GLR-183

LABORATORY TESTS FOR A MODEL THIN ROD HEAT FLUX TRANSDUCER

For

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I. INTRODUCTION

A model of a thin rod heat flux transducer was constructed for the purpose of performing some laboratory performance verification tests (prior to shallow hole testing). The model was installed in a sand volume that had a controlled vertical linear temperature gradient at its boundary. At steady state, transducer thermopile outputs and peripheral vertical sand temperature gradients were measured. From the rod heat flux transducer theory previously developed* and these measurements, the thermal conductivity and vertical heat flux were extracted. The thermal conductivity results were compared with known measured values for the sand.

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*"A Thin Rod Heat Flux Transducer Positioned in the Earth Having a Uniform Temperature Gradient: A Closed Form Solution;" H. F. Poppendiek, D. J. Connelly; GLR-178.

II. METHOD

A small-scale reproduction of a field measurement system was constructed in the laboratory (see Figure 1). A small-diameter, thick-walled stainless steel tube was instrumented with a thermopile; this model has all of the elements of a full-scale rod heat flux transducer. In addition, a large, cylindrical container was fitted with a heater which produced a controlled vertical temperature gradient. The container was filled with sand with the model transducer placed vertically at the center of the sand mass. The heater was then turned on and after several days, a quasi-steady-state was achieved. Temperature and thermopile readings were then taken at intervals for several days.

The equations used for interpreting the data obtained in these model experiments are described in GLR-178. In this case, the temperature gradient in the sand at a relatively great distance from the rod was known; thus, only the thermal conductivity of the sand was evaluated for the data set.*

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*When using the rod transducer in a borehole, the vertical temperature gradient (in the earth at a radial distance where the temperature field is not disturbed by the transducer) is obtained by using a low thermal conductivity rod.

