5.3.2 Results of Trial Run and Performance Test

(5.3.2)

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1. Introduction

The installation of the MSF Test Plant has started on June 31, 1993. On the 10th week, the commissioning of the parts and units, such as pumps, has started. On the 14th week, November 1, the completion ceremony had been held. Each stage of the installation work is shown in 5.3.1 summarized in week period.

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

2. Results of performance test of MSF Test Plant

Prior to the ceremony for the completion of the work on November 1, a trial run and a performance test of the equipment were carried out.

Table 1 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 0.80ton/h, which was about 1.07 times as large as the designed value of 0.75ton/h. Thus, it was proved that the design value was satisfied sufficiently.

Following this, the overall heat transfer coefficient of each heat transfer tube was measured as a part of the performance test. The result of this measurement is shown in Table 2. According to this results, variations in the value of the overall heat transfer coefficient are recognized at each evaporation stage.

It is considered, however, that this problem can be solved by the adjustment of the venting system. This overall heat transfer coefficient is 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 3 shows a recording form in which records are to be entered by operation personnel in order to monitor the operation state. It also shows an example of entry.

In addition, Figs.1 and 2 shows the appearance of the plant and the state of the control board when the test plant is in operation.

Table 1 Heat Balance of MSF Test Plant

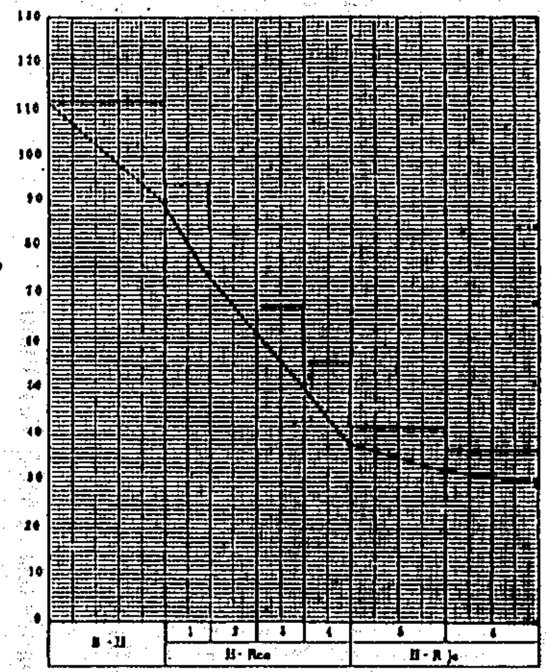
Run No.	—	Measuring Date	29-OCT-'93	14°45'	Total Ope. Time	hrs
Flow Rate (l/h)	Feed SW (FR201)	Recir.B. (FR301)	Product W(FR401)	Condens. (FR601)	HRje SW (FR101)	
	3.25	6.53	1060-260=800	260	17	
Pressure	Supply S. (PI605)	BH Shell (PI603)	Eject.S. (PI604)	BH Out B. (PI303)	Deaerator (PI)	
	8.2 kg/cm²G	0.6 kg/cm²G	8 kg/cm²G	1.0 kg/cm²G	torr	
Concentration	Feed SW ( )	Recir.B. ( )	Product (CRA401)	Condens. (CR601)		
	ppm	ppm				
Efficiency	Performance R.	Concentration R.				
	3.08 (2.4)					

Temperature			Brine HTR		Heat Recovery Section				Heat Rejection Section		
Position				1S	2S	3S	4S		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	Y. Miyamoto	

Table 2 Overall Heat Transfer Coefficient

Operation Date, Time	Calculation Item		Unit	Brine Heater	No. 1 Stage	No. 2 Stage	No. 3 Stage	No. 4 Stage	No. 5 Stage	No. 6 Stage	NOTE
										RUN No.	-
Date	Flow Rate	W	kg/h	6530	6530	6530	6530	6530	17000	17000	
29. OCT '93	Specific heat	Cp	kJ/(kg K)	3.966	3.943	3.929	3.917	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	36.767	
	H. Trans. Area	S	m²	4.6723	1.937	1.937	1.937	1.937	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	10.487	6.548	5.944	
Frequency	U Value	U	kW/(m² K)	3.8995	6.2912	2.8994	3.818	4.8793	3.400	1.2475	
	Clean-U Value	U_c	kW/(m² K)								
!	Fouling Factor	f_1	(m² K)/kW								

MEMORANDUM : $1J = 2.38809 \times 10^{-4} kcal = 2.77778 \times 10^{-7} kW \cdot h = 0.101972 kgf \cdot m$
$1kW = 860 kcal/h = 3,600 kJ/h$

Calculation Formula	
	$\Delta T = T_2 - T_1$ $\Delta t_1 = t - T_1$ $\Delta t_2 = t - T_2$ $\Delta T_m = \Delta T / \ln(\Delta t_1 / \Delta t_2)$
	$Q = WCp\Delta T$ $U = Q/(S\Delta T_m)$ $f_1 = (1/U) - (1/U_c)$

Table 3-1 LOG Sheet (Part 1)

Table 3 LOG Sheet(1)

Unit No. ______ Data 29/10/'93

Item	Tag No.	Unit	Time											
			10:45	11:45	12:45				13:45	14:45				
Seawater reject.out temp.	TR - 102	℃	39	39	39				39	38				
Top brine temp.	TR - 303	℃	112	112	112				112	112				
Last stage vacuum	PR - 506	cmHgV	72	72	72				72	72				
Decarbonator out PH	PHR - 201		–	–	–				–	–				
Recirc brine PH	PHR - 301		–	–	–				–	–				
Make up DO2	DOR - 201	ppb	–	–	–				–	–				
Brine DO2	DOR - 301	ppb	–	–	–				–	–				
Condensate conductivity	CR - 601	μv/cm	24	20	20				18	20				
Product conductivity	CR - 401	μv/cm	50	40	35				30	30				
Seawater to reject. flow	FR - 101	m³/hr	15	15.5	16				17	17				
Make up flow	FR - 201	m³/hr	3.25	3.25	3.25				3.4	3.3				
Recirc. brine flow	FR - 301	m³/hr	6.2	6.25	6.25				6.53	6.53				
Seawater reject. out temp.	TIC - 102	℃	39	39	39				37	39				
Top brine temp.	TIC - 303	℃	112	112	112				112	112				
Heating steam press.	PIC - 606	kg/cm²G	2.0	2.0	2.0				2.0	2.1				
Make up flow	FIC - 201	m³/hr	3.25	3.25	3.30				3.25	3.4				
Ratio control for acid inject.	Fr - 201	%												
Ratio control for anti scale inject.	Fr - 202	%												
Recirc brine flow	FIC - 301	m³/hr	6.25	6.25	6.25				6.53	6.53				
Deaerator level	LIC - 202		230	230	230				230	230				
Last stage brine level	LIC - 507		215	200	200				200	208				
Supply steam press.	PI - 605	kg/cm²G	8	8	8				7.8	8.1				
Seawater temp.	TR - 101	℃	29	29	29				29	29				
Make up temp. (Deaerator)	TR - 201	℃	38	38	39				39	39				
Recirc. brine temp.	TR - 301	℃	37.5	38	38				39	39				
Brine heater inlet brine temp.	TR - 302	℃	90	90	90				90	91				
Brine heater shell temp.	TR - 602	℃	114	114	114				114	114				
Anti scale inject. pump speed														
Acid inject. pump speed														
Sodium inject. pump speed														
Antifoam inject. pump speed														
Distillate water flow	TR-401		1020	1030	1030				1060	1060				
Condensate flow	FR-601		230	240	240				250	260				

29/10/93

29. Oct '93

Table 3-2 LOG Sheet (Part 2)

Table 3 LOG Sheet(2)

Unit No. ______ Data 29/10/93

Item	Tag No.	Unit	Time											
			10:45	11:45	12:45				13:45	14:45				
Heating steam temp.	TI - 601	℃	125	125	125				125	120				
Brine heater shell press.	PI - 603	kg/cm²G	0.6	0.6	0.6				0.6	0.6				
Brine heater condensate level	LIC - 601	mm	150	150	150				150	150				
Brine heater outlet brine temp.	TI - 309	℃	112	112	112				112	112				
Brine heater outlet brine press.	PI - 303	kg/cm²G	1.0	1.0	1.0				1.0	1.0				
Brine heater inlet brine temp.	TI - 304	℃	91	91	91				90	90				
Brine heater inlet brine press.	PI - 302	kg/cm²G	1.8	1.9	1.9				2.1	2.1				
Vapour temp. 1st st.	TI - 501	℃	92	93	93				94	94				
Vapour temp. 2st st.	TI - 502	℃	82	82	82				83	84				
Vapour temp. 3st st.	TI - 503	℃	67	68	68				68	68				
Vapour temp. 4st st.	TI - 504	℃	56	56	56				57	56				
Vapour temp. 5st st.	TI - 505	℃	41	41	41				42	42				
Vapour temp. last st.	TI - 506	℃	38	36	36				37	37				
1st st.press.	PI - 501	mm Hg	120	120	120				160	100				
Recirc. brine temp ST 1/2	TI - 307	℃	77	78	78				78	74				
Recirc. brine temp ST 2/3	TI - 306	℃	64	64	64				65	62				
Recirc. brine temp ST 3/4	TI - 305	℃	51	51	51				52	51				
Recirc. brine temp ST 4 inlet	TI - 304	℃	38	38	38				38	37				
Seawater temp ST 5 outlet	TI - 106	℃	39	39	38				40	38				
Seawater temp ST 5/6	TI - 105	℃	33	33	33				34	32				
Seawater temp ST 6 inlet	TI - 104	℃	29	30	30				30	30				
Ejector steam press.	PI - 604	kg/cm²G	8.0	8.0	8.0				8.0	8.0				
E/C inlet S.W. press	PI - 102	kg/cm²G	1.7	1.7	1.8				1.5	1.5				
E/C outlet S.W. temp.	TI - 103	℃	34	34	34				35	34				
Decarbonator level	LIC - 201		—	—	—				—	—				
Flash tank level	LIC - 401		165	160	160				160	160				
Flash tank press.	PI - 401	mmHgV	700	700	700				700	700				

29/10/93

29. oct '93

Table 3-3 LOG Sheet (Part 3)

Table 3 LOG Sheet(3)

Unit No. ______ Data 29/10/'93

Item	Tag No.	Unit	Time											
			10:45	11:45	12:45				13:45	14:40				
S.V. supply press.	PI - 101	kg/cm²G	2.0	2.0	2.0				1.8	1.9				
Brine recirc. pump discharge press.	PI - 301	kg/cm²G	5.4	5.4	5.4				5.4	5.4				
Make up pump discharge press.	PI - 201	kg/cm²G	5.0	5.0	5.0				5.0	5.0				
Distillate pump discharge press.	PI - 402	kg/cm²G	2.4	2.4	2.4				2.4	2.4				
Antifoam tank level	LI - 804													
Antifoam flow	FI - 804	l/hr												
Antifoam pump disch. press.	PI - 804	kg/cm²G												
Antiscale tank level	LI - 801													
Antiscale flow	FI - 801	l/hr												
Antiscale pump disch. press.	PI - 801	kg/cm²G												
Sodium tank level	LI - 803													
Sodium flow	FI - 803	l/hr												
sodium pump disch. press.	PI - 803	kg/cm²G												
Acid tank level	LI - 802													
Acid flow	FI - 802	l/hr												
Acid pump disch. press	PI - 802	kg/cm²G												
Acid cleaning tank level	LI - 805													
Acid cleaning pump disch. press.	PI - 805	kg/cm²G												
Air tank press.	PI - 001	kg/cm²G												
Water tank level	LI - 402	%	90						70	50				
Oil tank level	LI - 901	m	1.12	1.12	1.12				1.1	1.1				

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29. Oct '93

Table 3-4 LOG Sheet (Part 4)

Table 3 LOG Sheet(4)

(Boiler) Unit No. ______ Data 29/10/93

Item	Tag No.	Unit	Time: 10:45	11:45	12:45				13:45	14:45				
Oil press.		kg/cm²G	1.3	1.3	1.3									
Oil temp		℃												
Oil flow		L	1457	1482	1506				1527	1553				
Oil pump press.		kg/cm²G	20	20	20				20	20				
Heated oil temp.		℃	98	98	98				98	98				
Boiler pressure		kg/cm²G	8	8	8.5				8.5	8.5				
Water boost pump press.		kg/cm²G												
Softner inlet press.		kg/cm²G												
Feed water flow		L	15581	15870	16153				16401	16712				
Blow water flow		m^3/hr												

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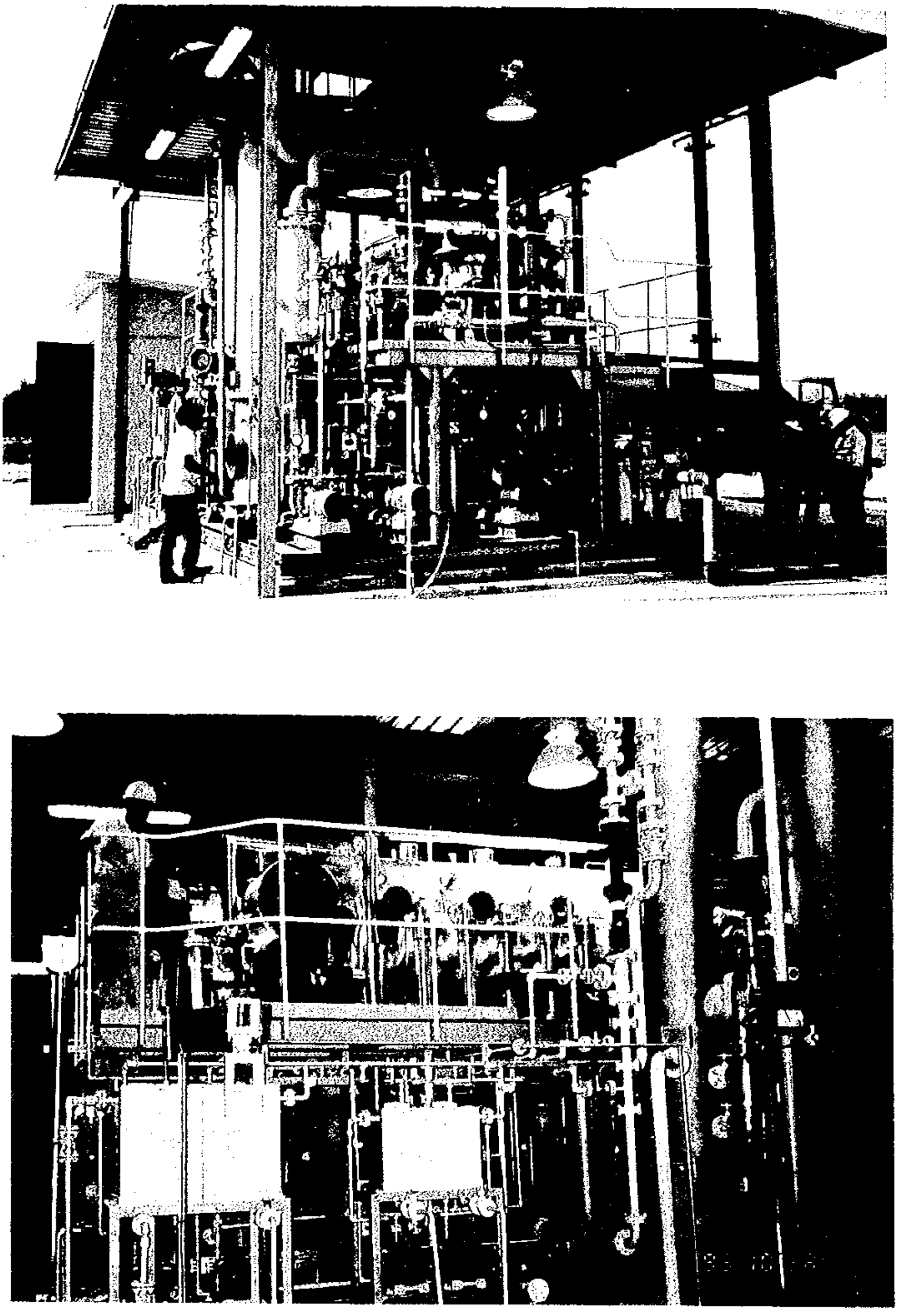

Fig. 1 The Appearance of the MSF Test Plant that is in Operation

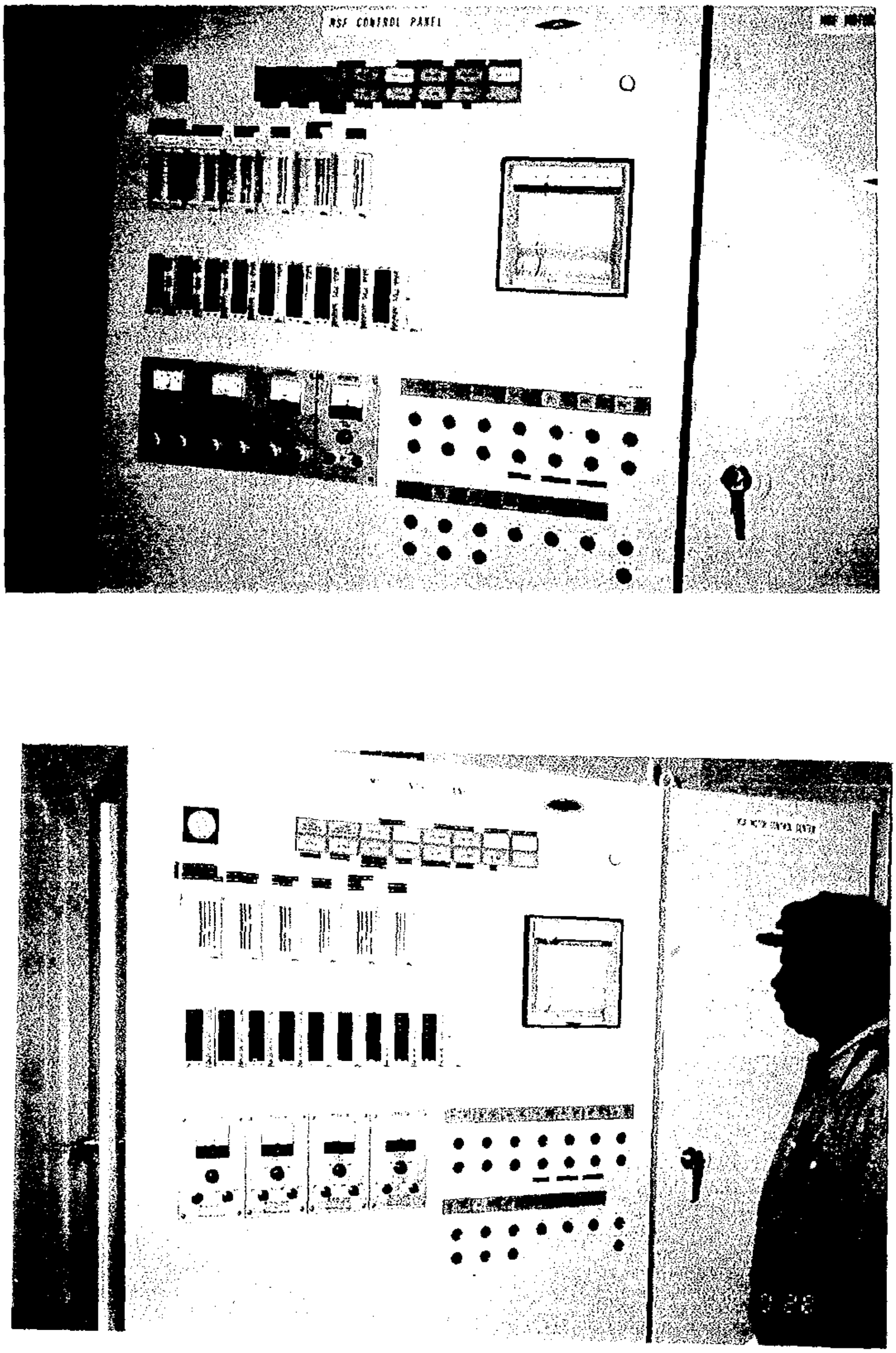

Fig. 2 The Status of the Control Board when the Plant is in Operation

5.3.3 Test with a Single Scale Inhibitor

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1. Introduction

The purpose of MSF-1 is to establish procedure for the selection of best scale inhibitors out of those in the commercial market for the normal temperature and the high temperature application and then apply them to the MSF Test Plant experiment to demonstrate their scale prevention effect under operation conditions similar to that of the actual plants. Furthermore, to prove the enhanced effect of the scale prevention by acid dosing together with the scale inhibitor.

The threshold effect, which is one of the criteria for the evaluation of performance of scale inhibitors, has been measured for eight different kinds of scale inhibitors and the results are reported in 5.1.2. The scale prevention effect under the thermal flux has been reported in 5.2, taking the crystal distortion effect, another criteria for the evaluation of performance, into consideration.

The conclusion of those results is that PPN(M) shows the best performance both at the maximum brine temperature of 90℃ and 112℃. Therefore, 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. The first experiment, RUN-1, has been started in February, 1994.

