ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

Progress Report No. 5

THERMAL CONDUCTIVITIES OF LUBRICATING OILS AND HYDRAULIC FLUIDS

D. W. McCready

Project 2510

WRIGHT AIR DEVELOPMENT CENTER
WRIGHT-PATTERSON AIR FORCE BASE
CONTRACT NO. AF 33(616)-3543

April 1957

SUMMARY OF WORK DONE

This reports in some detail the work done over a period of several months, including primarily the selection, manufacture, and calibration of thermocouples. Satisfactory procedures and acceptable thermocouples have resulted.

Also reported are the results of the first measurements on the thermoconductivities of glycerin, water, and toluene. Measurements at first were twenty percent above or below accepted values. Recent measurements on glycerin at 125°F and 280°F are consistent with accepted values.

THE THERMAL-CONDUCTIVITY CELL

The components and method of assembly of the thermal-conductivity cell are shown in Figs. 1 and 2. Figure 1 shows the components, the filling and emptying tubes in the foreground, the central electric heater behind them, and in the rear, the bottom seal, seal gaskets, central core with top seal, and Sink I and Sink II (these designations are the same as on the drawings in Progress Report No. 2). The central core and Sink I are of electrolytic copper and chromium-plated. Sink II is anodized aluminum. The seals are chromium-plated brass.

The thermocouple holes (8) in the central core are arranged around the circle, the diameter of which is pictured as about 3 times that of the hole through which the heater is placed. The bottoms of these holes are 1, 2, 3, 4, 4, 5, 6, and 7 inches from the top.

The thermocouple holes in Sink I are shown at the 7-, 8-, and 4-inch level, as holes drilled through to the inner face and with channels leading from the holes to the top, through which the thermocouple wires pass. This Sink is tapered to fit a similiar taper in the central hole in Sink II.

Figure 2 shows the means of assembling; the heater centered in the central core; the core is centered and bolted by the seals to Sink I, and Sink I is centered in Sink II.

In operation, the whole is insulated and may be heated by electrical tapes wound around Sink II.

The filling and emptying tubes connect to the top and botton seals as shown with the top seal.

