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SUBJECT: Metallographic Examination of Cambridge Nos. 1 and 2
Metallography Report No. 267

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Introduction:

The radiators designated Cambridge # 1 and # 2 were visually examined and modified before operation by H. C. Hopkins.¹ The modifications included the removal of the heavy side plates and slitting of the heavy base plate.

The initial examination revealed poor quality braze joints at the top and bottom plates of Cambridge # 1. However, the same plates of Cambridge # 2 were adequately brazed. The copper core of the fins was exposed in many of the tube-to-fin joints on both radiators, indicating that the braze material had not covered the fin collars.

The radiators were first operated using intermediate heat exchangers ORNL # 1 and # 2, type I.H.E. # 3, the first of which failed after 648 hours operation. The examination of these heat exchangers has previously been reported.² These heat exchangers were replaced by B.S. and B # 1 and # 2, type I.H.E. # 3, which operated 1397 additional hours without apparent failure. The examination of these heat exchangers is now being conducted.

Fig. 1 shows the radiators in the as-received condition after cleaning. The operation of the radiators was halted June 14, 1956 after a total operating time of 2045 hours without failure; of the total time, 579 hours were under isothermal conditions between 1200 and 1400°F, and 1466 hours were at a ΔT of 200°F. The radiators endured 12 thermal cycles during this period.

Mass Transfer:

Four samples were removed from each radiator and examined for evidence of mass transfer. Two samples were taken from the air inlet banks and two from the air outlet banks of each radiator, as shown in Figs. 2, 3, 4 and 5. In these figures the sample locations, numbered one through four, appear as cut-away areas. The sample numbers increased in the direction of increasing NaK fluid temperature. The tubes in these samples were split longitudinally slightly off the center line of the tubes, and the samples were then mounted and ground down to the exact center of the tube. In this manner it was hoped that a viewing edge would be provided in which no mass transfer was lost due to the sectioning and grinding operation.

Fig. 7 shows the mass transfer encountered in sample number four taken from Cambridge number one. This sample contained the coolest NaK among the samples examined, and the deposits at this point reached a maximum thickness of .005 inches.

Fig. 8 shows the mass transfer deposit in sample number one from the same radiator. This sample contained the hottest NaK. The deposit as shown measures .001 inches.

Fig. 9 shows the mass transfer deposited in sample number four taken from Cambridge # 2. The appearance and extent of the deposit is similar to that observed in the number four sample from Cambridge # 1. (Fig. 7).

Fig. 10 shows the mass transfer deposited in sample number one from Cambridge # 2. Again the deposits are similar to those in the corresponding sample from Cambridge # 1. (Fig. 8).

In both radiators the average thickness of the deposit was .004 inches. There was little or no difference in the appearance of the deposit in the two radiators.

Tube-To-Fin Joints:

Twelve samples were removed from the air inlet and air outlet banks of both radiators and numbered from one to twenty-four as shown in Figs. 2, 3, 4, and 5. Each sample contained a portion of three tubes joined to nineteen or more fins. The samples were cross-sectioned to reveal two opposed joint areas, then mounted, polished, and examined at 80 X.

A total of 2718 joint areas from Cambridge # 1 and 2664 joint areas from Cambridge # 2 were examined. The percentages of tube-to-fin adherence and the degree of oxidation of the fin collars were noted and are tabulated in columns 1 and 2 of Table 1. In Table 1 the results of the examination of tube-to-fin joints in these radiators can be compared with five previously examined radiators. These figures indicate that the Cambridge brazing technique was better than the York technique in two cases out of the three tabulated but still does not meet the specifications.

While examining the samples for fin-to-tube integrity, a total of eight small cracks were found in the brazing alloy fillets of the six samples having sump plates cut from Cambridge # 1. Eight more small cracks were found in the six samples having sump-support plates cut from the same radiator. Twelve samples having sump plates were removed from Cambridge # 2. Six samples had a total of twelve cracks, while the remaining six were free from cracks.