However, several unexpected problems have happened such as the malfunctioning of the boiler which had to be replaced by a new one[1], installation of a new boiler and connections with MSF test plant and the congestion at the level control valve of the condensate in the brine heater system of the Test Plant during the period of second experiment, RUN-2, and considerable time was consumed for solving those problems. On 25th of July, the operation of the MSF Test Plant has been restarted for RUN-3.

Since then, stable and smooth operation had been established and experiments were carried out for the test of varied concentration factors and of ball cleaning.

This section reports the results of those tests.

---

1) The new boiler : A fire tube boiler type with a maximum capacity of 1ton/hour at maximum operating pressure of 11 bar.

2. Test Plan

2.1 Basic concept of the test

The most direct method for evaluating the scale adhering to inner surface of the heat transfer tube is to take out one from the tube bundle of the plant and measure the amount of scale. However, the performance ratio, which is the main interest for the task, will remain uncertain.

Thus 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.

$$\Delta T = T_2 - T_1 \quad (2.1)$$

$$\Delta T_1 = T - T_1 \quad (2.2)$$

$$\Delta T_2 = T - T_2 \quad (2.3)$$

Using the equations 2.1, 2.2 and 2.3,

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

On the other hand,

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

Using the equations 2.4 and 2.5

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

The fouling factor F_0 is defined as

$$F_0 = (1/U - 1/U_c) \quad (2.7)$$

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**	**℃**
ΔTm	:	**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

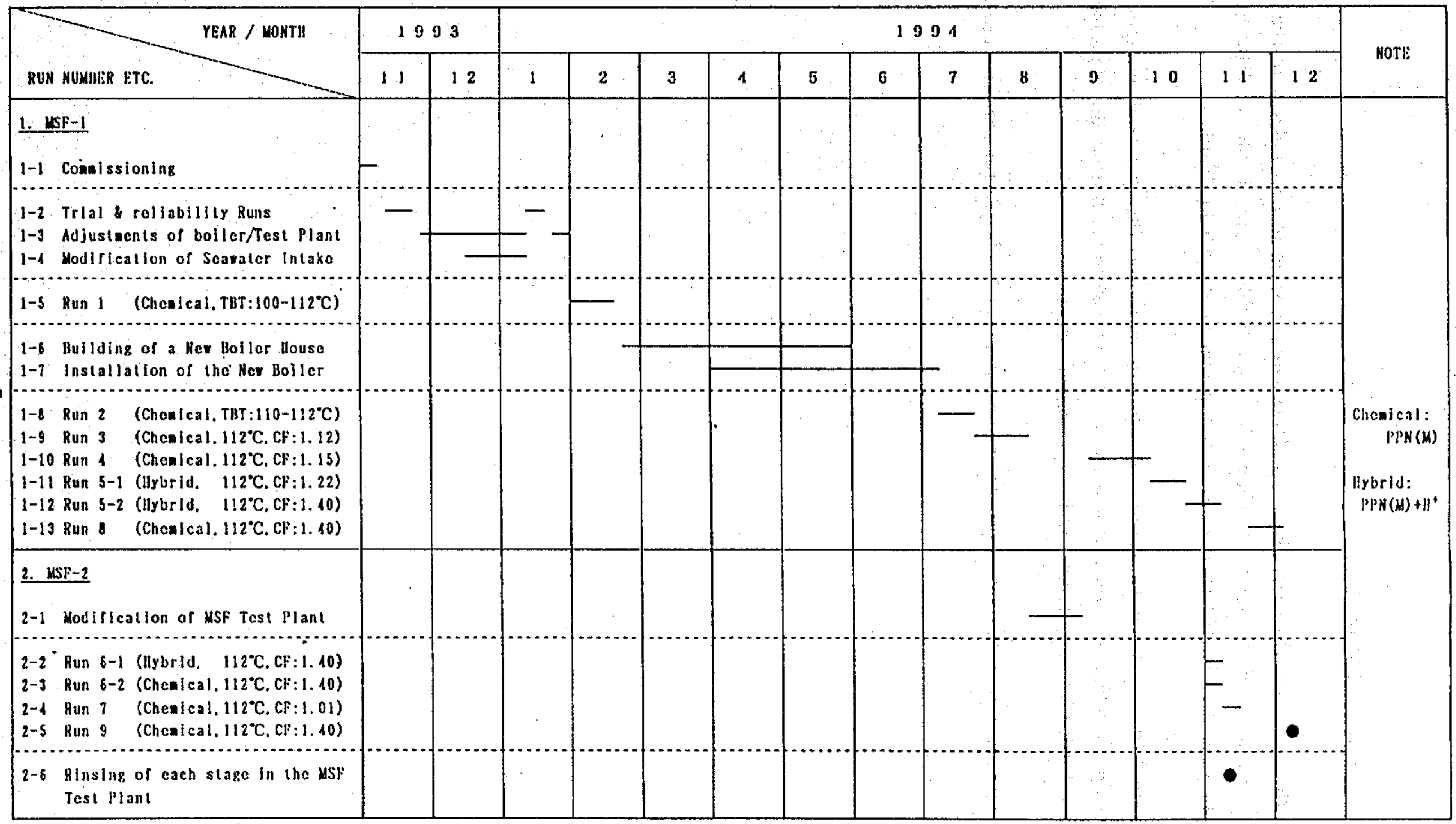
The operation conditions planned in May, 1994 and conducted are shown in Table 1. The details of the test plant operation progress are shown in Fig. 1.

Table 1 Operation Conditions of MSF Test Plant for MSF-1, 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 *3 needed	As *3 needed	As *3 needed	None	As *3 needed	None	
7. Top brine temperature	℃	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℃	-	—	—	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 o.34-0.36 m^2K/kW

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



3. Experimental Method

The flow diagram, the sheet of mass balance and the sheet of heat balance of the MSF test plant, capacity of 20ton/day, is shown in Fig.2, Table 2 and Table 3. The instrument designations used for the calculation of fouling factors are listed in Table 4.

The fouling factors were calculated automatically by the personal computer, IBM compatibles, 486. The variation of the operation conditions during the experiments had been recorded by the operators in the prescribed format.

The operation data sheets used for the calculation of the fouling factor are shown in Table 5.

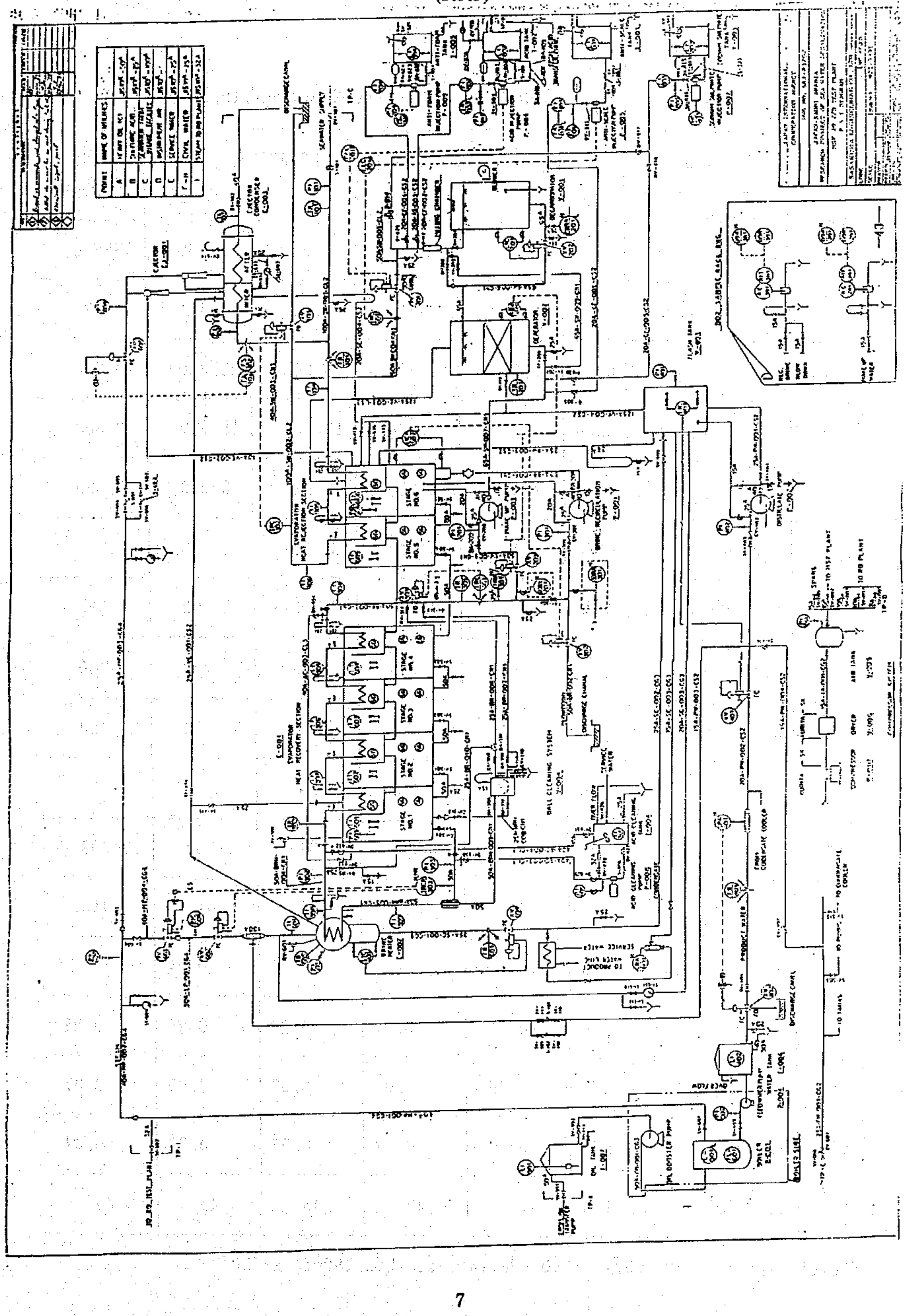


Fig. 2 Flow Diagram of the Test Plant

Table 2 Design Specification of the Test Plant (Mass Balance)

LINE No.	OPE. MODE		RECIRCULATION OPERATION				ONCE THROUGH
	METHOD OF SCALE PREVEN.	UNIT	CHEMICALS			CHEMICAL /H_2SO_4	CHEMICAL
	MAXIMUM TEMP.	℃	90.5	112	120	112	112
1	SW to Supply	kg/h	23,300	23,300	23,300	23,300	23,300
2	SW to Rejec.	kg/h	18,300	18,300	18,300	18,300	18,300
4	Feed Sea W.	kg/h	2,650	3,250	3,620	3,250	6,430
5	Recycle Brine	kg/h	7,450	6,530	6,580	6,530	—
6	Blow Down	kg/h	2,000	2,500	2,790	2,500	5,680
7	Distillate	kg/h	605	750	830	750	750
13	Steam to Eje.	kg/h	50	50	50	50	50
14	Desuper H.W.	kg/h	10	10	10	10	10
12	Steam to B.H.	kg/h	10+260	10+303	10+323	10+303	10+303
15	Condensate	kg/h	270	313	333	313	313
16	H_2SO_4 (98 %)	kg/h	—	—	—	0.52	—
17	Scale Inhi.*1	kg/h	0.18	0.22	0.22	0.22	0.22
18	Anti Foam *2	kg/h	0.06	0.07	0.07	0.07	0.07
19	Na_2SO_3 S. *3	kg/h	0.06	0.07	0.07	0.07	0.07
20	Heavy Oil*4	l/h	41	45	45	45	45

(Note) *1:15 %, *2:0.5%, *3:0.5%, *4:Less than 190cSt at 50℃

Table 3 Design Specification of the Test Plant (Heat Balance)

LINE No.	OPE. MODE		RECIRCULATION OPERATION				ONCE THROUGH
	METHOD OF SCALE PREVEN.	UNIT	CHEMICALS			CHEMICAL /H_2SO_4	CHEMICAL
	MAXIMUM TEMP.	℃	90.5	112	120	112	112
1	SW to Supply	℃	30	30	30	30	30
2	SW to Rejec.	℃	30	30	30	30	30
4	Feed Sea W.	℃	39.5	39.5	40	39.5	39.5
5	Recycle Brine	℃	39.5	39.5	40	39.5	39.5
6	Blow Down	℃	39.5	39.5	40	39.5	39.5
7	Distillate	℃	37.2	37.2	37.7	37.2	37.4
13	Steam to Eje.	℃	175	175	175	175	175
14	Desuper H.W.	℃	100	120	127	120	120
12	Steam to B.H.	℃	100	120	127	120	120
15	Condensate	℃	100	120	127	120	120
16	H_2SO_4 (98 %)	℃	–	–	–	–	–
17	Scale Inhi. *1	℃	35	35	35	35	35
18	Anti Foam *2	℃	35	35	35	35	35
19	Na_2SO_3 S. *3	℃	35	35	35	35	35
20	Heavy Oil *4	℃	–	–	–	–	–

(Note) *1:15%, *2:0.5%, *3:0.5%, *4:Less than 190cSt at 50℃

Table 4 Instrument Name for Calculation of Fouling Factor

NO.	Measurements Item		Instru. Name
1	Flow	Seawater in Heat Rej. Section	FR101
2	(W)	Recirculation Brine	FR301
3		Inlet Temp. of No.6 H.T.Tubes	TI104
4		Inlet Temp. of No.5 H.T.Tubes	TI105
5	S.Water	Outlet Temp. of No.5 H.T.Tubes	TI106
6	&	Inlet Temp. of No.4 H.T.Tubes	TI304
7	Brine	Inlet Temp. of No.3 H.T.Tubes	TI305
8	Temp.	Inlet Temp. of No.2 H.T.Tubes	TI306
9	(T)	Inlet Temp. of No.1 H.T.Tubes	TI307
12		Inlet Temp. of Brine Heater	TI308
13		Outlet Temp. of Brine Heater	TI309
		Steam Temp. of Brine Heater	TI602
14		No. 1 Evaporator Steam	TI501
15	Chamber	No. 2 Evaporator Steam	TI502
16	Temp.	No. 3 Evaporator Steam	TI503
17	(t)	No. 4 Evaporator Steam	TI504
16		No. 5 Evaporator Steam	TI505
17		No. 6 Evaporator Steam	TI506

Table 5 Formation of Operation Conditions

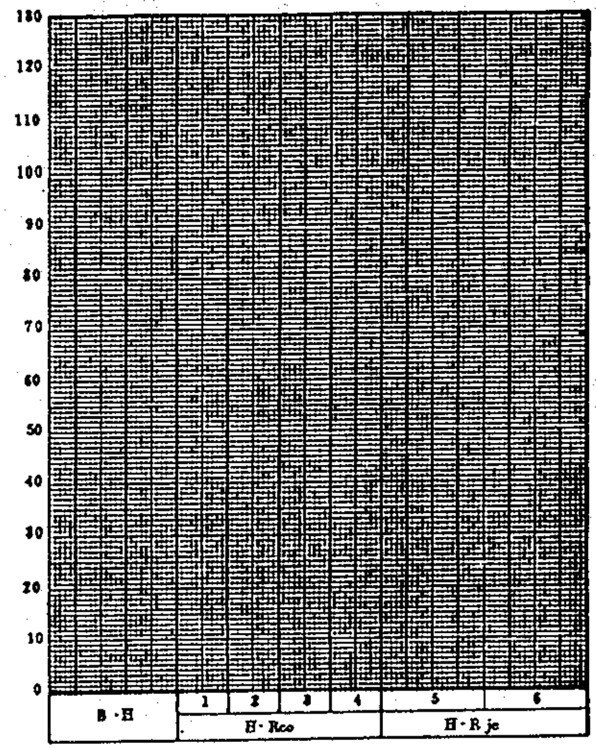
Run No.	—	Measuring Date	— —	• •	Total Ope. Time	hrs
Flow Rate (t/h)		Feed SW (FR201)	Recir. B. (FR301)	Product W(FR401)	Condens. (FR601)	HRje SW (FR101)
Pressure		Supply S. (PI605)	BH Shell(PI603)	Eject. S. (PI604)	BH Out B. (PI303)	Deaerater(PI)
		kg/cm²G	kg/cm²G	kg/cm²G	kg/cm²G	torr
Concentration		Feed SW ( )	Recir. B. ( )	Product (CRA401)	Condens. (CR601)	
		ppm	ppm			
Efficiency		Performance R.	Concentration R.			

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
	℃										
F. Chamb. G. Phase	TI	602	501	502	503	504			505	506	
	℃										
F. Chamb. L. Phase	TI										
	℃										
Steam	TI	Heating Steam	601	Condensate		Product Water					
	℃										

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 ______________

4. Results

The continuous operation has been conducted from RUN 1 to RUN 9, as shown in Table 1.

Data obtained during the RUN 1 before installation of the new boiler is shown in Appendix 5.3.3-1.

Data obtained during the RUN 2 is shown in Appendix 5.3.3-2. The flow of seawater feed was out of order and air was present in the sensor of thermometer installed in the vapor zone during the RUN 2.

The RUN 5 and RUN 6-1 are for the hybrid operation. The RUN 6, RUN 7 and RUN 9 are for the task MSF-2. The RUN 3, 4 and 8 are the operation for the 5.3.3.

The RUN 3 was operated under concentration factor of 1.12 with chemical dosing. The ball cleaning was done every 8hr.

The RUN 4 was operated under concentration factor of 1.15 with chemical dosing but without any ball cleaning.

The RUN 8 was operated under concentration factor of 1.4 with chemical dosing without ball cleaning.

4.1 Results of fouling factor measurement

The time dependency of fouling factor (Overall heat transfer coefficient) during RUN 3, 4 and 8 is shown in Fig. 3, 5 and 7.

The heat balance corresponding to each Uvalue at the start, middle and end of the operation, is shown in Fig. 4, 6 and 8.

The measured data together with calculated LMTD, Uvalues are shown in Table 7, 8, and 9.

The data show that there is no significant change of Uvalue in case the concentration factor is less than 1.2, up to 300 hours, consequently no effect of ball cleaning.

However, in case when the concentration factor is raised to 1.4, Uvalue 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.

4.2 Analysis of water constituent

The make-up water(MU), recirculating brine(BR) and blow brine(BD) had been sampled periodically during the test plant operation and pH, M-alkalinity, chloride concentration and conductivity were analyzed. Those data are plotted in Figs. 10, 11 and 12.

The analyzed results are stable at every position during 300 to 500 hours.

