Reducing Contact Resistance Errors in KD2 Thermal Properties Measurements

The KD2 Pro measures thermal conductivity, resistivity and diffusivity of samples using a single heated needle. The needle contains a heater and a temperature sensor. The temperature of the needle is monitored as heat is applied. The thermal properties of the sample are found using a model for the thermal behavior of a line heat source. This method is described in detail (for resistivity/conductivity) in ASTM D5334-08.

The model assumes good thermal contact between the probe and the sample under test. Liquid samples have excellent thermal contact with the probe. Thermal property measurements on these samples, as well as on granular materials with high water content, are accurate. In dry granular materials, especially materials with large grain size, the minute contact points between the probe and the sample under test give rise to a contact resistance which impedes the flow of heat away from the probe. Contact resistance is not included in the line heat source model, and can therefore contribute to errors in measuring thermal properties of these materials. The purpose here is to assess the magnitude of errors in thermal resistivity resulting from contact resistance in dry granular materials and to test the use of thermal grease, as recommended in ASTM D-5334-08, for reducing these errors.

Characteristics of the materials for test are given in Table 1.The actual thermal resistivity of these materials was determined by measuring the heat flow and temperature difference in a radial, steady-state heat flow cell. The apparatus consisted of a 25 cm-long heater (1 cm in diameter), and a 3 cm i.d. copper tube. The heater was made by wrapping 14.6 m of #30 insulated copper wire on a graphite tube. A #40 chromel-constantan thermocouple was attached to the center of the heater and another to the outside of the copper tube at the same height. The space between the heater and the copper tube was packed with the test material. The bulk density of the test material was determined by dividing the total mass of the material by volume between the heater and the tube. After steady state obtains, the heat input and temperature difference are measured. Thermal conductivity is computed from:

$$\rho = \frac{2\pi l \Delta T}{Q \ln\left(\frac{r_2}{r_1}\right)}$$

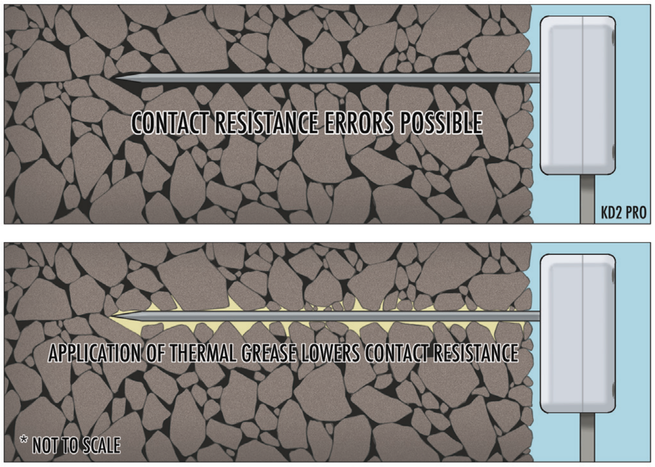
where Q (watts) is the heat input to the heater, *l* is the length of the heater (in meters), r_1 is the heater radius, r_2 is the inside tube radius, and ΔT is the temperature difference between the heater and the tube. Tests were run for at least three hours, and the results monitored to be sure that the system was at steady state. Results of these measurements are given in Table 1.

Table 1 Thermal conductivity (W/mK) of several dry, granular test materials measured with a steady state method with the KD2 with and without coating the probe with thermally conductive grease. KD2 values shown are means of 3-4 measurements.

Material	Bulk Density (g/cc)	Steady-state Thermal Cond.	KD2 without grease	KD2 with Thermalloy grease	KD2 with Artic Silver grease
Quartz sand	1.398	0.226	0.150	0.179	0.185
50 um glass beads	1.493	0.180	0.137	0.178	0.186
2 mm glass beads	1.583	0.200	0.100	0.175	0.187
4 mm glass beads	1.489	0.175	0.073	0.177	0.171
6 mm glass beads	1.430	0.175	0.060	0.160	N/A

ASTM D-5334-08 suggests use of thermal grease with a thermal conductivity greater than 4 W/mK to minimize contact resistance errors. We tried two types of grease; Thermal Cote, a white thermal grease with a conductivity of 0.4 W/mK from Thermalloy, Inc., Dallas, TX (www.thermalloy.com), and Arctic Silver Premium Silver Polysynthetic Compound, a silver-filled thermal grease with a thermal conductivity of 8 W/mK from Arctic Silver, Visalia, CA (www.arcticsilver.com).

Measurements were made with a KD2 with and without grease. For those measurements where grease was used, a thin coat of grease was applied to the entire needle. Thermal conductivity tests were performed in two ways. For one, a layer of test material was packed into the sample container, the heated needle was placed on top of the test material, and an additional layer of material was packed on top of the needle. For other measurements, the coated needle was inserted into the already compacted material. Materials tested were 30-mesh quartz sand and four sizes of glass beads. Values for the measurements are shown in Table 1.



Findings

TThe thermal resistivity values obtained with the KD2 improved with increasing moisture content and decreasing particle size when compared with the values obtained using the steady state apparatus. Measurements without grease showed substantial error. The use of thermally conductive grease to improve the contact between the soil and the probe made it possible to obtain thermal conductivity values that were comparable to, but still slightly below those obtained with the steady state apparatus. The results of the tests are shown in Table 1. The agreement between the needle and steady state measurements is likely within the limits of error of the experiment, since it was not possible to duplicate the bulk density for the two measurements, and the steady state analysis assumed one dimensional radial flow, while the measurement cell lost heat out the ends. The differences between the silver grease and the white grease were not statistically significant, though the means for the silver grease were generally a little higher. Increasing the particle diameter increased the measurement error in the glass bead samples when no grease was used, but the thermal conductivity of even 6 mm diameter beads was fairly accurate with the thermal grease. Sample to sample variation (not shown) increased with the larger bead size.

Conclusions

Contact resistance can produce large errors in KD2 measurements of thermal resistivity of granular materials, especially when the particle diameter is large. These errors appear to be largely eliminated by use of a high conductivity thermal grease to coat the probe. In materials that have particles substantially larger than the probe, contact resistance errors can be greater than 50%. Use of the thermal grease decreases errors, even in these materials, to a few percent. Silver-filled grease gives only slightly lower resistivity values than a thermal joint compound, even though the silver-filled grease has 20 times lower thermal resistivity than the joint compound.

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