Discussion:

Both Cambridge # 1 and # 2 radiators showed poor adherence of sump and sump-support plates to the tubes which tended to limit the number and extent of cracks. All the cracks found were in the braze alloy fillets as shown in Fig. 6. Note that the sump-support plate does not contact the tube wall on the right, a very common occurrence in the radiators.

The maximum thickness of mass transfer deposits in these radiators is approximately one third the maximum thickness observed in ORNL # 1 intermediate heat exchanger, which operated in conjunction with the radiators. This heat exchanger exhibited .015 inches of mass transfer after 993 hours of ΔT operation in the temperature range of 1500-1600°F.³ This compares with a maximum value of .005 inches (Figs. 7 and 9) for each radiator following 1466 hours of ΔT operation in the temperature range of 1300-1400°F. The maximum ΔT utilized through the heat exchanger was 300°F, while that across the radiators was 200°F.

Although a direct comparison with other dynamic tests is difficult because of differences in system surface areas and volumes, it is nevertheless interesting that the deposit thickness in these heat exchanger test components show good agreement with sodium pump loops operated strictly as corrosion tests. These latter systems yield a maximum deposit of .015 inches at 1500°F and .003 inches at 1300°F in tests operating for 1000 hours at a ΔT of 300°F.

¹Experimental Report No. 7405-2-4, "Cambridge Radiators # 1 and # 2 Performance Test and Operating History" H. C. Hopkins, August 8, 1956.

²CF 56-7-123, "Examination of ORNL # 1 and # 2 Intermediate Heat Exchangers, Type I.H.E. # 3 J. H. DeVan and R. S. Crouse, July 20, 1956

Memo to W. D. Manly from G. M. Slaughter, "Metallographic Examination of I.H.E. # 3 Failure" April 11, 1956

CF 56-7-82 "Metallographic Examination of I.H.E. # 3," J. E. VanCleve, Jr. July 12, 1956

Y-19370

Fig. 1
Cambridge Radiators As Received After Operation

Y-19532

Fig. 2
Cambridge # 1 Showing Location of Sample

Y-19533

Fig. 3
Cambridge # 1 Showing Location of Sample

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Fig. 4

Cambridge # 2 Showing Location of Sample

Y-19651

Fig. 5

Cambridge # 2 Showing Location of Sample

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Y-20409

Fig. 6
Line Drawing in Sump and Sump-Support Plate

Y-19616

Fig. 7
Sample No. 4 From Cambridge # 1. Note Mass Transfer to .005 inches.

200 X

Y-19614

Fig. 8

200 X

Sample No. 1 From Cambridge # 1. Note Mass Transfer to .001 inches.

Y-19674

Fig. 9

200 X

Sample No. 4 From Cambridge # 2. Note Mass Transfer to .005 inches.

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Y-19673

Fig. 10

200 X

Sample No. 1 From Cambridge # 2. Note Mass Transfer to .001 inches.

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	Cambridge # 1	Cambridge # 2	York # 9	York # 4	York # 3	PWA # 2	ORNL # 3
Number of joint areas examined	2718	2664	2608	2757	2684	3210	2282
Percent of joint areas having 75-100% adherence	91.6	92.9	44.6	60.7	90.4	100	87.7
Percent of joint areas having 50-74% adherence	2.9	4.6	21.2	18.8	5.9		3.5
Percent of joint areas having 25-49% adherence	0.5	0.5	9.4	5.5	1.1		1.4
Percent of joint areas having 0-24% adherence	5.0	2.0	24.8	15.0	2.6		7.4
Percent of joint areas having non-oxidized copper fins	81.3	37.0	23.5	61.9	84.5	100	12.1
Percent of joint areas having slightly oxidized copper fins	4.0	5.3	8.5	19.5	7.5		2.5
Percent of joint areas having heavily oxidized copper fins	14.7	57.7	68.0	18.6	8.0		85.4
Number of hours of 1000-1600°F service	2045	2045	1283	1356	361	1199	716