WANL-TMI-397

From: Engineering Mechanics

Date: November 30, 1962

Subject: Experimental Determination of
Thermal Conductivity of Graphite
Felt at Elevated Temperatures,
in Hydrogen and Nitrogen
Atmospheres.

WESTINGHOUSE ASTRONUCLEAR LABORATORY

Distribution:

W. H. Esselman

J. Kenney, Jr.

F. D. Retallick

K. L. Rieke

A. H. El-Waziri

R. Gray

F. R. Spurrier

File (5)

Library (2)

A summer report by:

Joseph M. Makiel, Jr.

Supervisor:

M. J. Manjoine

Engineering Mechanics

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TECHNICAL REPORT

APPROACH TO PROBLEM:

There exist a number of experimental methods for determining the thermal conductivities of various materials. Most of them involve measurements of temperature gradients through material samples of fixed geometry. The sample geometries are such that known heat fluxes pass uniformly through them. The most frequently used sample geometries are spherical shells, hollow cylinders, and rectangular parallelepipeds.

One of the existing laboratory furnaces was selected for the thermal conductivity experiments. This furnace was an electric powered resistance type, cylindrical in shape. The heating element was a hollow graphite cylinder, tapered in the center for about one inch to provide an isothermal surface. The furnace had water cooled electrodes and was air tight to allow for various types of gaseous atmospheres. Figure 1 represents a schematic of this furnace.

To determine the thermal conductivity of the graphite felt, it was decided to wrap the felt around the heating element and experimentally measure the radial heat flow through it and the radial temperature gradient. It was planned to measure the radial temperature gradient using fixed thermocouples embedded in the felt.

Because of the complex heat flows in the furnace, an accurate estimate of the radial heat flow presented a problem. After much deliberation, it was decided to enclose the felt sample in a steel tube of known conductivity. It was hoped to measure the temperature drop across the tube thickness and thus determine the radial heat flow. To reduce the axial heat flow along the tube, which would effect an error in the estimate of the radial heat flux, a composite steel tube as shown in Figure 2 of the Appendix was used. Actually, the radial flux would be measured by a steel ring, (.3 inches wide), insulated from the other two sections of the steel tubing by two ring type transite spacers. The formula below, which can be readily derived,^{*} is applicable under steady radial heat flow conditions:

$$Q_s = \frac{2\pi K_s (T_i - T_o)}{\ln (r_o / r_i)} \quad (1)$$

Where Q_s = Heat flow through the steel
"heat metering" ring per unit
length.

K_s = Thermal conductivity of .1%
carbon steel.

^{*}For derivation, see Elements of Heat Transfer, by Jacob and Hawkins, Wiley, P. 30

Measuring the radial temperature gradient through the felt along with Q_s , formula 1 is then employed to calculate the thermal conductivity of the felt at various temperatures.

GENERAL INSTRUMENTATION:

(A) Thermocouples:

In setting up experiments, 6 thermocouples were arranged so as to measure:

- 1) the radial temperature gradient through the felt,
- 2) the axial temperature gradient along the steel tube enclosing the felt, and
- 3) the temperature drop across the steel ring.

(See Figure 2 of the Appendix for the location of the thermocouples on the steel ring and in the graphite felt.)

Since the thermocouples used for purposes 1 and 2 were located either on the inside or outside surfaces of the steel tube, locating them accurately presented a problem. In sliding the tube over the felt, they could not be held in place. Therefore, rather than use beaded thermocouples, these thermocouple wires (chromel and alumel), were spot welded to the steel tubing to form the "beads" of the couples. An experiment conducted on these couples, attached to the steel ring, showed that they produced millivolt outputs comparable with the regular beaded type couples.

Two platinum-platinum 10 % rhodium "bead" type couples were placed in the felt. The couples were made from .008 inch diameter wire to reduce conduction errors. Unfortunately, these small diameter wires were difficult to work with, and larger diameter wires could have been used. The wires were insulated in a thin ceramic tube and the beads were not protected.

Both types of thermocouples passed through conex fittings to prevent leakage. All millivolt readings were made on a Mite-Mite recorder manufactured by Thermo-Electrics, Inc. The millivolt readings were converted to temperatures with the use of conversion tables provided by the Thermo-Electric Company.

