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INTRODUCTION

This report discusses a new heater for use in a model gas loop. This heater is prototypic of the one being built for use in the gas loop of the Advanced Test Reactor (ATR) at Idaho Falls. Design calculations for this heater are the trial and error type and will, therefore, not be included in this report.

To evaluate various design parameters of the ATR Gas Loop an approximately one-tenth scale model loop was constructed at Pacific Northwest Laboratory.* The ATR Loop is a high temperature, high purity, recirculating, helium gas loop.

The model gas loop (Figure 1) in its original form operated successfully for approximately 700 hr at various heater outlet temperatures up to 2100 °F. Later when the designs of the ATR Loop were taken beyond the scope stage, it became apparent that the original gas loop was no longer an adequate model. Since the new design contained features that were

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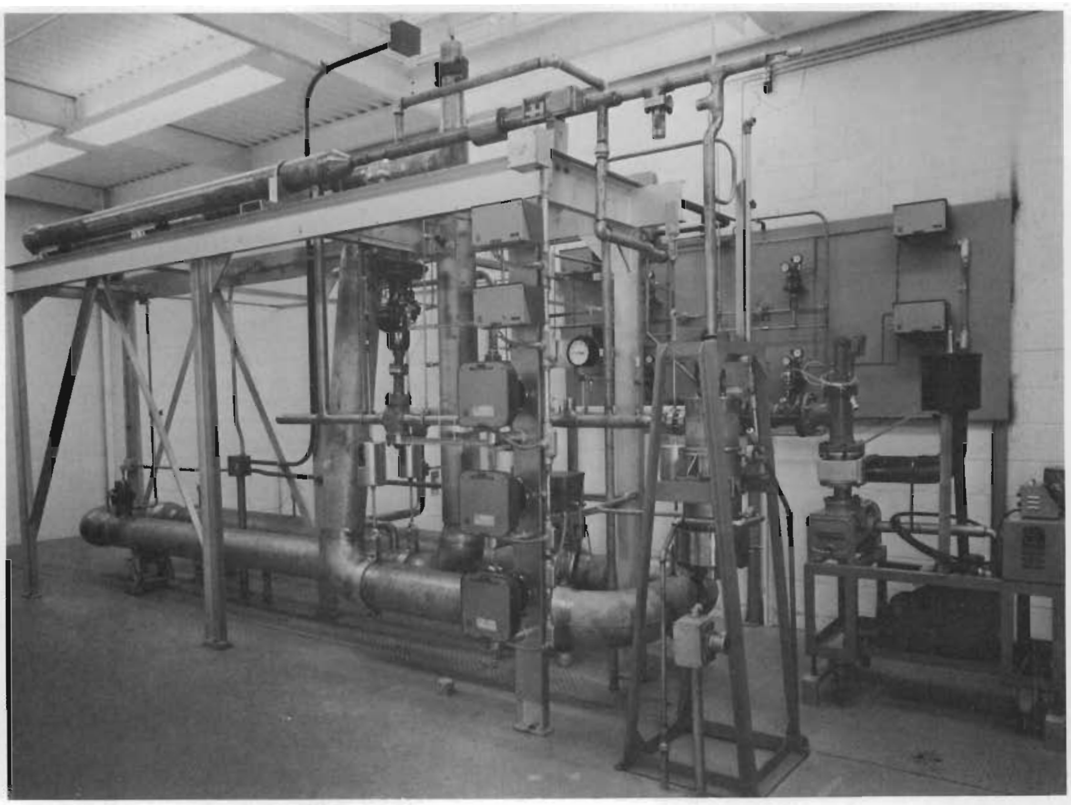

FIGURE 1. Original High Temperature Model Gas Loop Before Application of Outer Insulation.

significant departures from commercial practice, it was decided to modify the model loop (Figures 2-4).

Extrapolation of data from the original model loop heater indicated that this type of heater would not meet the requirements for the heater in the ATR Loop; therefore, a new model heater was constructed.

SUMMARY

A gas heater incorporating the major design features of the ATR gas heater has been built, installed, and operated successfully in the model gas loop. The heater represents a significant departure from commercial practices of gas heating, and a number of technical problems applicable to both the ATR heater and the model heater were solved during the fabrication of the model heater.

