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Measurement of Apparent Thermal Conductivity by the Thermal Probe Method

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ABSTRACT: Three thermal probes were constructed in accordance with ASTM D 5334 and calibrated using heat-flow metre data. The temperature-time response of the thermal probes for determining apparent thermal conductivity λ under transient state conditions was logged at 1 s intervals. The instrumentation used reduced the determinate error associated with voltage and current measurements to a negligibly small value that made the uncertainty in λ dependent on the uncertainty of the slope $dT/d\ln t$. A test method was run in 1000 s, in which a criterion of 2.5% spread among three consecutive slope values was used to determine the extent of the linear segment of the *T*-ln *t* curve.

The probes demonstrated repeatability within ±3.5% but had definite individual bias indicating a need for individual calibration. Using individual probe calibration factors, the experimentally determined λs for all-purpose sand, sifted sand, and soil were determined to be 0.520, 0.445, and 2.11 W/m·K, respectively.

KEYWORDS: thermal probe, thermal conductivity, line source method

Nomenclature

- n Number of data points in chosen time interval
- Q Power emitted by probe per unit length, W/m
- R Electrical resistance, Ω
- r Radial distance from probe, mm
- T Temperature, °C
- T_o Initial temperature, °C
- t Time, s
- V Voltage, V
- κ Thermal diffusivity, m²/s
- λ Apparent thermal conductivity, W/m·K

The use of small-diameter heated probes to approximate a line-source in a semi-infinite medium has been in the literature for many years [*1–4*]. The probe normally consists of an electrical heater and a temperature sensor, typically a thermocouple. The probe is inserted into an isothermal material and powered. The time-temperature data from the probe are analyzed to obtain the mean apparent thermal conductivity λ for the material over the temperature range introduced in the experiment. Apparent thermal conductivities are obtained from the data using Eq 1, which is an approximation of the solution for the boundary value problem describing the physical situation [*4*].

$$\lambda = \frac{(Q/4\pi)}{(dT/d\ln t)} \tag{1}$$

Equation 1 indicates an attractive method for thermal conductivity measurement with the advantages of low cost and short test time. Hence, this method would be ideal for conducting many tests per day and testing material with moisture. However, in the past the reliability of the results was poor [*1–4*] and hence the method was seldom used.

This study concentrated on improving the reliability of the test method by reducing the associated equipment error and monitoring the time-temperature response of the thermal probe at 1 s intervals. This paper focuses on probe calibration, data acquisition, and apparent thermal conductivity data obtained for four materials.

Thermal Probe

The thermal probes in this work were constructed from seamless thin-walled stainless steel tubes, 100 mm long and 3 mm outer diameter. The main probe components are a manganin heater wire and a thermocouple as shown in Fig. 1. The probe assembly is similar to that described in ASTM D 5334 [*5*].

Insulated manganin heater wire, 0.358 mm in diameter, was looped and inserted into the full length of the tube to form the heating element; a 30 gage T-type thermocouple (wires supplied by Cole-Parmer) was inserted midway along the length of the tube. Both ends of the heating element and the thermocouple wires protruded from the same end of the tube and were passed through a nylon cap. Following the procedure described in ASTM D 5334 [*5*], the tube was filled with a clear plastic epoxy resin and a metal tip was placed on the open end of the tube. The epoxy was allowed 24 h setting time, and the extended heater wire ends were cut close to the thermal probe and power supply leads were soldered to them.

Electrical Circuit

The thermal probe was powered by a regulated d-c power supply. The electrical circuit used is shown schematically in Fig. 2. The system employed a Hewlett Packard 6114A precision power supply capable of varying the voltage in steps of 0.001 V from 0 to 30 V and holding steady at the set value. The voltage across the thermal probe was monitored continuously with a 7081 Schlumberger precision voltmeter [*6*]. The voltmeter was calibrated by the manufacturer and checked with the Hewlett Packard precision

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