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Prepared by:
C. Eicheldinger

J. J. O'Brien
PROJECT ENGINEER

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FOREWORD

This quarterly report is submitted by the Nuclear Division of The Martin Company to the Nuclear Power Field Office, Engineer Research and Development Laboratories, U.S. Army Corps of Engineers, in compliance with Contract DA-44-009-ENG-3581. The report describes progress from January through March 1961 in the ANPP Corrosion Program.

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SUMMARY

The first series of three 2000-hour autoclave tests on Monel and nickel coupons was completed. In one autoclave, charged with water containing 1000-ppm chloride and 13-ppm oxygen, the Monel coupon in the vapor phase experienced mild pitting. Average corrosion rates were: for Monel, 0.51 mdd; and for nickel, 0.37 mdd (milligrams per square decimeter per day).

A 2050-hour autoclave test on nickel, under conditions which caused pitting of Monel, was initiated. A total of 672 hours of testing was accumulated.

The corrosion loop operated virtually continuously during the quarter. Average operating time efficiency (OTE) was approximately 84%. The only major shutdown was caused by failure of terminals on one of the primary 50-kw line heaters.

Testing of the bimetal model vessels (MOD SX-4) and the Inconel model vessels (MOD SX-7) continued. Cumulative test time to date is approximately 2350 hours.

Testing of the bimetal miniature vessels (MIN 15 and 16) and the Inconel miniature vessels (MIN 10 and 11) continued. Average cumulative test time is approximately 2420 hours.

Analysis of heat transfer data was started. Preliminary results for the model vessels indicate that large effects on heat transfer due to scaling have not occurred.

I. HEAT EXCHANGER CORROSION PROGRAM *

The objectives of the heat exchanger corrosion program are:

- (1) The determination of the effect of secondary water conditions on heat exchanger life, using various exchanger materials. The most severe water conditions are limited to 1000-ppm chloride with air cover gas and air-saturated water.
- (2) The examination of the technique of test heat exchanger fabrication.
- (3) The recommendation of materials and service conditions for operating units.

Model and miniature heat exchangers currently under test, fabrication or design are shown in Table 1.

A. AUTOCLAVE TESTS

1. Testing

The first series of 2000-hour autoclave tests was completed. The conditions for these three tests are summarized below:

<u>Test No.</u>	<u>Material</u>	<u>Time (hr)</u>	<u>Oxygen (ppm)</u>	<u>Chloride (ppm)</u>
1	Monel	2000	1	10
2	Monel	2000	15	1000
3	Nickel	2000	1	10

pH adjusted to 10 with Na_3PO_4 in all tests.

Figures 1, 2 and 3 show the appearance of the coupons as they were removed from the autoclaves. Post-test analysis results for these tests are given in the following section.

A 2000-hour test on nickel was initiated during the quarter. Conditions for this test are 1000-ppm chloride, 15-ppm oxygen and pH adjusted to 10 with Na_3PO_4 . At the end of the quarter, 672 hours of test time had been accumulated.

*J. McGrew, J. Mueller, M. Norin, E. Jules, T. Page, W. Taylor

TABLE 1
Test Heat Exchanger Status

Heat Exchanger Type	Number	Tube Material	Tube Sheet Material	Overlay	Shell Material	Water Conditions	Status
Steam Generator	MOB SG-1	304 SS	304 SS	304 SS	304 SS	1	Service--1937 hr (sealined)
Superheater	MOB SH-1	304 SS	304 SS	308 SS	304 SS	1	Failed--1937 hr (sealined)
Steam Generator	MOB SG-2	Aluminum ^(a)	Carbon Steel	308 SS	Carbon Steel	1 (3)	Service--5041 hr
Superheater	MOB SH-2	Aluminum ^(a)	Carbon Steel	308 SS	Carbon Steel	1 (3)	Service--5041 hr
Steam Generator	MOB SG-3	304 SS	304 SS	308 SS	304 SS	2	Fabrication complete
Superheater	MOB SH-3	304 SS	304 SS	308 SS	304 SS	2	Fabrication complete
Steam Generator	MOB SG-4	Aluminum ^(a)	Carbon Steel	308 SS	Carbon Steel	13	Under test--2413 hr
Superheater	MOB SH-4	Aluminum ^(a)	Carbon Steel	308 SS	Carbon Steel	13	Under test--2413 hr
Steam Generator	MOB SG-5	Croloy 10-1	A350LP-1	308 SS	Carbon Steel	3	Service--4253 hr
Superheater	MOB SH-5	Croloy 10-1	A350LP-1	308 SS	Carbon Steel	3	Service--4253 hr
Steam Generator	MOB SG-6	Inconel	AISI-1020 CS	Inco "A"	Carbon Steel	3	Service--3811 hr
Superheater	MOB SH-6	Inconel	AISI-1020 CS	Inco "A"	Carbon Steel	3	Service--3811 hr
Steam Generator	MOB SG-7	Inconel	AISI-1020 CS	Inco "A"	AISI-1020 CS	12	Under test--2300 hr
Superheater	MOB SH-7	Inconel	AISI-1020 CS	Inco "A"	AISI-1020 CS	12	Under test--2300 hr
Steam Generator	MOB SG-8	Monel or Nickel	SA-105-II	Monel or Nickel	SA-212-II		In design
Superheater	MOB SH-8	Monel or Nickel	SA-105-II	Monel or Nickel	SA-212-II		In design
Miniature	MIN-1	304 SS	304 SS	308 SS	304 SS	4	Failed--42 hr
Miniature	MIN-2	304 SS	304 SS	308 SS	304 SS	5	Service--1020 hr
Miniature	MIN-3	304 SS	304 SS	308 SS	304 SS	6	Failed--1080 hr
Miniature	MIN-4	430-M (H W)	15 Cr, 0.17 Ni	430-M (H W)	15 Cr, 0.20 Ni	7	Failed--2570 hr
Miniature	MIN-5	430-M (H W)	15 Cr, 0.17 Ni	430-M (H W)	15 Cr, 0.20 Ni	8	Failed--841 hr
Miniature	MIN-6	430-M (H W)	15 Cr, 0.17 Ni	430-M (H W)	15 Cr, 0.20 Ni	9	Service--2707 hr
Miniature	MIN-7	Aluminum ^(a)	Carbon Steel	308 SS	Carbon Steel	4	Service--2250 hr
Miniature	MIN-8	Inconel	Inconel	Inco "A"	Inconel	10	Service--5200 hr
Miniature	MIN-9	Inconel	Inconel	Inco "A"	Inconel	11	Service--3031 hr
Miniature	MIN-10	Inconel	Inconel	Inco "A"	AISI-1020 CS	14	Under test--2433 hr
Miniature	MIN-11	Inconel	Inconel	Inco "A"	AISI-1020 CS	15	Under test--2413 hr
Miniature	MIN-12	Monel	AISI-1020 CS	Nickel	AISI-1020 CS	2	Fabrication complete