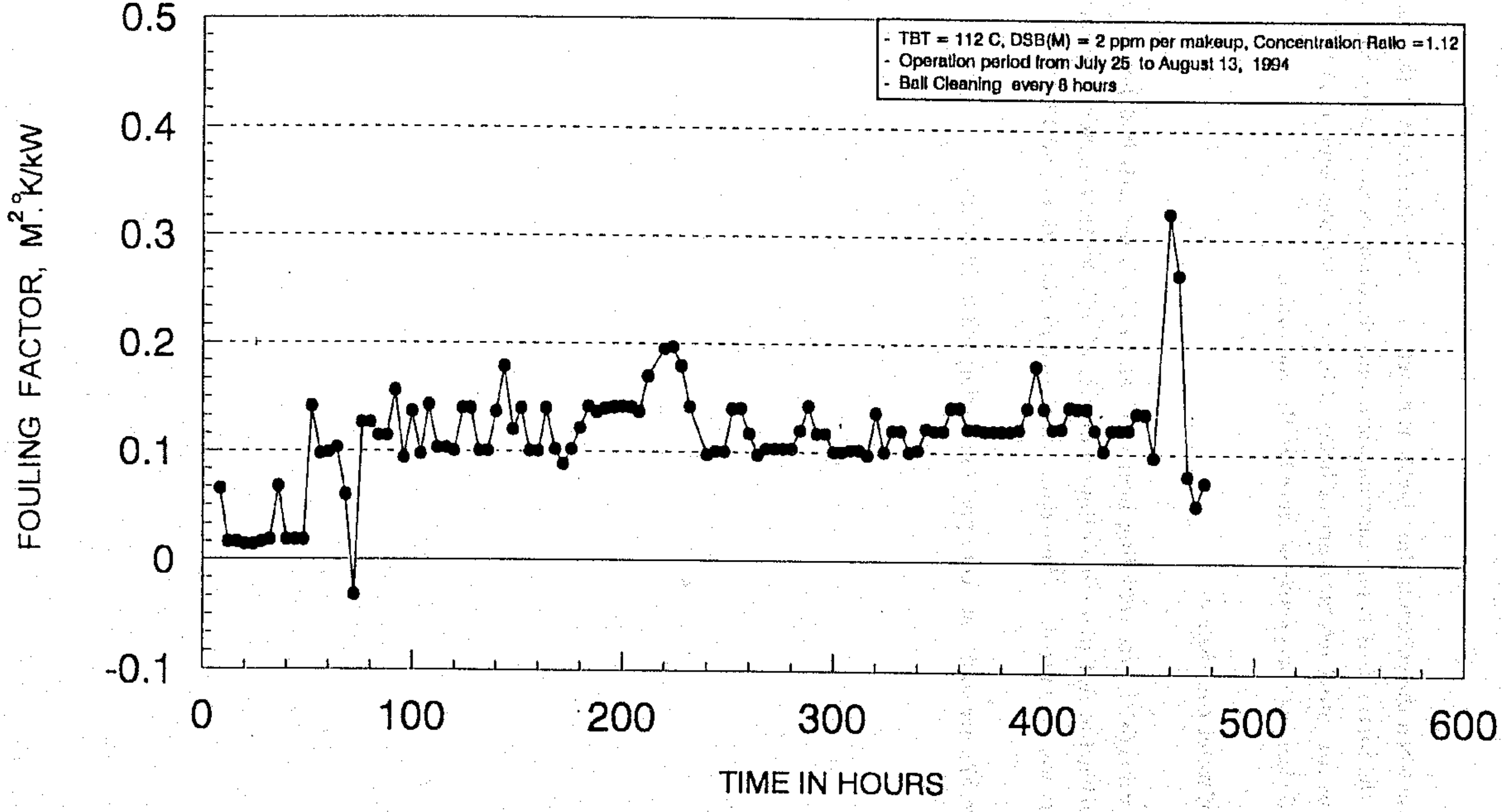


Fig. 3 **Time Dependency of Fouling Factor of Brine Heater in RUN–3**

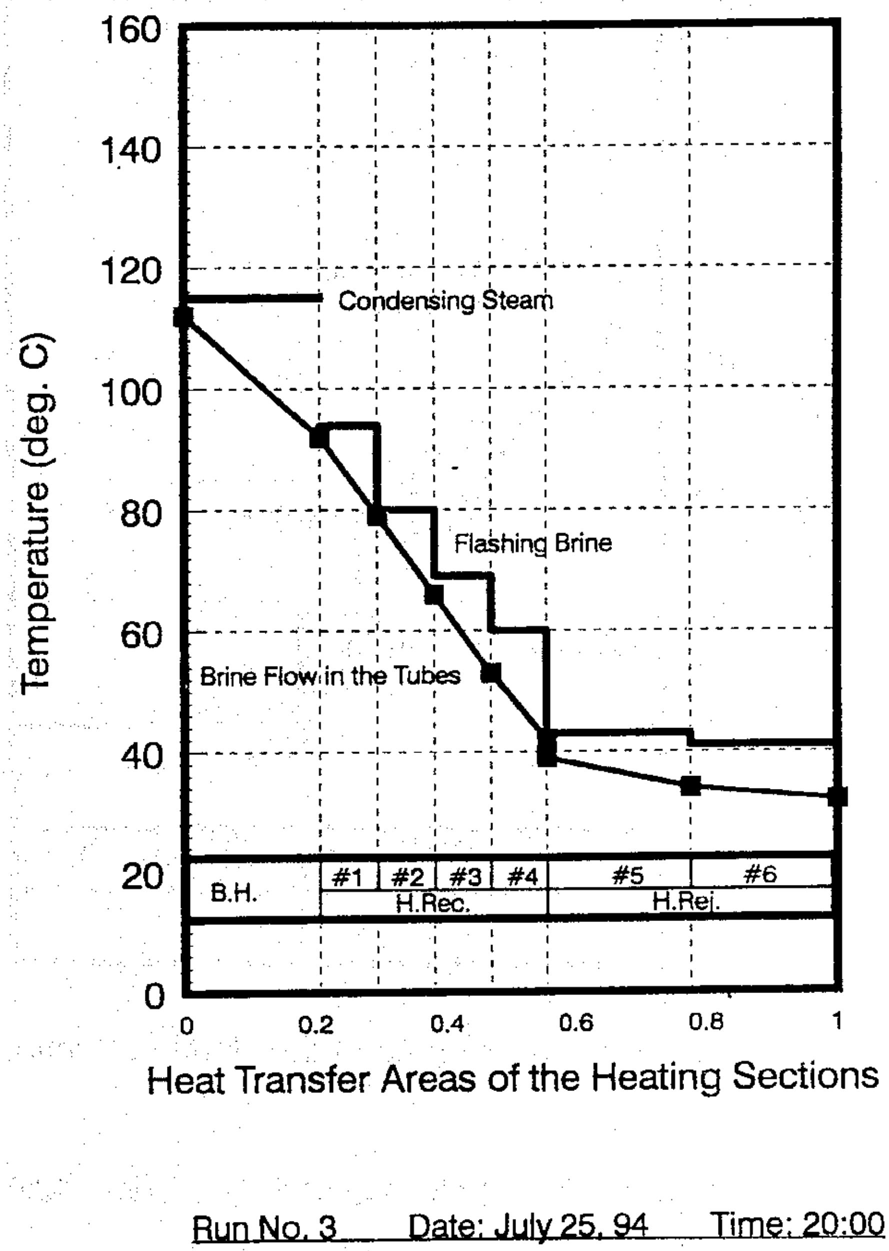


Fig. 4-1 Heat Cycle at Start of RUN-3

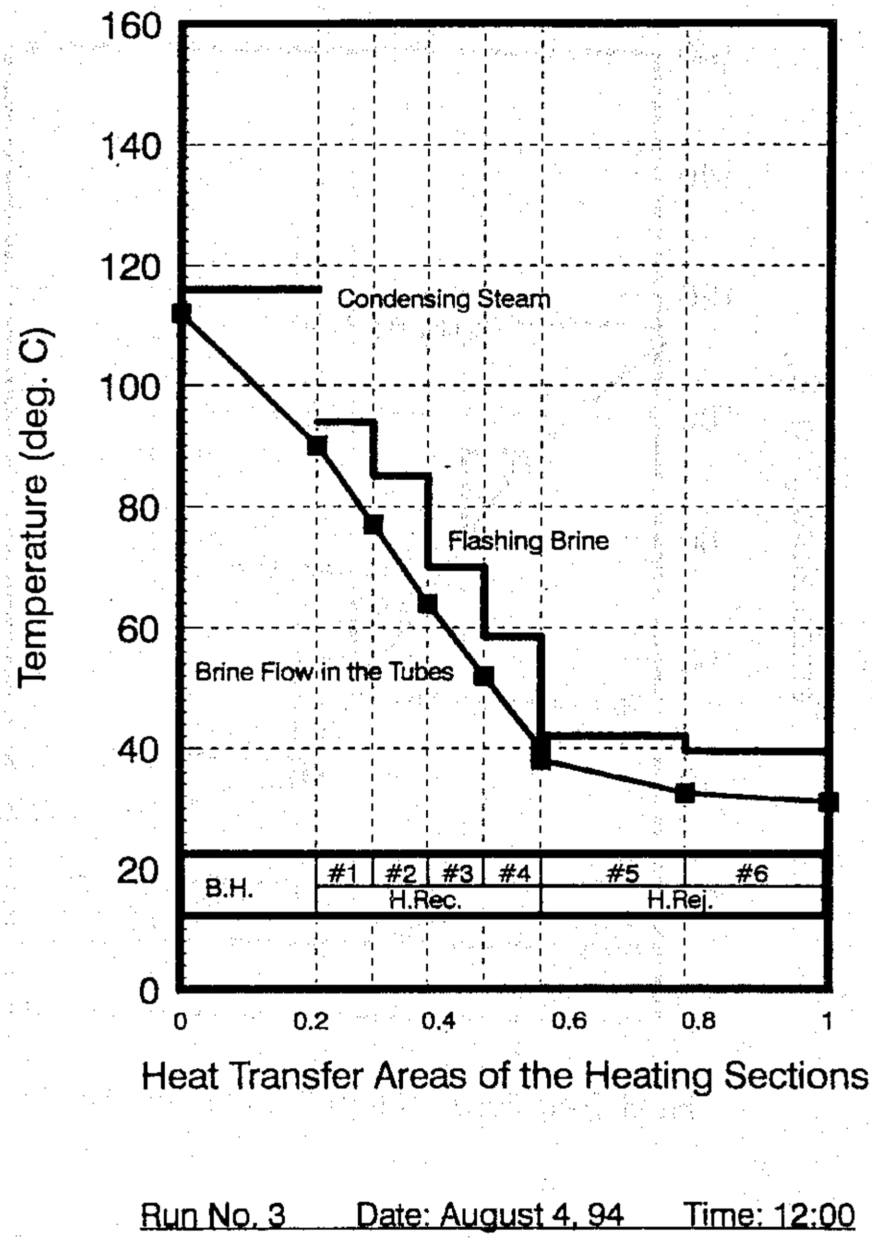


Fig. 4-2 Heat Cycle after 240hrs of RUN-3

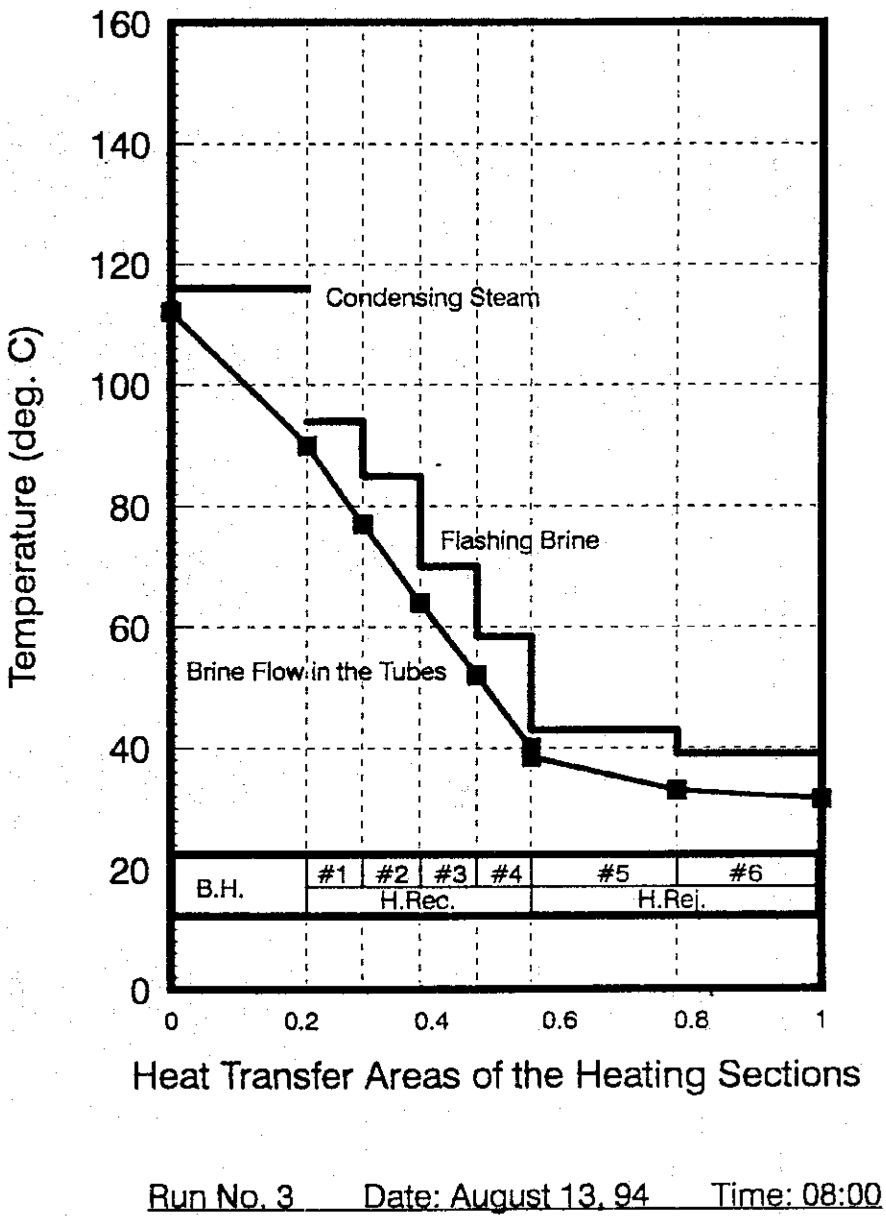


Fig. 4-3 Heat Cycle after 450hrs of RUN-3

Table 6–1 Calculation of Overall Heat Transfer Coefficient (U) and Fouling Factor at Start of RUN–3

Run No. 3 **Date: July 25, 94** **Time: 20:00** **Total Operation Time: 8 hr.**

Variables	*Brine Heater*	*Evaporator Stages*					
		# 1	# 2	# 3	# 4	# 5	# 6
Flowrate (kg/h)	6450	6450	6450	6450	6450	18100	18100
Specific Heat (kJ/kg/K)	3.989	3.970	3.956	3.943	3.933	3.969	3.967
Inlet Temp. (deg. C)	92	79	66	53	42	34	32
Outlet Temp. (deg. C)	112	92	79	66	53	39	34
Temp. Rise (deg. C)	20	13	13	13	11	5	2
Flashing Temp. (deg. C)	115	94	80	69	60	43	41
Heat Transfer Rate (kJ/S)	142.955	92.468	92.144	91.850	77.512	99.773	39.888
Heat Transfer Area (Sq.m)	4.6723	1.937	1.937	1.937	1.937	4.9556	4.9556
L.M.T.D. (deg. K)	9.819	6.452	4.926	7.766	11.647	6.166	7.958
U (kW/sq.m/K)	3.116	7.399	9.657	6.106	3.436	3.265	1.011
Clean-U Value (kW/sq.m/K)	3.9	6.6	5.1	5.1	5.1	5.1	5.1
f (sq.m K/kW)	0.0645	-0.0164	-0.0925	-0.0323	0.0950	0.1102	0.7926

Table 6–2 Calculation of Overall Heat Transfer Coefficient (U) and Fouling Factor after 224hrs of RUN–3

Run No. 3 **Date: August 03, 94** **Time: 20:00** **Total Operation Time: 224 hr.**

Variables	*Brine Heater*	*Evaporator Stages*					
		# 1	# 2	# 3	# 4	# 5	# 6
Flowrate (kg/h)	6450	6450	6450	6450	6450	18500	18500
Specific Heat (kJ/kg/K)	3.989	3.969	3.955	3.943	3.932	3.968	3.966
Inlet Temp. (deg. C)	91	77.5	65	53	40	33	31
Outlet Temp. (deg. C)	112	91	77.5	65	53	38	33
Temp. Rise (deg. C)	21	13.5	12.5	12	13	5	2
Flashing Temp. (deg. C)	118.5	96	86	70	58	42	38.5
Heat Transfer Rate (kJ/S)	150.079	95.991	88.572	84.775	91.586	101.962	40.764
Heat Transfer Area (Sq.m)	4.6723	1.937	1.937	1.937	1.937	4.9556	4.9556
L.M.T.D. (deg. K)	14.559	10.318	13.820	9.806	10.149	6.166	6.448
U (kW/sq.m/K)	2.206	4.803	3.309	4.463	4.659	3.337	1.276
Clean-U Value (kW/sq.m/K)	3.9	6.6	5.1	5.1	5.1	5.1	5.1
f (sq.m K/kW)	0.1969	0.0567	0.1062	0.0280	0.0186	0.1036	0.5878

Table 6–3 Calculation of Heat Transfer Coefficient (U) and Fouling Factor after 452hrs of RUN–3

Run No. 3 **Date: August 13, 94** **Time: 08:00** **Total Operation Time: 452 hr.**

Variables	*Brine Heater*	*Evaporator Stages*					
		# 1	# 2	# 3	# 4	# 5	# 6
Flowrate (kg/h)	6450	6450	6450	6450	6450	18800	18800
Specific Heat (kJ/kg/K)	3.989	3.968	3.954	3.942	3.932	3.968	3.966
Inlet Temp. (deg. C)	90.5	77	64	52	40	33	31.5
Outlet Temp. (deg. C)	112	90.5	77	64	52	38.5	33
Temp. Rise (deg. C)	21.5	13.5	13	12	12	5.5	1.5
Flashing Temp. (deg. C)	116	94	85	70	58.5	43	38
Heat Transfer Rate (kJ/S)	153.641	95.977	92.097	84.755	84.532	113.982	31.070
Heat Transfer Area (Sq.m)	4.6723	1.937	1.937	1.937	1.937	4.9556	4.9556
L.M.T.D. (deg. K)	11.607	8.542	13.470	10.923	11.473	6.888	5.717
U (kW/sq.m/K)	2.833	5.801	3.530	4.006	3.804	3.339	1.097
Clean-U Value (kW/sq.m/K)	3.9	6.6	5.1	5.1	5.1	5.1	5.1
f (sq.m K/kW)	0.0966	0.0209	0.0872	0.0536	0.0668	0.1034	0.7158