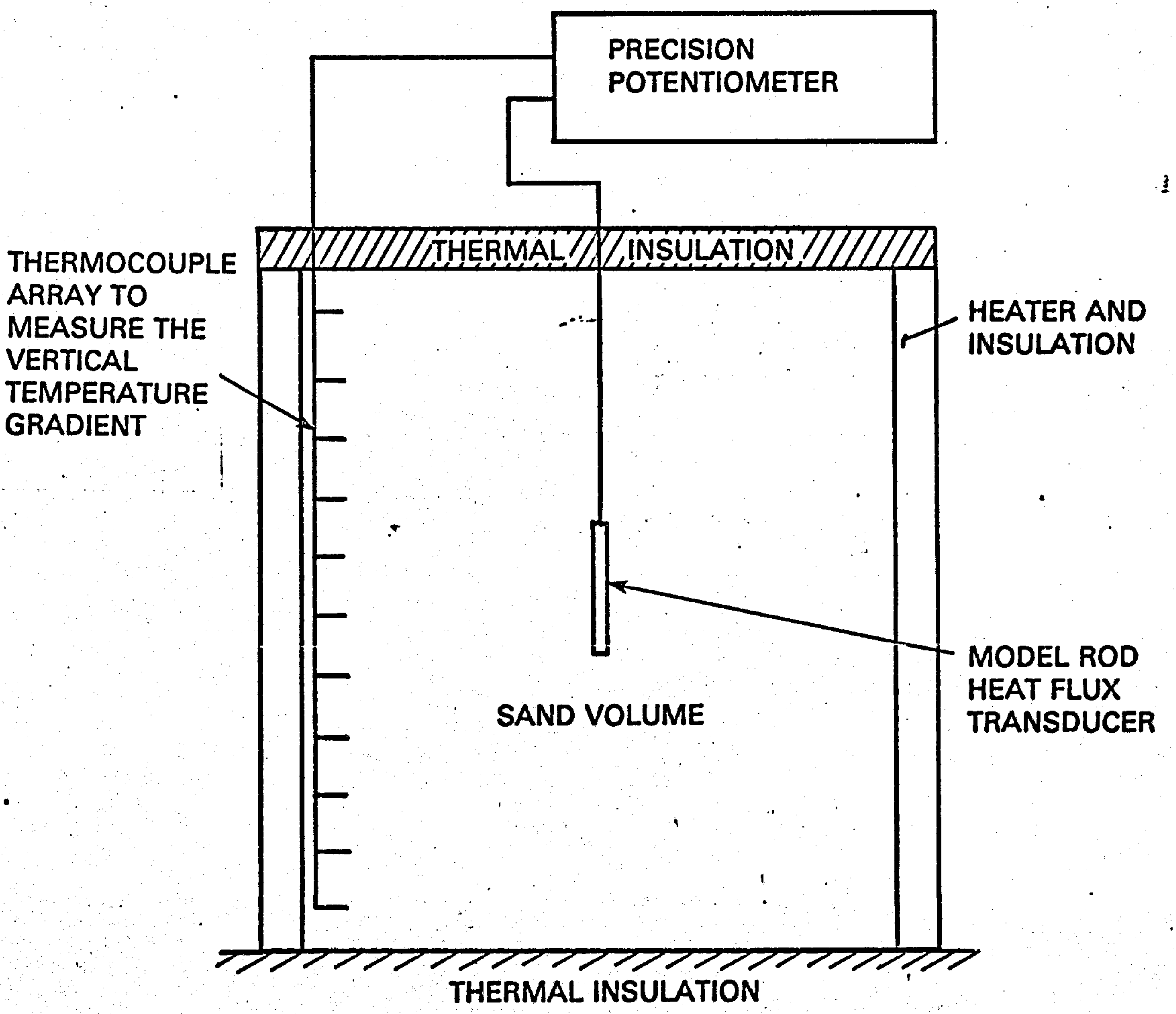

Figure 1. A block diagram of the laboratory testing system.

III. LABORATORY TEST SYSTEM

A. Transducer

The model heat flux transducer was nine inches in length and 3/16 inches in diameter, composed of type 321 stainless steel tubing with a 0.090-inch central hole. This tubing was fitted with a thermopile consisting of three iron-constantan thermocouple junction pairs which extended the full length of the tube. A small, conical wooden plug was inserted into each end of the tube to hold the thermopile junctions against the tube wall. A schematic diagram of the transducer is shown in Figure 2.

B. Sand Test Volume

The sand container used was fifteen inches in diameter and 36 inches long, composed of steel. The heater was wrapped on the outside of this cylinder (previously electrically insulated) in a spiral with a constantly increasing turn per inch density. This heater was then divided into four sections, each powered by a separate Variac to provide control of the vertical temperature gradient. A separate flat, circular heater was also placed on top of the assembly. Thick aluminum plates were used on the top and bottom of the sand to help provide a uniform temperature at these planes. The sand used was clean, washed, and homogeneous. The assembly was insulated with one-inch thick foam plastic. A schematic diagram of the test sand volume can be seen in Figure 3.

Figure 4 shows the spiral heater installation and Figure 5 shows the sand cylinder with the heater insulation in place.