DISCUSSION

DESIGN CRITERIA

Preliminary calculations made for the ATR heater indicated a novel design would be required to match heat transfer requirements with the allocated space for the heater.

A heater concept that would meet the requirements of the ATR heater would have two concentric stages of tubular heating elements with gas flow through the inside of the heating element tubes. The first stage heating elements would be Nichrome, and the second-stage hotter elements, a

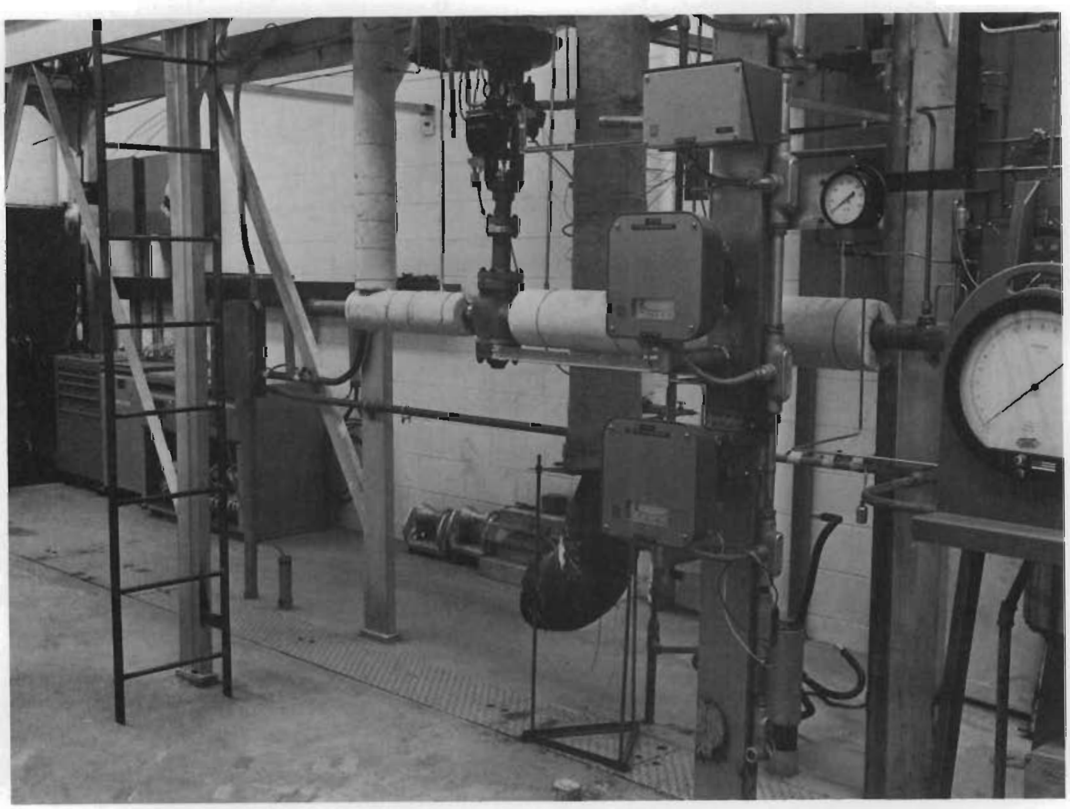

FIGURE 2. Model Loop During Modifications.

FIGURE 3. Model Loop After Modifications.

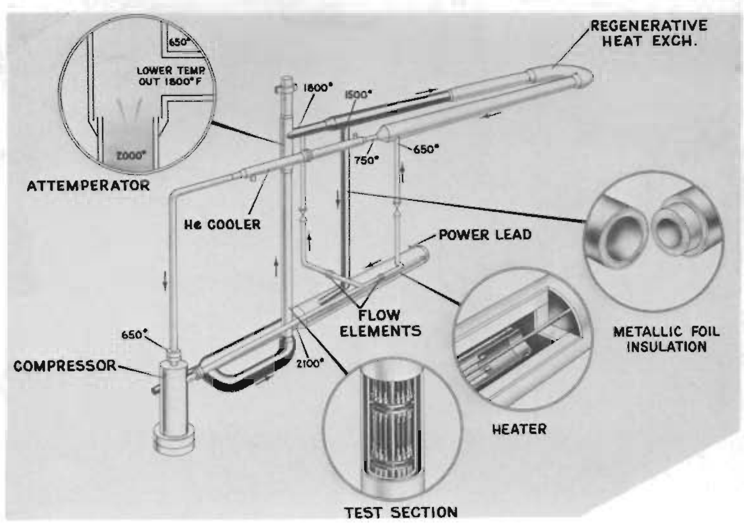

FIGURE 4. High Temperature Gas Loop

refractory metal. The tube would be resistance heated and surrounded by ceramic insulation. Gas inlet would be through a side of the heater near the outlet end, while electrical lead-ins would also be through the side, but at the opposite end from the inlet.