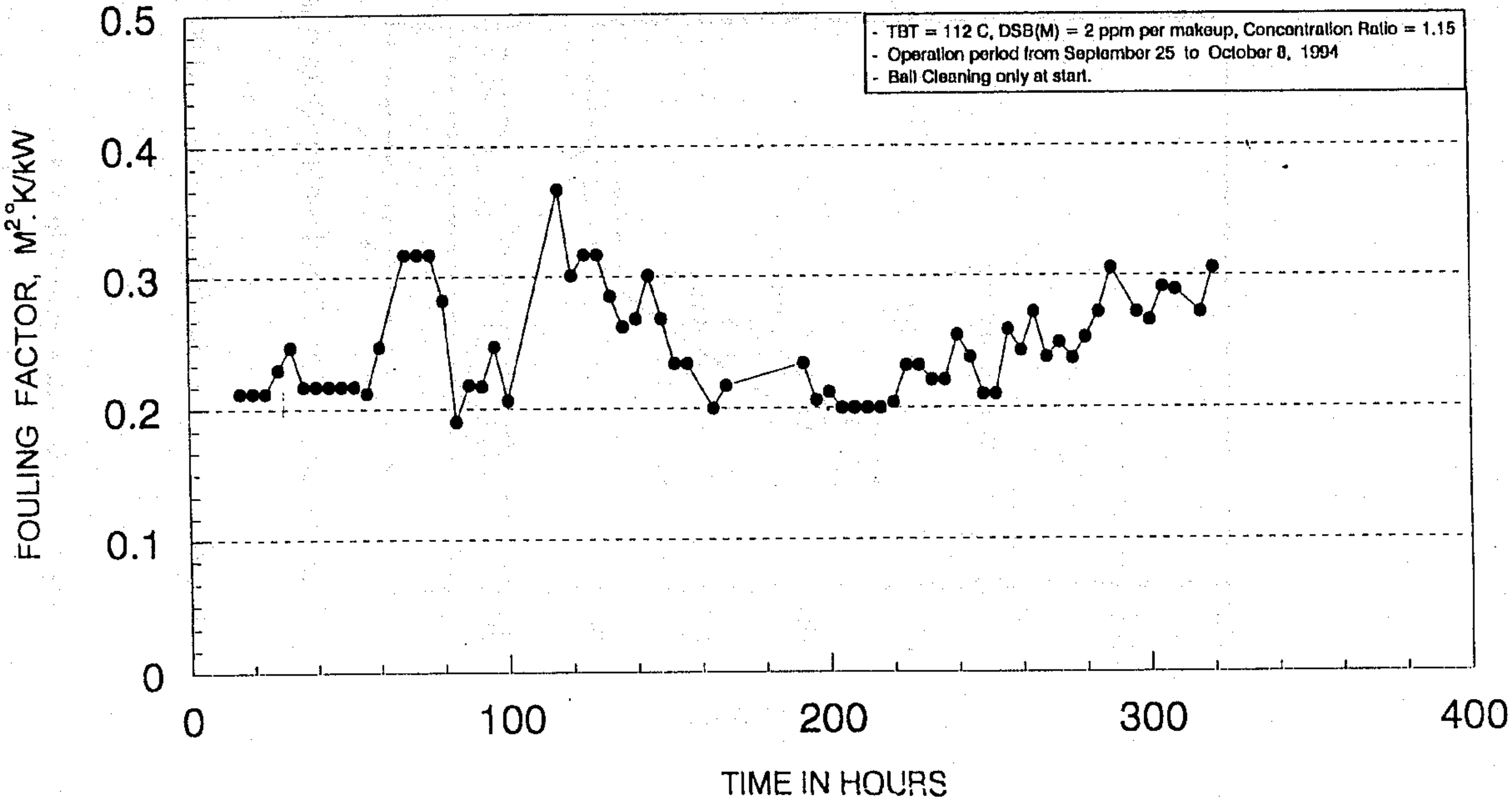


Fig. 5 Time Dependency of Fouling Factor of Brine Heater in RUN-4

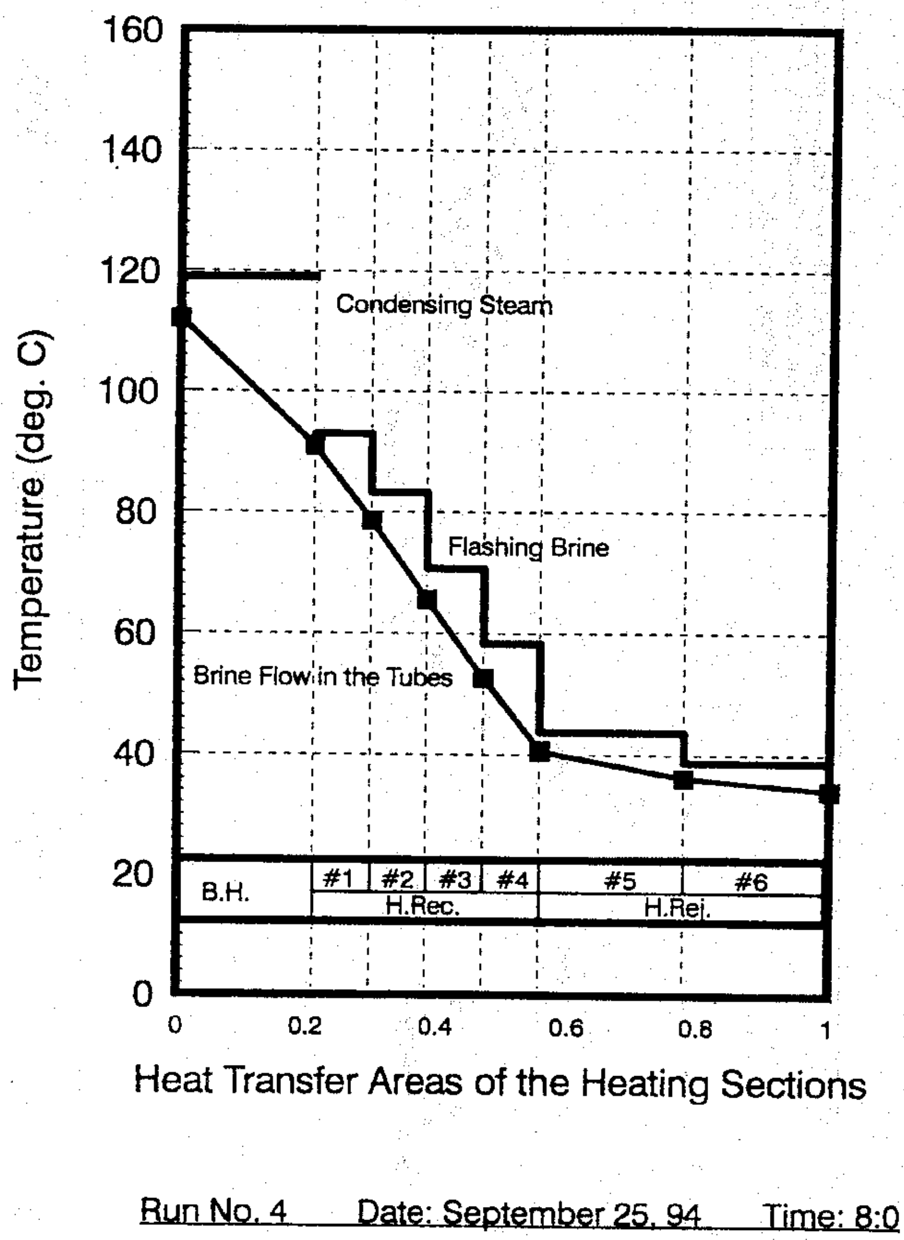


Fig. 6-1 Heat Cycle at Start of RUN-4

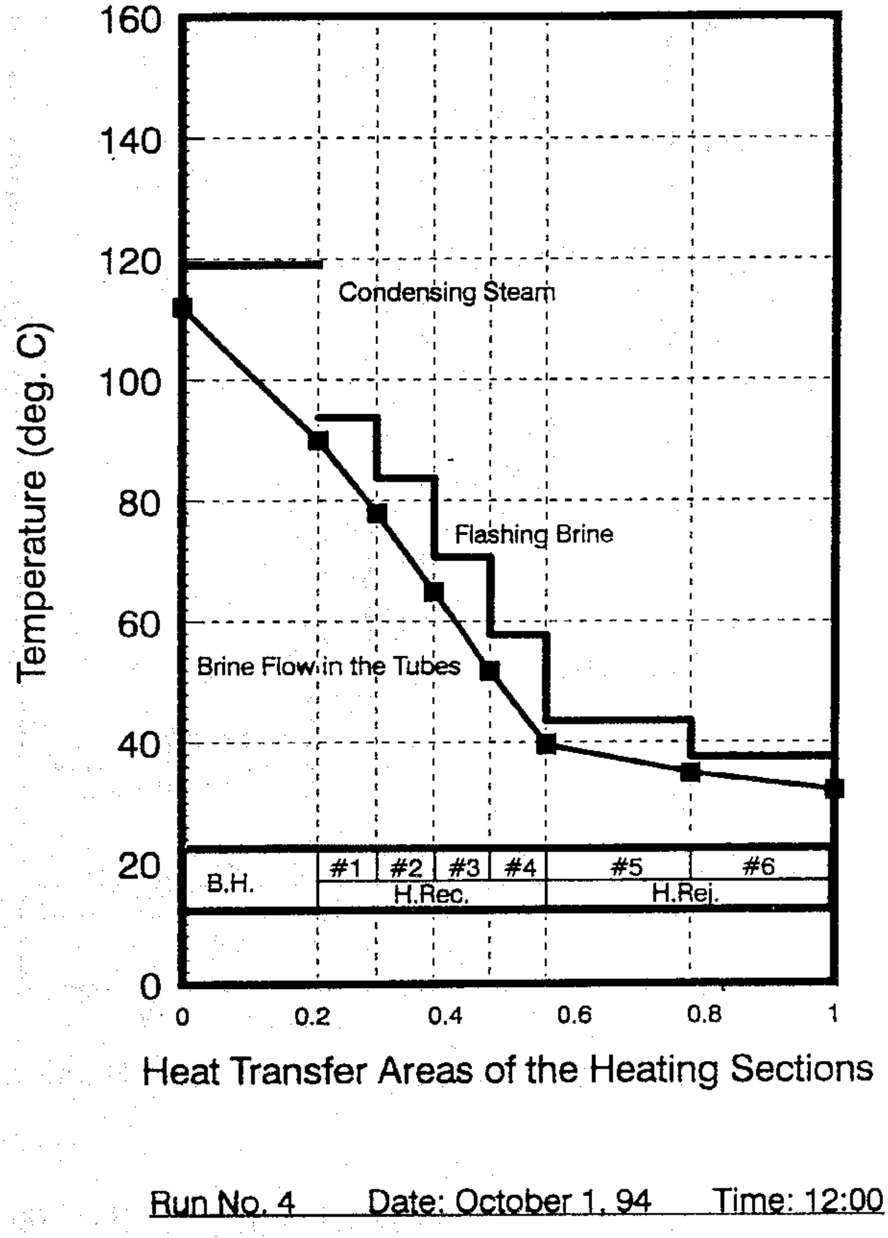
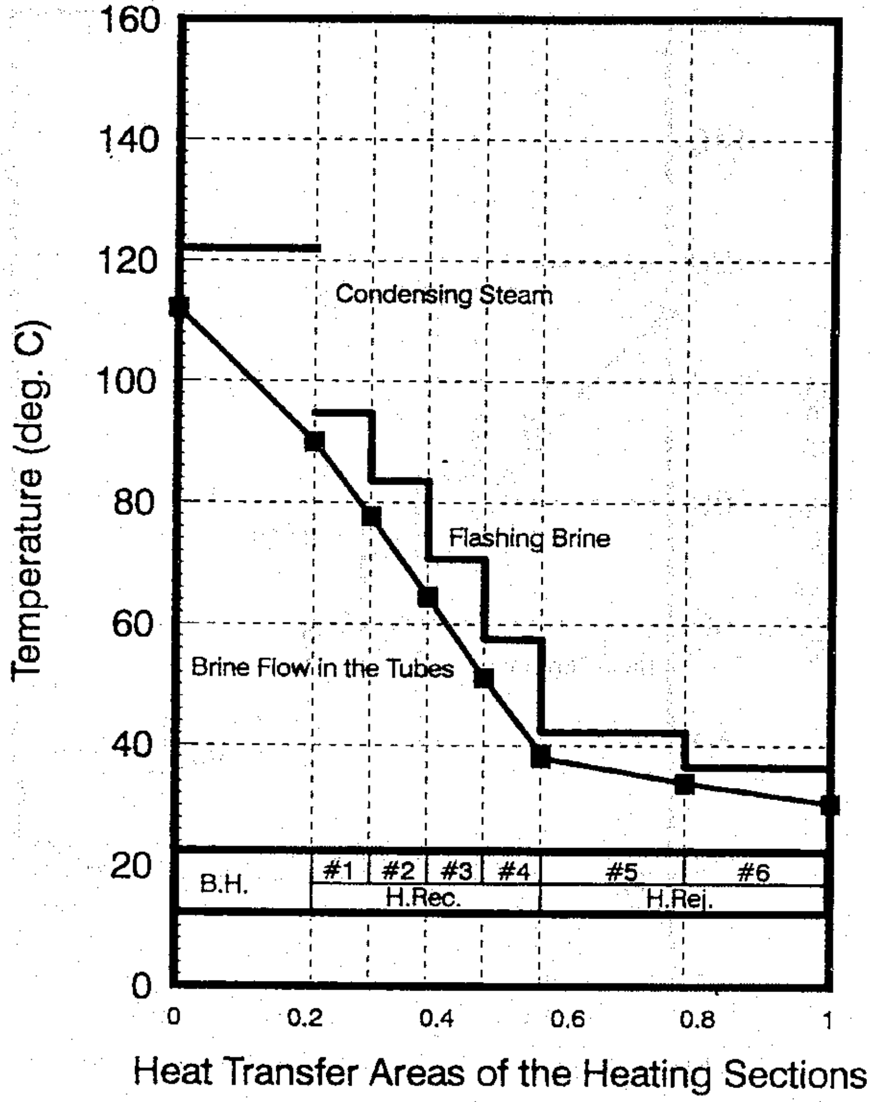


Fig. 6–2 Heat Cycle after 164hrs of RUN–4



Run No. 4 Date: October 8, 94 Time: 00:00

Fig. 6-3 Heat Cycle afttr 320hrs of RU-4

Table 7–1 Calculation of Overall Heat Transfer Coefficient (U) and Fouling Factor at Start of RUN–4

Run No. 4 **Date: September 25, 94** **Time: 8:00** **Total Operation Time: 16 hr.**

Variables	*Brine Heater*	*Evaporator Stages*					
		# 1	*# 2*	*# 3*	*# 4*	*# 5*	*# 6*
Flowrate (kg/h)	6500	6500	6500	6500	6500	18500	18500
Specific Heat (kJ/kg/K)	3.989	3.969	3.956	3.943	3.932	3.970	3.968
Inlet Temp. (deg. C)	91	78.6	65.5	52.6	40.8	36.1	34
Outlet Temp. (deg. C)	112	91	78.6	65.5	52.6	40.5	36.1
Temp. Rise (deg. C)	21	12.4	13.1	12.9	11.8	4.4	2.1
Flashing Temp. (deg. C)	119	93	83.2	70.6	58.3	43.7	38.7
Heat Transfer Rate (kJ/S)	151.243	88.866	93.562	91.841	83.779	89.766	42.821
Heat Transfer Area (Sq.m)	4.6723	1.937	1.937	1.937	1.937	4.9556	4.9556
L.M.T.D. (deg. K)	15.148	6.281	9.722	10.229	10.519	5.087	3.547
U (kW/sq.m/K)	2.137	7.304	4.969	4.635	4.112	3.561	2.436
Clean-U Value (kW/sq.m/K)	3.9	6.6	5.1	5.1	5.1	5.1	5.1
f (sq.m K/kW)	0.212	-0.015	0.005	0.020	0.047	0.085	0.214

Table 7–2 Calculation of Overall Heat Transfer Coefficient (U) and Fouling Factor after 164hrs of RUN–4

Run No. 4 | Date: October 01, 94 | Time: 12:00 | Total Operation Time: 164 hr.

Variables	*Brine Heater*	*Evaporator Stages*					
		# 1	*# 2*	*# 3*	*# 4*	*# 5*	*# 6*
Flowrate (kg/h)	6500	6500	6500	6500	6500	18500	18500
Specific Heat (kJ/kg/K)	3.988	3.968	3.955	3.942	3.932	3.969	3.967
Inlet Temp. (deg. C)	90	77.9	64.9	51.8	39.7	34.9	32
Outlet Temp. (deg. C)	112	90	77.9	64.9	51.8	39.5	34.9
Temp. Rise (deg. C)	22	12.1	13	13.1	12.1	4.6	2.9
Flashing Temp. (deg. C)	119	93.8	83.7	70.6	57.8	43.5	37.5
Heat Transfer Rate (kJ/S)	158.420	86.696	92.832	93.249	85.892	93.830	59.120
Heat Transfer Area (Sq.m)	4.6723	1.937	1.937	1.937	1.937	4.9556	4.9556
L.M.T.D. (deg. K)	15.478	8.454	11.054	10.977	10.959	6.009	3.871
U (kW/sq.m/K)	2.191	5.294	4.335	4.386	4.046	3.151	3.082
Clean-U Value (kW/sq.m/K)	3.9	6.6	5.1	5.1	5.1	5.1	5.1
f (sq.m K/kW)	0.200	0.037	0.035	0.032	0.051	0.121	0.128

(5.3.3)

Table 7–3 Calculation of Overall Heat Transfer Coefficient (U) and Fouling Factor after 320hrs of RUN–4

Run No. 4 **Date: October 08, 94** **Time: 00:00** **Total Operation Time: 320 hr.**

Variables	*Brine Heater*	*Evaporator Stages*					
		# 1	# 2	# 3	# 4	# 5	# 6
Flowrate (kg/h)	6450	6450	6450	6450	6450	18400	18400
Specific Heat (kJ/kg/K)	3.988	3.968	3.955	3.942	3.931	3.969	3.966
Inlet Temp. (deg. C)	90	77.7	64.5	51.1	38.7	33.8	30.5
Outlet Temp. (deg. C)	112	90	77.7	64.5	51.1	38	33.8
Temp. Rise (deg. C)	22	12.3	13.2	13.4	12.4	4.2	3.3
Flashing Temp. (deg. C)	122	94.7	83.5	70.8	57.6	42.3	36.5
Heat Transfer Rate (kJ/S)	157.202	87.448	93.528	94.639	87.329	85.191	66.898
Heat Transfer Area (Sq.m)	4.6723	1.937	1.937	1.937	1.937	4.9556	4.9556
L.M.T.D. (deg. K)	18.914	9.567	11.124	11.754	11.617	6.163	4.133
U (kW/sq.m/K)	1.779	4.719	4.340	4.157	3.881	2.789	3.266
Clean-U Value (kW/sq.m/K)	3.9	6.6	5.1	5.1	5.1	5.1	5.1
f (sq.m K/kW)	0.306	0.060	0.034	0.044	0.062	0.162	0.110