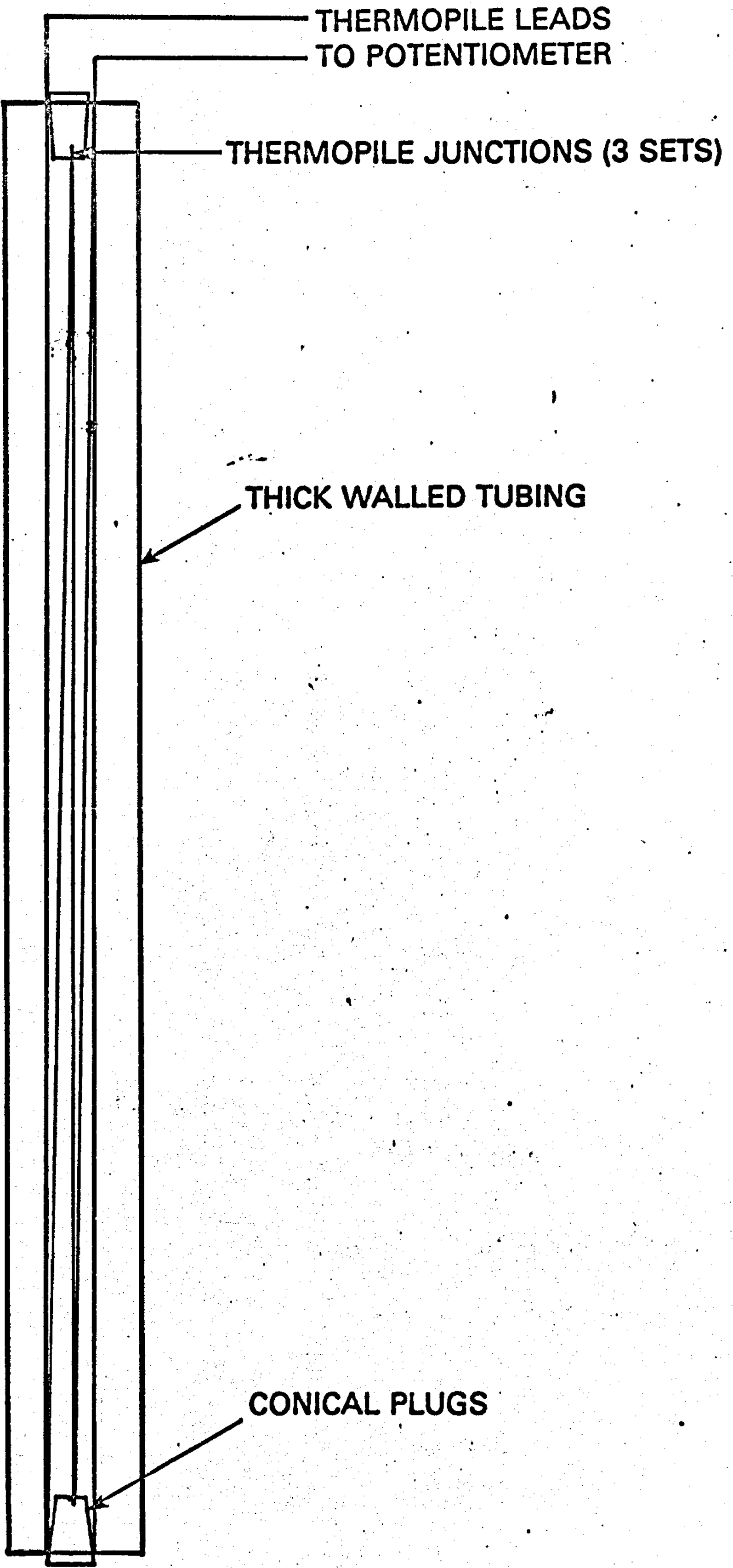

Figure 2. A schematic diagram of the rod heat flux transducer.