Miniature	MIN-3	304 SS	304 SS	304 SS	304 SS	0	Failed--1088 hr
Miniature	MIN-4	430-M (H W)	10 Cr, 0, 17 Ni	430-M (H W)	10 Cr, 0, 20 Ni	7	Failed--2378 hr
Miniature	MIN-5	430-M (H W)	10 Cr, 0, 17 Ni	430-M (H W)	10 Cr, 0, 20 Ni	8	Failed--041 hr
Miniature	MIN-6	430-M (H W)	10 Cr, 0, 17 Ni	430-M (H W)	10 Cr, 0, 20 Ni	0	Service--2707 hr
Miniature	MIN-7	Monel ^(u)	Carbon Steel	308 SS	Carbon Steel	4	Service--3200 hr
Miniature	MIN-8	Inconel	Inconel	Inco "A"	Inconel	10	Service--3200 hr
Miniature	MIN-9	Inconel	Inconel	Inco "A"	Inconel	11	Service--2031 hr
Miniature	MIN-10	Inconel	Inconel	Inco "A"	AlSi-1030 CS	14	Under test--2433 hr
Miniature	MIN-11	Inconel	Inconel	Inco "A"	AlSi-1030 CS	16	Under test--2413 hr
Miniature	MIN-12	Monel	AlSi-1020 CS	Nickel	AlSi-1030 CS	2	Fabrication complete
Miniature	MIN-13	Monel	AlSi-1020 CS	Nickel	AlSi-1030 CS	2	Fabrication complete
Miniature	MIN-14	Monel	AlSi-1020 CS	Nickel	AlSi-1030 CS	2	Fabrication complete
Miniature	MIN-15	Blmetal	AlSi-1020 CS	---	AlSi-1030 CS	10	Under test--2410 hr
Miniature	MIN-16	Blmetal	AlSi-1020 CS	---	AlSi-1030 CS	19	Under test--2424 hr
Miniature	MIN-17	Nickel	AlSi-1020 CS	Nickel	AlSi-1030 CS	2	Fabrication complete
Miniature	MIN-18	Nickel	AlSi-1020 CS	Nickel	AlSi-1030 CS	2	Fabrication complete
Miniature	MIN-19	Nickel	AlSi-1020 CS	Nickel	AlSi-1030 CS	2	Fabrication complete

NOTES

(a) Primary Side--Type 304 SS

Secondary Side--Carbon Steel

1. Chloride--40-50 ppm
Phosphate--40-80 ppm
Sulfite--0-10 ppm
pH--10.5-10.8
2. To be determined
3. Cl--800-1000 ppm
O₂--none (controlled with sodium sulfite)
pH--8.3-9.5 with PO₄
4. Chloride--0-1.0 ppm
Phosphate--0.1 ppm
O₂--40 ppm
pH--10.5

5. Chloride--0-5 ppm
Phosphate--30 ppm
O₂--7.0-8.0 ppm
pH--10.5
6. Chloride--100.5 ppm
Phosphate--none
O₂--7.0-8.0 ppm
pH--11.5
7. Chloride--800 ppm
Phosphate--30 ppm
O₂--21% by volume
pH--10.5
8. Chloride--800 ppm
Phosphate--none
O₂--21% by volume
pH--10.5
9. Chloride--400 ppm
Phosphate--none
O₂--10% by volume
pH--8.5
10. Chloride--1000 ppm
O₂--Air sat, water, air as cover gas
pH--8.3-9.5 with PO₄ water treat
11. Chloride--1000 ppm
O₂--Air sat, water, air as cover gas
pH--8.3-9.5 with NaOH
PO₄--none
12. Chloride--0.5 ppm max
Phosphate--150 ppm
Sulfite--10 ppm
pH--10 to 10.5

13. Chloride--0.5 ppm max
Sulfite--10 ppm
Total Solids--200 ppm max
pH--8.5 (PO₄)

14. Chloride--1000 ppm
pH--10 (NaOH)
O₂--no treatment**
15. Chloride--1000 ppm
pH--10 (35% Na₂PO₄ and 0.7% Na₂HPO₄)
O₂--no treatment**
16. Chloride--800 ppm
pH--10 (35% Na₂PO₄ and 0.7% Na₂HPO₄)
O₂--no treatment**

* Operating times are cumulative to March 31, 1961.

**The secondary makeup tank will be maintained at 100° F, open to the atmosphere, which will maintain the oxygen concentration at somewhat less than 0.5 ppm.