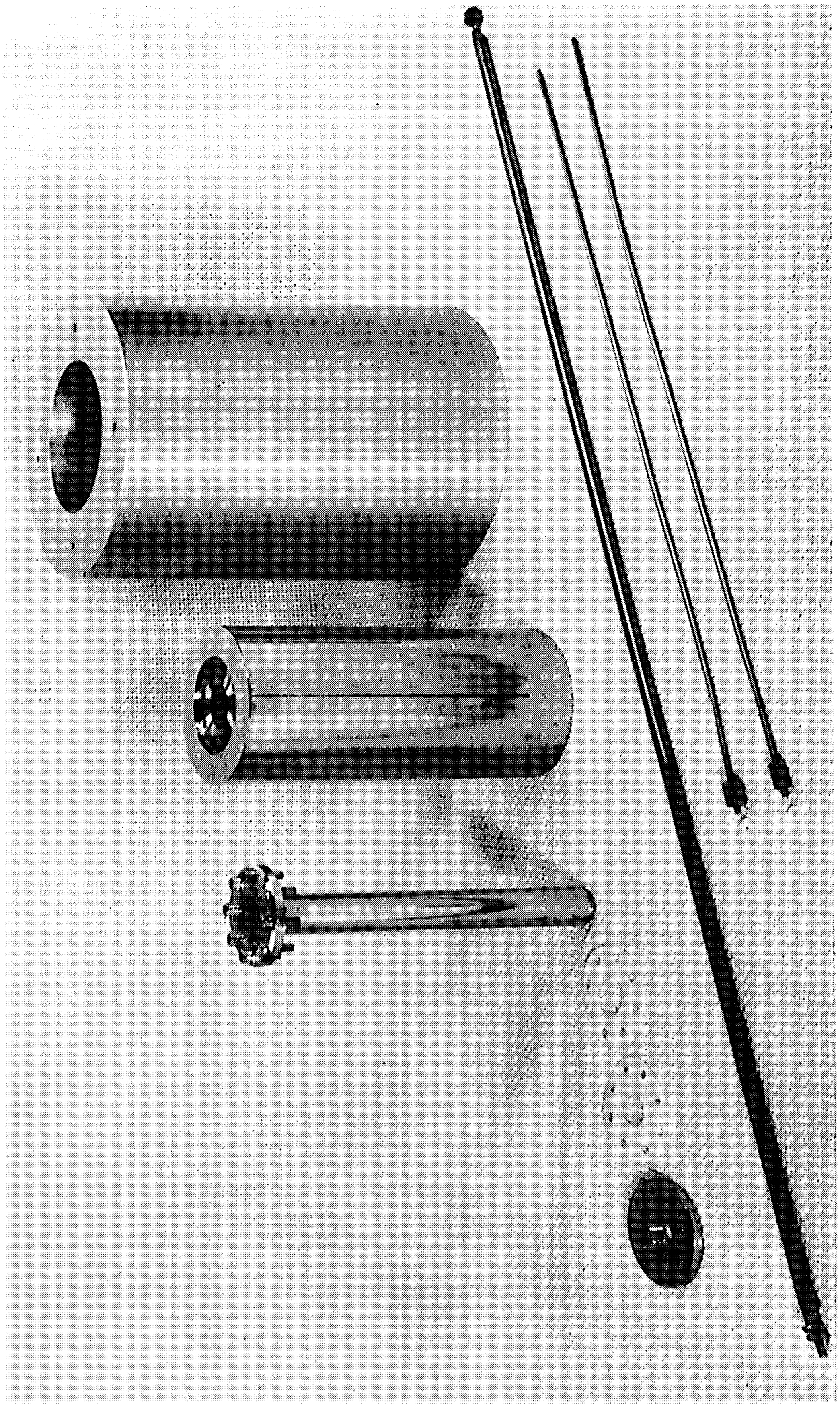

Fig. 1. Components of cell.