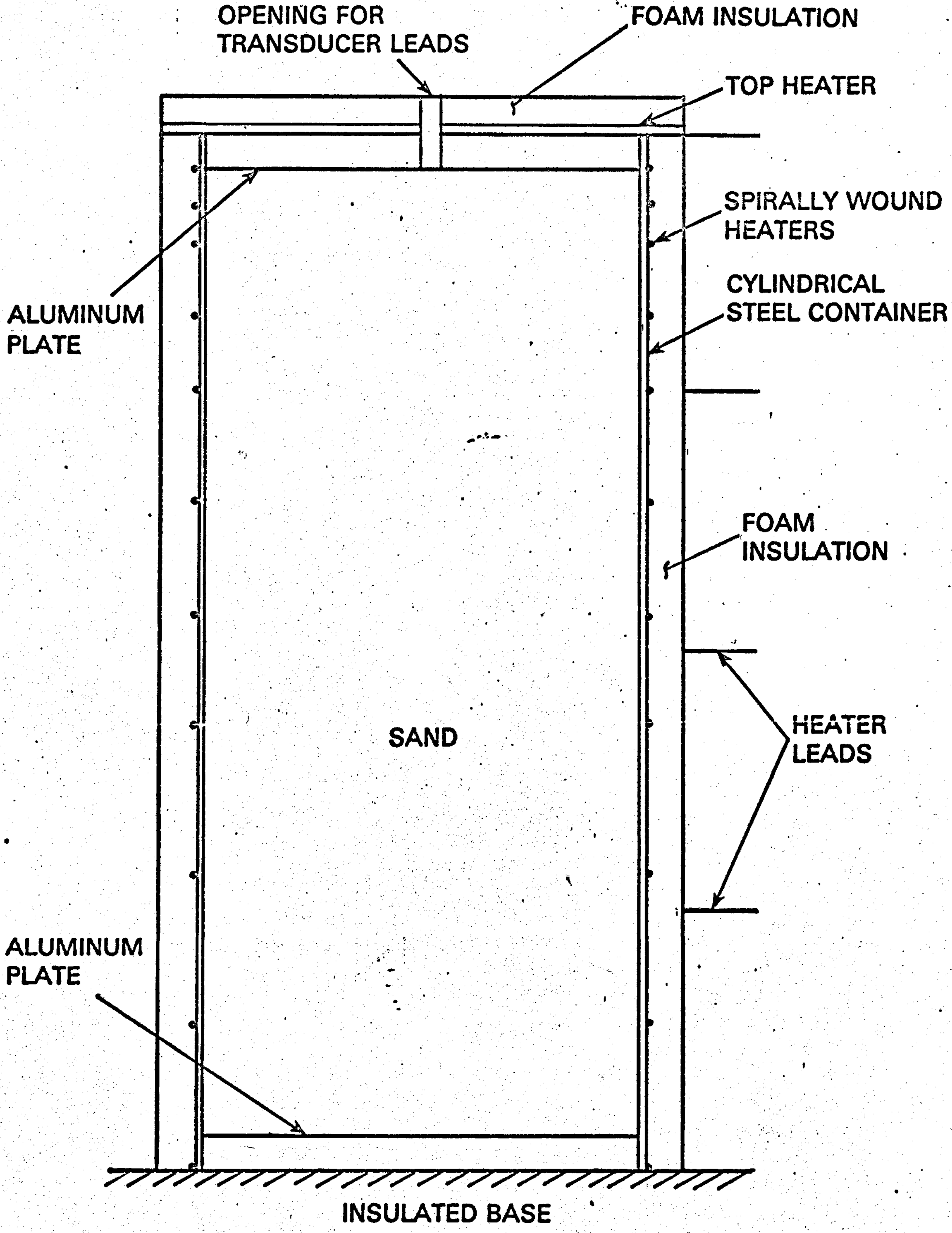

Figure 3. A schematic diagram of the test sand volume.

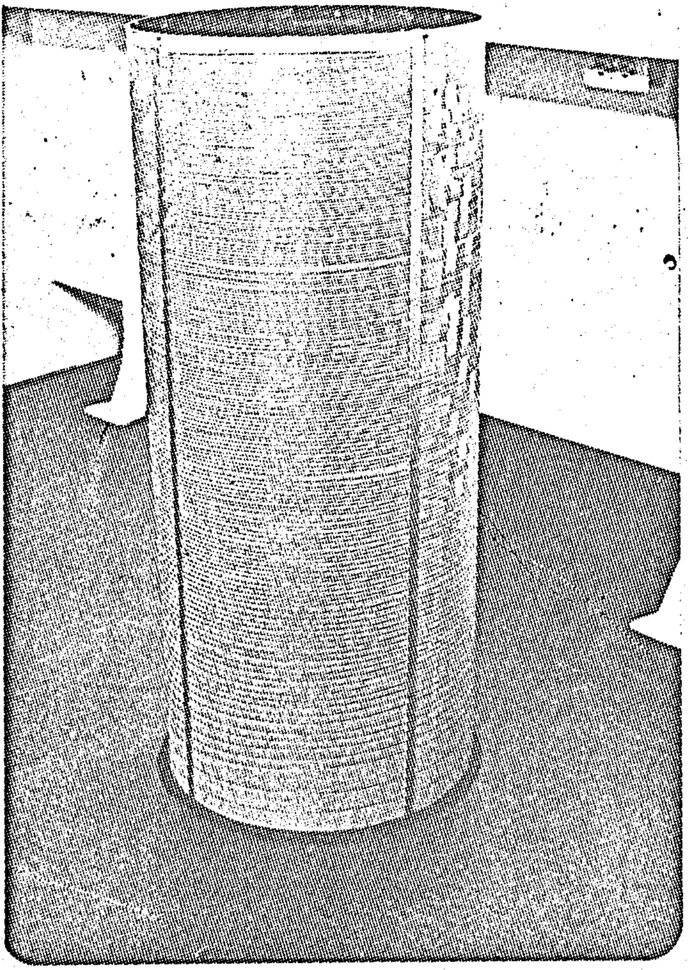

Figure 4. Spiral heater installation.

