

A New Constant Power Line Heat-Source Temperature Sensor for Determining the Thermal Conductivity of Porous Mediums

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Abstract

A new constant power line heat-source temperature sensor was developed at Harbin Institute of Technology (HIT), China. This sensor was based on the line heat-source method, and it can be applied to determine the thermal conductivities of porous mediums at different depths. The application setup was also introduced in this study.

Keywords: Thermal conductivity; Porous mediums; Constant power line heat-source temperature sensor

Introduction

Porous mediums are quite common in our daily life in engineering applications, geology researches, architecture structures, food science astronautics, and so on. A number of methods are available for determining the thermal conductivities of porous mediums, and these can be classified to steady-state and transient unsteady-state techniques. Compared with the transient methods, the steady-state method may require a much longer measurement time (12 h or more, depending on the sample size), especially for poor thermally conductive samples. On the other hand, moisture migration and property change may occur due to long exposure to high temperatures during the measurement, significantly affecting the measure accuracies. Thus, this method may not be suitable for determining the thermal conductivities of porous mediums whereas the transient techniques are considered more suitable since the test is very fast and it yields more accurate results. The objective of this study was therefore to introduce a new constant power line heat-source temperature sensor which can be used to determine the thermal conductivities of porous mediums at different depths.

The Line Heat-Source Method

Line heat-source method has been extensively employed by researchers to measure the thermal conductivities of fluids, gases [1], molten silicates [2], and porous mediums [3,4]. In this study, the line heat-source method was introduced to measure the thermal conductivity of porous mediums at different depths.

Line heat-source method, as a transient method, records the temperature rise ΔT of the temperature sensor which is a function of time t and heating power per unit length $q = P_w/l$. For line heat-source with length much greater than its radius ($l > 30r$ where r is the radius of the line heat-source), the temperature is given by [4],

$$\Delta T = \frac{q}{4\pi\lambda} \left[\ln\left(\frac{4v}{r^2 C}\right) + \ln(t) \right] + \delta T \quad (1)$$

where v is the thermal diffusivity of the sample, r is the radius of the sensor, $C = \ln \gamma$ and $\gamma = 0.5772$ is Euler's constant. δT is an error in the determination of ΔT that arises from the finite radius and heat capacity of the sensor and is given by [4],

$$\delta T = -\frac{q}{4\pi\lambda} \left[\frac{r^2(\rho_s C_{p,s} - \rho C_p)}{2\lambda t} \cdot \ln\left(\frac{4v}{r^2 C}\right) + \ln(t) \right] + \delta T \quad (2)$$

where C_p is constant pressure heat capacity, ρ is the density and

subscript s denotes the property of the sensor. Then, the thermal conductivity can be determined by,

$$\lambda = \frac{q}{4\pi} \frac{d(\ln t)}{d\Delta T} \quad (3)$$

Equation (3) can be simplified to,

$$\Delta T = k \ln(t) \quad (4)$$

where k expresses the linear relationship between \ln (time) $\ln(t)$ and temperature difference ΔT ,

$$k = \frac{q}{4\pi\lambda} \quad (5)$$

Constant Power Line Heat-Source Temperature Sensor

Figure 1 shows the schematic diagram of the constant power line heat-source temperature sensor (CPLHSTS) developed at Harbin Institute of Technology (HIT), Harbin, China. The constant power line heat-source temperature sensor consists of an inner power cord with a total length of 160 cm, eight temperature sensors with an interval of 20 cm, and an outer copper pipe with a total length of 160 cm.

Application

Figure 2 shows the application setup of the constant power line heat-source temperature sensor for determining the thermal conductivities of porous mediums at different depths. This experimental setup is composed of four parts: (1) a container with soil and thermal insulation layer, (2) a constant power line heat-source temperature sensor, (3) a data collector, and (4) a computer. Based on this application setup, the thermal conductivities of porous mediums at different depths can be determined.

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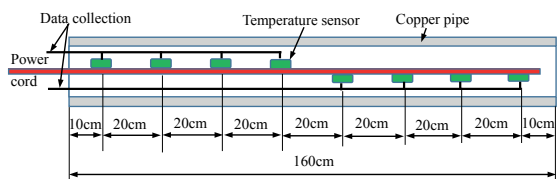


Figure 1: Schematic diagram of constant power line heat-source temperature sensor.

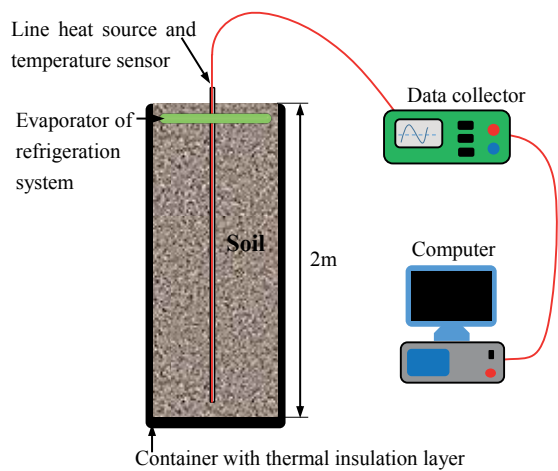


Figure 2: Schematic diagram of experimental setup.

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