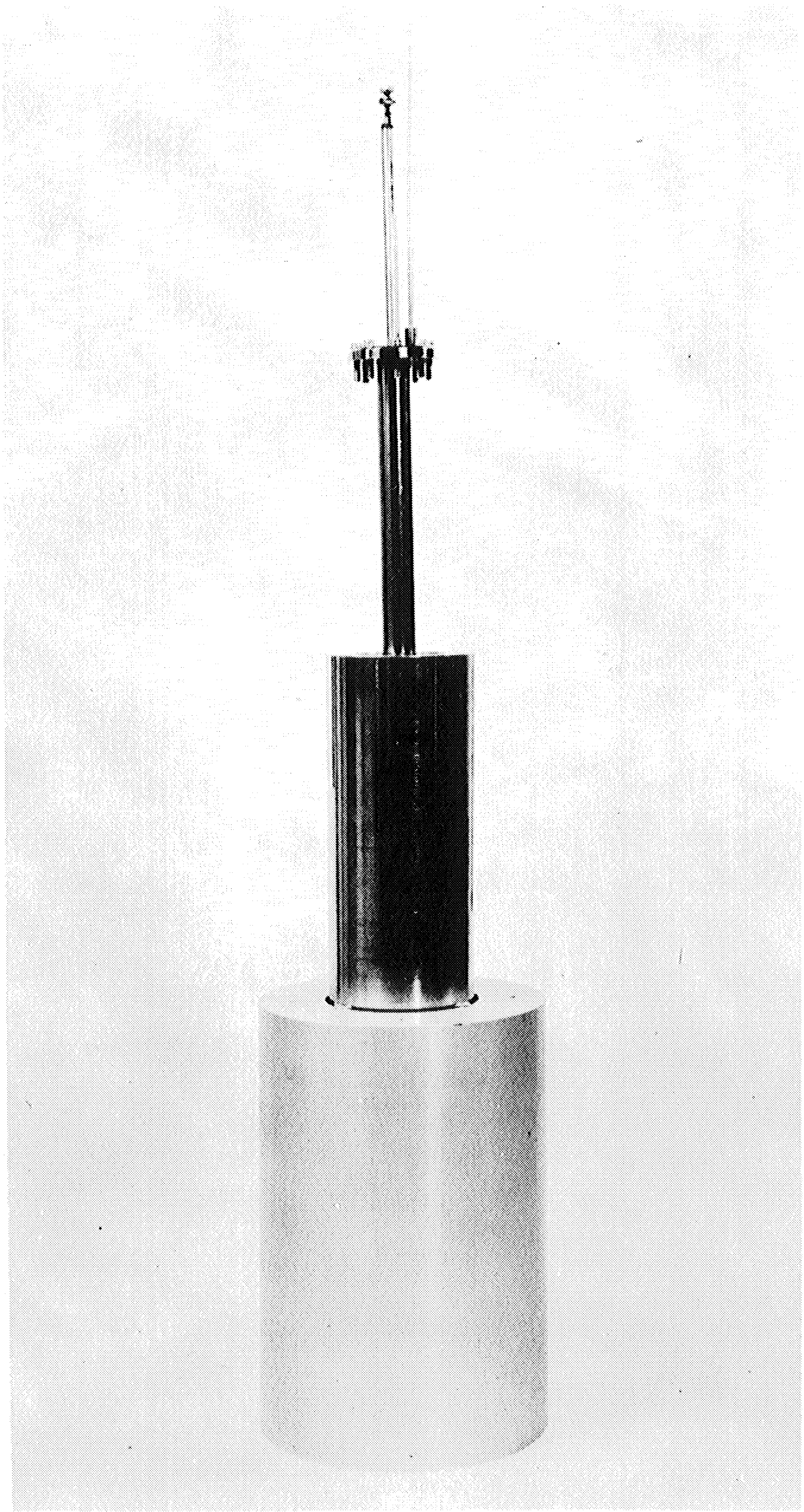

Fig. 2. Assembly of cell.

Only minor modifications have been made in the cell since its delivery.

THERMOCOUPLES

Precise determinations of thermal-conductivities is dependent on precision temperature measurements. In this research, thermocouples are being used to measure temperature and a great amount of effort has been spent in calibrating them.

COUPLES CALIBRATED

The first couples calibrated were the sheathed couples obtained from Aero Research Co. These are iron-constantan couples, insulated with M_gO, and swaged in stainless-steel sheaths (diam = 0.04 in.). They were selected as ideal for research at a temperature of 500°F and the conductivity cell was designed for their use. These proved to be too erratic for precise temperature measurements, as is shown later.

The next group of couples calibrated was laboratory manufactured from 30-gage wires, glass- and silicon-insulated. There was some difficulty in making satisfactory couples. In all about 60 were made, of which 16 were proven satisfactory and are now in use. The procedure of making them appears in the appendix.

METHODS AND RESULTS OF CALIBRATION IN CONSTANT TEMPERATURE BATH

First calibrations were made using a precision-controlled temperature bath as the hot junction and melting ice as the cold junction. Temperatures of the hot junction were measured by a calibrated mercury thermometer and a calibrated resistance thermometer. Deviations in both the hot and cold junctions were evaluated by Beckmann thermometers. The emf of the thermocouples were measured by a K-2 potentiometer obtained for this research.

The first calibrations were very erratic and much effort was spent investigating the methods used, electrical contacts, shielding, and personal factors. But the sheathed couples still gave erratic results and it was considered necessary to abandon them.

Typical results with two of the sheathed couples are shown in Fig. 3. The plot shows that over a period of four hours the Beckmann thermometer in the hot junction indicated a maximum temperature variation of 0.07°F, while the variations for couples 6 and 12 were 0.27°F and 0.45°F, respectively. Of