(B) Pyrometer:

The temperature at the center of the heating element was measured by sighting down the inside of the heater tube with a disappearing filament optical pyrometer onto a

small graphite block located inside the heater near its center. The pyrometer was manufactured by Leeds and Northrup.

(C) Power Supply:

The power supply was a Westinghouse Induction transformer. This supply could generate 5-6 kw.

EXPERIMENTAL PROCEDURE AND RESULTS:

A brief description of the three experiments performed, along with some of the results obtained follows below:

EXPERIMENT I:

This experiment was conducted to determine the operational characteristics of the furnace. The experiment provided these results:

- 1) The maximum attainable temperature in nitrogen was 4200°F, (this could be maintained for only 15 minutes, as the power supply tended to overheat).
- 2) With the high heater temperature, the temperature at a radius of 1.75 in. was approximately 2000°F. This information provided assurance that a 4 in. O. D. steel tube could be used for heat metering purposes.

EXPERIMENT II:

For this experiment, the heater was wrapped with a piece of .25 in. thick felt, 7 in. wide and 45.5 in. long. There were 6 layers of felt between the heater and the steel tube. One platinum thermocouple was placed two layers from the heater and the other thermocouple four layers away.

It was desired to test 3 different chromel-alumel couples, so they were placed close together on the steel "heat metering" ring. (See Figure 2 for their approximate locations and a brief description of the 3 different types of beads used.)

In setting up the apparatus, difficulty was encountered in getting the platinum couples through the conex fittings and sealing against leaks. Unfortunately, only one couple of the two couples used, functioned properly in this and the following experiment.

Figure 3 contains the measured radial temperature gradients for the three different trials. During trial one, thermocouple No. 1 worked satisfactorily. But, during trials

2 and 3, an A. C. Voltage of approximately .24 volts was superimposed on the thermocouple signal. This A. C. voltage did not effect the temperature indication, but it is believed that it indicated there was heating taking place in the felt sample. This is further brought out by a calculation of the heat passing through the heat metering ring for the 3 different trials. For Trial 1, about .84 kw/in. was dissipated by the heater at its center. This was 43% of the input energy. For Trials 2 and 3, with similar input power settings, about 1.85 kw/in. was measured as passing through the metering ring.

Since it is believed that Trial 1 was the only test during which no heat was generated in the felt sample, Trial 1 was used to estimate the conductivity of the felt.

The estimates are:

$$K_{1\% \text{ steel}} = 18 \text{ BTU/hr}^\circ\text{F ft. at } 1300^\circ\text{F}$$

(Assuming conductivity is $K_{1\% \text{ steel}}$)

$$K_{\text{felt}} \approx 7.3 \text{ BTU/hr ft}^\circ\text{F in N}_2 \text{ at } 2650^\circ\text{F}$$

$$K_{\text{felt}} \approx 3.5 \text{ BTU/hr ft}^\circ\text{F in N}_2 \text{ at } 1600^\circ\text{F}$$

(See the Appendix for some sample calculations.)

EXPERIMENT III

For this experiment, a new piece of felt was used and the platinum couples were moved back into the 5th and 6th layers of the felt since the couple in the 2nd layer melted during Trial 3 of Experiment II. Also, during the dismantling of the apparatus after Experiment II, both transite spacers were broken. Since there was insufficient time to have new ones machined, three short pieces of the old spacers were inserted on each side of the heat metering ring to line it up with the two other steel tubes. This procedure rendered the heat metering ring useless as the readings on couples 3 and 4 indicate. Either the ring was not being centered, or convective heat transfer was taking place, causing the ring to be heated nearly uniformly on both inside and outside surfaces.

The radial temperature gradients for this experiment appear on Figure 4. A comparison with Figure 3 indicates a good correlation between the temperature at the .42 in. and 1.9 in. radii for comparable input power in N_2 and H_2 atmospheres. Using the gradient for Trial 2 and the heat flux estimate for Trial 1 of Experiment II, the thermal conductivity of the felt is estimated to be:

$$K_{\text{felt}} \approx 8.3 \text{ BTU/ft hr}^\circ\text{F in H}_2 \text{ at } 2650^\circ\text{F}$$

The curve for Trial 3 is an extrapolation of steady state from time-segmented data. Since the heat metering ring was inoperative, no estimate of the thermal conductivity can be made.

It was noticed in this experiment that both couples 5 and 6 were recording temperatures higher than the ones on the heat metering ring. This indicates that either the heating element was not centered, or there was appreciable heat being generated somewhere near the potential end of the furnace. Nevertheless, it is felt that such readings would warrant closer attention should any further work be performed in this area.