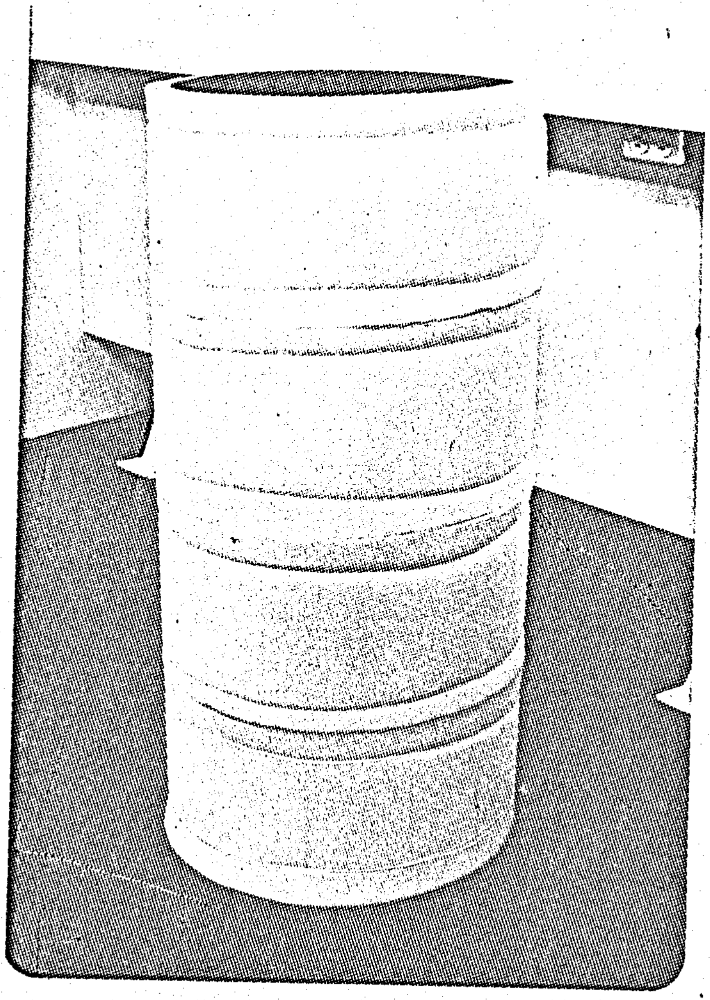

Figure 5. Sand cylinder with heater insulation in place.

C. Potentiometric Measurements

The temperature gradient was measured with ten chromel-Alumel thermocouples arranged vertically about three inches apart in the sand near the container wall. The thermocouple and thermopile voltages were read with a precision laboratory potentiometer.

IV. RESULTS

A typical temperature profile in the sand is shown in Figure 6. The temperature profiles in the transducer and sand are presented in Figure 7.

Table I shows the sand temperature gradient, $\frac{dt}{dz}$, the measured temperature difference between the midpoint and the end of the model heat flux transducer, t, and the resulting predicted thermal conductivity, K, for a number of runs where the vertical temperature gradient was nearly linear as measured by the thermocouples near the container wall.

$\frac{dt}{dz}$		t		K	
(°F/ft)	(°C/cm)	(°F)	(°C)	$\left(\frac{\text{Btu}}{\text{hr ft}^2\ {}^\circ\text{F/ft}}\right)$	$\left(\frac{\text{cal}}{\text{sec cm}^2\ {}^\circ\text{C/cm}}\right)$
6.0	0.109	1.745	0.969	0.091	3.76×10^{-4}
7.1	0.129	2.140	1.189	0.130	5.38×10^{-4}
9.7	0.177	2.815	1.564	0.089	3.68×10^{-4}
9.9	0.180	2.875	1.597	0.090	3.72×10^{-4}
9.9	0.180	2.930	1.628	0.110	4.55×10^{-4}
9.7	0.177	3.010	1.722	0.162	6.70×10^{-4}
9.9	0.180	3.040	1.889	0.150	6.20×10^{-4}

The average thermal conductivity for these points is 0.12 Btu/hr ft^2 °F/ft.