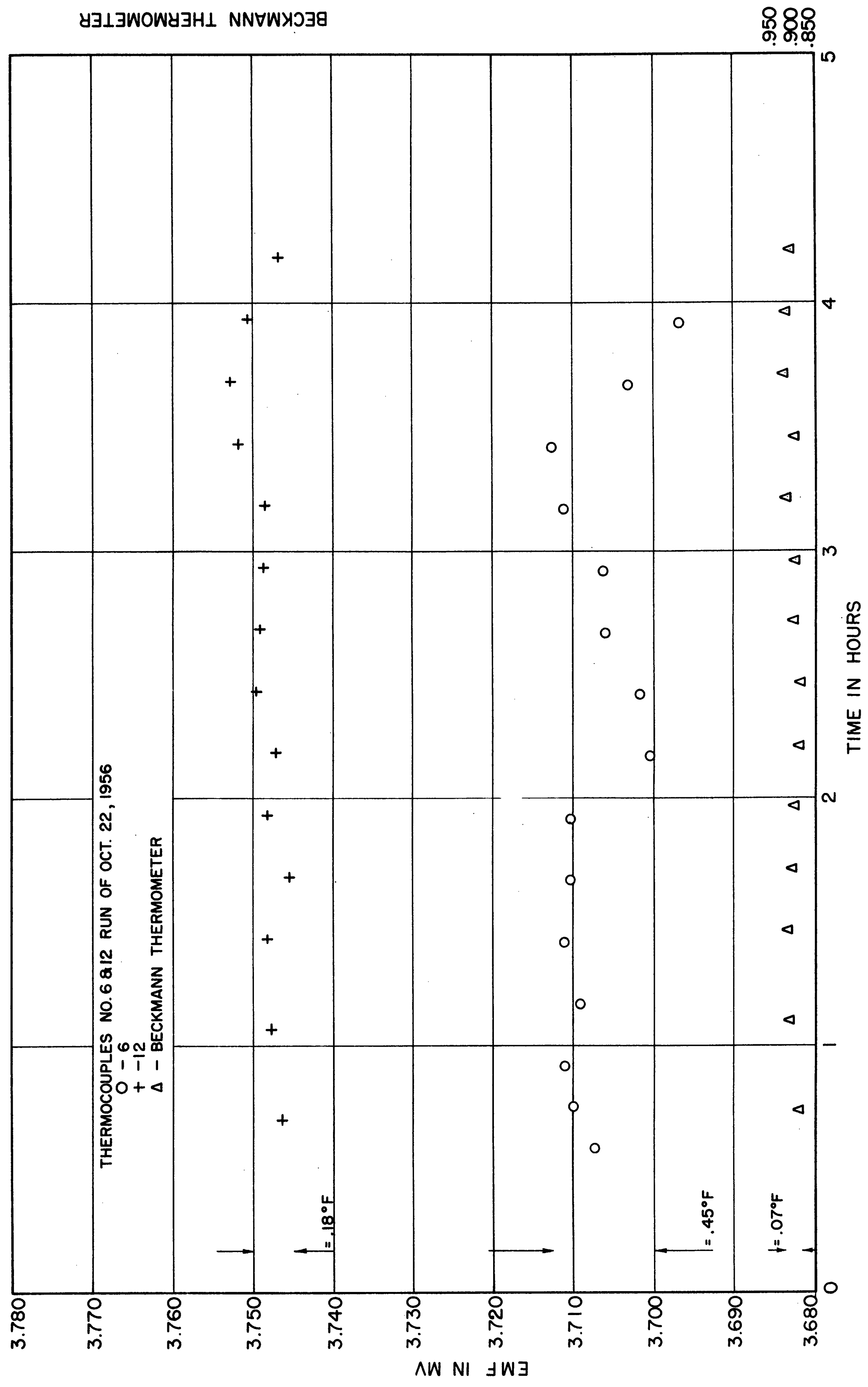

Fig. 3. Calibration of sheathed couples (constant-temperature bath).

greater concern are the actual readings of couples 6 and 12, and the plot shows a difference in them of 1.25°F.

CALIBRATION IN A RISING AND FALLING TEMPERATURE BATH

Calibrations of couples either sheathed or laboratory-made were always rather erratic in the controlled-temperature bath under static conditions. Further, the controlled bath was limited to rather low temperatures.

Thus a kinetic type of calibration was adopted, using a silicon bath controlled by an automatic temperature controller, the one obtained to operate the cell. First calibrations were made on a rising temperature but were again a bit erratic, although much better than with the constant-temperature bath. The final procedure was to calibrate with a slowly falling temperature. The sheathed couples were again tried but they proved as erratic as before.

The calibration of the final group of laboratory-made thermocouples is plotted in part in Fig. 4. Several runs were made in steps from 500°F down to 100°F. The data plotted in Fig. 4 shows good agreement between couples, although erratic at the begining of any one step. From this group of twenty couples, sixteen were selected for use in the thermal-conductivity cell.

It must be made clear that although most of the tested couples did evaluate the true temperature within the usual limits of accuracy, it is necessary in this work that the couples do so with a uniformity that does not allow temperature differences between couples greater than about 0.1°F. It is felt that this last group of uniformly made couples meets this requirement.

MEASUREMENT OF THERMAL-CONDUCTIVITIES

After the thermocouples had been selected, and the cell had been slightly modified to accept them, preliminary runs on the cell were made. The first run with glycerin gave results that were about 25% low. More precise methods of computation reduced this error to about 17% low. The method of computation follows at the end of this report.

When the first run on glycerin and a following run on water were evaluated, it was found that end temperatures of the central core were considerably higher than the middle temperatures. This indicated that heat entered the core from the projecting ends of the heater. The heat, unmeasured, would give a higher heat flow and greater temperature drops across the fluid layer and thus lower thermal-conductivities.

The heater was removed and an 8-in. section of it obtained. This is the length of the central core. A rerun on water with the 8-in. heater still gave low values for thermal conductivities, but the temperature distribution was still erratic and the cell had not settled down to a steady-state.

