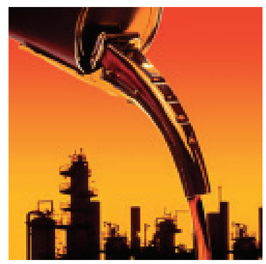
Exploring Thermal Properties Measurement of Natural & Engineered Materials

HEAT PULSE

2007

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Artifact Preservation p8

Blue Dragon of Takamatsuzuka Tumulus Japan

DECAGON DEVICES

Thermal Resistivity of Porous Materials (Soils) Change with Changes in Density, Water Content, Temperature and Composition

Decagon's KD2 measures the thermal resistivity of materials. These measurements are fast and accurate, but there is a limit to the number of samples that can be tested, and the sampling and testing procedure itself may affect the reading obtained. Insight into the factors that may affect thermal resistivity of porous materials will make the measurements made with the KD2 as useful, representative and as accurate as possible.

Table 1. Thermal properties of soil materials (T is Celsius temperature) [modified from Campbell and Norman, 1998]

Material	Density ($Mg m^{-3}$)	Specific Heat ($J g^{-1} K^{-1}$)	Thermal Cond. ($W m^{-1} K^{-1}$)	Therm. Resistivity ($m K W^{-1}$)
Soil minerals	2.65	0.87	2.5	0.40
Granite	2.64	0.82	3.0	0.33
Quartz	2.66	0.80	8.8	0.11
Glass	2.71	0.84	1.0	1.00
Organic matter	1.30	1.92	0.25	4.00
Water	1.00	4.18	0.56+0.0018T	1.65 @25C
Ice	0.92	2.1+0.0073T	2.22-0.011T	0.45 @ 0C
Air (101 kPa)	(1.29-0.0041T * 10^{-3})	1.01	0.024+0.00007T	38.8 @25C

Soils and other porous materials vary in density, water content, temperature and composition which affects the thermal resistivity of porous material. *Table 1* shows thermal properties of typical soil constituents. These constituents occur as mixtures in typical porous materials. The thermal resistivity of the mixture is quite difficult to compute, since it depends, not only on the thermal resistivities of the components, but also on their geometric arrangement. Methods for making this computation are given by Campbell and Norman (1998) and deVries (1963). These methods were used to compute the thermal resistivity of soils as they vary with water content, composition, density and temperature. The results of these computations are shown in *Figures 1, 2 and 3.*

In general, the thermal resistivity of a mixture is strongly influenced by the component with the highest resistivity. Dry quartz sand and dry loam soil have about the same resistivity, even though the resistivity of the minerals differs by a factor of 3 *(Figure 1 and Table 1)*. As the limiting resistivity becomes larger, differences in the resistivities of the other components have a larger effect. For example, dry quartz and loam differ in resistivity by about 10%, while water saturated quartz sand has about half the resistivity of saturated loam *(Figure 1)*.

As the water content of unsaturated porous materials increases, a threshold is reached where resistivity decreases rapidly with increasing water content. This is evident in all three figures. This threshold is more closely related to hydraulic than thermal properties of the material. It is the water content at which liquid water can flow across particle surfaces to re-evaporate and transport latent heat across pores in the medium.

Papers

■ Campbell, G.S., Huffaker, E.M., Wacker, B.T. and Wacker, K.C. 2003. Use of the line heat source method to measure thermal conductivity of insulation and other porous materials. In Wang, H. and Porter, W. (eds.) *Thermal Conductivity 27.* DEStech Publications, Inc., Lancaster, PA. p.87–206.

■ Fontana, A.J., Wacker, B.T., Campbell, C.S. and Campbell, G.S. 2001. Simultaneous thermal conductivity and thermal diffusivity of selected foods. In Dinwiddie, R.B. (ed.) *Thermal Conductivity 26.* DEStech Publications, Inc., Lancaster, PA. p.38–44.

In other words, the soil acts like a "heat pipe", an engineering device which makes use of latent heat transport for rapid and effective heat transfer. In a moist soil at room temperature 10 to 20% of the total heat transport is as latent heat through the pores. This portion of the heat transport is strongly temperature dependent, roughly doubling for each 10°C temperature rise.

The effective thermal resistivity of moist, air-filled pores is about the same as the thermal resistivity of water at 60°C, so, at this temperature, changing the water content of the material does not affect its resistivity. In *Fig. 3*, the 50°C curve shows almost no change in resistivity with increasing water content once the water content is high enough to sustain the liquid return flow within the pores. ■

References

1. Campbell, G. S. and J. M. Norman. 1998. An Introduction to Environmental Biophysics, 2nd Ed. Springer Verlag, New York.