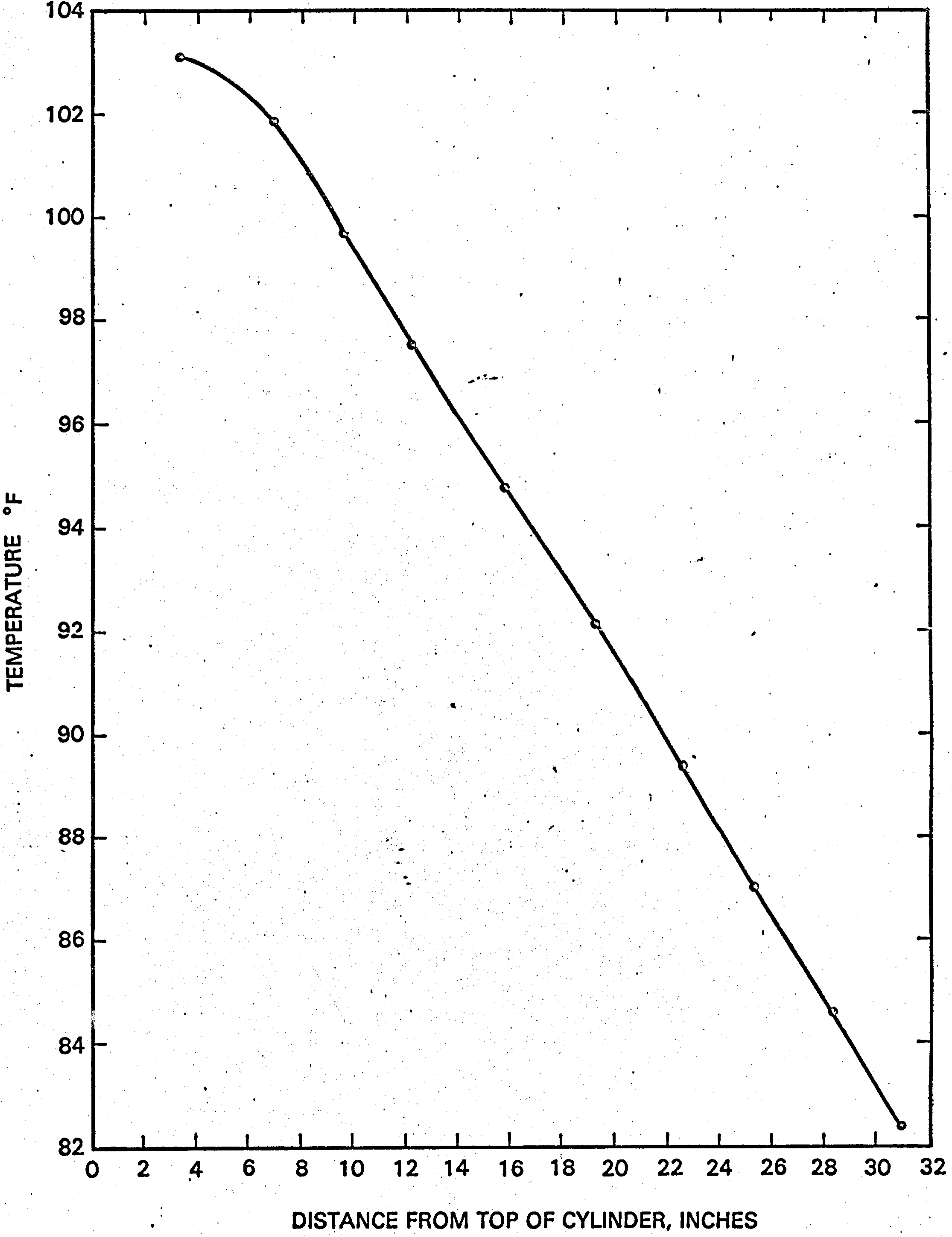

Figure 6. A typical temperature profile in the sand volume.