2

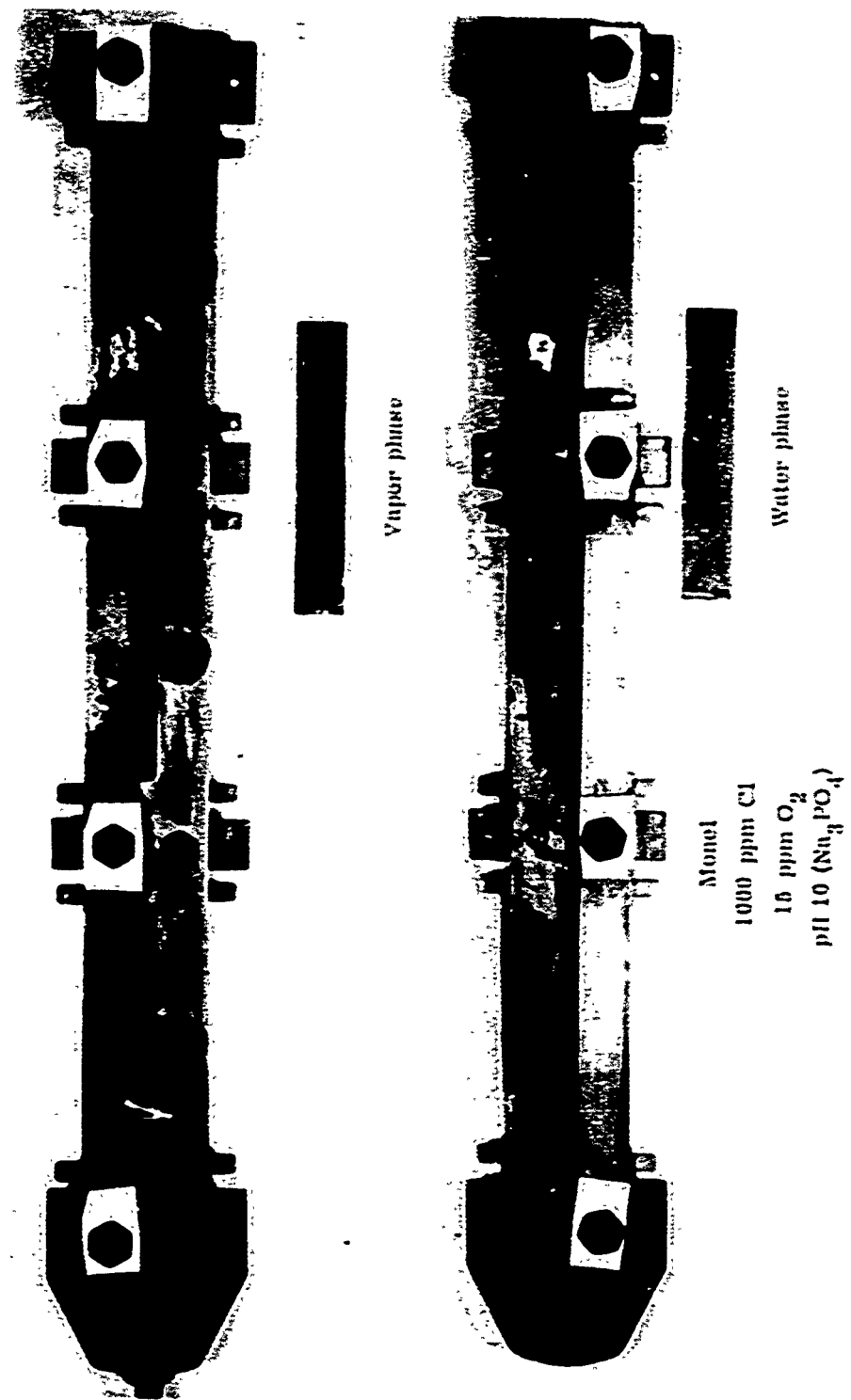


Fig. 1. Appearance of Monel Coupons as They Were Removed from the Autoclave

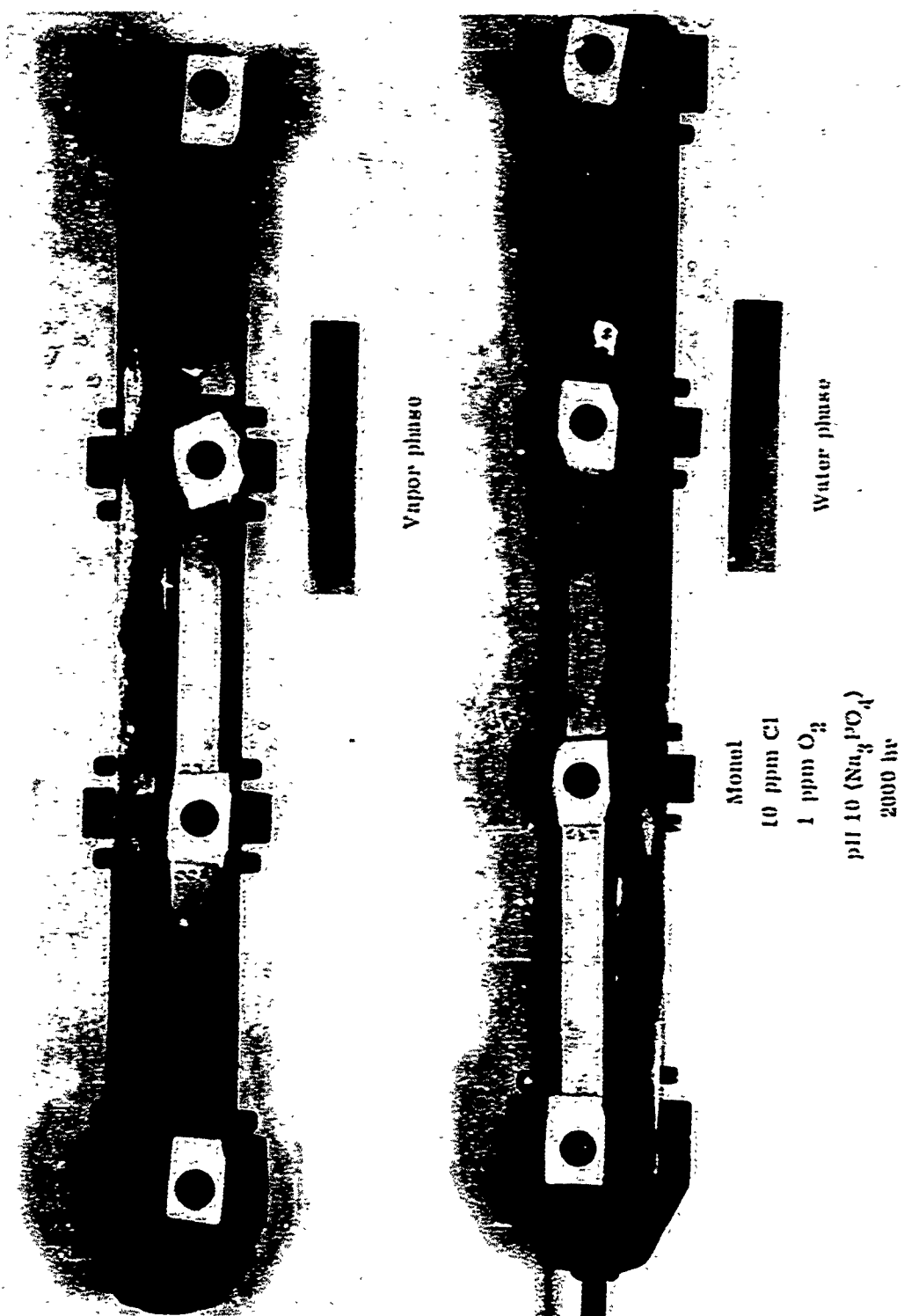
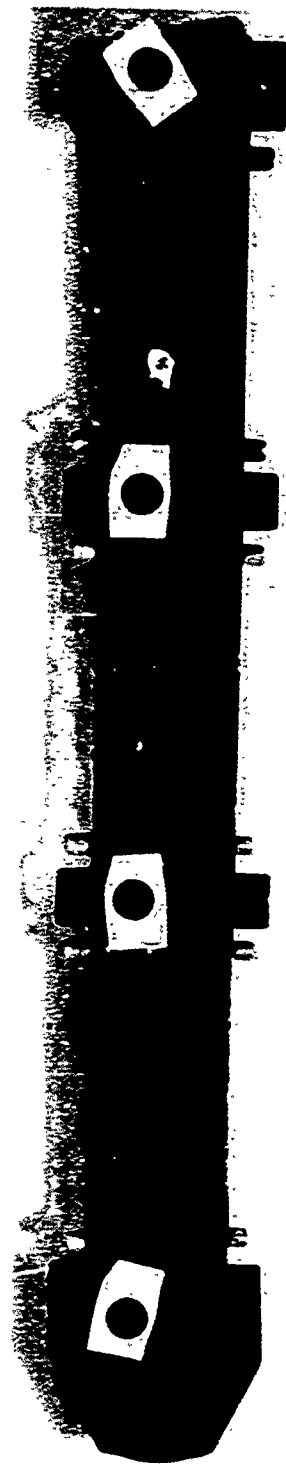


Fig. 2. Appearance of Monel Coupons as They Were Removed from the Autoclave



Vapor phase



Water phase

Nickel

10 ppm Cl

1 ppm O₂

pH 10 (Na₃PO₄)

2000 hr

Fig. 3. Appearance of Nickel Coupons as They Were Removed from the Autoclave

The 2000-hour Inconel autoclave tests were delayed due to a material discrepancy. The material which was supplied as Inconel was analyzed and found to be a high chrome, iron-based alloy. Replacement material was obtained and pretest preparations were nearly complete at the end of the report period.

2. Analysis of Initial 2000-Hour Tests

All of the coupons from the initial 2000-hour tests were descaled, using the sulfamic acid process. Weight losses are listed in Table 2 along with the results from the 50- and 200-hour tests. Weight loss as a function of time for the two metals is plotted in Figs. 4 and 5. In general, the nickel corrosion rate appears to be somewhat lower than Monel for comparable conditions, the average values over the 2000-hour test period being 0.51 mdd for Monel and 0.37 mdd for nickel in the low oxygen, low chloride environment.

No cracking of any coupons has been observed. However, mild pitting corrosion occurred on Monel coupons in the vapor phase of the high chloride, high oxygen autoclave test (see Fig. 1). All 12 of the vapor phase coupons were pitted, while none of the liquid phase coupons suffered pitting. No significant difference in attack was noted between stressed and unstressed coupons or between annealed and stress-relieved coupons. Pitting generally occurred randomly over the tension and compression surfaces of the stressed specimens. The general appearance and distribution of pits may be seen in Fig. 6, which is a photograph of a portion of specimen No. 202. This coupon was stress-relieved prior to testing and was unstressed during the test. The pits were relatively large in area but shallow, the average depth being approximately 1 mil. A photomicrograph through one pit on specimen No. 731 (fully annealed) is shown in Fig. 7. Maximum penetration was 1.4 mils.

No pitting occurred on coupons in either the vapor or liquid phase of the low chloride, low oxygen tests.

B. CORROSION LOOP OPERATION

Operation of the loop during the report period was virtually continuous; approximately 1840 hours of test time were logged. The test time accumulated for each vessel and for each day during the report period is indicated in Figs. 8, 9 and 10.

1. Loop Shutdown

The only major shutdown during the quarter was caused by failure of electrical terminals on one of the 50-hw primary line heaters. The spare heater-flange assembly was installed in the loop. The spare unit was

TABLE 2
Summary of Weight Loss Data From Autoclave Tests

Monel										Nickel					
10 ppm Chloride 1 ppm Oxygen					1000 ppm Chloride 15 ppm Oxygen					10 ppm Chloride 1 ppm Oxygen			1000 ppm Chloride 15 ppm Oxygen		
Hours	50	200	2000	50	200	2000	50	200	2000	50	200	2000	50	200	2000
	V	0.0	1.4	8.8	1.1	6.0	7.1	1.1	0.4	6.5	2.5	2.3			
S	L	0.3	1.2	11.3	0.2	2.2	6.3	0.6	0.7	5.8	0.5	2.6			
U	V	0.1	1.1	10.8	1.8	6.0	8.5	0.9	0.5	4.9	2.5	1.5			
	L	0.3	1.4	10.2	0.0	2.4	6.7	0.4	0.6	7.4	0.4	1.9			
Stress-relieved	V	0.6	2.5	7.9	1.6	4.9	9.2	1.2	0.8	8.8	1.9	2.5			
	L	0.3	1.6	8.2	0.8	2.1	5.0	0.5	0.9	6.8	0.6	2.7			
U	V	0.7	2.4	8.4	2.1	4.8	9.0	1.2	0.4	7.2	2.2	2.5			
	L	0.3	1.5	6.7	0.7	1.9	7.6	0.6	0.8	6.0	1.2	1.3			
Total		2.6	13.1	72.3	8.3	30.3	60.4	6.5	5.1	53.4	11.8	17.3			

