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Heat Exchanger (SHE # 1)

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For The Atomic Energy Commission

H. F. Canale
Chief, Declassification Branch *md*

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METALLOGRAPHIC EXAMINATION OF HIGH VELOCITY HEAT EXCHANGER (SHE # 1)

Summary:

A high velocity heat exchanger known as ORNL # 1 type SHE 1 was operated for a total period of 1645 hours with heat exchanger fluid and NaK. The last 456 hours of test conditions were conducted to obtain a wide temperature differential for the study of mass transfer effects. Complete test procedures and operation details are available in ORNL CF 56-1-187.

Procedure:

The heat exchanger, shown in Fig. 1 was sectioned for metallographic examination. The principle parts in the examination were the NaK carrying Inconel tubes identified as part 16 in Fig. 2. Principle areas of examination are identified as "A, B, C, D and E". The tubes were carefully cut into suitable size samples and mounted in a non-pressure setting plastic for metallographic grinding and polishing. Area "A" (Fig. 1) is shown in Fig. 3 with the fuel and NaK flow directions indicated. A sectioned view of area "A" is shown in Fig. 4. It was immediately noticeable that the inside surface of the tube in this area had been brightened by a reaction with the NaK flowing through the tubes. The NaK outlet temperature in this area was approximately 1495°F during the last 456 hours of test.

A photomicrograph made directly on the inner surface in contact with the NaK is shown in Fig. 5. The rate of attack is much deeper at the grain boundaries with some uniform dissolution of the inner wall surface. A longitudinal view of the tube showing the NaK exposed surface is shown in Fig. 6. The intergranular attack is very pronounced.

Tube-to-header welds were also examined in the "A" area. A representative photomicrograph is shown in Fig. 7 of a weld and tube exposed to NaK at the NaK exit end (hot) of this heat exchanger. A photomicrograph at a higher magnification is shown in Fig. 8. It is evident that the depth of intergranular attack is not as deep as in the tubes and there was no evidence of selective attack in the cored structure typical of a weld.

A photomicrograph of an entire tube wall in area "A" is shown in Fig. 9. The outer surface of the tube exposed to the hot fuel also shows considerable attack by the depth of voids. The fuel inlet temperature in area "A" was approximately 1505°F for the last 456 hours of test. The grain size is noticeably large in the tubes, averaging about two grains across the entire wall. Along with this grain size the microstructure is free of much of the precipitate usually found in commercial grade Inconel. The large grain size and the small amount of precipitate can be accounted for by the 1505°F (fuel) to 1495°F (NaK) operating temperature in area "A" and the probable elemental diffusion at these temperatures of Ti, Al, and C into the NaK and fuel. These elements are found as compounds of Ti-Al , Cr_3C_2 and Cr_{23}C_6 in Inconel. The stress condition on the tubes at these temperatures would also accelerate grain growth.

A longitudinal view of the tube wall at about the center of the heat exchanger is shown in Fig. 10 (Area "B"). It might be assumed that the operating temperatures in this location would be near to the mean temperatures of the fuel (1455°F) and the NaK (1250°F). The microstructure in this central location does indicate a lower NaK temperature from the amount of diffusion which occurred by the amount of precipitate still present on the fuel half of the tube wall. The amount of sub-surface voids on the fuel side is less and the average depth of intergranular attack on the NaK side is slightly less.

The fuel outlet and NaK inlet header is shown in Fig. 11 with the examination areas "C", "D" and "E". A longitudinal examination at the first bend near the fluoride outlet is shown in Fig. 12 (Area "C"). A comparison with the microstructures from areas "B" and "A" shows a heavier precipitate in the microstructure across the entire tube wall in area "C" with no attack on the inner wall exposed to the NaK and a small amount of sub-surface voids on the fuel side.

A longitudinal examination of the bend area "D" showed a mass transfer layer about 0.003 in. deep at the outer surface of the bend. There is a radical difference in the amount of mass transfer which exists on the inner surface of the tubes at the outside and inside bend as shown in Fig. 13 and 14. Apparently the flow of NaK impinging against the outer part of the bend accounts for a greater deposition than the deposition on the inner curvature. A higher magnification photomicrograph of the deposit on the outside bend is shown in Fig. 15. The growth pattern of the deposit is curved with the flow direction. A spectrographic ratio analysis of the deposit as compared with Inconel is shown as follows:

	Deposit	Inconel
Ni-Fe ratio	7.9 to 1	9.5 to 1
Ni-Cr ratio	12.2 to 1	5. to 1
Cr-Fe ratio	1 to 1.5	1.9 to 1

The fuel side (outside) of the tube was also examined in area "D" and a tightly adhering gold colored layer about .0001 in. thick was found as shown in Fig. 16. This layer was analyzed spectrographically as a titanium rich layer and identified by x-ray as titanium oxide (TiO).

The tube to header welds at area "E" were examined primarily for comparison with the welds from the hot end (area "A") of the heat exchanger. A longitudinal view of a weld from area E is shown in Fig. 17 and Fig. 18. The difference in operating temperature is very evident at area "E" which operated at 1005°F (NaK) inside and 1405°F (fuel) outside. The heavy precipitate in the microstructure of the header plate tube wall and the weld is typical of Inconel subjected to this temperature. A difference in the amount of deposit is evident on the orifice of the tubes and just inside the weld. Flow velocity through the orifice produced a deposit although just inside the tube, past the weld in a location of comparative static flow, there was little deposit.