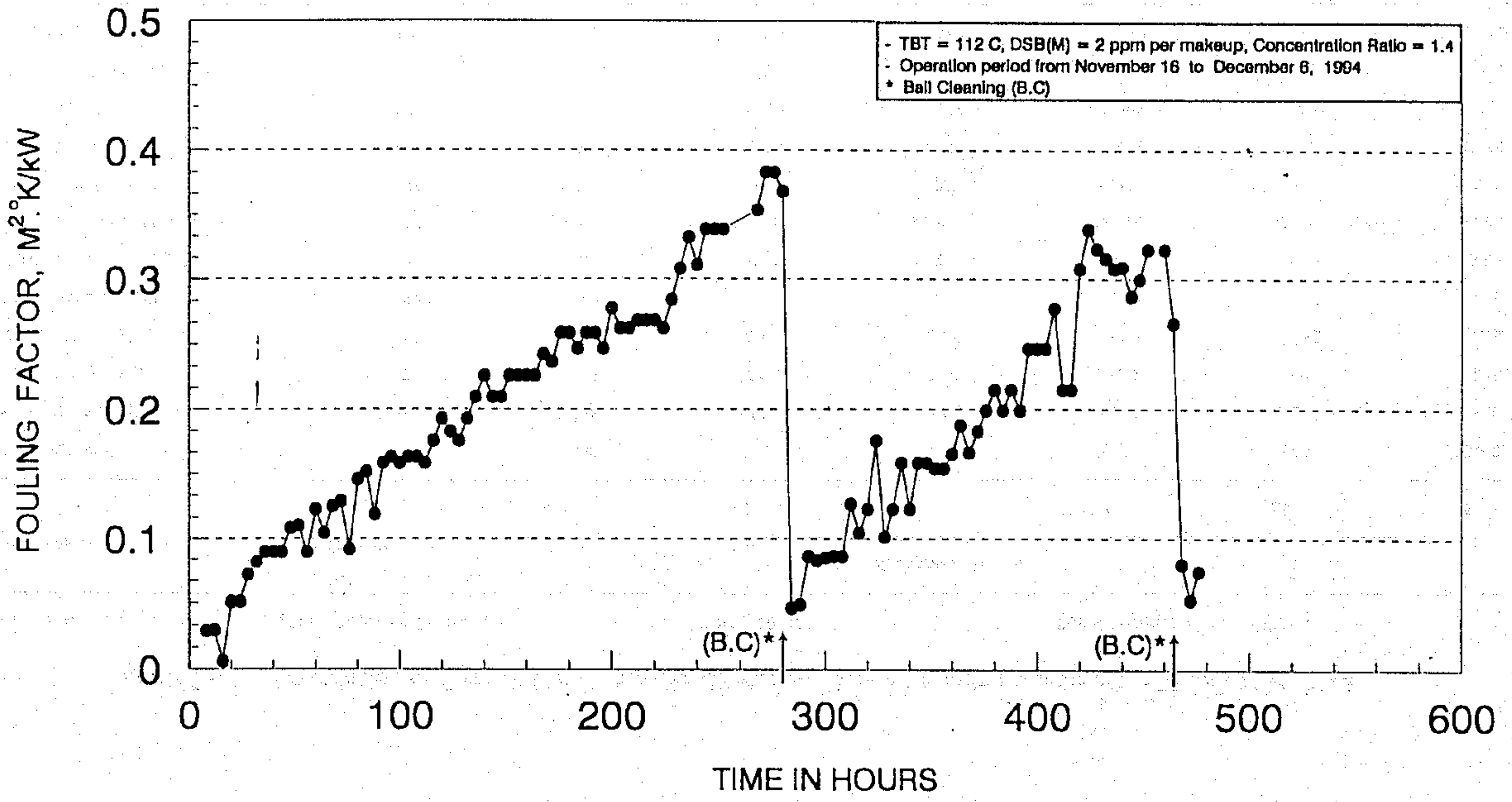


Fig. 7 Time Dependency of Fouling Factor of Brine Heater in RUN-8

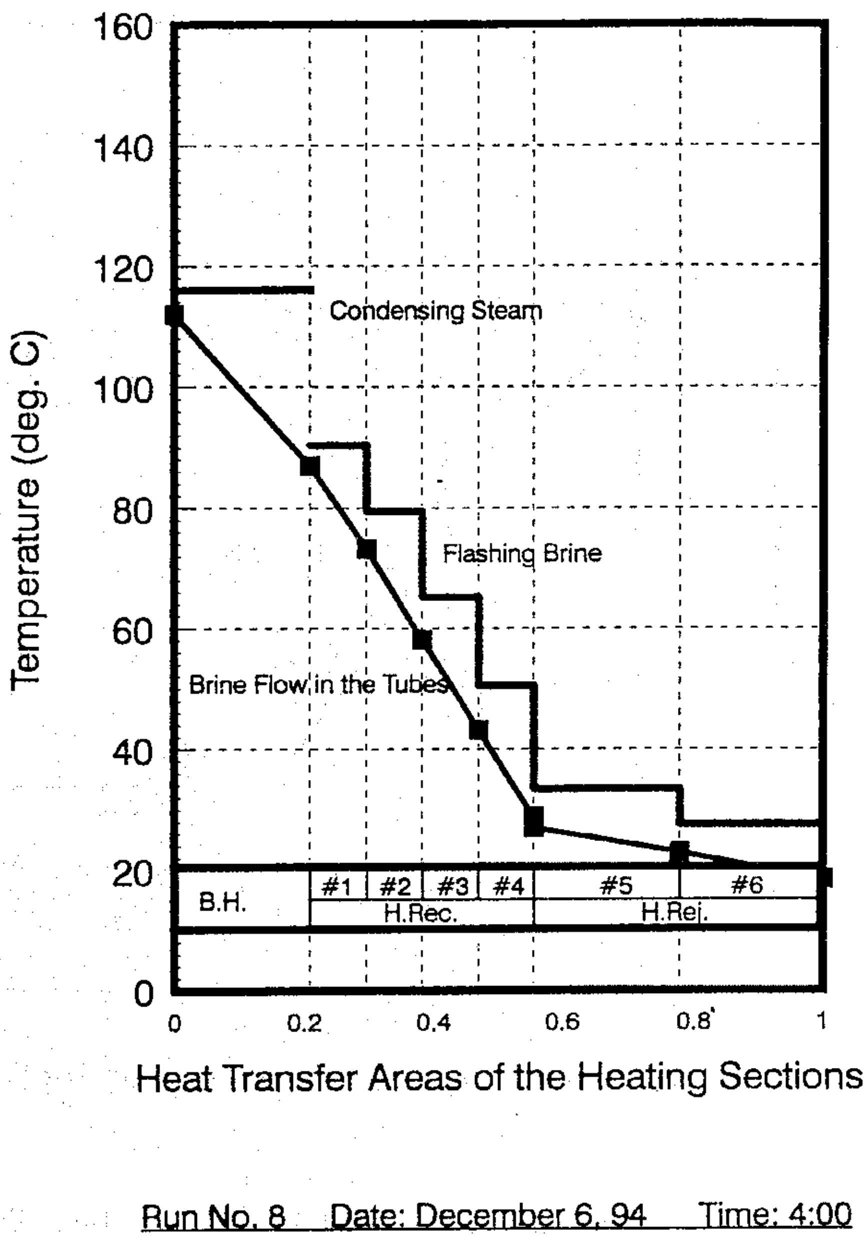


Fig. 8-1 Heat Cycle at Start of RUN-8

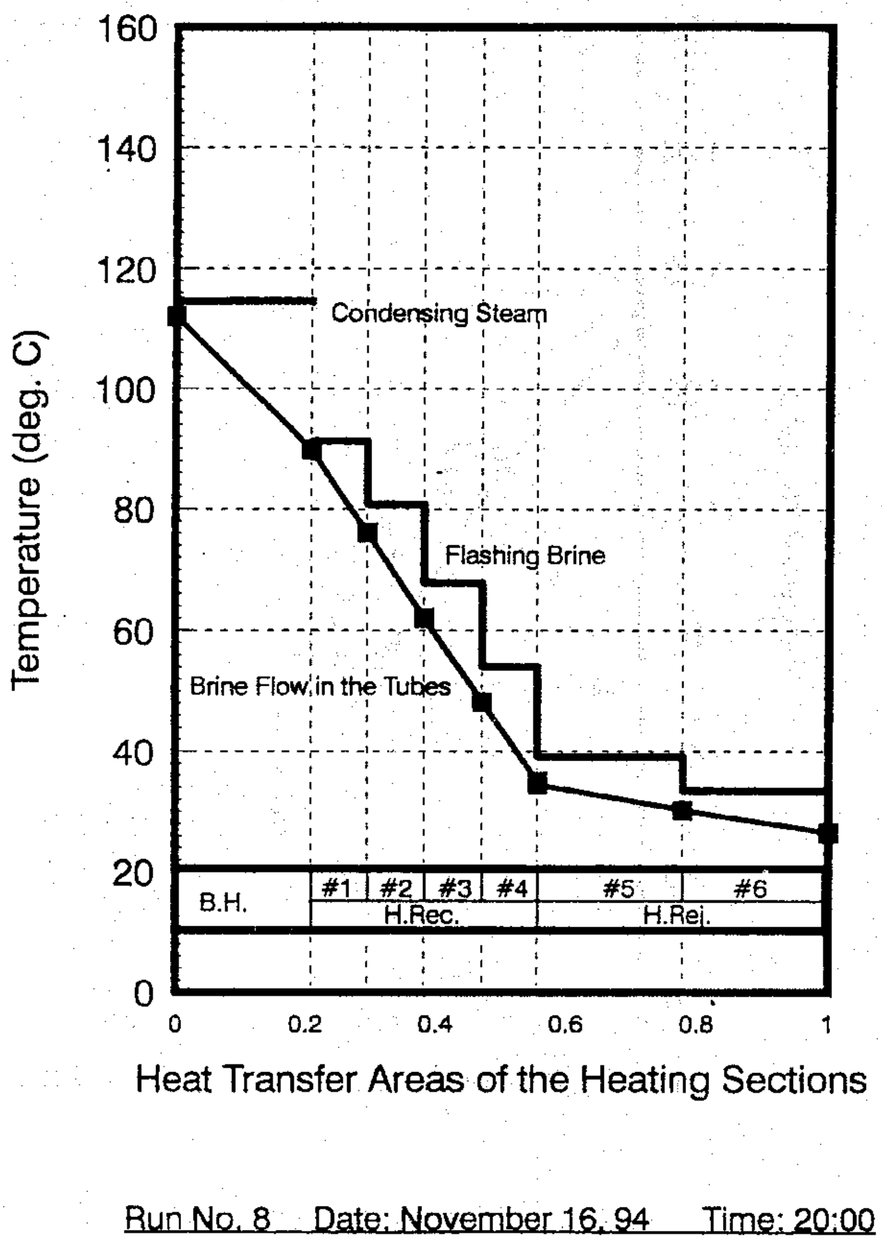
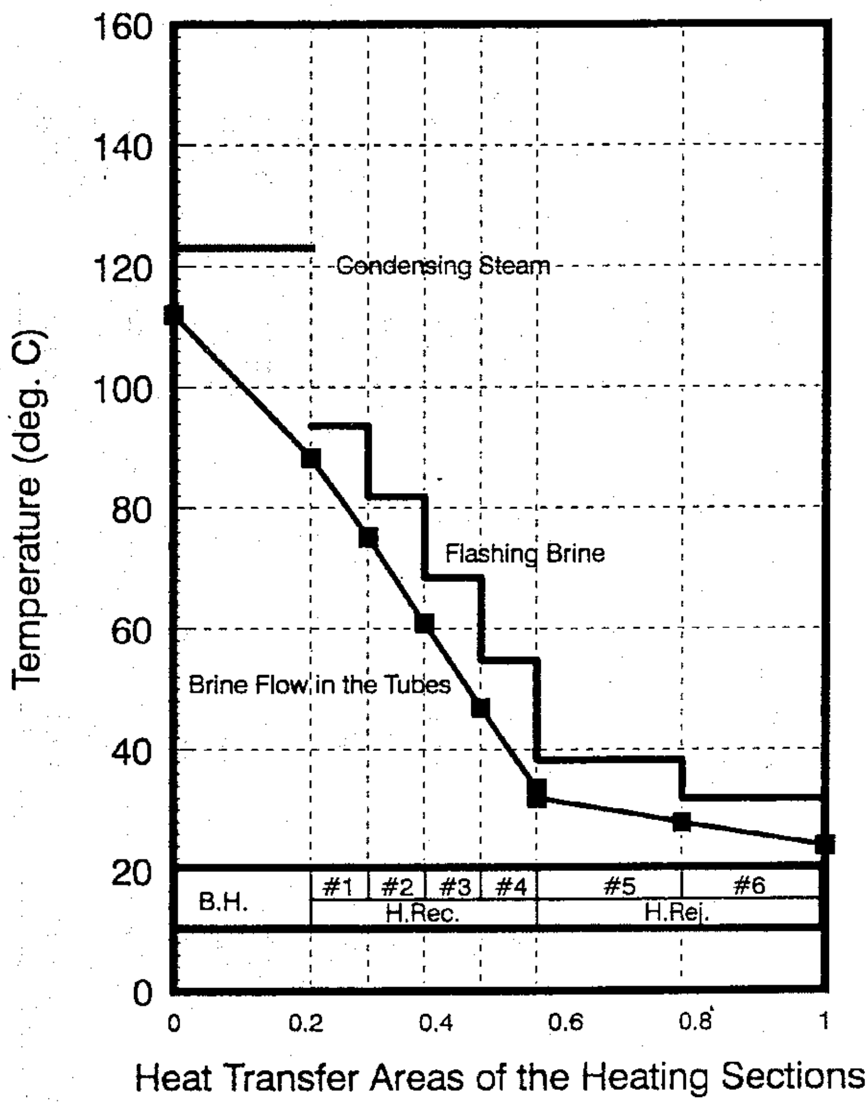


Fig. 8–2 Heat Cycle after 240hrs of RUN–8



Run No. 8 Date: November 26, 94 Time: 12:00

Fig. 8-3 Heat Cycle after 472hrs of RUN-8

Table 8–1 Calculation of Overall Heat Transfer Coefficient (U) and Fouling Factor at Start of RUN–8

Run No. 8 Date: November 16, 94 Time: 20:00 Total Operation Time: 8 hr.

Variables	*Brine Heater*	*Evaporator Stages*					
	-	*# 1*	*# 2*	*# 3*	*# 4*	*# 5*	*# 6*
Flowrate (kg/h)	6500	6500	6500	6500	6500	18500	18500
Specific Heat (kJ/kg/K)	3.962	3.940	3.925	3.911	3.898	3.966	3.964
Inlet Temp. (deg. C)	89.8	76.1	62	48.2	35	30.2	26.5
Outlet Temp. (deg. C)	112	89.8	76.1	62	48.2	34.5	30.2
Temp. Rise (deg. C)	22.2	13.7	14.1	13.8	13.2	4.3	3.7
Flashing Temp. (deg. C)	114.5	91.3	80.8	67.6	54.1	39.1	33.4
Heat Transfer Rate (kJ/S)	158.794	97.460	99.916	97.440	92.908	87.646	75.374
Heat Transfer Area (Sq.m)	4.6723	1.937	1.937	1.937	1.937	4.9556	4.9556
L.M.T.D. (deg. K)	9.692	5.916	10.171	11.107	11.237	6.515	4.815
U (kW/sq.m/K)	3.507	8.505	5.072	4.529	4.269	2.715	3.159
Clean-U Value (kW/sq.m/K)	3.9	6.6	5.1	5.1	5.1	5.1	5.1
f (sq.m K/kW)	0.0288	-0.0339	0.0011	0.0247	0.0382	0.1723	0.1205

Table 8–2 Calculation of Overall Heat Transfer Coefficient (U) and Fouling Factor after 236hrs of RUN–8

Run No. 8 **Date: November 26, 94** **Time: 08:00** **Total Operation Time: 236 hr.**

Variables	*Brine Heater*	*Evaporator Stages*					
		# 1	# 2	# 3	# 4	# 5	# 6
Flowrate (kg/h)	6500	6500	6500	6500	6500	18500	18500
Specific Heat (kJ/kg/K)	3.960	3.938	3.923	3.909	3.897	3.965	3.963
Inlet Temp. (deg. C)	88	75	60.8	46.7	33.3	28	25
Outlet Temp. (deg. C)	112	88	75	60.8	46.7	32	28
Temp. Rise (deg. C)	24	13	14.2	14.1	13.4	4	3
Flashing Temp. (deg. C)	123.8	92.1	80.4	68.1	54	37.9	31.8
Heat Transfer Rate (kJ/S)	171.620	92.441	100.594	99.525	94.282	81.504	61.098
Heat Transfer Area (Sq.m)	4.6723	1.937	1.937	1.937	1.937	4.9556	4.9556
L.M.T.D. (deg. K)	21.625	9.103	11.015	13.110	12.857	7.728	5.155
U (kW/sq.m/K)	1.699	5.243	4.715	3.919	3.786	2.128	2.392
Clean-U Value (kW/sq.m/K)	3.9	6.6	5.1	5.1	5.1	5.1	5.1
f (sq.m K/kW)	0.3323	0.0392	0.0160	0.0591	0.0681	0.2738	0.2221

Table 8–3 Calculation of Overall Heat Transfer Coefficient (U) and Fouling Factor after 472hrs of RUN–8

Run No. 8 **Date: December 06, 94** **Time: 04:00** **Total Operation Time: 472 hr.**

Variables	*Brine Heater*	*Evaporator Stages*					
		# 1	*# 2*	*# 3*	*# 4*	*# 5*	*# 6*
Flowrate (kg/h)	6500	6500	6500	6500	6500	18500	18500
Specific Heat (kJ/kg/K)	3.960	3.937	3.921	3.906	3.893	3.962	3.960
Inlet Temp. (deg. C)	87	73.2	58.1	43.1	28.8	22.9	18.5
Outlet Temp. (deg. C)	112	87	73.2	58.1	43.1	27	22.9
Temp. Rise (deg. C)	25	13.8	15.1	15	14.3	4.1	4.4
Flashing Temp. (deg. C)	116	90.4	79.4	65.2	50.5	33.4	27.2
Heat Transfer Rate (kJ/S)	178.743	98.090	106.906	105.797	100.526	83.484	89.545
Heat Transfer Area (Sq.m)	4.6723	1.937	1.937	1.937	1.937	4.9556	4.9556
L.M.T.D. (deg. K)	12.620	8.513	12.235	13.210	13.292	8.282	6.244
U (kW/sq.m/K)	3.031	5.949	4.511	4.135	3.904	2.034	2.894
Clean-U Value (kW/sq.m/K)	3.9	6.6	5.1	5.1	5.1	5.1	5.1
f (sq.m K/kW)	0.0735	0.0166	0.0256	0.0458	0.0600	0.2955	0.1495

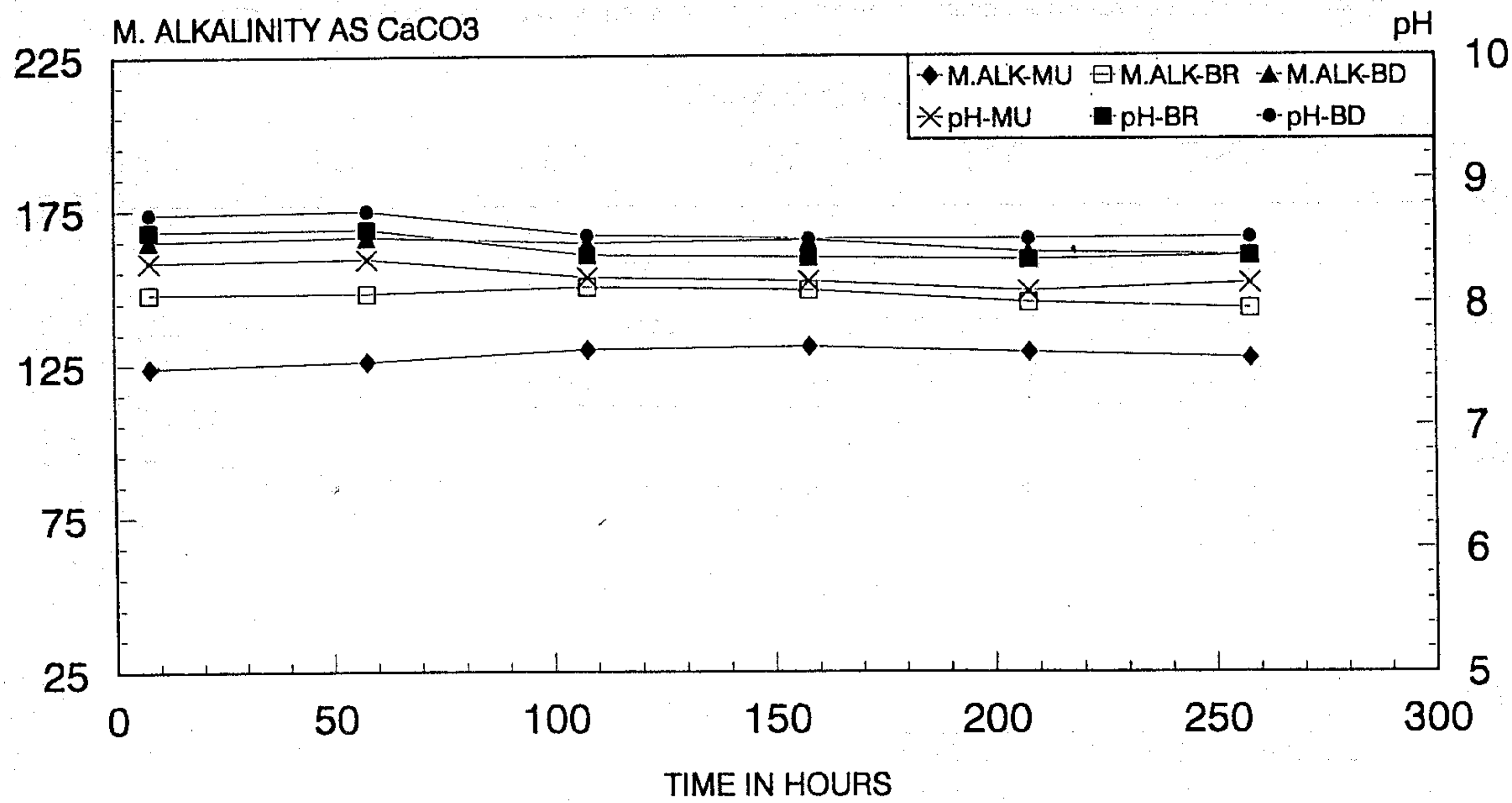


Fig. 9–1 Water Constituent of the Make–up, Recirculation and Blow Down during RUN–3 (Part 1)

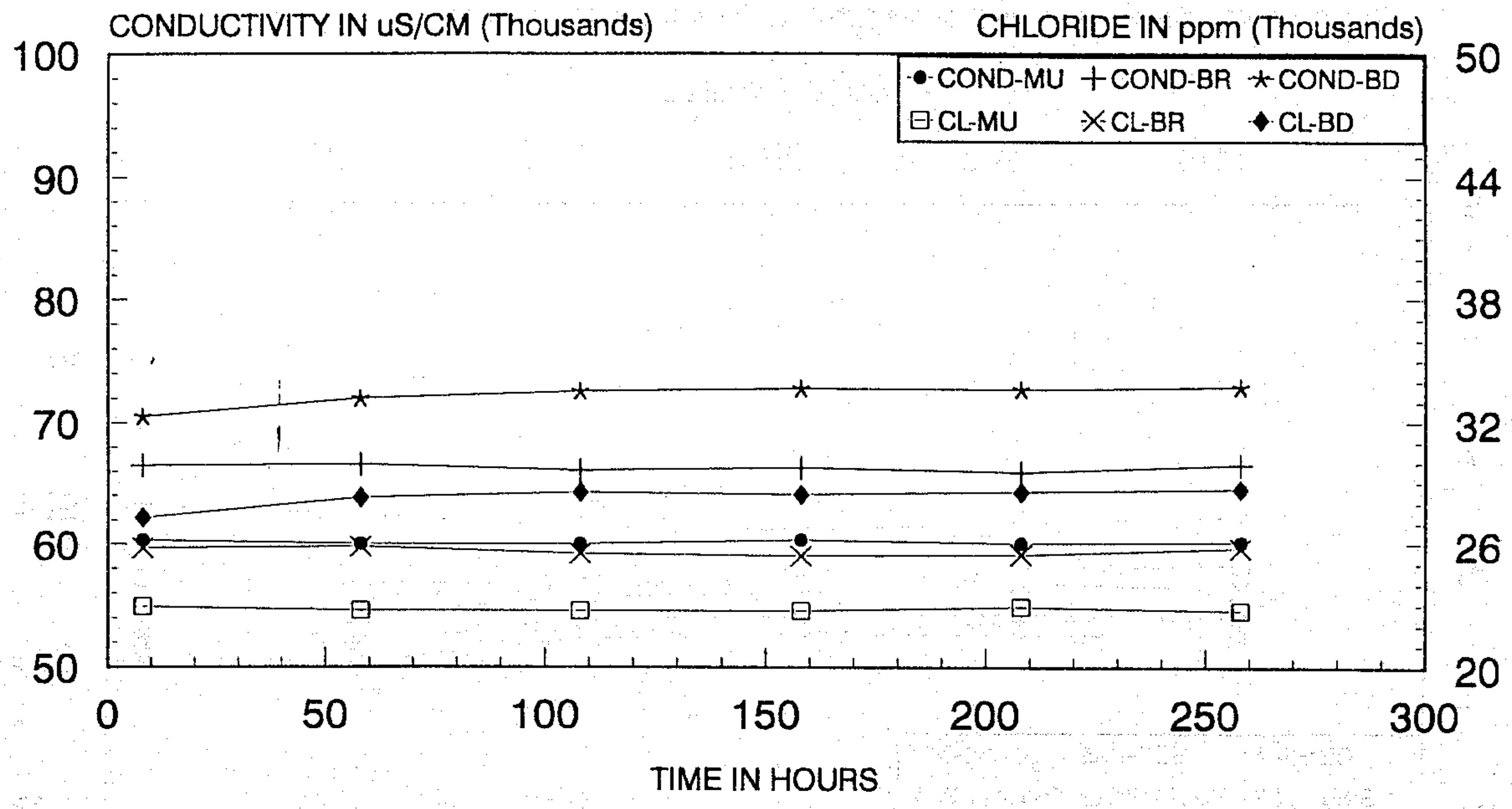


Fig. 9–2 Water Constituent of the Make–up, Recirculation and Blow Down during RUN–3 (Part 2)