2. Campbell, G. S., J. D. Jungbauer, Jr., W. R. Bidlake and R. D. Hungerford. 1994. Predicting the effect of temperature on soil thermal conductivity. Soil Sci. 158:307-313

3. De Vries, D. A. 1963. Thermal properties of soil. In Physics of Plant Environment. W. R. van Wijk (ed.) North Holland Pub. Co. Amsterdam pp. 210-235

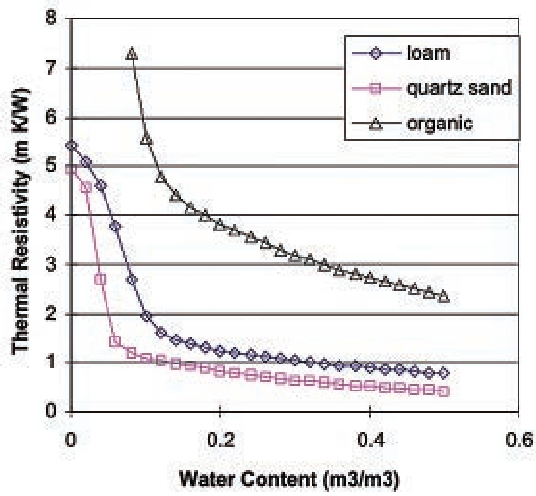

Figure 1
The thermal resistivity of three soil materials as a function of water content. The solid fraction in each was 0.5.

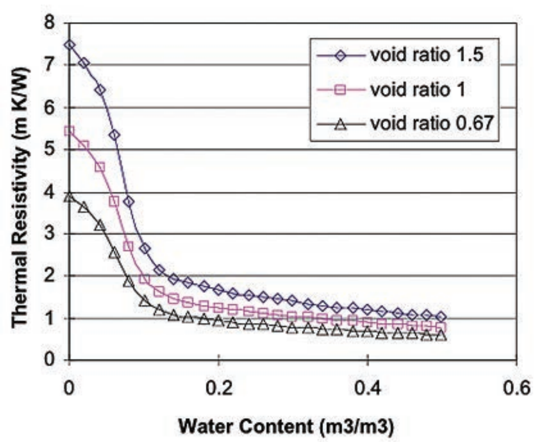

Figure 2
Effect of density and water content on thermal resistivity of a loam soil. The void ratio 1 curve is the same as in Fig. 1. The bulk densities are 1.06 Mg/m^3 for void ratio of 1.5, 1.33 Mg/m^3 for void ratio 1, and 1.59 Mg/m^3 for void ratio of 0.67.

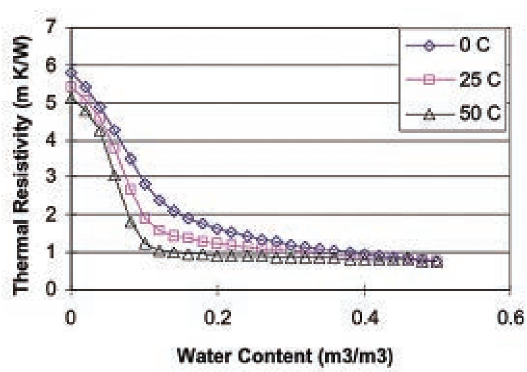

Figure 3
Effect of temperature and water content on thermal resistivity of a loam soil. The 25 C curve is the same as in Fig. 1.

Finding the R value of Insulation using the KD2

The R value of a material is a measure of its resistance to heat flow. The higher the R value, the lower the heat flow for a given temperature difference. In winter, a house with an average R value of 10 will lose heat twice as fast as a house with an average R value of 20. Therefore, the R value is critical for determining energy requirements associated with heating and cooling of homes and other buildings. The KD2 can't measure the average R value of a building, but it can measure the thermal resistivity of the materials that make up the building. The most important and most variable of these is the insulating material.


■ Good R value reduces heat costs.