A run was then made on toluene. The thermoconductivities measured were about 15-20% high. Temperature distributions were such that the top and bottom temperatures were considerably lower than those of the middle positions. This indicates a heat loss through the end seals.

Glycerin was carefully placed in the cell and rerun, with attempts made to obtain a more uniform temperature distribution in the central core. This was fairly well done. The results on two different runs checked within 0 to-5% of the best reported values in the literature. Glycerin and the apparatus is being further evaluated.

The variations in temperature along the central core were considered possible when the cell was first designed. Several methods of compensating for this are available. The method used will be determined after runs have been made at the higher temperatures. Both glycerin and a lubricating oil fraction of paraffin base crude will be used to adjust these variations in temperature.

As this is being written, good values are being obtained on glycerin at 280°F. It is also apparent that a better temperature distribution is obtained at the higher temperature and with higher heat fluxes. The temperature drop across the glycerin layer is 10°F, about 10 times the usual value used in this type of research.

FUTURE WORK

Work in the immediate future will be concerned with proving the cell. The latest excellent results with glycerin indicate that there may be little to do.

When the cell is proved, determinations on the oils will start. At first these will cover the range of 300°F down to 100°F.

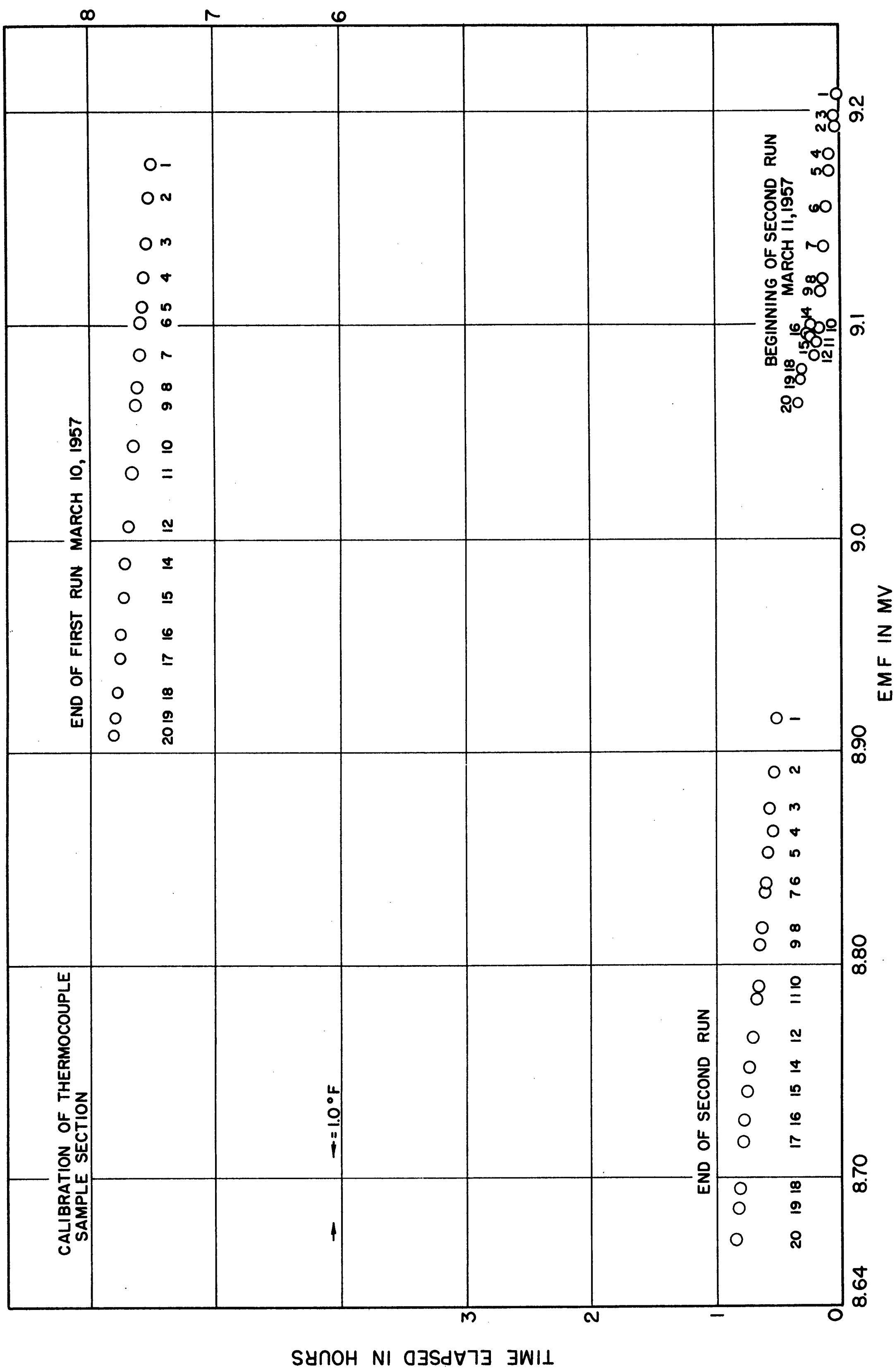

Fig. 4. Calibration of laboratory-made thermocouples.

APPENDIX A

CALCULATION OF K FROM DATA

Nomenclature

q	=	heat/time	r_o	=	outside radius of central core
k	=	heat/time length temp	r_1	=	inside radius of Sink I
A	=	length^2 normal to flow	V	=	voltage
T	=	temperature	I	=	current
X	=	distance along direction of flow	EMF	=	EMF of thermocouples

a) $$q = kA \frac{dT}{dX}$$

Since the annular spacing is only .036 in., ΔX may be used in place of dX.

Solving for k, then,

b) $$k = q \frac{1}{A} \frac{\Delta X}{\Delta T}$$

$$\Delta X = (r_1 - r_o/12) \text{ ft}$$

$$A = [\pi(r_1+r_o)/144] \text{ ft}^2/\text{in.}$$

$$\Delta T = [\text{EMF(MV)}/.0294 \text{ MV}/°\text{F}]$$