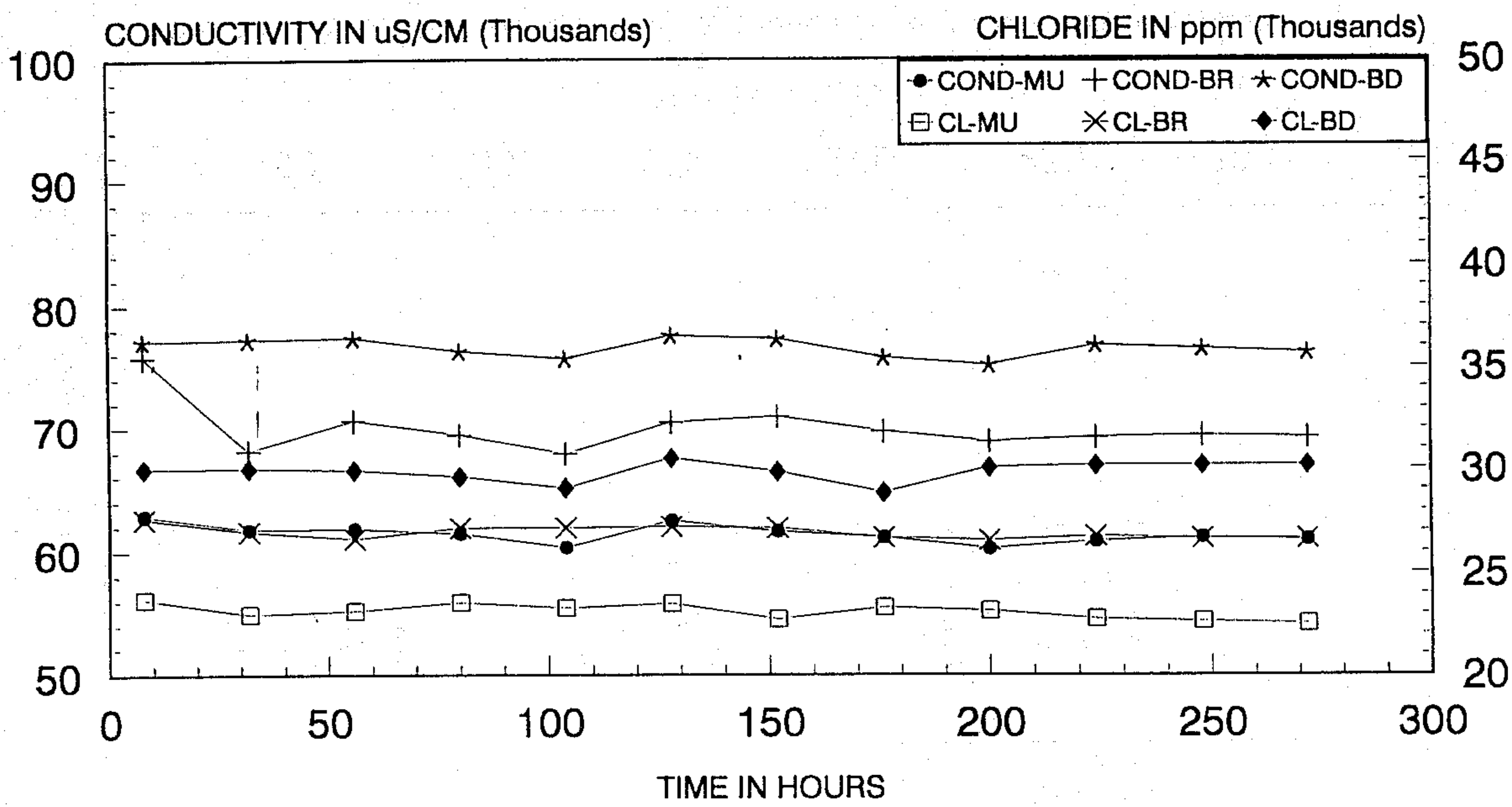


Fig. 10–1 Water Constituent of the Make–up, Recirculation and Blow Down during RUN–4 (Part 1)

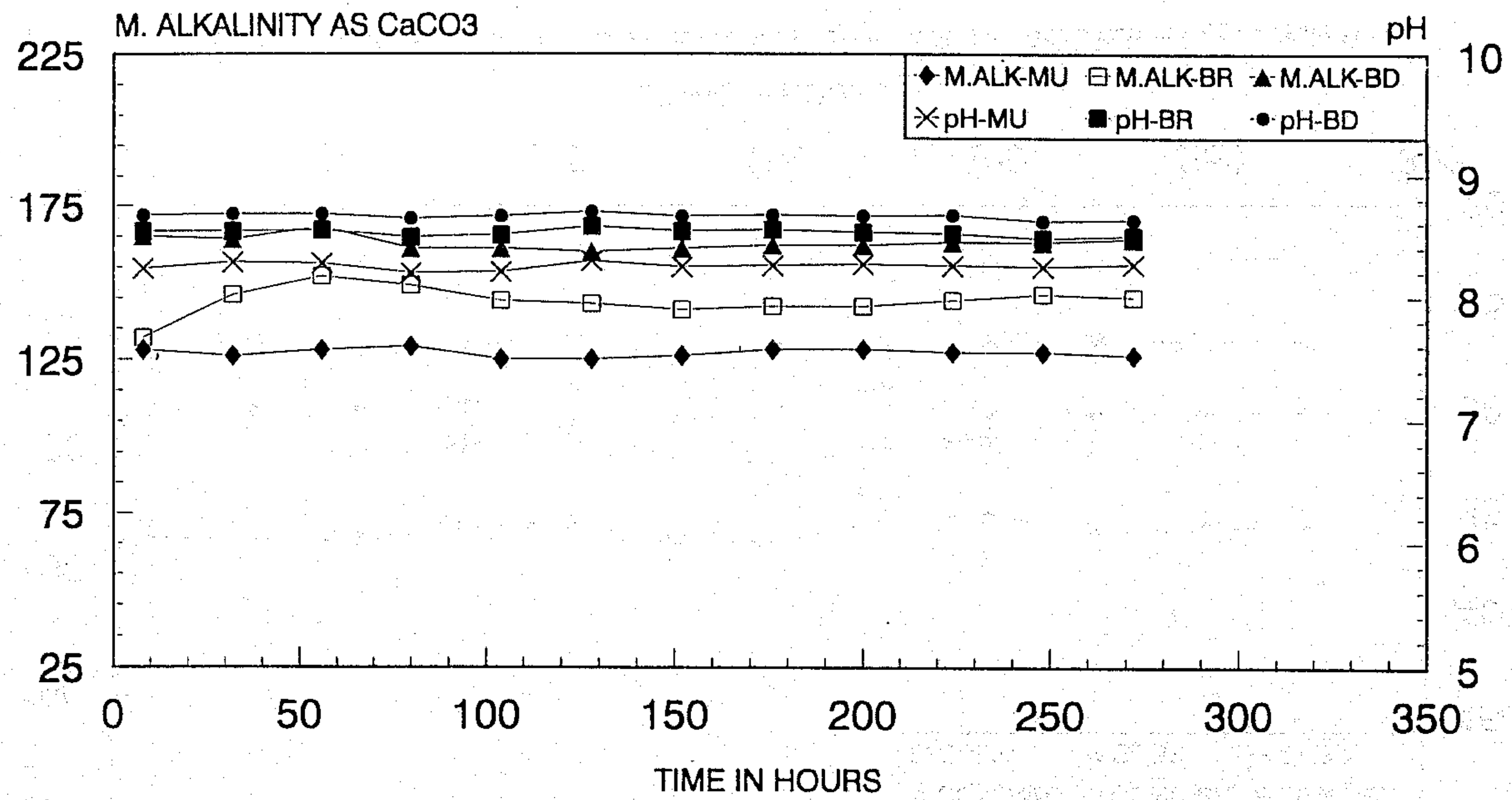


Fig. 10–2 Water Constituent of the Make–up, Recirculation and Blow Down during RUN–4 (Part 2)

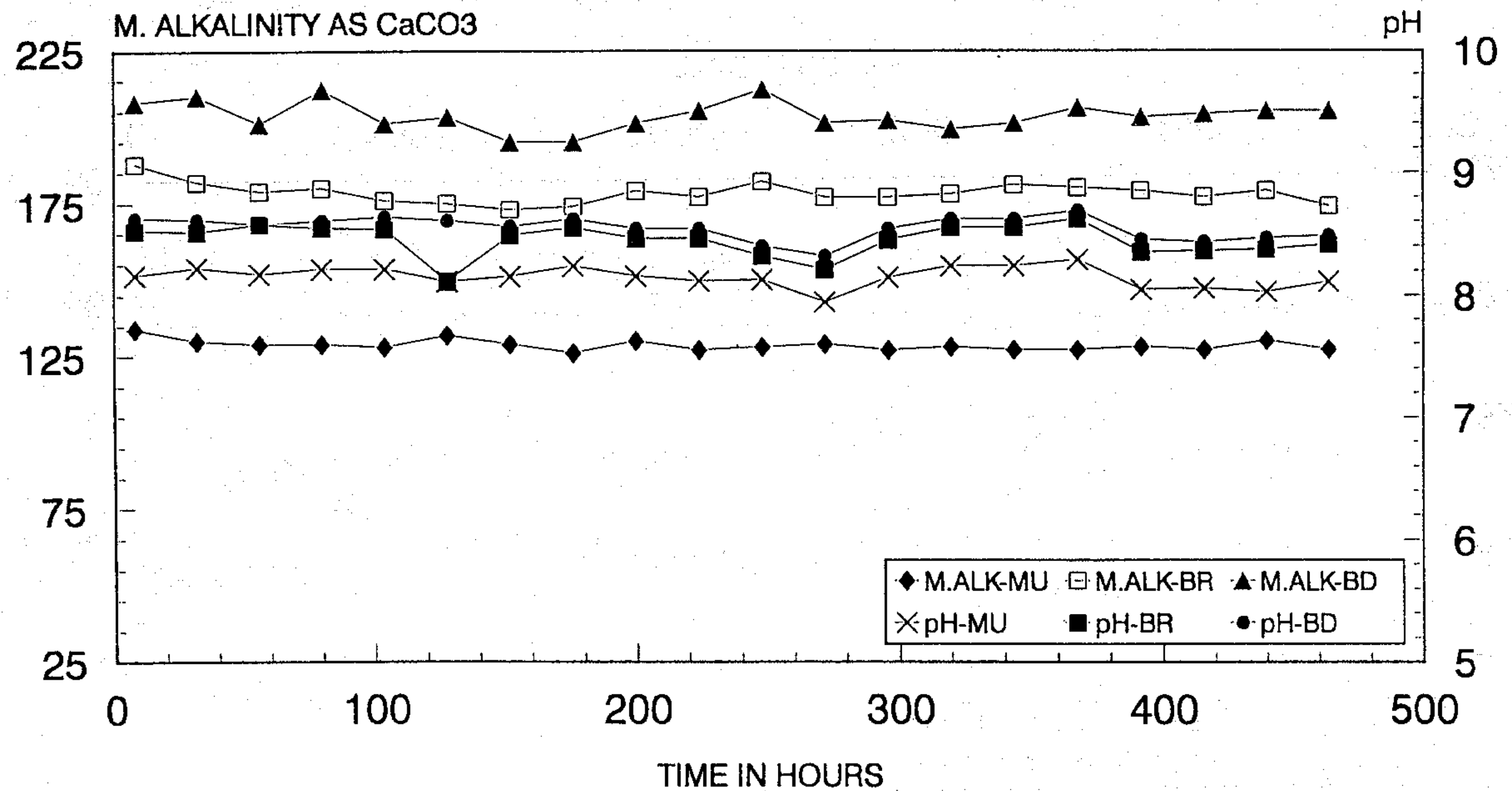


Fig. 11–1 Water Constituent of the Make–up, Recirculation and Blow Down during RUN–8 (Part 1)

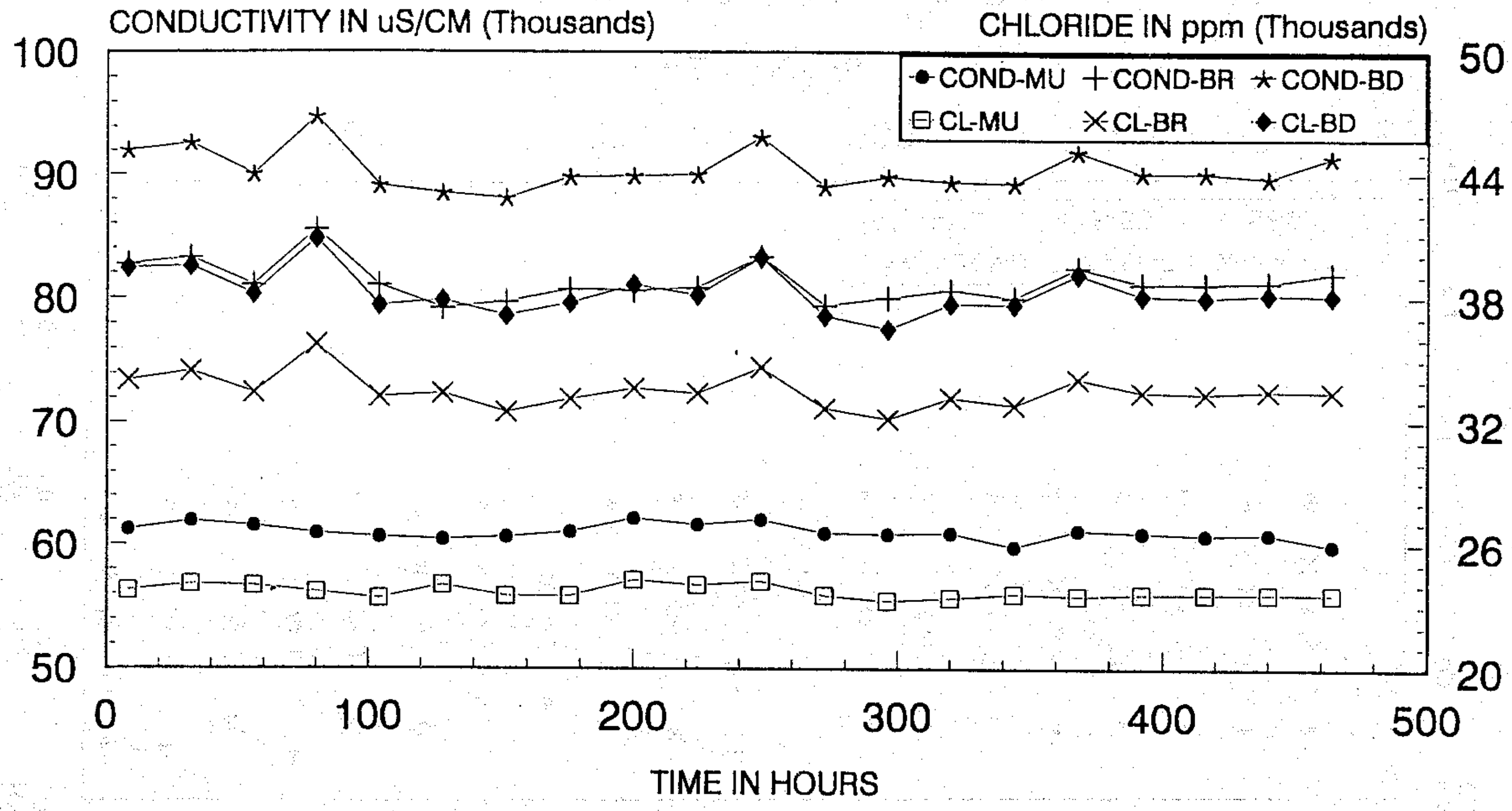


Fig. 11–2 Water Constituent of the Make–up, Recirculation and Blow Down during RUN–8 (Part 2)

4.3 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.

Overall heat transfer coefficients were calculated for the brine heater and heat recovery stages of the MSF test plant using the physical dimensions as per the drawings and transport properties of steam and liquid water at the prevailing temperatures. The calculated values were found to be in very good agreement with design values provided by the manufacturer. Comparisons between these theoretical values with values obtained from the first performance tests during commissioning show good agreement only for stages 2, 3 and 4 in the heat recovery section. The experimental value of the overall heat transfer coefficient for the brine heater was found to be significantly lower than the theoretical values. On the other hand, the experimental value for the first stage in the heat recovery section was higher than the theoretical values.

Experimental data of Runs 1–5 and 8 were reviewed to examine the consistency of these 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	**: 3.9 kW/m^2K**
Stage #1	**: 6.6 kW/m^2K**
Stage #2, 3 & 4	**: 5.1 kW/m^2K**

5. Discussions

The obtained data of RUN 3, 4, 5 & 8 have been compared as follows.

RUN NO.		3	4	5-1	5-2	8
Ball CLEANING		●	●			
CONC	Chemical		●			●
	Hybrid			●	●	
M-alk.	CF ≤ 1.2		●	●		
	CF = 1.4				●	●

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 have 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 maintained around 0.1–0.15m²K/kW during whole test period, while that of RUN 4 increased to 0.3m²K/kW because ball cleaning was not applied.

In the case of concentration factor 1.4, RUN 8, fouling factor increases linearly with time due to scaling. The ball cleaning has been conducted when the U value reached 3.70kW/m²K, and the results are shown in Fig.7. The recovery of Uvalue is not complete and still fouling factor of $0.05m^2K/kW$ remained after ball cleaning. This is the characteristics of the single scale inhibitor dosing which is different from the case of hybrid method. During the hybrid operation, 100% recovery of Uvalue had been observed. The frequency of ball cleaning was three times a day and 30 minutes cleaning was applied.

5.2 The effect of concentration factor on the fouling factor

In case of the concentration factor of 1.15, M-alkalinity of 140mg/L as $CaCO_3$, RUN 4, little increase in fouling factor was observed. However, when the concentration factor has been raised to 1.4, M-alkalinity of 180mg/L as $CaCO_3$, RUN 8, the fouling factor showed apparent increase.

Despite the decrease of the M-alkalinity to less than half of the above value, the fouling factor increased as the concentration factor was increased, as shown in RUN 5.

The effect of M-alkalinity on scaling will be discussed in 5.3.4.

5.3 Time dependency of the fouling factor

The increasing rate of fouling factor was calculated from the data obtained from RUN 8, which concentration factor was 1.4 and M-alkalinity was 180mg/L as $CaCO_3$.

The fouling factor of #5 and #6 stage has been omitted from the calculation since raw seawater without scale inhibitor was used in the heat rejection section.

As shown in the table below, the scaling at brine heater is one order larger than that of following stages. Thus, the deterioration of the performance ratio of MSF plant should be controlled by the scaling at brine heater.

The fouling factor increases linearly after 30 hours and the increasing rate after ball cleaning become larger than the initial stage. Furthermore, the fouling factor recovery after ball cleaning is only 85.7%. Consequently, the ball cleaning should be applied before the significant increase of fouling factor. Every eight hours of ball cleaning, like this test, would be appropriate.

(5.3.3)

Heat Transfer Tube	Increasing Rate of F.F.(FF/hr)		Temperature (℃)	
Position	Initial State	After #1 B.C.	Inlet	Outlet
Brine Heater	0.0013	0.0018	88	112
#1 Stage	0.0003	0.00035	75	90
#2 Stage	0.00015	0.00015	61	76
#3 Stage	0.00015	0.00015	46	62
#4 Stage	0.00012	0.00012	33	48

Note : •(FF/hr) is {(m^2 K/kW)/hr}
•Increasing Rate is average of 30 to 300 hrs.

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 little when the concentration factor is less than 1.2, but scalings become apparent when concentration factor is increased to 1.4.

(2) The increasing rate of fouling factor of the brine heater in case of concentration factor of 1.4 is 0.0013m^2K/kW/hr. However, the fouling factor decreases to 0.05m^2K/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 continues.

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

5.3.4 Test with the Simultaneous Use a Single Inhibitor and Acid

CONTENTS

List of Tables

List of Figures

1. Introduction

The single inhibitor dosing test to investigate the effect of concentration factor and ball cleaning on fouling factor using PPN(M) has been conducted in 5.3.3.

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 "Hybrid Method" mentioned in this section is explained as follows.

When the seawater is concentrated and/or the temperature elevated, $CaCO_3$ deposits. This is because the concentration of $CaCO_3$ exceeds that of its solubility in seawater. However, scale deposition can be suppressed when the supersaturation can be maintained. The scale inhibitor has the effect to prolong the state of supersaturation. The detail about the effect of scale inhibitor is mentioned in 5.1.2.

"Hybrid Method" is to reduce the bicarbonate ion concentration, M-alkalinity, which is the source of $CaCO_3$ deposition, by dosing acid and to enhance the effect of the scale inhibitor, and thus reduce the amount of scale inhibitor dosing. The lower pH results in the reduction in the M-alkalinity and thus the scaling, however, arouse the more rigorous condition for the corrosion problem of the plant. Consequently, the M-alkalinity has to be optimized to compromise the scaling and the corrosion[1]. The control of the M-alkalinity will be the most crucial point for the hybrid operation.

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.

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

The brine analysis results sampled from various stages of the plant during the hybrid operation is shown in Table 1. In this plant, the brine quality is controlled as follows.

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

Table 1 Water Constituent of Qurayyah Power Plant Phase-1 Desalination Plant Unit B

DATE: 19 MAY '94

ITEM		UNIT	TIME				LIMIT
			1,100 H	1,400 H	1,600 H	1,750 H	
DISTILATE FLOW RATE		kg/ℓ	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	
M-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 %.

3. Test Program

3.1 Basic principle

The feature of the hybrid method is to prevent scaling by acid dosing, which is highly effective in scale depression, and scale inhibitor dosing, which is advantageous to avoid corrosion problem of the metallic installations. The critical point for the hybrid operation will be the accurate control of the pH and the M-alkalinity of the brine in order to attain the benefit of both measures.

In this test, the avoidance of corrosion are assumed as the first priority, and thus the pH of the brine is controlled at 8.0. The experiment RUN-5 was conducted under such condition.

The scale prevention effect was evaluated by the fouling factor, the same to that of the test for single inhibitor, mentioned in 5.3.3.