NOTE: Values are weight loss in milligrams--average of three specimens in all tests, pH adjusted to 10 with Na_3PO_4

S--Stressed to 90% at yield strength 0.02% offset

U--Unstressed

V--Vapor phase

L--Liquid phase

Curve No.	Symbol	Conditions	Curve No.	Symbol	Conditions
1	○	1 ppm oxygen 10 ppm chloride Vapor phase pH 10 (Na_3PO_4)	3	△	10 ppm oxygen 1000 ppm chloride Vapor phase pH 10 (Na_3PO_4)
2	□	1 ppm oxygen 10 ppm chloride Liquid phase pH 10 (Na_3PO_4)	4	◇	10 ppm oxygen 1000 ppm chloride Liquid phase pH 10 (Na_3PO_4)

Experimental points plotted are average values for twelve coupons exposed to conditions indicated in the legend.

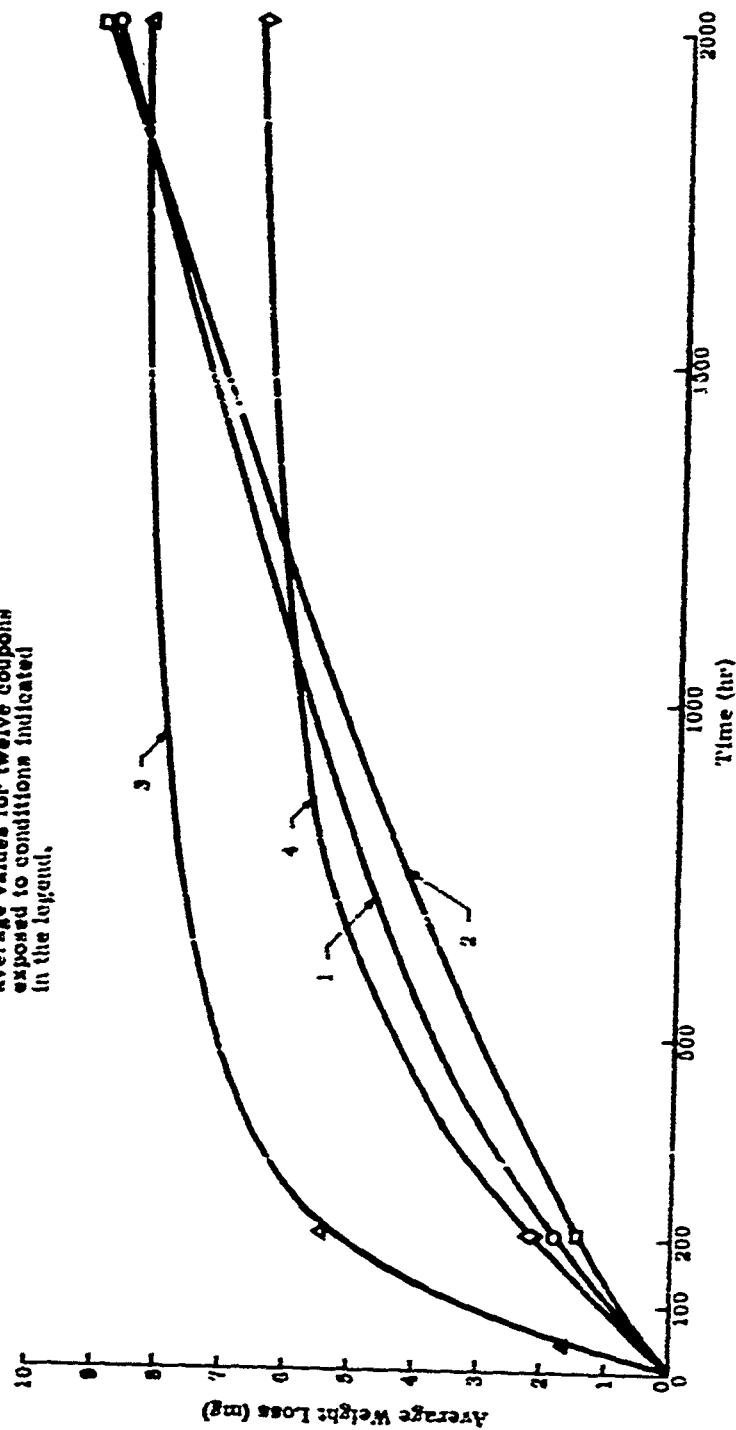


Fig. 4. Weight Loss as a Function of Time for Monel Coupons

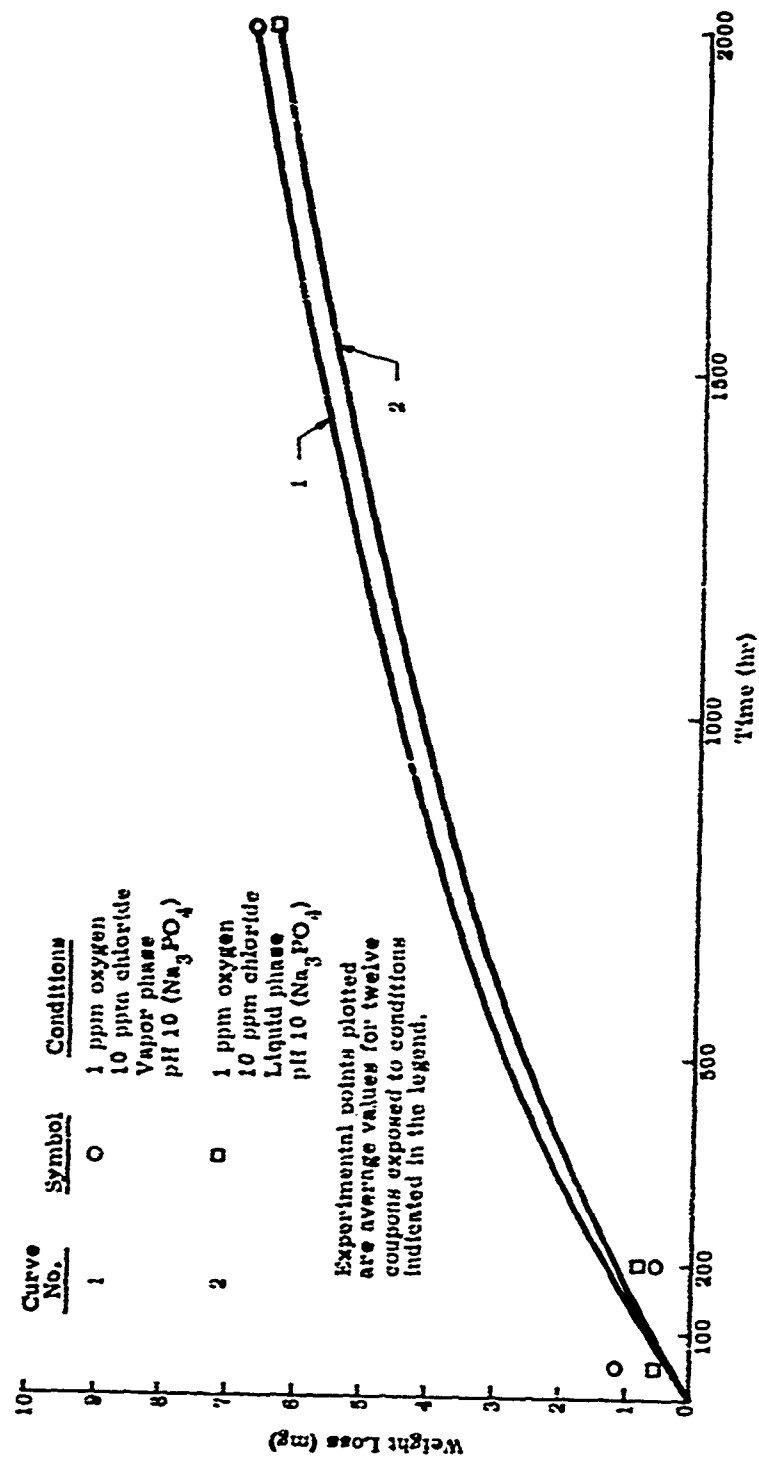
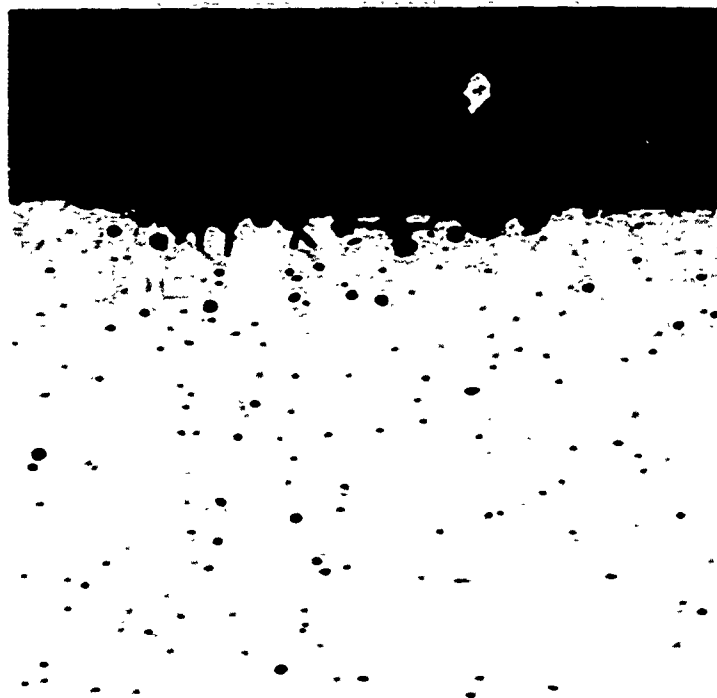