The model loop further restricted the design of the model heater to the following:

- Inlet gas temperature--1500 °F
- Outlet gas temperature--2100 °F
- Atmosphere--pure helium gas
- Maximum working pressure--350 psig
- Maximum flow rate--500 lb/hr
- Maximum pressure drop--1.5 to 2.0 psi

These scope designs and the preliminary calculations were used as a base to design and build a heater to fit the model gas loop.

DESIGN DESCRIPTION

The new model loop heater (Figure 5) has an outer ring of Nichrome tubes and employs a flow reversal to an inner ring of molybdenum tubes. Alumina surrounds all heating tubes to act as an electrical insulator and flow block to force the majority of gas through the inside of the heated tubes. A thin walled cylinder (Haynes-25) surrounds the inner second stage ceramic to act as a flow separator between the two stages of the heater. Another thin walled cylinder (Hastelloy-X) surrounds the outer 1st stage ceramic and connects with the inlet opening to help channel the gas through the heating elements.

Heating element tubes for each stage of the heater form a single phase series electrical circuit. Each tube is connected to its neighbor and to power supply electrodes by a "Dogbone" shaped

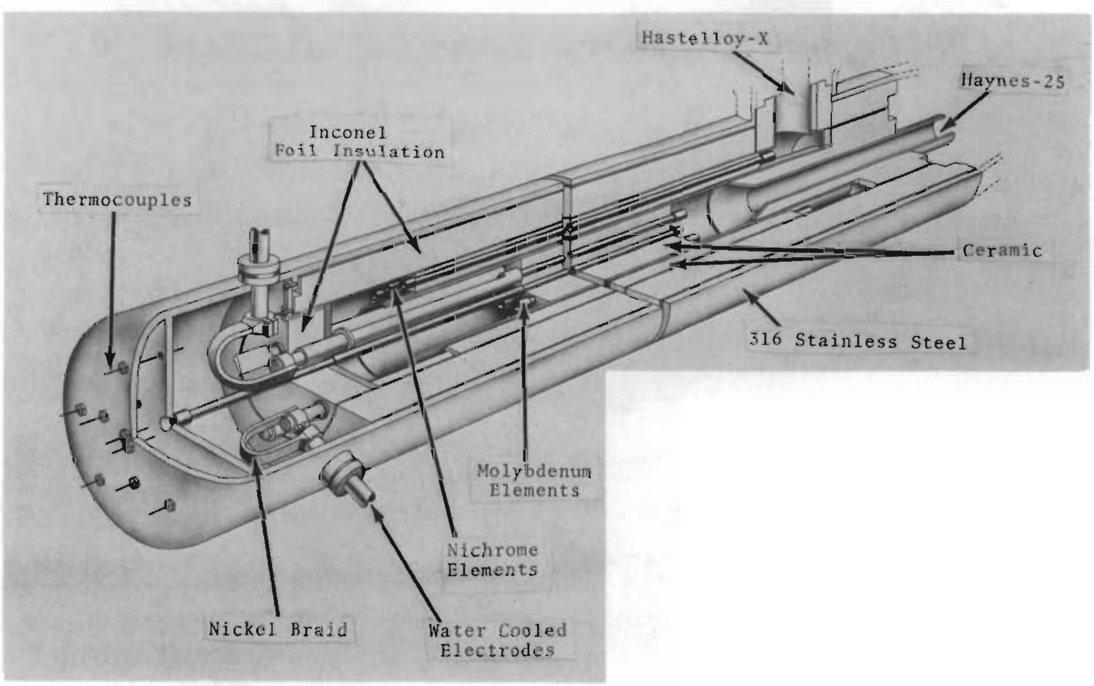

FIGURE 5. High Temperature Gas Loop Heater

connector (Figure 6). One inch diameter rods of molybdenum connect two of the molybdenum tubes to flexible nickel braid (Figure 7), which in turn are connected to water cooled nickel electrodes that penetrate the pressure shell. Two of the Nichrome tubes are connected to nickel braid and outer electrodes through 1 in. diam nickel rods. This completes the internal to external electrical circuit. The electrodes penetrating the pressure shell are electrically insulated from the shell by a ceramic sleeve, and gas leakage around the electrodes is prevented by a combination of 3 rubber O-rings and silicone rubber sealant (Figure 8).