3.2 Operation Conditions

The feature of this test is low M-alkalinity of the feed seawater, normally 180mg/L as $CaCO_3$, which is altered by the following process.

When sulfuric acid is dosed into seawater, M-alkalinity decrease identical to the equivalent concentration of sulfuric acid by freeing carbondioxide and thus pH decreases. When the feed seawater including free carbondioxide decarbonated by the decarbonator, the free carbondioxide degases and pH increases. The decarbonated seawater is mixed with the circulating brine.

The operation conditions of the test RUN-5, based on the scheme of May, 1994, are shown in Table 2. The operation records of the test RUN are shown in Fig. 1 of 5.3.3.

The concentration of the scale inhibitor, PPN(M), was reduced to the half of the single inhibitor dosing (1mg/L).

Table 2 Operation Conditions of MS Test Plant for RUN 5

ITEMS	UNIT	5-1	5-2
1. Top Brine Temperature	℃	112	112
2. Flow Rate			
-Make up Seawater	m^3/h	3.25	2.45
-Recirculation Brine	m^3/h	6.50	6.5
-Product Water	m^3/h	0.76	0.79
-Blow Down Brine	m^3/h	2.99	1.66
3. Chemical Constituents of Make up seawater			
-pH at 25℃		7	6.5～7.0
-M-alkalinity as $CaCO_3$	mg/L	39	39
-Chloride Ion	mg/L	23,190	23,190
-Concentration Factor as Cl^-		1.0	1.0
4. Chemical Constituents of Brine			
-pH at 25℃		8.01	8.12
-M-alkalinity as $CaCO_3$	mg/L	45-50	55-60
-Chloride Ion	mg/L	28,290	32,730
-Concentration Factor as Cl^-		1.22	1.40
5. Dosing Rate of Chemicals			
-Scale Inhibitor = PPN(M)	mg/L	1	1
-Acid = 98% H_2SO_4	mg/L	80	80

4. Experiments

The flow diagram, the sheet of mass balance, the sheet of heat balance of the MSF Test Plant, capacity of 20 ton/day, are shown in Fig.2, Table 2 and 3 of 5.3.3. The instrument designations used for the calculation of fouling factor are listed in Table 4 of 5.3.3.

The fouling factors were calculated automatically by the personal computer, IBM compatibles, 486. The change in the operation conditions during the experiments had been recorded by the operators in the prescribed format.

The operation data sheets used for the calculation of the fouling factor are shown in Table 5 of 5.3.3.

The shift of operators contributed for the continuous operation are shown in Table 6.1~6.5 of 5.3.3.

5. Results

The operation of the MSF Test Plant for the hybrid method had been conducted twice as shown in Table 1.

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 0.34–0.36(m^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.

5.1 Time Dependency of Fouling Factor

The time dependency of the Uvalue of each RUN are shown in Fig.1 and 2. The heat balance corresponding to the Uvalue at the start and the end of the operation are shown in Fig.3 and 4. The measured data and the calculation process, including logarithmic mean temperature difference and quantity of heat exchange, are shown in Table 3 and Table 4, in accordance with the heat balance shown in Fig.3 and Fig.4.

(5.3.4)

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 Uvalue 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℃.

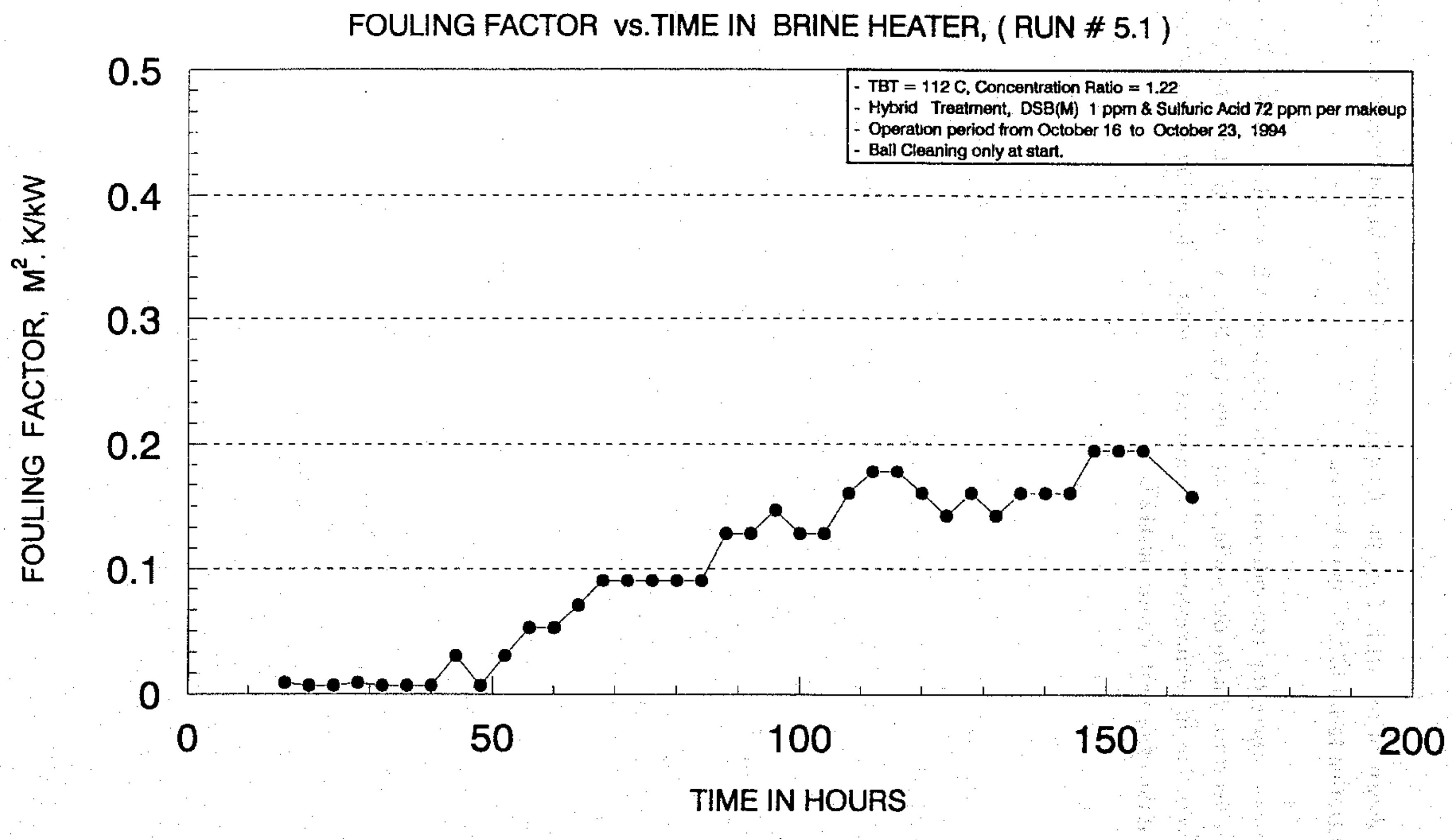


Fig. 1 **Time Dependency of Fouling Factor in RUN 5–1**

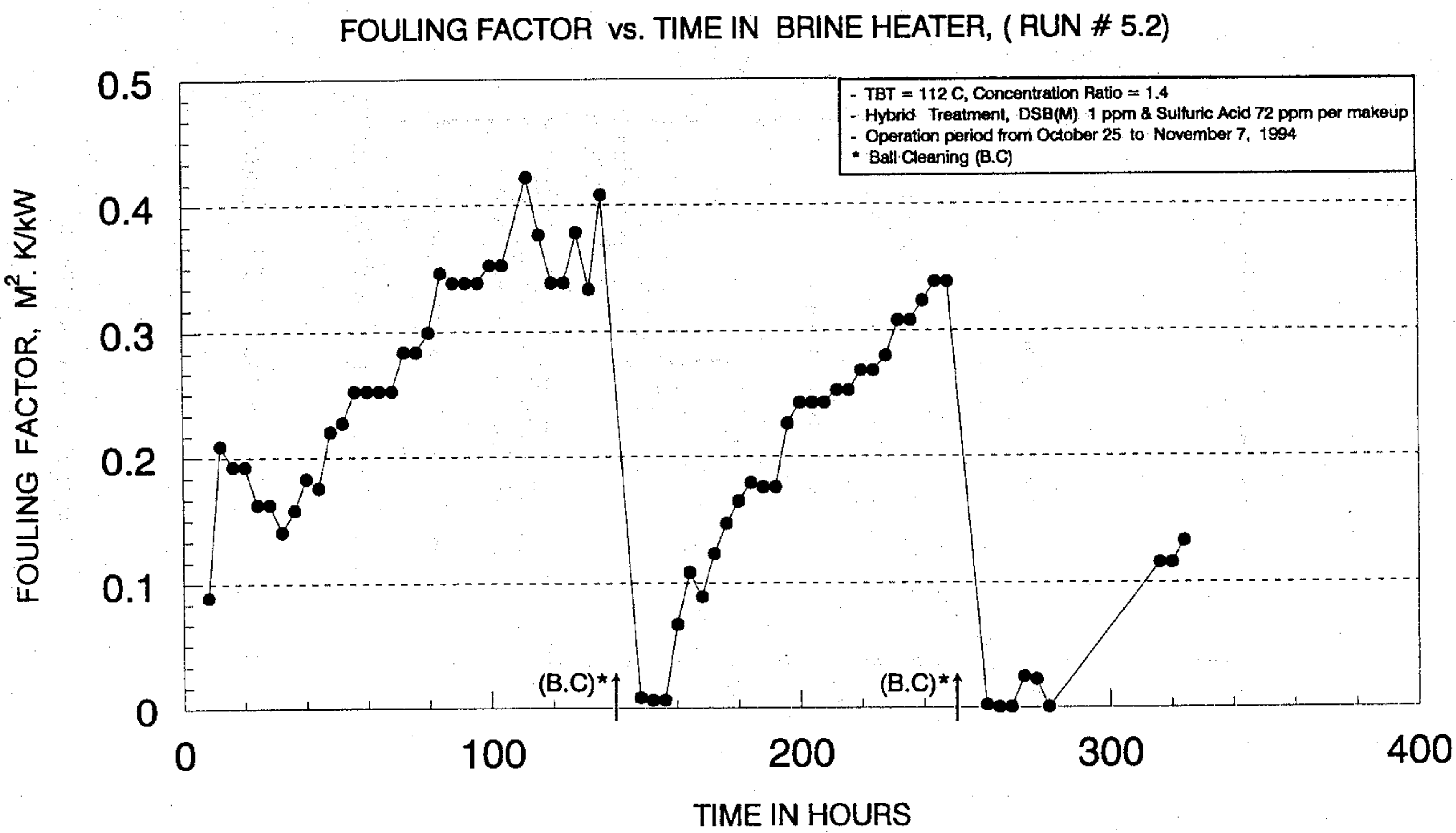
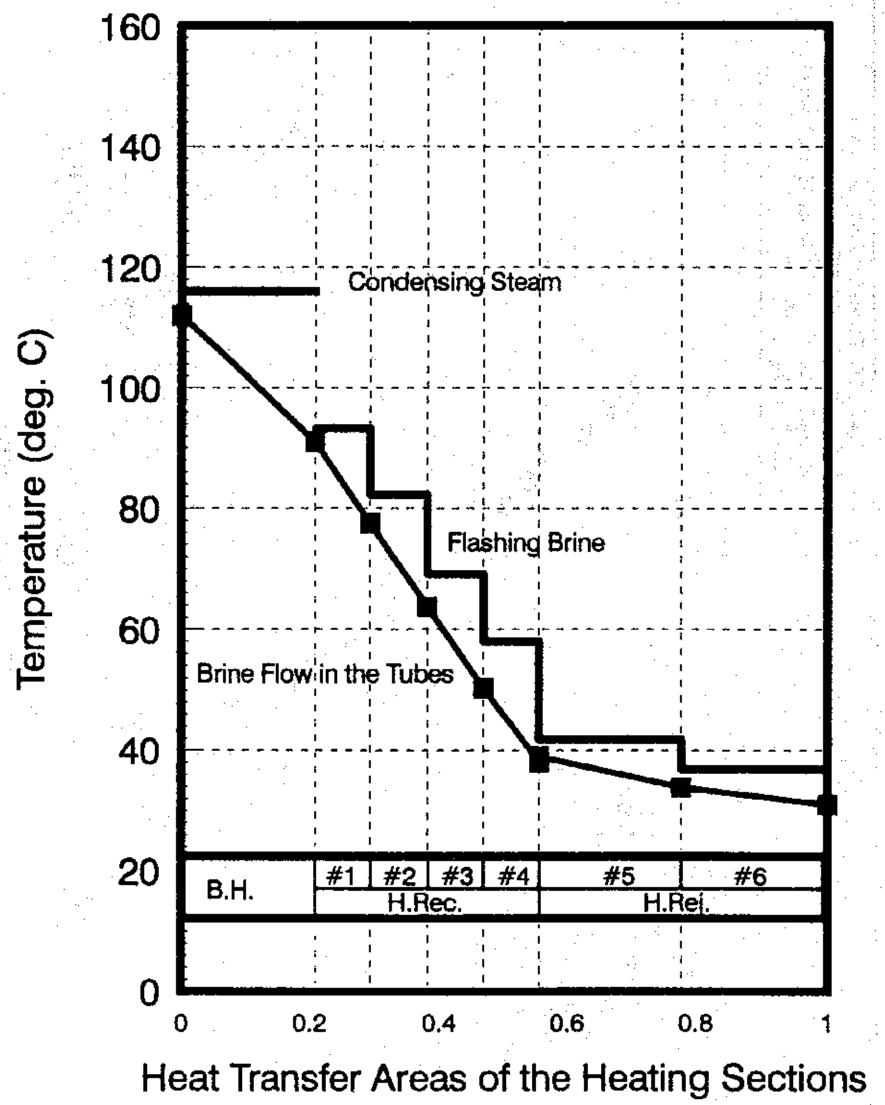
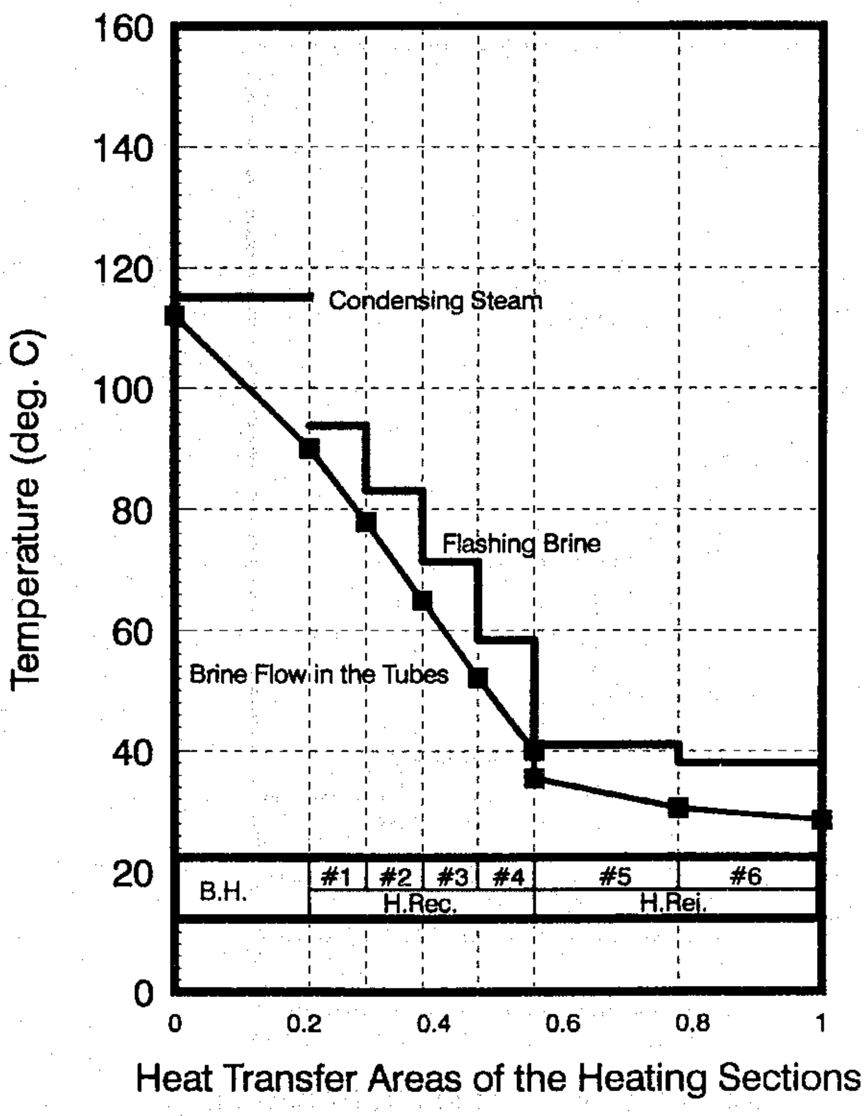


Fig. 2 **Time Dependency of Fouling Factor in RUN 5–2**



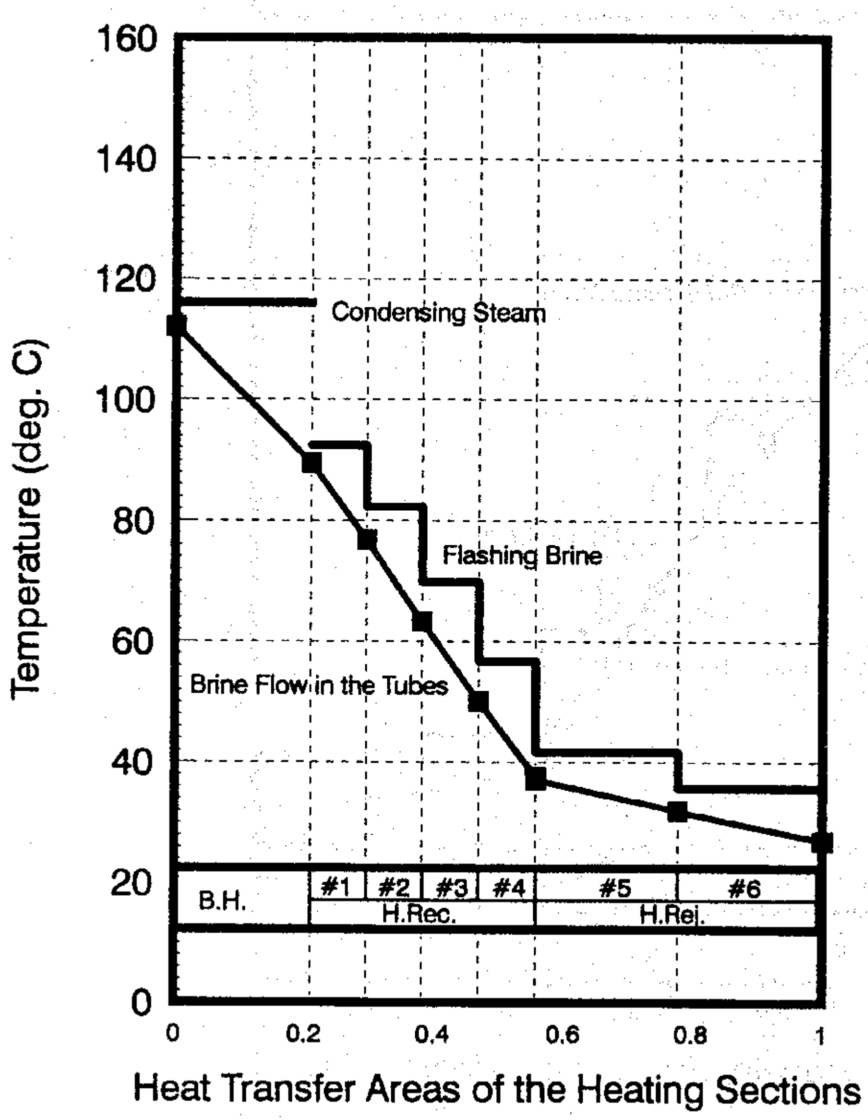
Run No. 5.1 Date: October 16, 94 Time: 8:00

