Standard Method of Test for Thermal Conductivity of Rock Using Divided Bar

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1. Scope
   1.1 This method presents a laboratory procedure for determining the thermal conductivity of hard rocks in the temperature range 5-95°C (40-203°F) using a steady state divided bar technique. The technique is a relative method and is applicable to rocks from which a coherent cylindrical sample can be cored and saturated.[1]
   1.2 For satisfactory results in conformance with this method, the principles governing the size, construction, and use of the apparatus described in this method should be followed. If the results are to be reported as having been obtained by this method, then all pertinent requirements prescribed in this method shall be met.
   1.3 It is not practicable in a method of this type to aim to establish details of construction and procedure to cover all contingencies that might offer difficulties to a person without technical knowledge concerning the theory of heat flow, temperature measurement, and general testing practices. Standardization of the method does not reduce the need for such technical knowledge. It is recognized also that it would be unwise, because of the standardization of this method, to resist in any way the further development of improved or new methods or procedures by research

reference standards run in place of the test sample. The technique was originally described by Birch (1950) and has been described in more detail recently by Goss and Combs (1976).

4. Apparatus

4.1 In detail the apparatus shall consist of the following (See Figure 1)

4.1.1 Two constant temperature circulating fluid baths capable of maintaining a specified temperature within the temperature range of 5-95°C (40-203°F) to ±0.5°C (±0.1°F).

4.1.2 A hydraulic frame, cylinder and pump to apply a desired axial load to the sample.

4.1.3 Temperature measuring devices such as thermocouples (Copper-Constantan), thermistors or RTD's with associated measuring instrumentation (a voltmeter, wheatstone bridge, etc.) and a rotary switch to place each of five pairs of thermocouples into the measuring circuit. The temperature measuring instruments should be accurate to ±0.1°C (±0.2°CF).

4.1.4 Two heat flow meters consisting of a layer of material of known (relative) thermal conductivity between two copper discs which have been drilled parallel to their faces for insertion of a thermocouple junction or thermistor. The construction of the meter is discussed in an appendix.

4.1.5 Heat transfer boxes for top and bottom (hot and cold) isothermal sections (heat sink and source).

4.1.6 Standard discs of silica glass (GE 101 or equivalent) and natural quartz (cut with axis of cylinder parallel to optic axis, ±1°) of same size as unknown core discs. Standards should be prepared with polished faces flat and parallel to ±0.004 mm (±0.001 inches). Typical sample dimensions are 2.5-3.7 cm (1-1.5 inches) in length and 2.5-10 cm (1-4 inches) in diameter.

4.1.7 Micrometer(s) with an accuracy of ±0.004 mm (±0.001 inches) for measuring length and

where T is temperature in °C.

9.2.2 The equation for the thermal conductivity of a natural quartz disk, with axis parallel to the optic axis, as a function of temperature is

$$K_{QTZ} \quad 16.470 \quad 0.06479T \quad 0.0002098T^{2}$$

where T is temperature in °C.

9.2.3 The temperature of the device at the standard and sample position should be constant to within 0.5°C (1°F) during a set of tests.

10. Report

10.1 The report shall include the following.

10.1.1 A discussion of the scope of the testing program, which includes the number of specimens, tested, rationale for sample selection and the limitations of the testing program.

10.1.2 Description of the specimens. The rock type, structure and fabric, grain size, discontinuities or voids, and weathering of the samples shall be describes as a minimum. Further detail depends on the application of the results.

10.1.3 A detailed listing of the equipment actually used for the test shall be included in the report. The name, model number, and basic specifications of each major piece shall be listed.

10.1.4 If the actual equipment or procedure has varied from the requirements contained in this procedure, each variation and the reasons for it shall be noted. The effect of the variation upon the test results shall be discussed.

10.1.5 A summary table of results including test suite designations, temperature ranges, average coefficients of thermal conductivity, ranges, and uncertainties shall be presented.

10.1.6 A table of results for individual samples including, as a minimum, individual specimen number, rock type, temperature range, and thermal conductivity shall be presented.

10.1.7 For each suite of rock samples, the mean value of thermal conductivity, range, standard deviation, and 95% confidence limits for the mean shall be calculated as a minimum. The uncertainty of the sample suite shall be compared with the measurement uncertainty to determine whether measurement error f sample variability is the dominant factor in the results.

11. Comments

11.1 Temperature effects on thermal conductivity

11.1.1 This standard is designed for measurements between temperature limits obtainable using water as a circulating medium in a constant temperature bath and at temperatures near enough to room temperature that side heat losses (or gains) can be controlled by insulation alone rather than the use of guard heaters. With minor modifications the same apparatus could be used for higher temperature thermal conductivity measurements.

11.1.2 Thermal conductivity of rock is a function of temperature. The effect has been described most recently by Roy et al. (1981). Typical effects for granites are 1-2%/10°C. Hence measurement temperature must be specified for each test and use of measured values at other than test temperatures must involve a correction.

11.1.3 The standard technique is a one-dimensional measurement of thermal conductivity. Anisotropic rock must be cored in different orientations and enough samples run to determine the tensor components for complete specification of thermal conductivity.

12. Precision and Accuracy

References Cited

Birch, F., Flow of heat in the Front Range, Colorado, Bull. Geol. Soc. Amer., 61, 567-630, 1950.

Chapman, D.S., Personal communication, 1981.

Goss, R. and J. Combs, Thermal conductivity measurement and prediction from geophysical well log parameters with borehole application, Second U.N. Symposium on the Dev. And Use of Geothermal Resources, U.S. Govt. Printing Office, Washington D.C., 1976.

Ratcliffe, E.H., Thermal conductivities of fused and crystalline quartz, Brit. J. Appl. Phys., 10, 22-25, 1959.

Roy, R.F., A.E. Beck, and Y.S. Touloukian, Thermophysical Properties of Rocks, Physical Properties of Rocks and Minerals, Ed. Y.S. Touloukian, C.Y. Ho, W.R. Judd, and R.F. Roy, Vol. II-