Fig. 5. Weight Loss as a Function of Time for Nickel Coupons



Autoclave conditions--1000 ppm
chloride, 15 ppm oxygen, pH
adjusted to 10 with Na_3PO_4 .
2000-hour exposure; coupon
was unstressed in vapor phase.

Fig. 6. Photograph of a Portion of Stress-Relieved Monel Coupon
Showing Appearance and Distribution of Pits (6.5X
magnification)



Autoclave conditions--1000 ppm
chloride, 15 ppm oxygen, pH
adjusted to 10 with Na_3PO_4 .
2000-hour exposure.

Specimen conditions--Monel, fully
annealed, stressed and in the vapor
phase of the autoclave

**Fig. 7. Photomicrograph Through Pit on Monel Coupon;
Maximum Penetration, 0.0014 inch (250X
magnification)**

Loop Vessel Designation	January						
	1	2	3	4	5	6	7
No. 1 Model	24.0	24.0	24.0	24.0	24.0	24.0	5.0
No. 2 Model	24.0	24.0	24.0	24.0	24.0	24.0	24.0
No. 1 Miniature	0.5	0.0	23.5	24.0	24.0	24.0	24.0
No. 2 Miniature	0.5	0.0	23.5	24.0	24.0	24.0	24.0
No. 3 Miniature	0.5	0.0	23.5	24.0	24.0	24.0	24.0
No. 4 Miniature	0.5	0.0	23.5	24.0	24.0	24.0	24.0
	8	9	10	11	12	13	14
No. 1 Model	0.0	18.0	24.0	24.0	24.0	24.0	24.0
No. 2 Model	21.0	15.3	24.0	24.0	24.0	24.0	24.0
No. 1 Miniature	21.0	17.5	24.0	24.0	24.0	24.0	24.0
No. 2 Miniature	21.0	17.5	24.0	24.0	24.0	24.0	24.0
No. 3 Miniature	21.0	15.5	24.0	24.0	24.0	24.0	24.0
No. 4 Miniature	21.0	18.3	24.0	24.0	24.0	24.0	24.0
	15	16	17	18	19	20	21
No. 1 Model	24.0	24.0	24.0	24.0	24.0	24.0	24.0
No. 2 Model	24.0	24.0	24.0	20.0	24.0	24.0	24.0
No. 1 Miniature	24.0	24.0	24.0	24.0	24.0	24.0	24.0
No. 2 Miniature	24.0	24.0	21.0	24.0	24.0	24.0	24.0
No. 3 Miniature	24.0	24.0	24.0	22.2	24.0	24.0	24.0
No. 4 Miniature	24.0	24.0	24.0	24.0	24.0	24.0	24.0
	22	23	24	25	26	27	28
No. 1 Model	24.0	24.0	24.0	24.0	24.0	24.0	24.0
No. 2 Model	24.0	15.5	18.5	24.0	24.0	24.0	24.0
No. 1 Miniature	24.0	24.0	21.5	24.0	24.0	24.0	24.0
No. 2 Miniature	24.0	24.0	24.0	24.0	24.0	21.5	24.0
No. 3 Miniature	24.0	24.0	24.0	24.0	24.0	21.7	24.0
No. 4 Miniature	24.0	24.0	24.0	24.0	24.0	21.9	24.0
	29	30	31				
No. 1 Model	24.0	24.0	24.0				
No. 2 Model	24.0	24.0	24.0				
No. 1 Miniature	24.0	24.0	24.0				
No. 2 Miniature	24.0	24.0	24.0				
No. 3 Miniature	24.0	24.0	24.0				
No. 4 Miniature	24.0	24.0	24.0				
No. 1 Model	MOD SG-4 and SH-4		1279.0 hr *				
No. 2 Model	MOD SG-7 and SH-7		1324.4 hr *				
No. 1 Miniature	MIN 10		1269.2 hr *				
No. 2 Miniature	MIN 15		1269.3 hr *				
No. 3 Miniature	MIN 11		1253.2 hr *				
No. 4 Miniature	MIN 16		1258.0 hr *				

Times shown are number of hours of test time on vessel in 24-hour period, starting at 8:30 on the morning of that day in which the time is shown.

*Total hours of test time to January 31, 1961.

Fig. 8. Distribution of Test Time for Each Vessel During the Month of January

Loop Vessel Designation	February							
No. 1 Model				1	2	3	4	
No. 2 Model				24.0	24.0	22.0		
No. 1 Miniature				24.0	24.0	22.0		
No. 2 Miniature				24.0	10.0	22.0		
No. 3 Miniature				24.0	24.0	22.0		
No. 4 Miniature				24.0	24.0	22.0		
No. 1 Model	5	6	7	8	9	10	11	
No. 2 Model		50-kw heater electrical terminal failure;				21.0	24.0	
No. 1 Miniature		line pump impeller replaced				21.0	24.0	
No. 2 Miniature						21.0	24.0	
No. 3 Miniature						21.0	24.0	
No. 4 Miniature						21.0	24.0	
No. 1 Model	12	13	14	15	16	17	18	
No. 2 Model	12.0	23.0	24.0	24.0	24.0	18.1	24.0	
No. 1 Miniature	12.0	23.0	24.0	24.0	24.0	18.1	24.0	
No. 2 Miniature	12.0	23.0	24.0	24.0	24.0	18.1	24.0	
No. 3 Miniature	12.0	23.0	24.0	24.0	24.0	18.1	24.0	
No. 4 Miniature	12.0	23.0	24.0	24.0	24.0	18.1	24.0	
No. 1 Model	19	20	21	22	23	24	25	
No. 2 Model	24.0	24.0	24.0	24.0	24.0	17.8	24.0	
No. 1 Miniature	24.0	24.0	24.0	24.0	24.0	0.0	0.0	
No. 2 Miniature	24.0	24.0	24.0	24.0	24.0	24.0	24.0	
No. 3 Miniature	24.0	24.0	24.0	24.0	24.0	24.0	24.0	
No. 4 Miniature	24.0	24.0	24.0	24.0	24.0	24.0	24.0	
No. 1 Model	26	27	28					
No. 2 Model	24.0	24.0	24.0					
No. 1 Miniature	0.0	24.0	24.0					
No. 2 Miniature	24.0	24.0	24.0					
No. 3 Miniature	24.0	24.0	24.0					
No. 4 Miniature	24.0	24.0	24.0					
No. 1 Model	MOD SG-4 and SH-4			1776.9 hr *				
No. 2 Model	MOD SG-7 and SH-7			1756.5 hr *				
No. 1 Miniature	MIN 10			1773.3 hr *				
No. 2 Miniature	MIN 15			1759.4 hr *				
No. 3 Miniature	MIN 11			1757.3 hr *				
No. 4 Miniature	MIN 16			1762.1 hr *				

Times shown are number of hours of test time on vessel in 24-hour period, starting at 8:30 on the morning of that day in which the time is shown.