We'll start by defining some terms. Thermal conductivity, *K* is the amount of heat (Watts or BTU) that flows across a plane of unit area (1 m^2 or 1 ft^2) in unit time (1 s or 1 hr) when there is unit temperature gradient (1 °C/m or 1 F/in). Units are W/(m °C) or BTU in/(ft^2 hr F). Thermal resistivity is the reciprocal of thermal conductivity (1/*K*), so units are m °C/W or ft^2 hr F/(BTU in). Thermal resistivity is the resistance per unit thickness of the material (per meter or inch). Thermal *resistance* is the product of the resistivity and the thickness of the material, so its value is specific not only to the material but also to its physical configuration. The R value, as used in U.S. building trades, is the thermal resistance in units of ft^2 hr F/BTU.

Determining an R value with the KD2 consists of measuring the thermal resistivity of the material, converting it to English units (the KD2 shows m °C/W), and multiplying by the insulation thickness in inches. The multiplier for converting to English units is 0.144.

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Application Notes

■ **All insulations have different R values.**

Taking a measurement with the KD2 is simple. Just insert the needle into a representative sample of the material to test, press the right button until the resistivity units appear at the left of the digits, press the left button to start a measurement, wait 90 seconds for the measurement to complete and record the reading.

As an example, assume we made a measurement with the KD2 and found that the thermal resistivity of an insulating material was 20 m °C/W. Converting this to English units gives

$$20\,\frac{m\,C}{W}\bullet 0.144 = 2.88\,\frac{ft^2\,hr\,F}{BTU\,in}$$

If the thickness of this insulation were 6 inches, the thermal resistance would be

$$2.88\,\frac{ft^2\,hr\,F}{BTU\,in}\times 6\,in = 17.28\,\frac{ft^2\,hr\,F}{BTU}$$

The R value of this insulation would therefore be approximately 17. Doubling the thickness would, of course, double the R value.

Using the KD2 to measure the thermal resistivity of insulation is a quick and portable method that anyone on a tight budget can do. For more information regarding the KD2, please contact the Decagon sales team at 509-332-2756 or via email at sales@decagon.com. ■

How to Bake the Perfect Cheesecake Every Time.

This cheesecake is not cooked in the center. This cheesecake is over-cooked and has cracked. This cheesecake is just right. Why can't I bake the perfect cheesecake every time? I use the same recipe and carefully measure and add all of the ingredients the same way every time. I have even made sure the bake time is the same and the oven is at the correct temperature, but the results are not always the same. Sometime it's the perfect cheesecake, but other times the cakes are under or over cooked. Why?

The problem does not lie in the oven or your recipe. Variation lies in the small differences in the thermal properties of the cream cheese. Dairy products like many other ingredients and foods vary slightly from lot-to-lot, season-to-season, and supplier-to-supplier. The important thermal properties are: thermal conductivity (k) and thermal diffusivity (D). Simple definitions are as follows: Thermal conductivity (k - W m^{-1} °C^{-1}) is the ratio of heat flux density to temperature gradient in a material. It measures the ability of a substance to conduct heat. Thermal diffusivity (D - mm^2 s^{-1}) is the ratio of thermal conductivity to specific heat. It is a measure of the ability of a material to transmit a thermal disturbance.

The importance of thermal conductivity is to predict or control the heat flux in food during processing such as cooking, frying, freezing, sterilization, drying or pasteurization. It is necessary to ensure the quality of the food product. Thermal diffusivity determines how fast heat

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Thermal Properties of Oils Measured With A Field Portable Meter

Statement of Work

Decagon Devices, Inc. is currently working in conjunction with the U.S. Government and the National Center for Manufacturing Sciences (NCMS) in an effort to find a solution for measuring the thermal properties of engine oil.

■ **Thermal properties of oil samples being measured with KD2 Pro.**

A primary function of engine oil is the transfer and storage of the thermal energy. Changes in thermal energy transfer and storage characteristics with use are significant in themselves, in terms of oil performance. However, they can also be correlated with other important properties, such as viscosity, fuel content, water content, impurities, etc. Measurement of thermal properties (conductivity and specific heat) may, therefore, provide a fast and accurate assessment of oil condition (need for change) in a vehicle. Such measurements are available in a laboratory setting, however, obtaining sufficient sample, transport of samples to the laboratory, analysis and cost of maintaining the laboratory itself, as well as returning the results to the relevant authority is expensive and inefficient.

Decagon Devices, Inc.'s solution proposal entails using a dual-probe line heat source method that will provide quick and accurate measurements of thermal properties of fluids, even under field conditions. The basis for the instrument is Decagon's existing KD2-Pro thermal properties analyzer. New probes were constructed to either measure thermal properties of a few drops of oil from a dipstick. A field measurement provides an on-the-spot assessment of fundamental physical properties of the oil, which can be used to assess oil quality. These measurements can be integrated with measurements from other hand-held instrumentation to provide a more complete picture of oil quality in the field.