An outer water jacket (not shown in Figure 5) and metallic foil insulation around the alumina will reduce the temperature of the pressure-bearing shell to less than 300 °F.

DESIGN DETAILS

Details of the heater as calculated for the design work are shown in Table I.

FABRICATION

The actual fabrication of the model heater became the proving ground for some of the detail designs. Some designs were, out of necessity, changed in the field; however, the major problems were in the following areas:

- Difficulty of obtaining components from industry
- Connection of tubular heating elements to "dogbone" connectors
- Flexible connections between external and internal electrodes

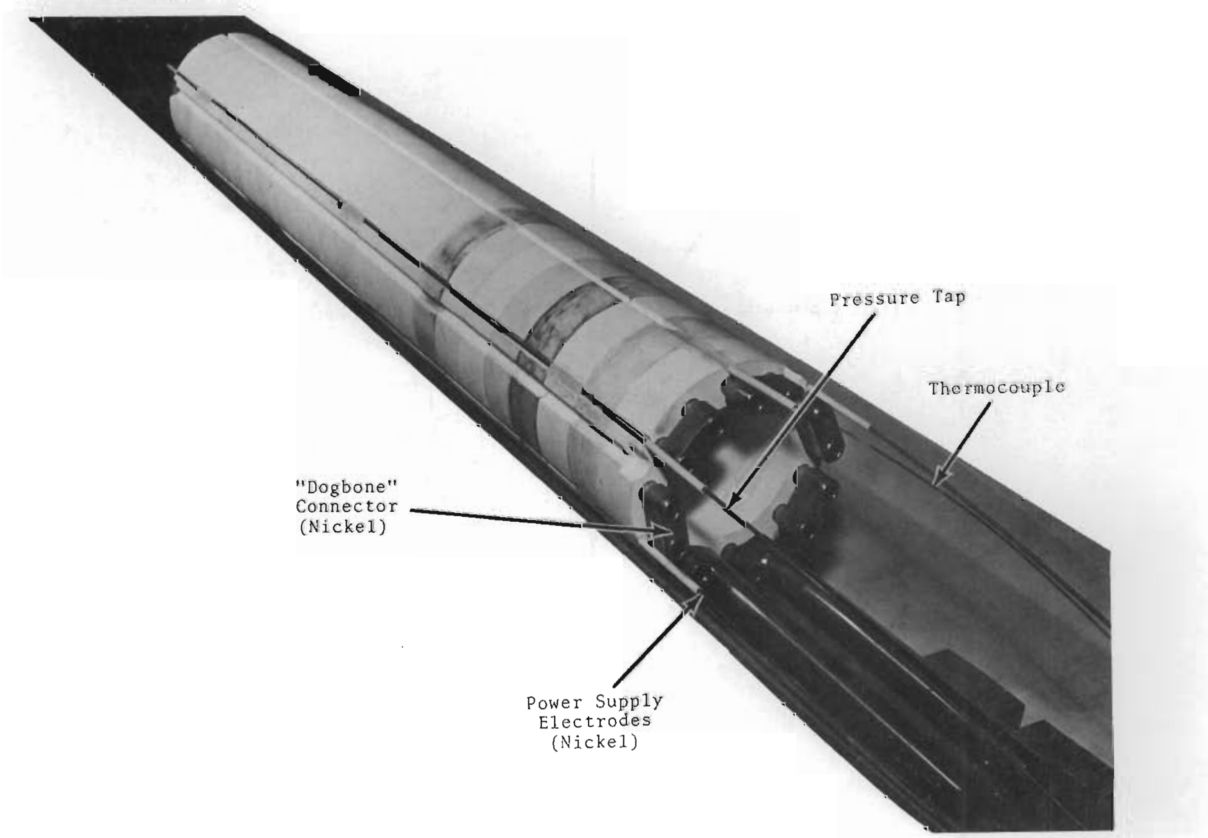

FIGURE 6. Heater 1st Stage (Nichrome Elements)

