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THERMAL PROPERTIES OF SOILS FOR ALEXANDRIA

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Abstract

Thermal properties of three different samples representing the sandy, sandy clayey and clayey soils were measured using the line heat source method.

The effect of temperature, in the range of $-10^{\circ}C$ to $35^{\circ}C$ and the moisture content, up to 40% on the thermal properties were investigated.

Notation

- H the thermal contact conductance,
- k the thermal conductivity of the sample,
- r the probe radius,
- T soil temperature,
- Q the power dissipated per unit length of the probe,
- α the thermal diffusivity of the sample,
- γ Euler's constant = 0.5772.

1. Introduction

Warming of soil below cold stores [1] and greenhouses [2] are widely used. The analysis of heat transfer between the soil and the warming layer depends on soil thermal properties, temperature and moisture content.

Experimental methods for determination of soil thermal properties are based on steady state or transient heat conditions. Many researchers have used the steady state methods to determine thermal conductivity of soils [3,4,5]. Also, transient heat flow methods have been extensively used [6,7,8]. The transient thermal probe method, based on the line heat source theory, was recommended since the experiment takes few minutes, the effect of moisture migration is limited and the method gives thermal conductivity and diffusivity by a single measurement.

Blackwell [9] has derived the following temperature-time solution for the transient method, using a line heat source, for a long period

$$T = A\ (\ln t + B) \tag{1}$$

where :

$$A = \frac{Q}{4 \pi k},$$

$$B = \left(\ln \frac{4 \alpha}{r^2} - \gamma + \frac{2k}{rH} \right),$$

The fitting of equation (1), using the least squares method, yields the thermal conductivity of the sample directly from the parameter A. The value of B can be used to estimate the thermal diffusivity if the value of H is very large.

The aim of this work is the determination of soil thermal conductivity and diffusivity for different localities in Alexandria.

2. Soil Samples

Soil samples were collected from nine different sites in Alexandria which represent the different types of soil in this region. Samples were collected by an auger from depths up to 150 cm from the ground surface.

Chemical and physical analyses of the samples were carried out in Faculty of Agriculture, Alexandria University. The results are given in detail in reference [10]. From these analyses, soil samples can be classified into three groups: sandy, sandy-clayey and clayey. Therefore, thermal properties will be determined for one sample only from each group.

Percentage moisture content and particle size distribution of the three samples are given in table 1.

Table 1. Moisture percentage and particle size distribution of soil samples.

Sample depth (cm)	Moisture Content %	Sand % (0.02-2 mm)	Silt % (0.002-0.02 mm)	Clay % (< 0.002 mm)	Texture class
Site-1. Rice Processing Co.					
10-30	14.6	75.8	7.6	16.6	sandy loam
30-80	16.4	83.4	7.7	8.9	loamy sand
80-120	18.1	70.7	10.2	19.1	sandy loam
Site-2. AL Behera Co. (AL Timawi)					
20-40	38.36	32.4	10.2	57.4	clay
40-80	29.59	52.8	7.7	39.5	sandy clay
80-120	35.66	50.3	10.2	39.5	sandy clay
Site-3. AL Sabahia- Potatoes Producers Coop. Co.					
15-30	39.43	32.7	9.2	58.1	clay
30-60	35.41	28.2	9.0	62.2	clay
60-100	41.21	30.3	10.2	59.5	clay

3. Sample Preparation

Preparation of soil samples was carried out in Soil Properties Laboratory, Faculty of Engineering, Alexandria University. The Laboratory is Equipped with an oven designed for temperatures up to 250°C, an electronic balance having a weighing accuracy of 0.1 g and a constant temperature cabinet operates from -20 to 55°C.

The following procedure was followed to prepare the soil samples:

a. Heating the soil sample at $110^{o}C$ for 24 hours.

b. Storing the dry sample in a closed metallic container of 98 mm diameter and 107 mm length. A hole was made in the center of the container's cover for the thermal probe.

c. Determining the density of the dry sample by weighing the full and empty container.

d. Adjusting the sample moisture content by mixing the dry sample with appropriate amount of distilled water.

e. Keeping the container in the constant temperature cabinet for 24 hours to insure uniform distribution of temperature and moisture content throughout the sample.

4. Test Instrumentation and Procedure

The equipment used to determine thermal properties of soil samples includes laboratory thermal probe, Thermal Property Analyzer (TPA) and printer. A schematic diagram of the experimental set-up is given in Figure 1.