* Total hours of test time to February 28, 1961.

Fig. 9. Distribution of Test Time for Each Vessel During the Month of February

Loop Vessel Designation	March							
				1	2	3	4	
No. 1 Model				24.0	24.0	24.0	24.0	
No. 2 Model				8.0	24.0	24.0	0.0	
No. 1 Miniature				21.9	24.0	24.0	24.0	
No. 2 Miniature				21.9	24.0	24.0	24.0	
No. 3 Miniature				21.9	24.0	24.0	24.0	
No. 4 Miniature				21.9	24.0	24.0	24.0	
	5	6	7		9	10	11	
No. 1 Model	2.0	22.6	24.0	24.0	24.0	24.0	21.0	
No. 2 Model	0.0	22.8	24.0	24.0	24.0	18.0	0.0	
No. 1 Miniature	2.0	22.8	24.0	24.0	24.0	24.0	21.0	
No. 2 Miniature	2.0	22.8	24.0	24.0	24.0	24.0	21.0	
No. 3 Miniature	2.0	22.8	24.0	24.0	24.0	24.0	17.0	
No. 4 Miniature	2.0	22.8	24.0	24.0	24.0	24.0	22.0	
	12	13	14	15	16	17	18	
No. 1 Model	0.0	2.5	17.0	21.8	24.0	24.0	23.0	
No. 2 Model	0.0	22.0	17.0	23.4	22.8	24.0	24.0	
No. 1 Miniature	0.0	22.0	17.0	24.0	24.0	24.0	24.0	
No. 2 Miniature	0.0	22.0	17.0	24.0	24.0	24.0	24.0	
No. 3 Miniature	0.0	22.0	17.0	24.0	24.0	24.0	24.0	
No. 4 Miniature	0.0	22.0	17.0	24.0	24.0	24.0	24.0	
	19	20	21	22	23	24	25	
No. 1 Model	0.0	22.0	24.0	24.0	24.0	24.0	24.0	
No. 2 Model	3.0	22.0	22.5	20.3	17.0	24.0	24.0	
No. 1 Miniature	3.0	22.0	24.0	24.0	24.0	24.0	24.0	
No. 2 Miniature	3.0	22.0	24.0	24.0	24.0	24.0	24.0	
No. 3 Miniature	3.0	22.0	24.0	24.0	24.0	24.0	24.0	
No. 4 Miniature	4.5	22.0	24.0	24.0	24.0	24.0	24.0	
	26	27	28	29	30	31		
No. 1 Model	24.0	24.0	24.0	24.0	24.0	24.0		
No. 2 Model	24.0	24.0	24.0	5.8	24.0	24.0		
No. 1 Miniature	24.0	24.0	24.0	24.0	24.0	24.0		
No. 2 Miniature	24.0	24.0	24.0	24.0	24.0	24.0		
No. 3 Miniature	24.0	24.0	24.0	24.0	24.0	24.0		
No. 4 Miniature	24.0	24.0	24.0	24.0	24.0	24.0		

No. 1 Model MOD SG-4 and SH-4 2413.0 hr *
 No. 2 Model MOD SG-7 and SH-7 2308.3 hr *
 No. 1 Miniature MIN 10 2433.0 hr *
 No. 2 Miniature MIN 15 2419.1 hr *
 No. 3 Miniature MIN 11 2415.0 hr *
 No. 4 Miniature MIN 16 2424.3 hr *

Times shown are number of hours of test time on vessel in 24-hour period, starting at 8:30 on the morning of that day in which the time is shown.

* Total hours of test time to March 31, 1961.

Fig. 10. Distribution of Test Time for Each Vessel During the Month of March

fabricated with heavy-duty terminal lugs, and recurrence of the failure is not expected. In the assembly which failed, no damage was experienced by the heater elements. The terminals on this unit will be replaced with the heavy-duty type and the assembly will then be available as a spare.

When the new heater was installed in the loop, a pinhole leak was discovered where the elements are welded into the flange. The joint was welded in place, and no further difficulties were experienced with the assembly.

While the loop was shut down for replacement of the heater, the primary line pump was disassembled for inspection. The bearings were found to be worn and near the point of causing rotor damage. The accelerated bearing wear was caused by imbalance of the impeller. The impeller and bearings from the stand-by pump were installed in the in-loop pump and subsequent performance was entirely satisfactory. The impeller has been balanced and a new set of bearings obtained for future use.

Replacement of the heater assembly and repair of the pump were accomplished during a loop shutdown which extended from February 4 to February 9.

Shutdowns occurred during the month of March on three successive weekends while the loop was unattended. These shutdowns were initiated by low water levels in the model secondary systems. The loss of water was traced to two causes: (1) leakage across the secondary feedwater sight gauge gaskets and (2) leakage through tube fitting pipe threads. The gaskets were replaced, and the leaking pipe threads were seal-welded. The loop operated over the final weekend of March with no unusual drop of water level.

2. Maintenance of Secondary Environments

Difficulty was experienced during the quarter in maintaining the specified environments in the miniature secondary systems. The steam separators are not effectively removing entrained moisture from the steam and this results in carryover of chemicals from the vessels to the common storage tank. Since all heat exchangers do not have exactly the same steaming rate or the same specified environments, some vessels tend to operate above specifications while others run low.

Operation was improved by diverting the condensate return line to the drain rather than to the storage tank. This prevents exchange of chemicals from one vessel to another. Of course, environmental chemicals are still lost and addition of makeup chemicals must be made more often. Attempts are being made to obtain a more effective steam separator.

Chloride contamination of the model secondary systems was observed during the report period. Both systems were flushed several times to bring the chloride level below the specified limit. The source of the chloride was ultimately traced to salt deposits in the cooling coils used as condensers and blowdown coolers. The coils were used in the loop prior to the recent modifications, and subsequent cleaning operations apparently failed to remove all of the deposits. The coils were removed from the loop and thoroughly cleaned with nitric acid. A leak developed in one coil; this coil was replaced. Since these measures were taken, no difficulty has been experienced in maintaining the model secondary environments.

3. Operating Time Efficiency

During the report period, overall operation of the loop was quite satisfactory. A quantitative measure of performance may be obtained by computing the operating time efficiency (OTE) as follows:

$$\text{OTE} = \frac{\text{Total hours of test time (all vessels)}}{\text{Total possible hours of test time (all vessels)}} \times 100\%$$

Figure 11 shows the OTE achieved since the start of test work. It can be seen that utilization of the loop was greatly improved during the quarter. The initial low values resulted from the intermittent operation when argon was used to pressurize the primary system. The OTE during this quarter has been high, except for that time lost because of the 50-kw line heater failure. It is expected that the cumulative OTE will approach 85% by the end of the next quarter. This is estimated to be near the practical limit, when allowances are made for downtime resulting from normal loop maintenance.