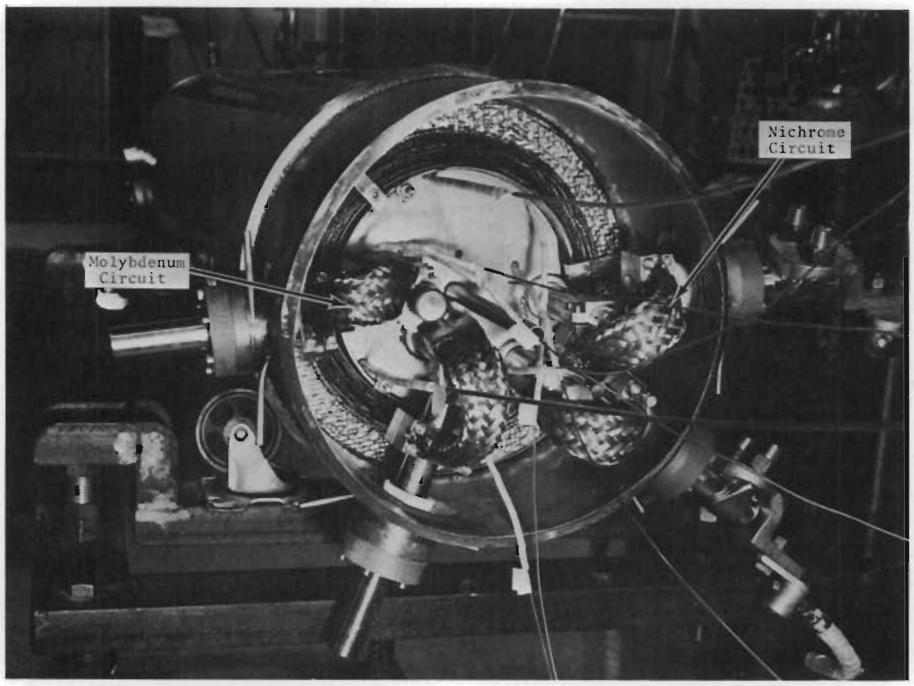

FIGURE 7. Nickle Braid Flexible Connectors

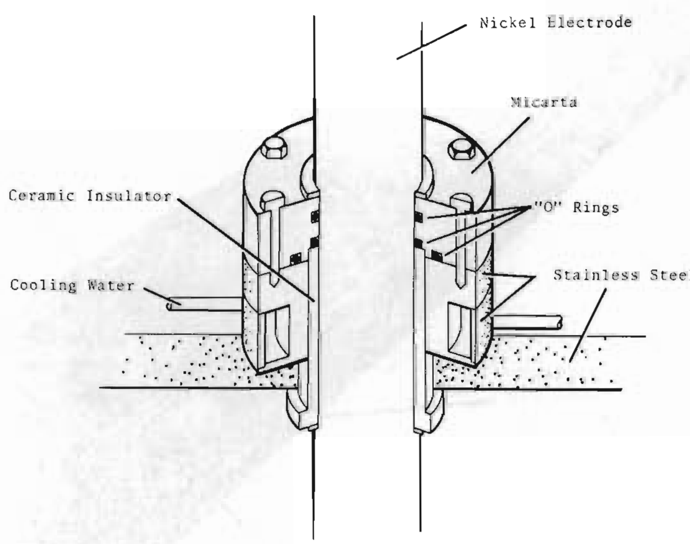

FIGURE 8. O-Ring Electrode Seal

TABLE I. Model Gas Loop Heater Calculated Values for Design

I. Environment

A. Atmosphere - Pure Helium
B. Pressure - 345 psig
C. Flow Rate - 500 lb/hr

II. Construction

Item	Material	Number of Tubes	Length	O.D.	Wall Thickness
1st Stage	Nichrome	12	51	0.640	0.0625 in.
2nd Stage	Molybdenum	6	39 1/2	0.635	0.045 in.
Pressure Shell	Stainless Steel		6 ft	12 in.	Schedule 40
Insulation	Inconel Foil				3 in.