Conclusion:

Judging from the condition of the tube walls, this heat exchanger was close to failure. The depth of intergranular attack on the inner NaK surface (.003 in.) and the depth of subsurface voids on the fuel side (.007 in.) were more than half the wall thickness and these measurements were only from a few scattered specimens and on one plane per specimen.

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The grain size was much larger in the hot end than in the cold end of the heat exchanger. This increased grain size in the hot end could be attributed to the absence of precipitate and greater triaxial stresses due to thermal expansion and a thermal differential across the tube wall. Also, the strain anneal effect due to the thermal cycling during operation at a specific temperature would accelerate grain growth. These stress conditions and the resulting change in microstructures are directly related to the operating temperature at the hot end. The greater depth of corrosion at the hot end could also be due to a greater stressed condition or a corrosion fatigue.

Mass transfer was present where the NaK entered the heat exchanger but this deposition was influenced greatly by flow against the tube walls. The maximum deposit was 0.003 in.

Spectrographic Analyses --- Cy Feldman

X-Ray Analyses --- R. M. Steele

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Fig. 1

High Velocity Heat Exchanger (SHE # 1)

Arrows indicate flow direction of NaK and fuel. Letters indicate areas of metallographic examination

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PARTS LIST			
PART NO.	QTY	NAME	REMARKS
1	1	INLET TUBE SHEET	
2	2	PIPE CAP	3" ST'D WT. BUTT WELD
3	1	STUB-NAK INLET	1 1/2" PIPE SCH'D 40
4	1	HOUSING-TUBE INLET	3" PIPE SCH'D 40
5	1	HOUSING-TUBE OFFSET	3" PIPE SCH'D 40
6	2	FLUORIDE BAFFLE	
7	1	STUB-NAK OUTLET	1 1/2" PIPE SCH'D 40
8	1	FILLER SUBASSEMBLY	
9	1	SPACER WIRE	.032 DIA.
10	1	STUB-FLUORIDE INLET	1 1/2" PIPE SCH'D 40
11	1	OUTLET TUBE HEADER	3" PIPE SCH'D 40
12	1	HEADER INNER RING	
13	1	PIPE	6" SCH'D 40
14	2	HEADER OUTER RING	
15	1	TRANSITION SLEEVE	
16	20	NAK TUBE	.1875 O.D. X .017 WALL
17	1	HEAT EXCHANGER SHELL	1 1/2" PIPE SCH'D 40
18	1	STUB-FLUORIDE OUTLET	1 1/2" PIPE SCH'D 40

Fig. 2

High Velocity Heat Exchanger Drawing
 "A", "B", "C", and "E" indicate areas of metallographic examination

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Fig. 3
Before Sectioning

Fig. 4
After Sectioning

High Temperature End (Area "A") of SHE # 1

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Y-18169

Fig. 5

100 X

Photomicrograph of Inner Surface (NaK Side) of Inconel Tube. Photo is made normal to the surface. Note selective attack at the grain boundaries.

Y-18169

Fig. 6

1000 X

Longitudinal View of Inconel Tube Exposed to NaK. Note the depth of selective attack at the grain boundaries.

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Y-18461

Fig. 7

50 X

Tube-To-Header Weld from Area "A"

Dark areas in the lower corners are due to field limitations of microscope

Y-18462

Fig. 8

250 X

Tube-To-Header Weld from Area "A"

Photomicrograph of area indicated in Fig. 7 at higher magnification

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Area "A"

Y-18149

Fig. 9

Area "B"

Y-18148

Fig. 10

Inconel Tube Wall from Indicated Areas

Top of Photomicrographs: Fuel side, showing intergranular and intragranular voids. Note the difference in attack in area "A" and the cooler area "B".

Bottom of Photomicrographs: NaK side, showing intergranular attack. Note the absence of precipitate in the entire tube in area "A" and the presence of some precipitate in half the tube near the fuel.

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Y-14799

Fig. 11

Coldest End of High Velocity Heat Exchanger Fuel Outlet and NaK header with Areas "C", "D", and "E" indicated.

Y-18147

Fig. 12

250 X

Inconel Tube Wall in Area "C". Note the small amount of sub-surface voids on fuel side (top of photomicrograph) and absence of intergranular attack on the NaK side (bottom). Note uniform distribution of precipitate.

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Fuel
Side

NaK

Fuel
Side

Y-18464

Fig. 13

Y-18463

Fig. 14

Outer Bend

Mass Transfer on NaK Side of Bend in Area "D"

Inner Bend

Note the difference in the amount of deposit on the diametrically opposite walls at the bend

Note sketch for location of photomicrographs

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Y-18465

Fig. 15
Photomicrograph of Inner Bend, Area "D", NaK Side
Similar area as Fig. 13 at higher magnification

1000 X

Y-18150

Fig. 16
Photomicrograph of Outer Surface (Fuel Side) in Area "D"
Note "gold" appearing deposit on surface

1000 X

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Y-18466

Fig. 17

50 X

Tube-To-Header Joint in Area "E"
Arrow indicates static area with very little mass transfer

Y-18467

Fig. 18

250 X

Same as Fig. 17 at higher magnification
Note deposit on NaK surface