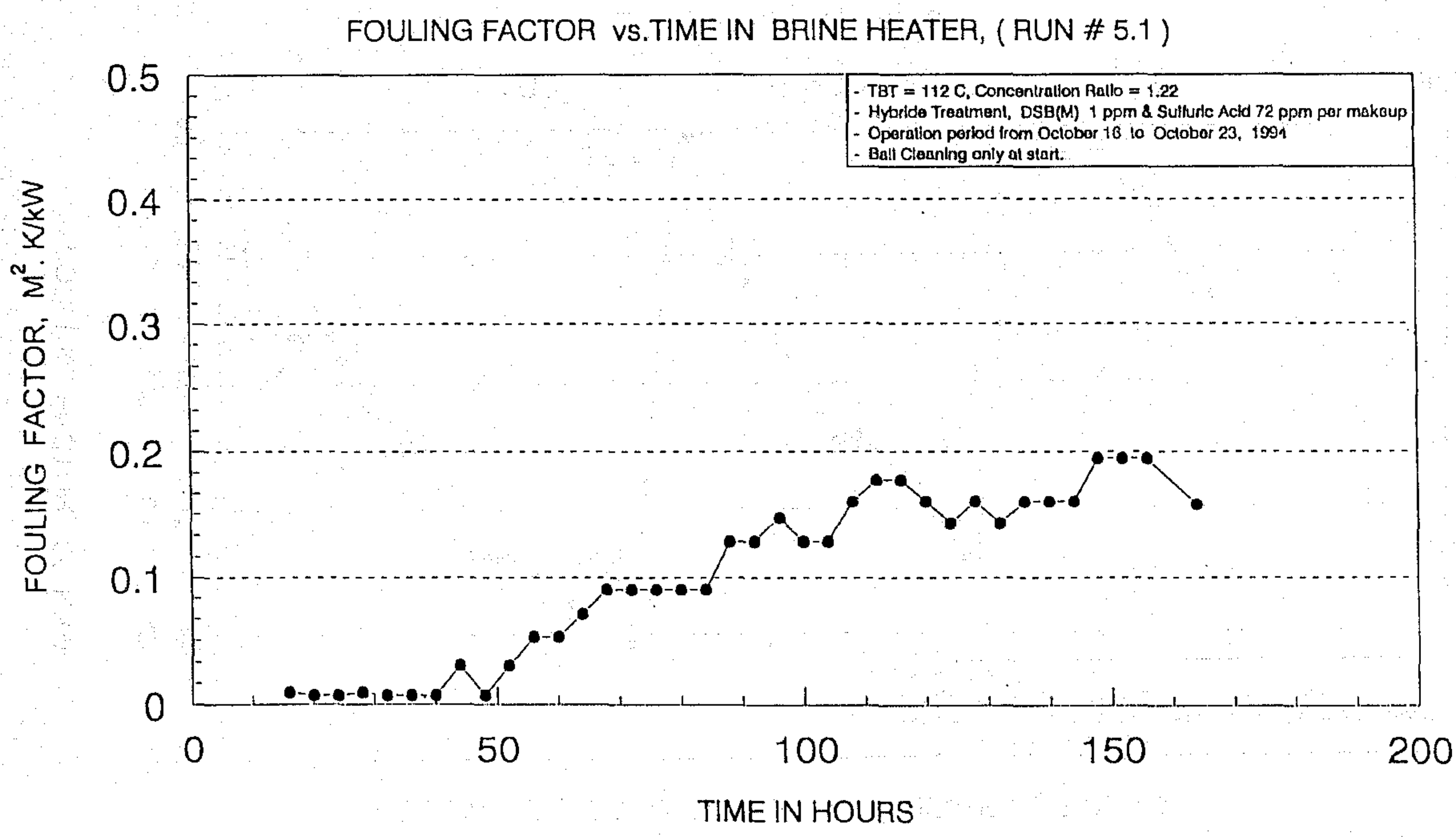

Fig. 10 Time Dependency of Fouling Factor of Brine Heater in RUN 5–1

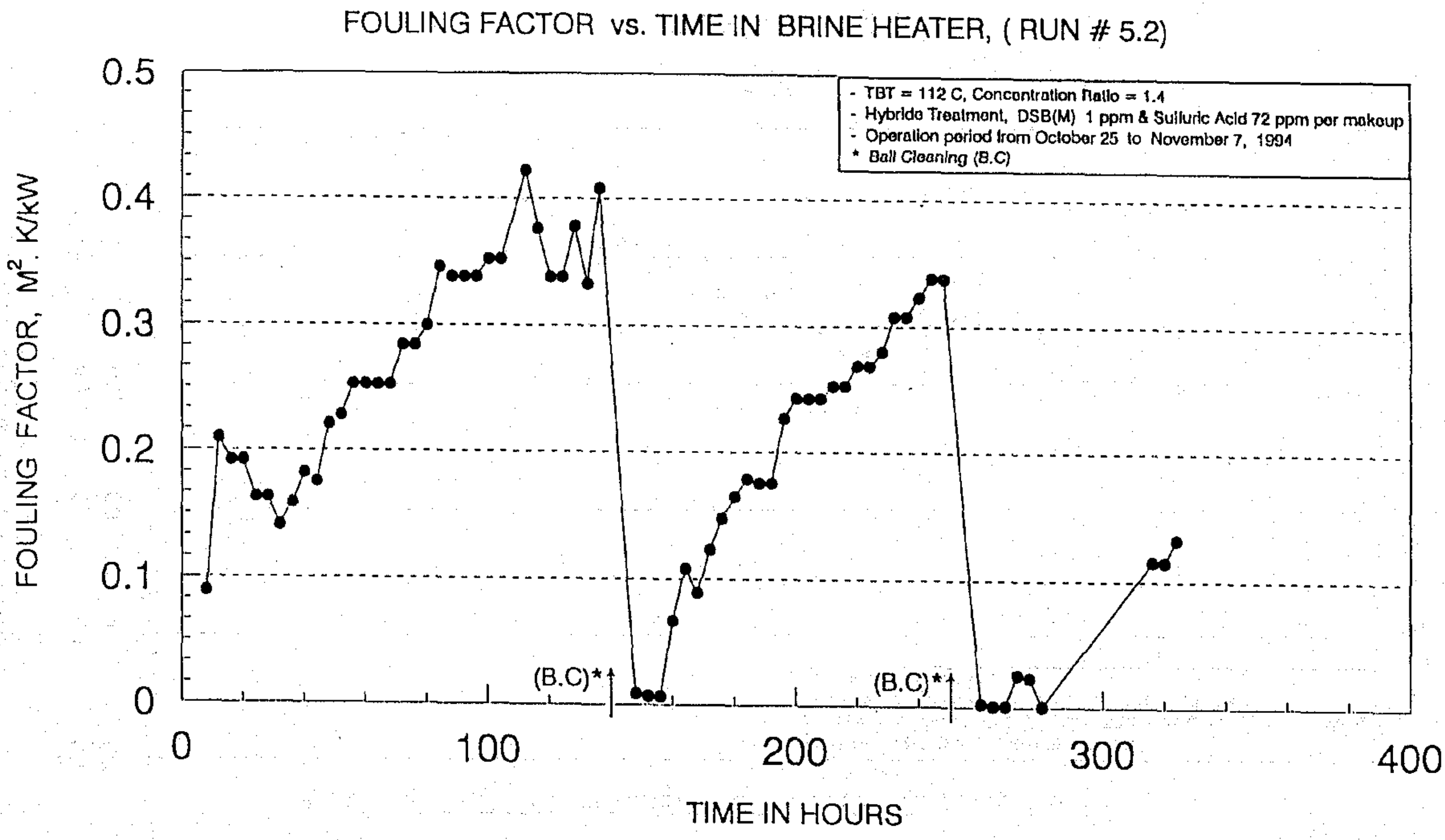

Fig. 11 Time Dependency of Fouling Factor of Brine Heater in RUN 5–2

4. Discussions

4.1 Effect of Concentration Factor on Fouling Factor

There is little change in fouling factor when the concentration factor is 1.22 (M-alkalinity = 140mg/L as $CaCO_3$), as shown in the case of RUN 5-1.

On the other hand, the fouling factor showed apparent increase when the concentration is raised to 1.4 (M-alkalinity = 60mg/L as $CaCO_3$) in RUN 5-2. However, the amount of increase of the fouling factor is less than that of RUN 8.