Fig. 3-1 Heat Cycle at Start of RUN 5-1



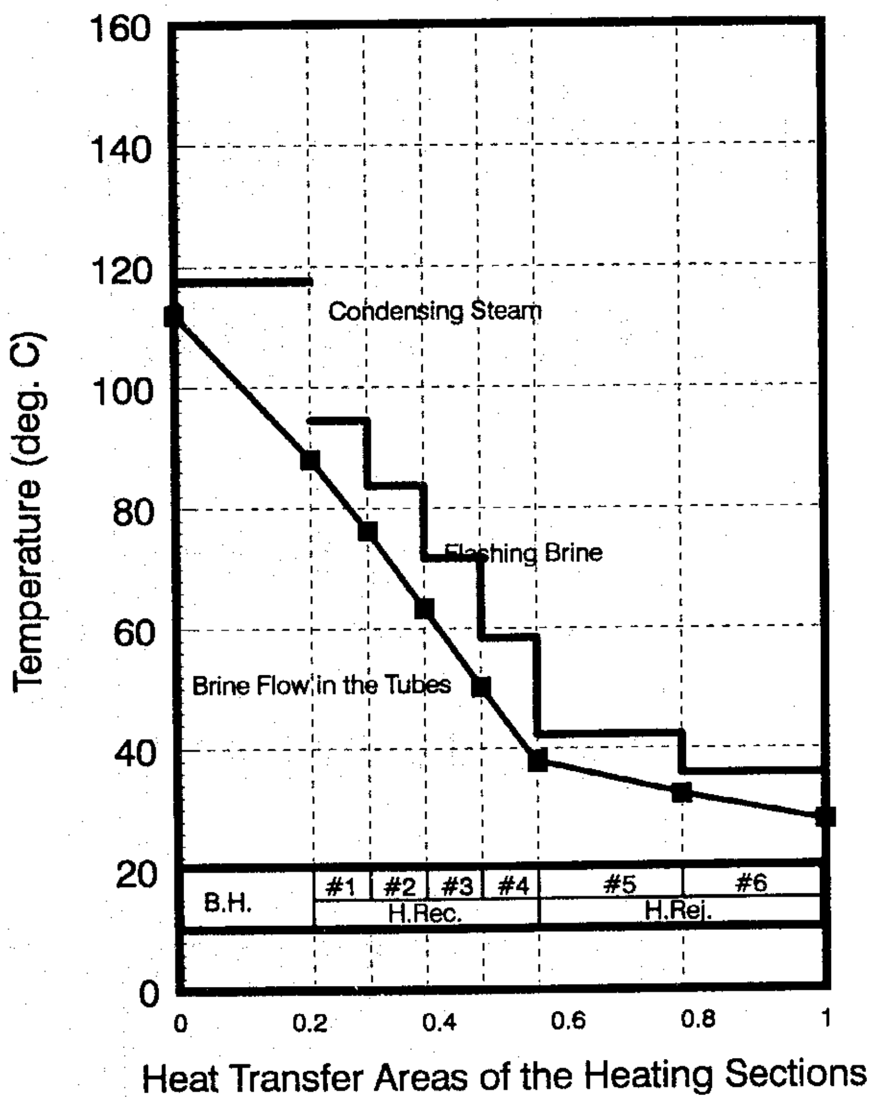
Run No. 5.1 Date: October 23, 94 Time: 8:00

Fig. 3-2 Heat Cycle after 180hrs of RUN 5-1



Run No. 5.2 Date: October 25, 94 Time: 0:00

Fig. 4–1 Heat Cycle at Start of RUN 5–2



Run No. 5.2 Date: November 7, 94 Time: 4:00

Fig. 4-2 Heat Cycle after 324hrs of RUN 5-2

Table 3-1 Calculation of Heat Transfer Coefficient(U) and Fouling Factor at Start of RUN 5-1

CALCULATIONS OF OVERALL HEAT TRANSFER COEFFICIENT AND FOULING FACTOR

Run No. 5-1 **Date: October 16, 94** **Time: 08:00** **Total Operation Time: 12 hr.**

Variables	*Brine Heater*	*Evaporator Stages*					
		# 1	*# 2*	*# 3*	*# 4*	*# 5*	*# 6*
Flowrate (kg/h)	6500	6500	6500	6500	6500	18500	18500
Specific Heat (kJ/kg/K)	3.989	3.969	3.954	3.941	3.930	3.969	3.966
Inlet Temp. (deg. C)	91	77.5	63.7	50.3	38	33.9	31
Outlet Temp. (deg. C)	112	91	77.5	63.7	50.3	39	33.9
Temp. Rise (deg. C)	21	13.5	13.8	13.4	12.3	5.1	2.9
Flashing Temp. (deg. C)	116	93.2	82.2	69.1	56	41.8	36.9
Heat Transfer Rate (kJ/S)	151.243	96.735	98.525	95.355	87.283	104.017	59.111
Heat Transfer Area (Sq.m)	4.6723	1.937	1.937	1.937	1.937	4.9556	4.9556
L.M.T.D. (deg. K)	11.459	6.870	10.071	10.742	10.697	4.917	4.288
U (kW/sq.m/K)	2.825	7.270	5.050	4.583	4.213	4.269	2.782
Clean-U Value (kW/sq.m/K)	3.9	6.6	5.1	5.1	5.1	5.1	5.1
f (sq.m K/kW)	0.0976	-0.0140	0.0019	0.0221	0.0413	0.0382	0.1634

(5.3.4)

Table 3–2 Calculation of Heat Transfer Coefficient(U) and Fouling Factor after 180hrs of RUN 5–1

CALCULATIONS OF OVERALL HEAT TRANSFER COEFFICIENT AND FOULING FACTOR

Run No. 5-1 **Date: October 23, 94** **Time: 08:00** **Total Operation Time: 180 hr.**

Variables	*Brine Heater*	*Evaporator Stages*					
		# 1	# 2	# 3	# 4	# 5	# 6
Flowrate (kg/h)	6500	6500	6500	6500	6500	18500	18500
Specific Heat (kJ/kg/K)	3.988	3.968	3.955	3.943	3.932	3.967	3.965
Inlet Temp. (deg. C)	90	77.9	64.9	52.1	40.1	30.5	28.5
Outlet Temp. (deg. C)	112	90	77.9	64.9	52.1	35.5	30.5
Temp. Rise (deg. C)	22	12.1	13	12.8	12	5	2
Flashing Temp. (deg. C)	115	93.7	83	71.4	58.4	41	38
Heat Transfer Rate (kJ/S)	158.420	86.696	92.832	91.117	85.189	101.924	40.749
Heat Transfer Area (Sq.m)	4.6723	1.937	1.937	1.937	1.937	4.9556	4.9556
L.M.T.D. (deg. K)	10.376	8.335	10.263	11.761	11.253	7.732	8.461
U (kW/sq.m/K)	3.268	5.370	4.670	4.000	3.908	2.660	0.972
Clean-U Value (kW/sq.m/K)	3.9	6.6	5.1	5.1	5.1	5.1	5.1
f (sq.m K/kW)	0.0496	0.0347	0.0181	0.0540	0.0598	0.1799	0.8328

(5.3.4)

Table 4–1 Calculation of Heat Transfer Coefficient(U) and Fouling Factor at Start of RUN 5–2

CALCULATIONS OF OVERALL HEAT TRANSFER COEFFICIENT AND FOULING FACTOR

Run No. 5-2 | **Date: October 25, 94** | **Time: 00:00** | **Total Operation Time: 8.0 hr.**

Variables	*Brine Heater*	*Evaporator Stages*					
		# 1	*# 2*	*# 3*	*# 4*	*# 5*	*# 6*
Flowrate (kg/h)	6500	6500	6500	6500	6500	15500	15500
Specific Heat (kJ/kg/K)	3.961	3.940	3.926	3.912	3.900	3.968	3.965
Inlet Temp. (deg. C)	89.5	76.8	63.3	50.1	37.5	31.9	27
Outlet Temp. (deg. C)	112	89.5	76.8	63.3	50.1	37	31.9
Temp. Rise (deg. C)	22.5	12.7	13.5	13.2	12.6	5.1	4.9
Flashing Temp. (deg. C)	116	92.4	82.3	69.8	56.7	41.6	35.7
Heat Transfer Rate (kJ/S)	160.932	90.351	95.690	93.240	88.729	87.122	83.645
Heat Transfer Area (Sq.m)	4.6723	1.937	1.937	1.937	1.937	4.9556	4.9556
L.M.T.D. (deg. K)	11.899	7.548	10.890	11.905	11.800	6.836	5.916
U (kW/sq.m/K)	2.895	6.180	4.536	4.044	3.882	2.572	2.853
Clean-U Value (kW/sq.m/K)	3.9	6.6	5.1	5.1	5.1	5.1	5.1
f (sq.m K/kW)	0.0891	0.0103	0.0244	0.0512	0.0615	0.1927	0.1544

Table 4–2 Calculation of Heat Transfer Coefficient(U) and Fouling Factor after 324hrs of RUN 5–2

CALCULATIONS OF OVERALL HEAT TRANSFER COEFFICIENT AND FOULING FACTOR

Run No. 5-2 | Date: November 07, 94 | Time: 04:00 | Total Operation Time: 324 hr.

Variables	*Brine Heater*	*Evaporator Stages*					
		# 1	# 2	# 3	# 4	# 5	# 6
Flowrate (kg/h)	6500	6500	6500	6500	6500	17200	17200
Specific Heat (kJ/kg/K)	3.960	3.939	3.925	3.912	3.900	3.968	3.965
Inlet Temp. (deg. C)	88	76.2	63.3	50.2	37.7	32.4	28
Outlet Temp. (deg. C)	112	88	76.2	63.3	50.2	38	32.4
Temp. Rise (deg. C)	24	11.8	12.9	13.1	12.5	5.6	4.4
Flashing Temp. (deg. C)	117.5	94.5	83.7	71.7	58.4	42.3	35.9
Heat Transfer Rate (kJ/S)	171.620	83.923	91.430	92.535	88.028	106.168	83.356
Heat Transfer Area (Sq.m)	4.6723	1.937	1.937	1.937	1.937	4.9556	4.9556
L.M.T.D. (deg. K)	14.289	11.400	12.892	13.939	13.499	6.715	5.405
U (kW/sq.m/K)	2.571	3.801	3.661	3.427	3.367	3.190	3.112
Clean-U Value (kW/sq.m/K)	3.9	6.6	5.1	5.1	5.1	5.1	5.1
f (sq.m K/kW)	0.1326	0.1116	0.0770	0.0957	0.1010	0.1174	0.1252

5.2 Determination of Uc

The overall heat transfer coefficient at the start of the operation, Uc, had been determined by the same method described in 5.3.3, as follows.

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

5.3 The quality of the feed seawater and circulating brine

The typical data of the water constituent of the make–up, recirculation and product during RUN 5–1 and 5–2 are shown in Fig. 5 and Fig. 6.

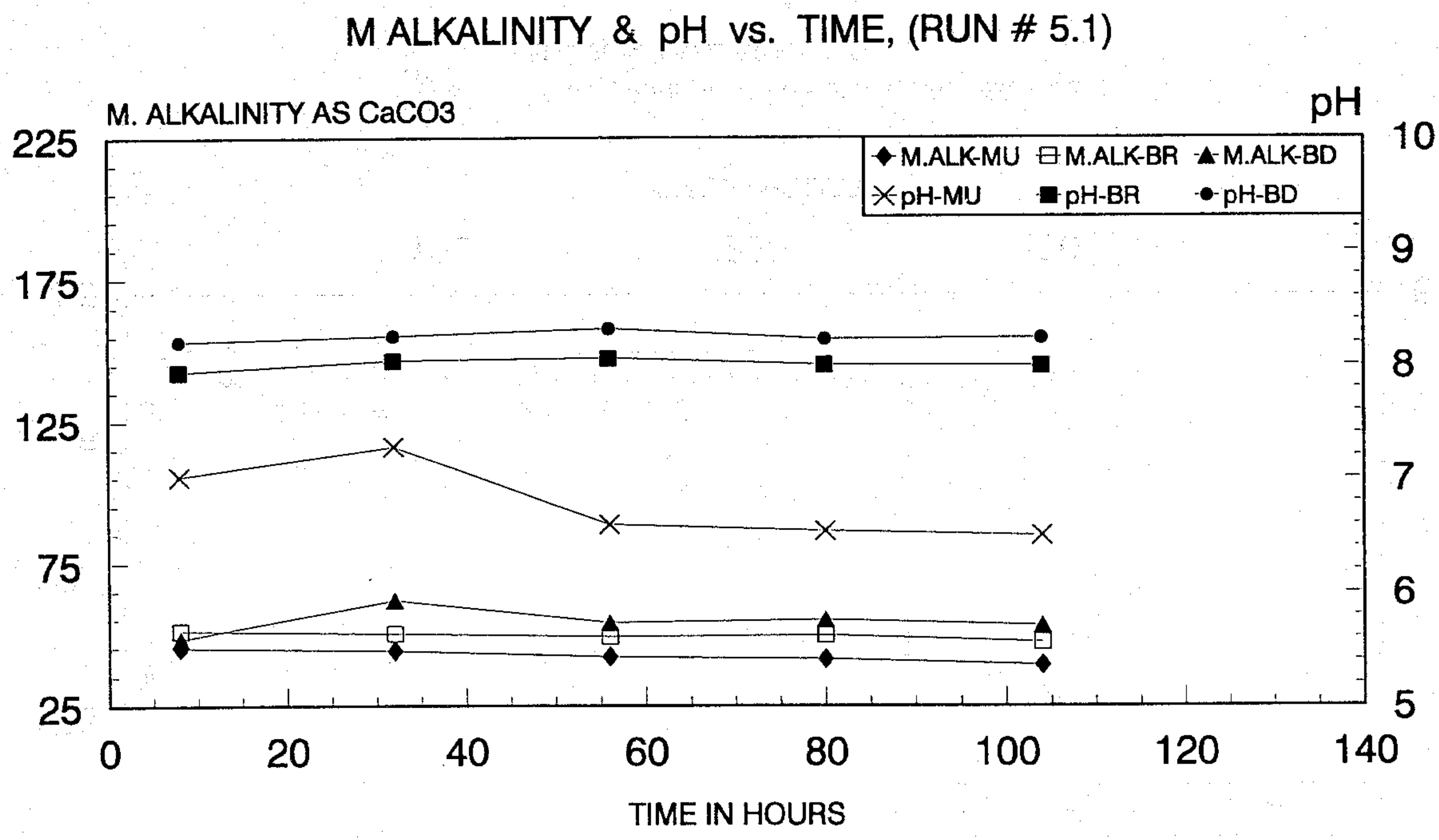


Fig. 5 **Water Constituent of the make-up, recirculation and blow down during RUN 5-1**

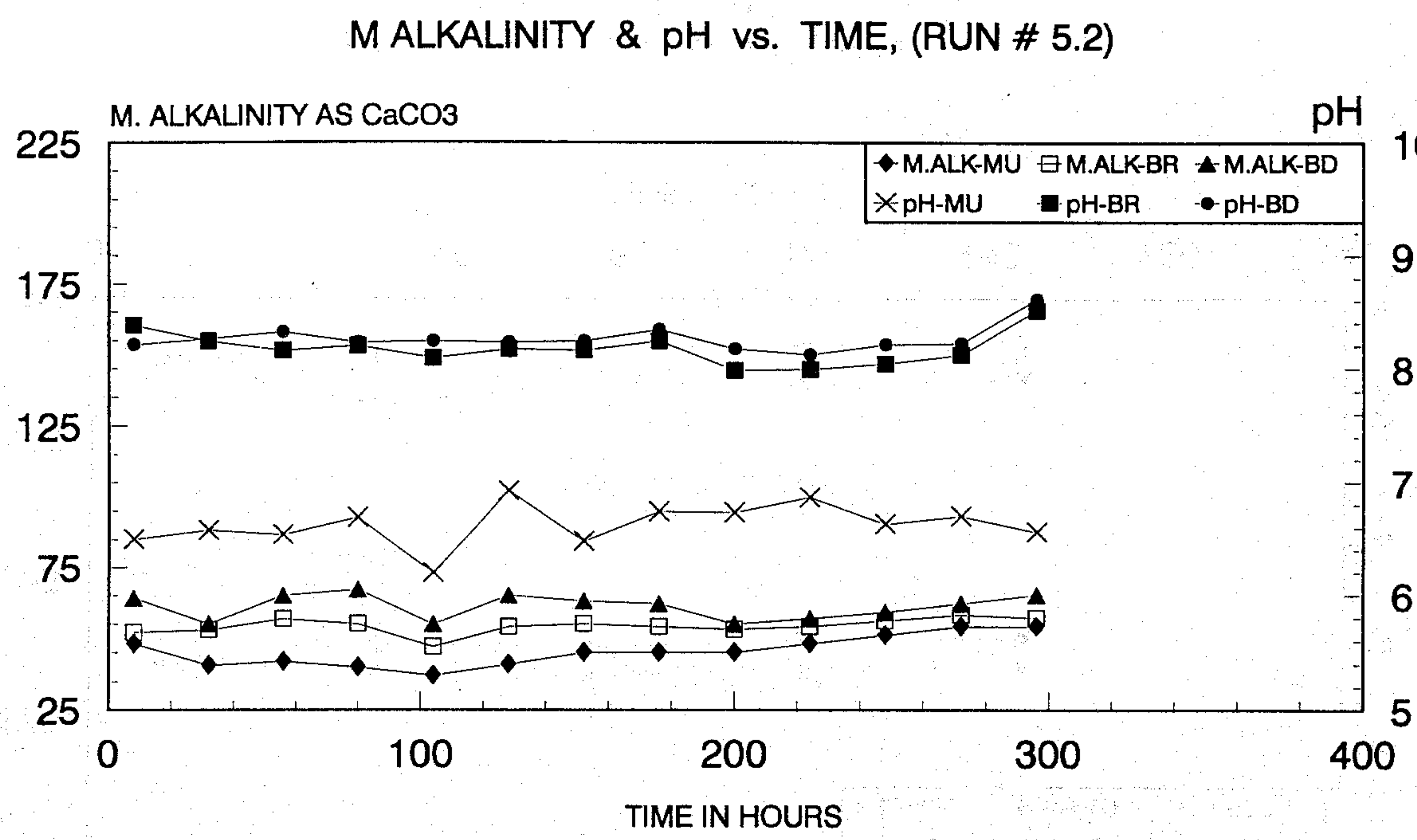


Fig. 6 **Water Constituent of the make–up, recirculation and blow down during RUN 5–2**

6. Discussions

The data obtained from RUN 4, 5 and 8 have been compared for the discussion as shown below.

RUN NO.		4	5-1	5-2	8
CONC.	Chemical	●			●
	Hybrid		●	●	
M-alk	CF≦ 1.2	●	●		
	CF = 1.4			●	●

6.1 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 increasing rate of the fouling factor is more than that of RUN 8.

6.2 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 have 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.

RUN No.	M-alkalinity	Initial Stage	After #1 BC	Recovery by #1BC
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%.

No conclusion can be reached at this stage with such short tests. Further tests are needed to confirm the above observation.

6.3 Hybrid Operation in Saudi Arabia

The hybrid operation had been conducted at SCECO Qurayyah in Saudi Arabia and it is assessed as follow;

The Qurayyah plant is designed to be capable of operating by either of (1)Chemical dosing method(Belgard Ev), (2)Hybrid method and (3)Acid dosing method. The performance ratio of chemical dosing method and hybrid method are 9.5-9.6 and 10.0, respectively, showing the superiority of the hybrid method.

However, the hybrid method is not recommended in the normal operation of the plant since the cost of the sulfuric acid is more expensive than Belgard Ev and the cost of steam is relatively low.

7. 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 effect of hybrid method 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

CONTENTS

List of Tables

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.
   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.

The target, procedure and results of the transfer of technologies are listed in Table 1 according to the subjects.

Table 1 Transfer of Technology for MSF-1

SUBJECT	TARGET	PROCEDURE	RESULTS
Evaluation technology of performance deterioration for actual MSF plants	To master the evaluation technology of causes and countermeasures against deterioration in MSF plants	1)Visit plants and hold discussions with engineers 2)Collect operational data and make analysis	The trainee became capable of understanding operational data, making analysis, judging performance and identifying causes of performance deterioration in actual plants.
Evaluation technology scale inhibitor	To master the evaluation technology on some of the evaluation methods for scale inhibitors	1)Assemble equipment 2)Plan and conduct experiments 3)Analyze results and make conclusion	The trainees have prepared a paper on the method of parformance evaluation of scale inhibitors and presented it at the "Second Gulf Water Conference"
	To master the evaluation technology on some of the evaluation methods for scale inhibitors in the presence of heat flux	1)Assemble equipment 2)Plan and conduct experiments 3)Collect data and perform calculations 4)Analyze results and make conclusions	The trainee has performed heat transfer calculations and prepared tables and figures to present the results obtained. Also be prepared section 5.2 of this report
Evaluation technology of fouling factor [Short term test using the Test Plant	To master the evaluation technology on causes of scaling and their countermeasures against performance deterioration in the MSF plants	1)Collect data and perform calculations 2)Analyze results and make conclusions	The trainees have performed heat transfer calculations and prepared tables and figures presented In section 5.3.3
Evaluation technology of fouling factor [Long term test using the MSF Test Plant]	To master the evaluation technology on the behavior of fouling factor in the MSF plants	1)Follow up the operation of test plant 2)Collect data and perform calculations 3)Analyze results and make conclusions	The trainees have prepared a manual for the operational procedure and were trained on the operation of the MSF test plant. Also, the trainees have performed heat transfer calculations and prepared tables and figure presented in section 5.3.3
Evaluation technology of fouling factor [Test with simultaneous use of scale inhibitor and acid]	To master the evaluation technology on the effectiveness of scale prevention methods	1)Collect data and perform calculations 2)Analyze reslts and make conclusions	The trainees have performed heat transfer calculations and prepared tables and figuires presented in section 5.3.4. Also, the trainees have understood the behavior of M-Alkalinity in hybrid operation as compared to the case of additives