$$q = (VI) \text{ watts } 3.42 \frac{\text{BTU/hr}}{\text{watt}} \times \left(\frac{1}{16.6}\right) \text{in.}^{-1} = VI\left(\frac{3.42}{16.6}\right) \frac{\text{BTU/hr}}{\text{in.}}$$

$$\therefore k = (VI)\left(\frac{3.42}{16.6}\right) \frac{144}{\pi} \frac{1}{(r_1+r_o)} \frac{(r_1-r_o)}{12} \frac{.0294}{\Delta\text{EMF}}$$

c) $$= \frac{VI}{\Delta\text{EMF}} \left\{\frac{\overset{1.20658}{3.42 \cdot 12 \cdot .0294}}{\underset{52.1506}{16.6\,\pi}}\right\} \left\{\frac{r_1-r_o}{r_1+r_o}\right\} = 2.3136 \times 10^{-2} \frac{VI}{\Delta\text{EMF}} \left[\frac{r_1-r_o}{r_1+r_o}\right]$$

Since there is some variation in the values of r_1 and r_o,

$\frac{r_1-r_o}{r_1+r_o}$ must be determined separately for each thermocouple position.

The values used for VI are the average values of the beginning and end of a line.

Sample Calculation

Data from water run of 3-17-57

$$\left.\begin{array}{l} EI \text{ line } 15 = 45.890 \\ EI \text{ line } 16 = 45.795 \end{array}\right\} EI_{avg.} = 45.842 \text{ watts}$$

Position: 4 $\quad D_o = .8855 \quad D_1 = .9217$ in.

$$\left\{\frac{r_1 - r_o}{r_1 + r_o}\right\} = \left[\frac{.9217 - .8855}{.9217 + .8855}\right] = \frac{.0362}{1.8072} = .020031$$

ΔEMF couples 7 and 8 = 0.0735

$$k = 2.3136 \frac{(45.842)}{.0735} (.020031) \times 10^{-2} = .2891 \text{ BTU/hr } \frac{ft^2}{ft} \text{ °F}$$

APPENDIX B

MANUFACTURING OF COUPLES

Two general types of couples are needed. Those couples for the inside core must have the outer insulation removed for a distance of about seven inches to allow for insertion into the deepest well. The couples for Sink I need only to have the insulation removed for a distance of two inches.

1) Remove outer insulation to required distance being careful not to unravel the inner glass insulation. This may be facilitated by twisting the two wire strands together at the tip.

2) Two coats of thermocouple insulating resin* are then applied. The resin should be diluted so as not to increase the thermocouple diameter appreciably.

3) The wire tips are then barred and twisted together for about 1/8 in.

4) The junction is then made by dipping the twisted end in flux and passing through an electric arc.

5) The thermocouple is completed by removing the excess flux and applying an additional coat of thermocouple insulating resin.

*Silicon resin supplied by Dow Corning.