4.2 The influence of M-alkalinity on Fouling Factor

To explain the effect of M-alkalinity, the time dependency of fouling factor of RUN 5-2 and RUN 8 has been studied.

The fouling factor increases abruptly up to 30 hours. After the initial increase, the fouling factor increases linearly with less increasing rate. The linear portion of the fouling factor at brine heater will be expressed by the following formula shown in the table.

RUN No.	M-alkalinity	Initial Stage	After 1st B.C.	Recovery by B.C.
5-2	60mg/L as $CaCO_3$	$Fo=1.80*10^{-3}t$	$Fo=2.77*10^{-3}t$	100%
8	180mg/L as $CaCO_3$	$Fo=1.31*10^{-3}t$	$Fo=1.80*10^{-3}t$	85.7%

where : BC : Ball Cleaning
Fo : Fouling Factor after t hours (m^2K/kW)
t : Time (>30 h) (h)

The tangent slope of the RUN 5-2 is larger than that of RUN 8, and the superiority of hybrid method was not recognized. However, the recovery ratio by ball cleaning showed some difference. The heat transfer coefficient of hybrid method recovered 100% by ball cleaning while that of single dosing method recovered only 85.7%.

This study revealed the merit and the demerit of the hybrid process.

5. Conclusion

The performance of the hybrid method for the scale prevention has been tested and the results obtained are as follows;

(1) The M-alkalinity has been lowered to 1/3 by dosing acid and the amount of dosing scale inhibitor, PPN(M), has been halved to 1ppm. The beneficial effect of hybrid dosing method on fouling rate was not apparent up to 300 hours.

(2) Longer testing period is necessary to confirm the effect of hybrid method.

(3) In order to adopt the hybrid method in Saudi Arabia, stable and low cost supply of acid, sulfuric acid for example, is necessary since the amount of acid required is 30 times more than that of scale inhibitor.

5.4 Transfer of Technology

(1) **Objective**

The technology transfer is aimed especially for the young researchers in SWCC to deepen their knowledge and understanding on the scaling of the heat exchanger tubes, which is one of the main causes for the MSF plant performance, through the cooperative research between SWCC and JICA.

(2) **Procedure of technology transfer**

Conduct the cooperative research on the establishment of the evaluation method of scale inhibitor by laboratory test, and then proceed the experiment by MSF test plant for the confirmation of the laboratory test results.

Those results would be prepared to a full paper together with the analysis of the MSF plant operation conditions and the calculation method of the fouling factor.

Subjects for the cooperative research work

1) Evaluation and analysis of the performance of the MSF plant.
2) Evaluation method for the scale inhibitor
3) Evaluation technology of fouling factor
   (Short term test by MSF test plant)
4) Evaluation technology of fouling factor
   (Long term test by MSF test plant)
5) Evaluation method of fouling factor
   (Test with the simultaneous use of scale inhibitor and acid)

(3) **Results**

1) Evaluation and analysis of the deterioration of the MSF plant

Visited several actual plants and the conditions has been studied.

The cause of the plant deterioration has been analyzed.

2) Evaluation method for the scale inhibitor

The laboratory test has been conducted and sophisticated method had been established for the evaluation of the effect of scale inhibitor.

The results had been presented at the Second Gulf Water Conference, Bahrain Nov. 1994.

The test by heat transfer equipment has been conducted and the evaluation method of the scale inhibitor under heat flux has been established.

3) **Evaluation technology of fouling factor**
(Short term test by MSF test plant)
The data obtained from the experiments by MSF test plant had been analyzed. The cause of scaling and countermeasures for the plant deterioration have been studied with evaluation technology of fouling factor.

4) **Evaluation technology of fouling factor**
(Long term test by MSF test plant)
Long term test by MSF test plant had been conducted and relationship between heat exchanger tube and fouling factor was studied. Mastering the operation of the MSF test plant was accomplished as well.

5) **Evaluation method of fouling factor**
(Test with the simultaneous use of scale inhibitor and acid: "Hybrid Method")
Combined dosing tests by MSF test plant have been conducted and the obtained data have been analyzed. The effect of hybrid method on scaling has been evaluated.