C. CORROSION VESSEL TESTING

1 Model Heat Exchangers

Testing of the bimetal (MOD SX-4) model vessels and the Inconel (MOD SX-7) model vessels was initiated during the quarter. The secondary environment in the Inconel vessels is as follows (PM-1 conditions):

pH	10 to 10.5
PO ₄	150 ppm
SC ₂	10 ppm

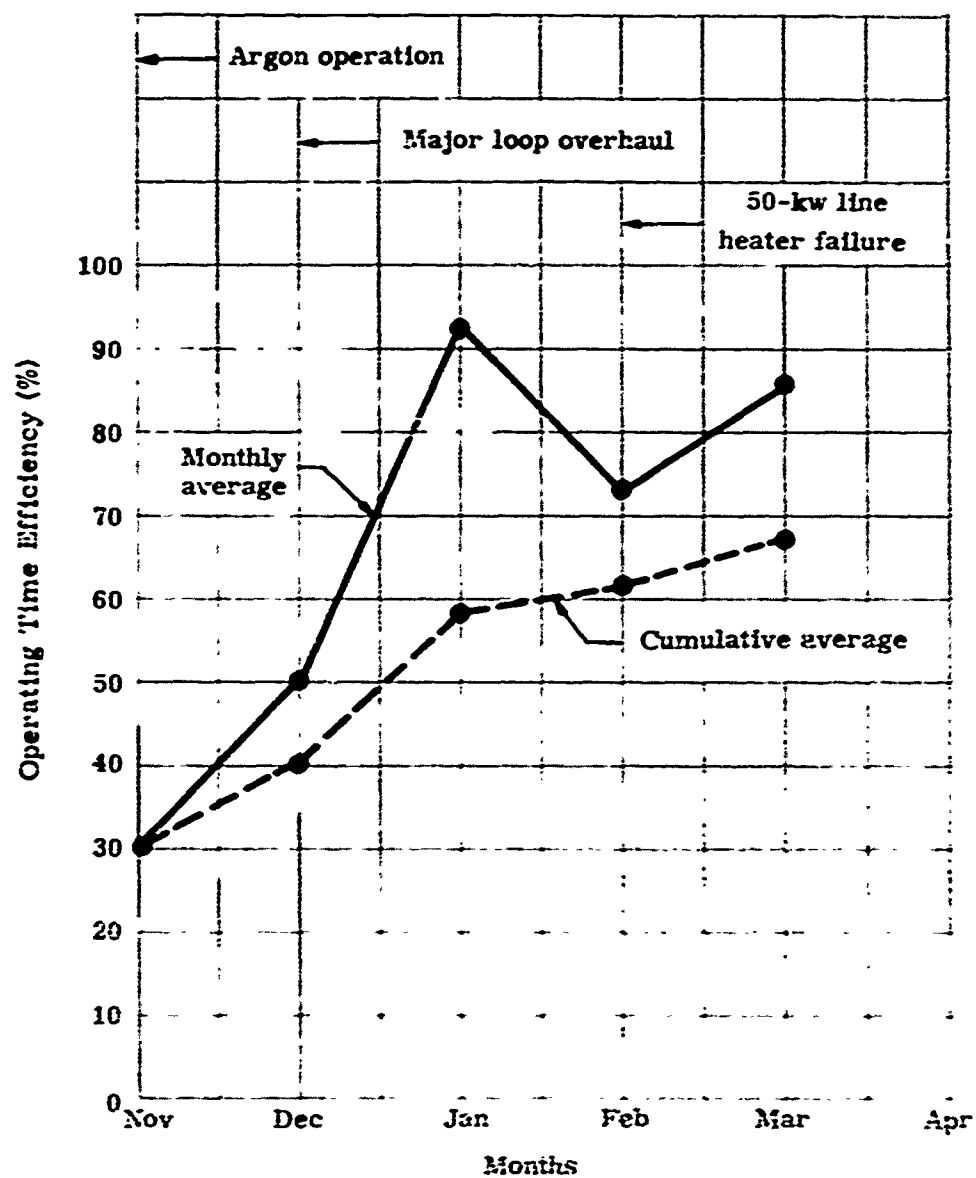


Fig. 11. Summary of Loop Operating Efficiency

Cl	0.5 ppm (max)
Total solids	175 to 200 ppm

The secondary environment for the bimetal vessels is as follows (SM-1 water conditions):

pH	Approximately 8.5 with Na_3PO_4
Cl	0.5 ppm (max)
O_2	0.5 ppm (max)
Total solids	200 ppm (max)

Accumulated test time, as of March 31, is as follows:

MOD SX-4	1413 hr
MOD SX-7	2308 hr

A regular schedule of water sampling and analysis has been established. Boiler water and condensate are sampled and analyzed Monday, Wednesday and Friday of each week. Makeup chemicals are added as required.

2. Miniature Heat Exchangers

Testing of the miniature Inconel (MIN 10 and 11) and bimetal (MIN 15 and 16) miniature heat exchangers was continued during the quarter. Accumulated test times are as follows:

MIN 10	2433 hr
MIN 11	2413 hr
MIN 15	2419 hr
MIN 16	2424 hr

The secondary environments for these vessels are summarized as follows:

MIN 10

Cl	1000 ppm
pH	10 (with NaOH)
O_2	Nc treatment (see note)

MIN 11

Cl	1000 ppm
pH	10 (with mixture of 33% Na_3PO_4 and 67% Na_2HPO_4)
O_2	No treatment (see note)

MIN 15 and 16

Cl	800 ppm
pH	10 (with mixture of 33% Na_3PO_4 and 67% Na_2HPO_4)

NOTE: The secondary makeup tank is maintained at 180° F, open to the atmcsphere, which will maintain the oxygen concentration at somewhat less than 0.5 ppm.

In MIN 15 the bimetallic tubing has been defected, exposing the stainless steel sublayer to the secondary environment. Defects are in the vapor phase, the liquid phase and at the vapor-liquid interface.

A regular schedule of water sampling and analysis has been established. Boiler water and condensate are sampled and analyzed Monday, Wednesday and Friday of each week. Makeup chemicals are added as required.

3. Reduction of Heat Transfer Data

Reduction of heat transfer data was started during this report period; the heat transfer index for each model steam generator has been determined as a function of time since testing was initiated. The index is a qualitative measure of the overall coefficient of heat transfer of the vessel. Because scale or corrosion products affect the quantity of heat transferred, the index should give an indication of scale buildup and a measure of its effect on the heat transfer rate in the generator.

The derivation of the index is as follows:

$$\text{Heat transfer index} = \frac{\text{Heat transfer to secondary fluid}}{\text{Primary fluid heat available for transfer}}$$

or

$$\text{Heat transfer index} = \frac{W_s (H_{so} - H_{sl})}{W_p (H_{pl} - H_{po})} \quad (1)$$

where

- W_s = Secondary steaming rate (lb/hr)
- W_p = Primary flow rate (lb/hr)
- H_{si} = Enthalpy of secondary water in (Btu/lb)
- H_{so} = Enthalpy of secondary steam out (Btu/lb)
- H_{pi} = Enthalpy of primary water (Btu/lb)
- H_{po} = Enthalpy of primary water out, if at the secondary steam saturation temperature.

After the data were carefully examined, it was determined that a more accurate index could be determined by using the primary fluid measurements because those data were taken more often during the test. The heat balance for the steam generator may be written:

$$W_s (H_{so} - H_{si}) = W_p (H_{pi} - H_{po}) - Q_L \quad (2)$$

where

- H_{po} = Enthalpy of primary water out (Btu/lb)
- Q_L = Thermal losses from the steam generator (Btu/hr).

Substituting in Eq (1) and reducing:

$$\text{Heat transfer index} = \frac{(H_{pi} - H_{po}) - Q_L / W_p}{(H_{pi} - H'_{po})} \quad (3)$$

Examination of the data shows that the quantity Q_L / W_p is very small compared to the quantity $(H_{pi} - H_{po})$ so that the use of an experimentally determined constant value for Q_L / W_p has no appreciable effect on the index.

Figures 12 and 13 show the results of the present data reduction effort. The curves appear to indicate that large effects on heat transfer by scaling have not occurred. Analysis of these data is still being conducted. Also, possible causes for the large deviation of a few scattered points are being investigated.