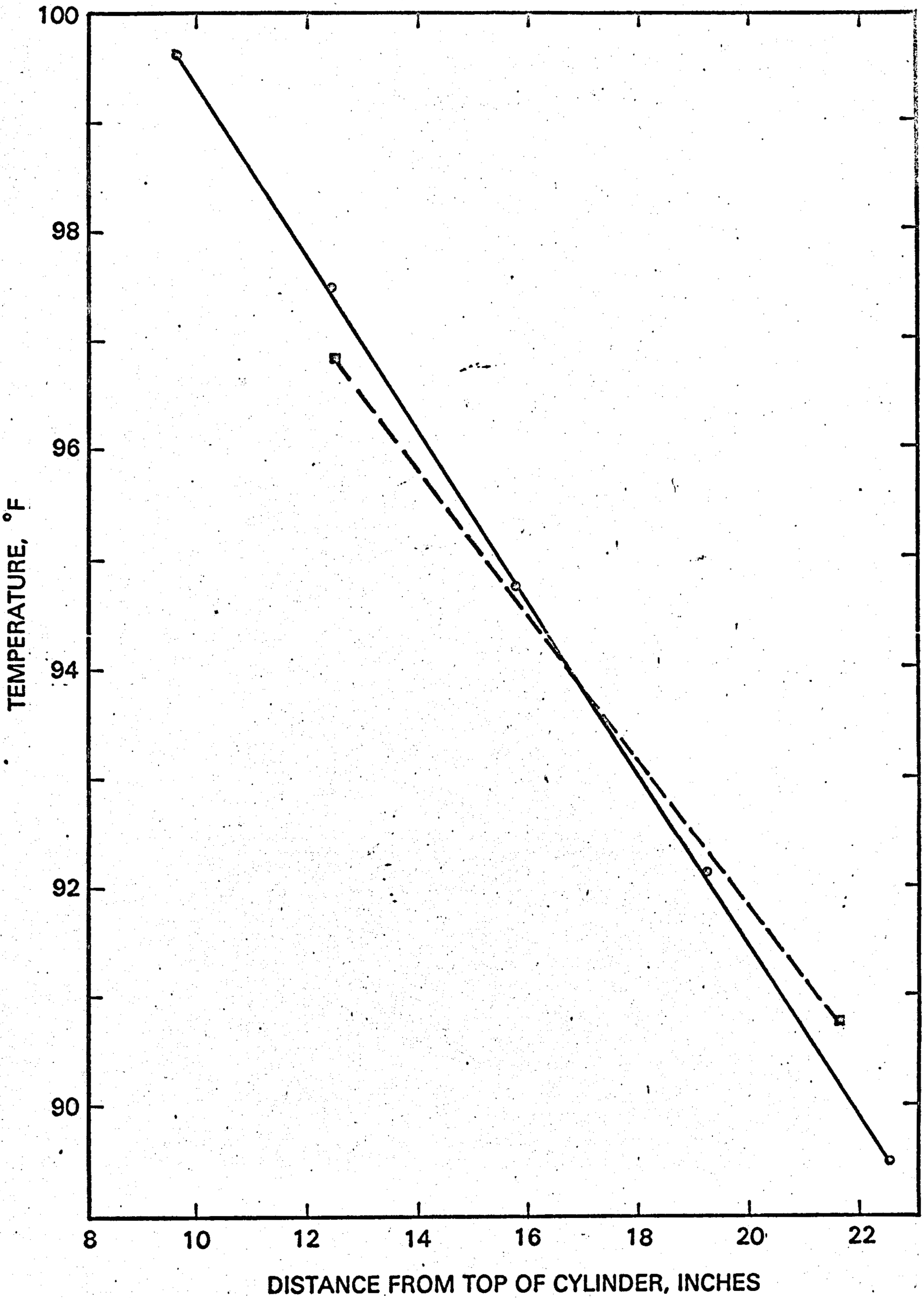

Figure 7. Typical temperature profiles in the transducer and the sand.

V. DISCUSSION

The thermal conductivity results shown in Table I show some degree of scatter. This is primarily attributed to the diurnal variations in room temperature in Geoscience's laboratory. These variations were transmitted through the sand volume foam insulation to influence the peripheral vertical temperature gradient. This effect would not be expected to exist in the earth when making downhole measurements.

The thermal conductivity of the sand used in this experiment was independently measured by a modified ASTM C-177 method. A nine-inch square aluminum clad heater was used together with a wooden frame which created two one-half inch thick sample cells on each side of the heater. The one-half-inch gaps were filled with sand. The edges of the apparatus were also insulated with plastic foam. Because of the large aspect ratio and the edge insulation, the end losses were small (less than two percent error). The thermal conductivity measured by this method was 0.14 Btu/hr ft^2 °F/ft.

The average thermal conductivity value for the results in Table I as determined by the model rod heat flux transducer was 0.12 Btu/hr ft^2 °F which is about 14 percent different from the value measured by the ASTM C-177 method. This agreement is considered acceptable because of (1) the probable variations in the sand thermal conductivity and (2) limitations in the theory.