Decagon Devices, Inc. will be delivering thermal properties measurements for a wide range of oil samples, both new and used, and contaminated with added water, antifreeze, and/or fuel. Thermal properties of the test samples will be measured over a range of temperature from -20 °C to 80 °C. These tests will determine the range of thermal properties and the KD2-Pro's effectiveness in detecting contamination or degradation. New probes for the KD2-Pro have been developed which are suitable for oil thermal properties assessment under field conditions. Three production-ready prototypes of the KD2-Pro and probe will be delivered along with the analysis of the data. ■

Bake the Perfect Cheesecake

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propagates or diffuses through a material. It helps estimate processing time of canning, heating, cooling freezing, cooking or frying. Water content, temperature, composition, and porosity affect thermal diffusivity. These properties are necessary for calculating energy demand for the design of equipment and optimization of thermal processing of foods (Polley et al., 1980).

To bake the perfect cheesecake every time, you need to measure the thermal properties on every batch of cream cheesecake batter using Decagon's KD2 Pro. Using these thermal properties values, the optimal cook time or belt speed can be determined to bake the perfect cheese cake every time. No more uncooked centers or dry, cracked cakes. ■

Reference:
Polley, S.L., Snyder, O.P. and Kotnour, P. 1980. A compilation of thermal properties of foods. Food Technology 34(11):76-94.

DECAGON TRADESHOWS 2007

- Geo-Denver—February 18–21, Denver, Colorado
- PITTCON—February 25–March 2, Chicago, Illinois
- ANTEC 2007—May 6–10, Cincinnati, Ohio
- 2nd Int'l Conference of Porous Media—June 17–24, Kauai, Hawaii
- International Thermal Conductivity Conference—June 24–27, Birmingham, Alabama
- Institute of Food Technologists—July 28–Aug 1, Chicago, Illinois
- North American Thermal Analysis Society—August 25–29, East Lansing, Michigan
- American Society of Agronomy—November 4–8, New Orleans, Louisiana

KD2 determines thermal properties of the Takamatsuzuka tumulus and surrounding soil.

■ Mural on inner walls of tomb.

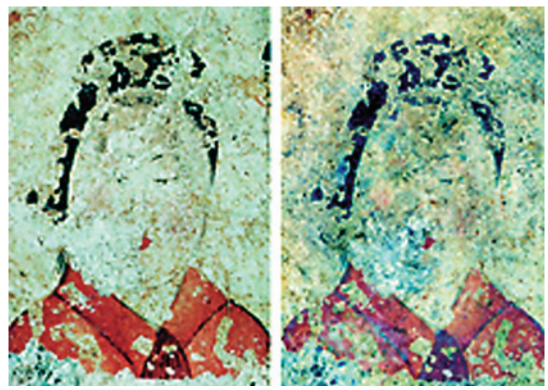
Takamatsuzuka tumulus is located in the Asuka village, just south of Nara, Japan. This area is a wonderful combination of urban living and ancient temples and tombs. Takamatsuzuka was named for the tall pine tree that sits at the top of the mound. Located within the tomb are some of the most beautiful and famous Japanese wall paintings. Discovered in 1972, the paintings are believed to have been made at the end of the seventh and beginning of the eighth centuries.

■ Commorative stamp circa 1973.

Though it is unknown who is actually buried in the tomb, the murals are worthy of a nobleman. They depict a small-scale universe, including star constellations, the sun, the moon, and guardian gods, for the deceased.

This national treasure became threatened in 2001 with the appearance of fungi growing on the interior lime plaster walls. Efforts began immediately to contain and stop the fungi growth within the tumulus. High humidity and high water content of the lime plaster walls were believed to be a contributor of the fungi growth. Scientists used Decagon's KD2 to determine the thermal properties of the tumulus and surrounding soil. As a result, it was determined that the best short-term solution would be to cool the entire mound to stop the fungi growth.

■ Takamatsuzuka tumulus cooling system in background.



■ A wall painting depicting a woman, found at the Takamatsuzuka, is shown at left in a 1972 photo; mold damage can be seen in the photo on the right, taken in 2002

The monstrous cooling system was installed over the mound, thus cooling it to a temperature where the fungi would be dormant. The Agency of Cultural Affairs is investigating ways to preserve these beautiful murals for future generations. ■

Heat Pulse is published annually by Decagon Devices, Inc.

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