III. Electric Power

A. Needed Power 55 kW per stage
B. Rated Power
1. Nichrome elements - 60 kW (120 V @ 500 A)
2. Molybdenum elements 60 kW (50 V @ 1200 A)
C. Each stage single phase series A.C. circuit

IV. Operating Tube Temperatures (500 lb/hr flow at full power)

Tube	Inlet	Outlet
Nichrome	1675 °F	1975 °F
Molybdenum	2075 °F	2420 °F

V. Gas Temperatures

A. Heater Inlet 1500 °F
B. Nichrome Outlet 1800 °F
C. Molybdenum Outlet 2100 °F

VI. Flow Data

A. Reynolds Number
1. Nichrome Tubes 1.095×10^4
2. Molybdenum Tubes 1.78×10^4
B. Total Pressure Drop at maximum flow 1.856 psi

VII. Control

By thermocouple response of gas temperature at outlet of each stage.

- Fit-up of super alloy liners with other components
- Metal foil insulation.

Component Acquisition

Industry, in general, is quite reluctant to bid on small orders of rather unusual items; especially when no future market can readily be seen. Such reluctance increased the time required for the construction of the heater and caused a greater number of parts to be fabricated onsite. For example, although Nichrome is a common heating element material, it was quite difficult to obtain in the tubular form and particular size that was needed for the heater (Table I). Molybdenum tubing, a relative newcomer to industry has made large strides in quality and availability in the last 2 years. Unfortunately, at the time the model heater order was placed it was necessary to accept the tubing on "best effort" basis. The molybdenum tubing that did arrive was badly striated on the inside and 3 months late on delivery. High purity alumina, another common material, is also quite difficult to obtain in the size and shape required. The ceramic surrounding the heating element tubes was made in 2 in. thick rings and disks because industry could not supply large sections of close tolerance alumina components.

Tube Connections

Heating element tubes for each stage of the heater are connected to its neighbor and to power supply electrodes to form a series electrical circuit. Since it is desirable to minimize connector heat losses, good electrical contact between the tube and connector must be maintained. The Nichrome tubes were joined through a nickel connector (Figure 6), and rolled out against the connector by an expanding mandrel. (This is a standard procedure for heat exchanger tubes.) The ends of the tubes were then seal welded to the connectors. A sample rolled tubing-connector joint placed in a vacuum furnace at 2000 °F for 1 week provided a completely diffusion bonded joint (Figure 9). This indicated that the joint would give excellent electrical as well as mechanical contact and should diffusion bond during service.

Molybdenum was selected as the material for the second stage, higher temperature, elements of the heater. Only a refractory metal (Mo, Ta, Cb, W) can be depended on for the high temperature elements because of the approximate 3000 °F temperature expected in the ATR heater. At the time a choice of metal had to be made the only industrial experience with refractory metal furnace elements in inert atmospheres was with molybdenum in hydrogen furnaces. Thus, it was on this basis that "moly" was selected.

Since the model heater was constructed primarily as a design aid for the ATR heater, the heating tubes with their connectors had to be applicable for use in the ATR heater. The fully assembled ATR heater must be transported from the construction site to Idaho Falls. The molybdenum tubing as received for the model heater was very brittle, and attempts to roll-fit the moly tubes into connectors, as was done with the Nichrome, was unsuccessful. Expansion rolling was tried at temperatures up to 500 °F with as-received tubing, tubing that had internal striations removed and heat-treated tubing (the

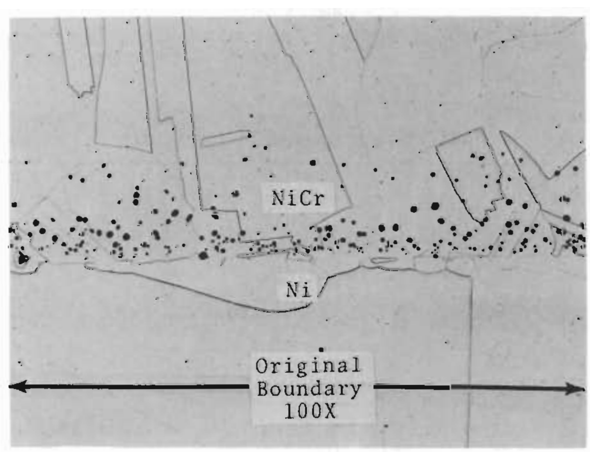

FIGURE 9. Diffusion Bond Ni-NiCr

as-received tubing was severely cold-worked). In almost all cases longitudinal cracks appeared in the tubing; therefore, rolling was dropped and considered not dependable for this order of molybdenum tubing. Shrink fitting, by dipping a sample of tubing into liquid nitrogen, did not produce a satisfactory joint because the coefficient of expansion of molybdenum is small, (2.7×10^{-6}/°F at room temperature) and very little dimensional change could be achieved.