CONCLUSIONS AND RECOMMENDATIONS:

Although the results of the two experiments are reasonable, they are far from conclusive. The experiments fell far short of the purely radial heat flow through a homogeneous cylindrical sample, with no internal heat generation, which was one of the desired goals. Also, the design of the heat metering ring was not completely satisfactory. It was located too far from the heating tube. Thus, the temperature drop across it was small.

Finally, two experiments were not enough to check the radial and axial gradients, let alone the heat flow through the heat metering tube.

Since thermal conductivities are very important design parameters, the work performed seems to indicate a need for experimentally determining these parameters. Although a plate-type set-up would be ideal, the furnace used could be adapted for this purpose. Whichever would be used, the following problems present the greatest obstacles:

- 1) Estimating the heat flow through the sample geometry.
- 2) Recording temperatures in the felt itself. (This felt is a very good electrical conductor.)
- 3) Attaining a true steady state at the elevated temperatures, and insuring conduction heat transfer.

APPENDIX

HEAT FLOW CALCULATIONS FOR EXPERIMENT II

Trial 1. Heat Flow Through Heat Metering Ring

$$T_1 = 1295^{\circ}\text{F} \text{ (See Figure 3)}$$

$$T_2 = 1275^{\circ}\text{F} \text{ (See Figure 3)}$$

$$r_1 = \frac{3.75''}{2}$$

$$r_2 = 2''$$

$$k \approx 18 \text{ BTU/hr. ft.}^{\circ}\text{F}$$

$$q = \frac{2\pi k (T_1 - T_2)}{\ln(r_2/r_1)}$$

$$q = \frac{(2\pi)(18)(20)}{\ln\left(\frac{4}{3.75}\right)} = \frac{(6.28)(18)(20) \text{ BTU}}{.0658 \text{ hr. ft.}}$$

$$q = 34,200 \frac{\text{BTU}}{\text{hr. ft.}} \times \frac{1 \text{ ft.}}{12 \text{ in.}} \times \frac{1 \text{ hr.}}{60 \text{ min.}} = 47.8 \frac{\text{BTU}}{\text{in. min.}}$$

$$\text{or, } q = .84 \frac{\text{kw}}{\text{in.}}$$

Approximately 1.95 kw was being supplied.

Thus, about 43% of the input energy was being dissipated by the center of the heater radially through the felt. (This is most likely a low estimate of the radial heat flux.)

By a similar calculation for Trial 2, where $T_1 = 1375^{\circ}\text{F}$ and

$$T_2 = 1331^{\circ}\text{F},$$

$$q = 1.85 \text{ kw/in.}$$

And, for Trial 3, where $T_1 = 1481^{\circ}\text{F}$ and $T_2 = 1437^{\circ}\text{F}$,

$$q = 1.85 \text{ kw/in.}$$

Estimate of thermal conductivity of the felt k_f for Trial 1

$$\frac{2\pi k_s (T_1 - T_2)}{\ln (r_2 / r_1)} = \frac{2\pi k_f (T_3 - T_4)}{\ln (r_4 / r_3)}$$

$$(T_1 - T_2) = 20^\circ\text{F}$$

$$(T_3 - T_4) = 500^\circ\text{F}$$

$$\ln (r_2 / r_1) = .0658$$

$$r_4 = .82''$$

$$r_3 = .42''$$

$$\ln (r_4 / r_3) = .668$$

Substituting numerical values and solving for k_f , one obtains:

$$k_f = \frac{18 (20)}{.0658} \times \frac{.668}{500}$$

$$k_f = 7.3 \frac{\text{BTU}}{\text{hr. ft. } ^\circ\text{F}}$$

at about 2650°F in Nitrogen atmosphere

Figure 1 SCHEMATIC OF APPARATUS

Figure 2.

THERMOCOUPLE LOCATIONS

EXPERIMENT No. 2.

Definition of symbols:

- ~ - Fused Bead-Type Couple
- x - Spot Welded Bead Couple
- ~ - Independently Welded Wires (Small portion of steel tube acts as the thermocouple bead.)

EXPERIMENT No. 3.

Figure 3. Results of Experiment II

Figure 4. Results of Experiment III

Figure 5. Results of Trial 3 of Experiment III