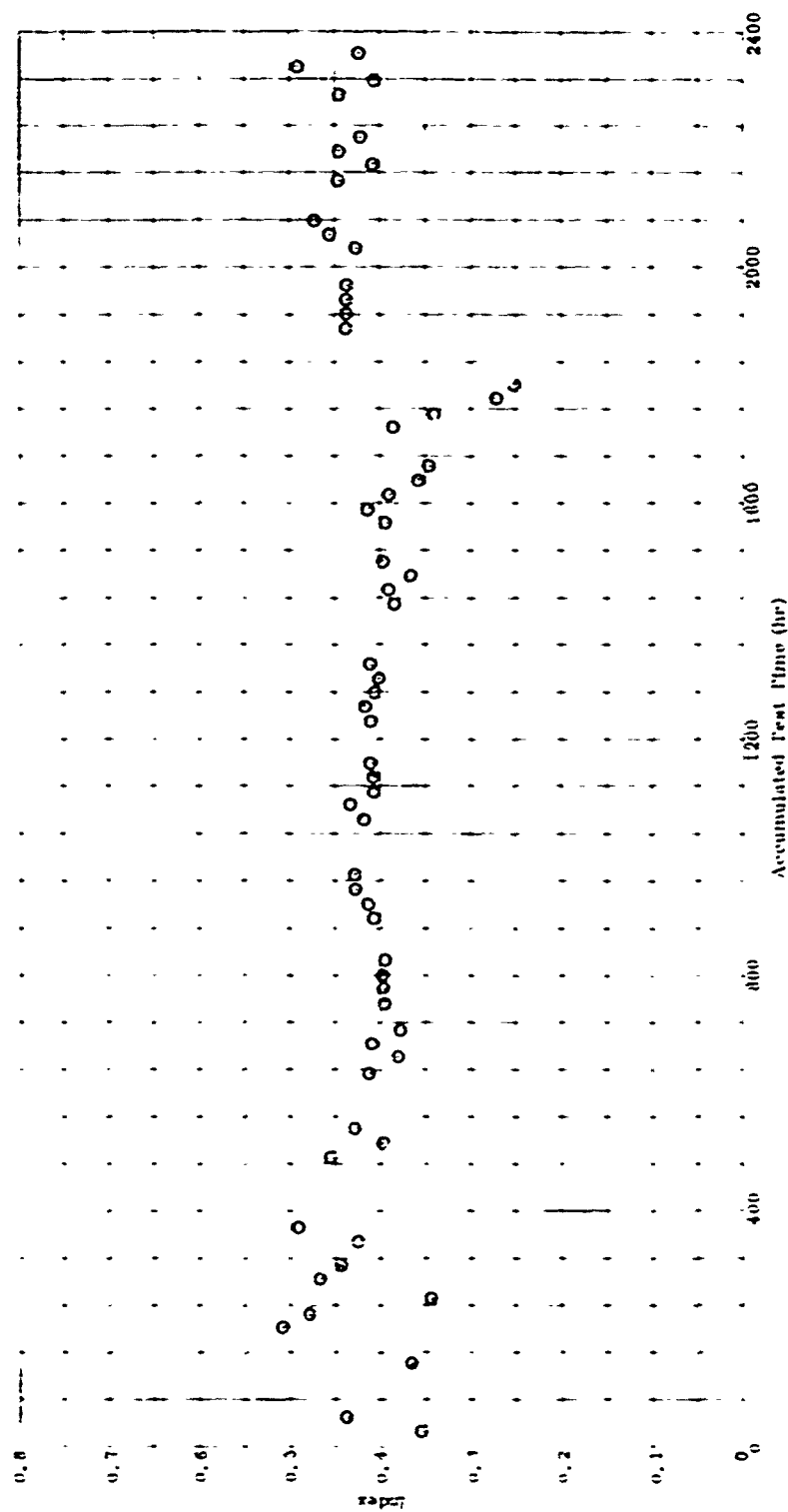


Fig. 12. Variation of Calculated Heat Transfer Index with Time--Bimetal Steam Generator (MOD SG-4)

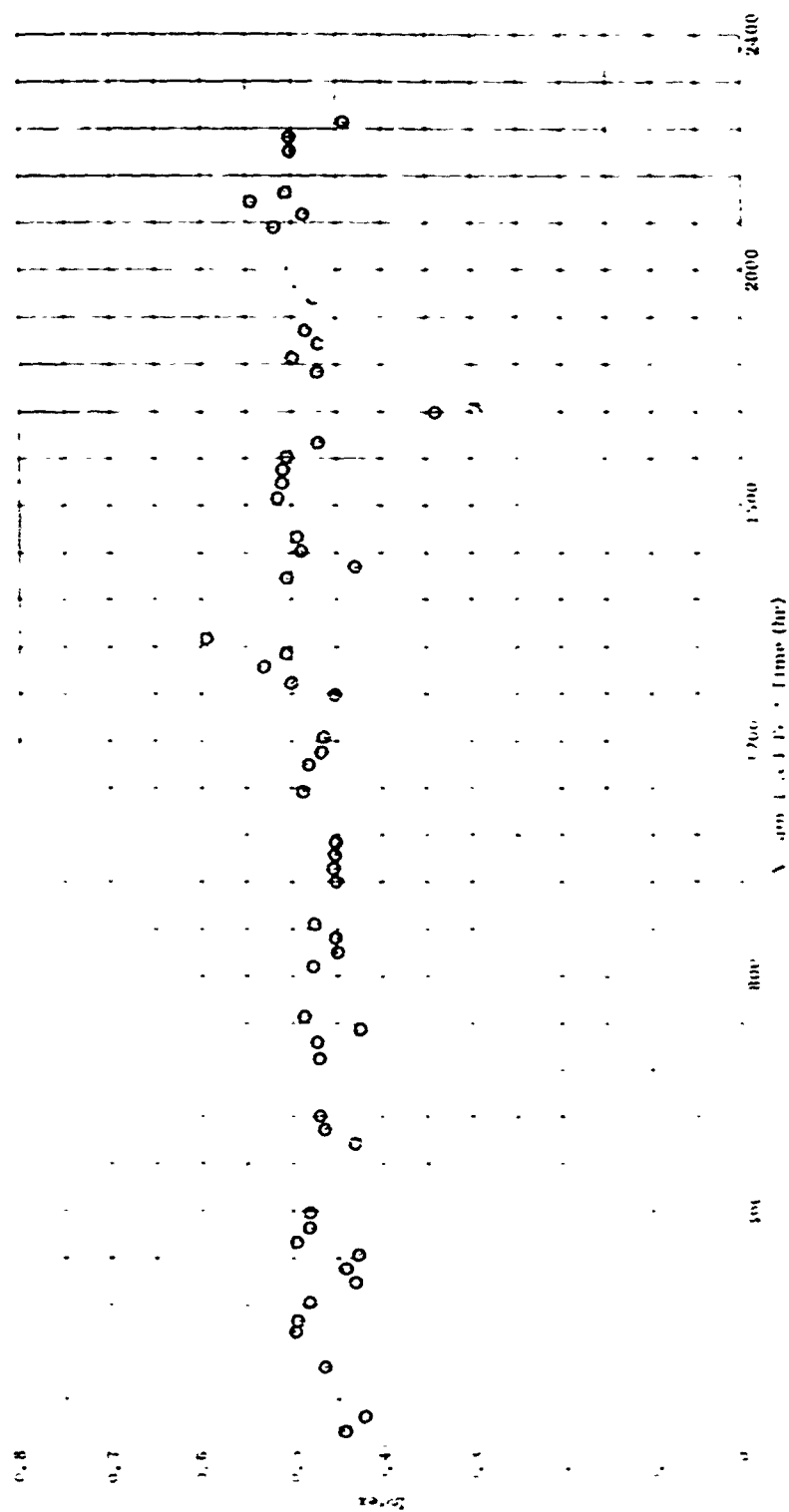


Fig. 13. Variation of Calculated Heat Transfer Index with Time--Inconel
Steam Generator (MOD SG-7)