Press fitting of the tube into a connector was tried with small tube samples. Extrapolation of the force required for the press and the consideration of the high tendency of molybdenum to gall indicated that buckling might occur with the full length tubes.

Welding of tubes to connectors was initially ruled out because previous industrial experience with welded molybdenum joints had shown extreme brittleness in the weld zones below about 400 °F.

Brazing was considered and dropped, because material of the brazing compound could diffuse down the heating tube and could cause hot spots. Braze joints are also considered brittle, so little gain would have been made.

Since the literature on molybdenum indicated that successful diffusion bonding must be done at temperatures above recrystallization, such bonding was dropped as a preoperational joining technique.

Information to be gained from construction and operation of the model heater was considered quite important for completion of the ATR heater design. To complete construction, the tubes and connectors fro the model heater were machined to form a locking taper. The tubes were gently tapped into place, and the ends of the tubes seal-welded to the connectors. The welding was done in a controlled atmosphere chamber by the tungsten-inert-gas method (TIG). Although welding was initially considered and dropped as a means of joining the moly tubes and connectors, seal-welding was considered satisfactory for the model heater while work continued on a method to form a good contact, ductile joint for the ATR heater molybdenum components.

Flexible Connectors

The restriction of external electrodes entering the side of the heater at right angles to the heating elements provided another problem area. Dimensional changes due to thermal expansion of the heating elements and the portion of external electrode penetrating the pressure shell had to be considered. Also this area of the model heater might reach 1700 °F, which meant there would be a materials problem as well as a structural problem. In an attempt to solve these problems, thin sheets of nickel were laminated between bolt-on nickel clamps, and the entire assemble was bent into a U shape. Since so many sheets were necessary to provide sufficient area for carrying the current, the structure became too rigid; therefore, nickel braid, being very flexible, was successfully substituted (Figure 7). However, purchasing this braid was difficult because industry was reluctant to supply small quantities.

Super-Alloy Liners

The inner liner (Haynes-25 0.1 in. thick) and the outer liner (Hastelloy-X 0.125 in. thick) were rolled into cylinders from sheet stock. Normal commercial procedures for forming cylinders from sheet stock did not provide close enough tolerances on ovality and diameter for the liners to fit with the close tolerance ceramic pieces. As a result, extensive boring of the cylinders was necessary to "true" them. The trueing process was very time consuming due to constant adjustments of the tool-work piece alignment (thin walled material tends to drift to the side) and the extreme hardness of super-alloys.

Metal Foil Insulation

The major problem with the fabrication of the internal insulation was mastering a fabrication technique. The insulation is composed of a metal (superalloy) inner liner, a continuous spiral wound sheet of inconel foil, and an outer liner of stainless steel. Although the inconel is only 2 mils thick, it is corrugated for extra strength and for providing a minimum contact area. After the foil was wound to form a section approximately 30 layers per inch thick, the outer liner was slid over the foil, and the assembly was partially filled with water which was then frozen by dipping in liquid nitrogen. Next, the frozen assembly was machined by normal machining techniques, and pins were driven through the inner and outer liners to act as supports while in service. The foil was thawed and baked to drive off moisture; the support pins were fused to the inner and outer liners; and the assembly was ready for installation.

Other Problem Areas

Most of the other problems that occurred were minor: 1) During final assembly, ceramic electrical insulators began cracking and a field redesign was made. 2) The main pressure shell was pipe ordered to commercial tolerance and had to be bored smooth on the inside. 3) Welding caused warping and misalignment which had to be corrected.

Despite the foregoing difficulties, this advanced design heater has been installed in the model loop and has been operated successfully for 1600 hr at outlet temperatures of 2000 °F to 2100 °F for most of its operating time. It is believed that the major technical problems facing the fabrication of the ATR heater were solved during construction of the model heater.

ACKNOWLEDGEMENT

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