The probe diameter is 3 mm, the heater length is 10 cm and the resistance per unit length is 456 m Ω/cm.

Thermal Property Analyzer (TPA model 1000) was developed by Ontario Hydro Research Laboratory and manufactured by Geotherm, Canada. The TPA consists of a current source and a six-input thermocouple reader under microprocessor control. The thermal resistivity (reciprocal of thermal conductivity) and thermal diffusivity are calculated by the microprocessor from a least squares fit to time-temperature data collected between 300 and 1005 seconds according to equation (1). The default value for the thermal contact conductance, H, is $3*10^{73}$

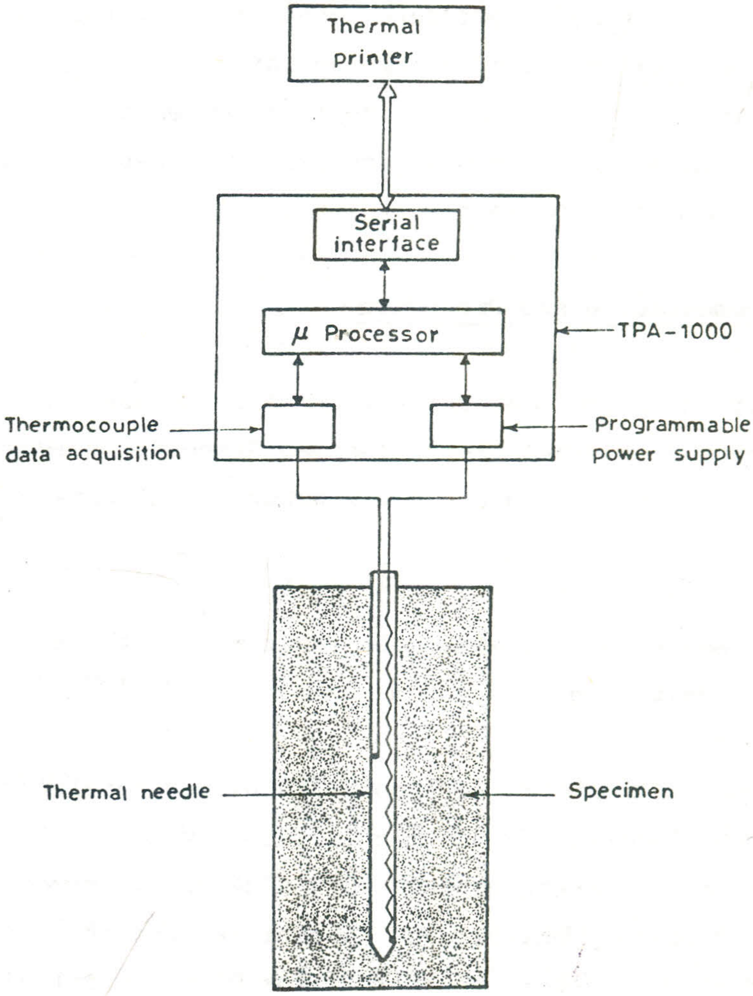


Fig. 1- Schematic diagram of thermal probe measurement instrumentation.

making the term (2k/rH) negligibly small.
The printer is provided to facilitate hard copy of time-temperature data and thermal properties. Since the value of thermal diffusuivity is given in three digits only, this copy was retained and used with equation (1) for more accurate determination of thermal diffusivity.

The accuracy of the probe in determining the thermal resistivity and diffusivity was estimated from the preliminary experiments using glycerin. The measuring errors for thermal resistivity and diffusivity were 3 and 5 percent, respectively.

5. Test Results and Discussions

Three soil samples representing the sandy, sandy-clayey and clayey groups were thermally analyzed for a temperature range from -10 to + $35^{o}C$ and moisture up to 40 % on dry weight basis.

Figures 2 and 3 show the dependence of the thermal conductivity and diffusivity on the moisture content for the three samples at positive and negative temperatures, respectively. It can be seen that:

a. For dry samples, thermal conductivity and diffusivity at positive temperatures increase slightly with temperature, while at negative temperatures they are nearly constant.

b. For wet sandy and sandy-clayey samples, thermal conductivity and diffusivity increase with increase of moisture content, increase of positive temperatures and decrease of negative temperatures.

c. For wet clayey sample at positive temperature, thermal conductivity

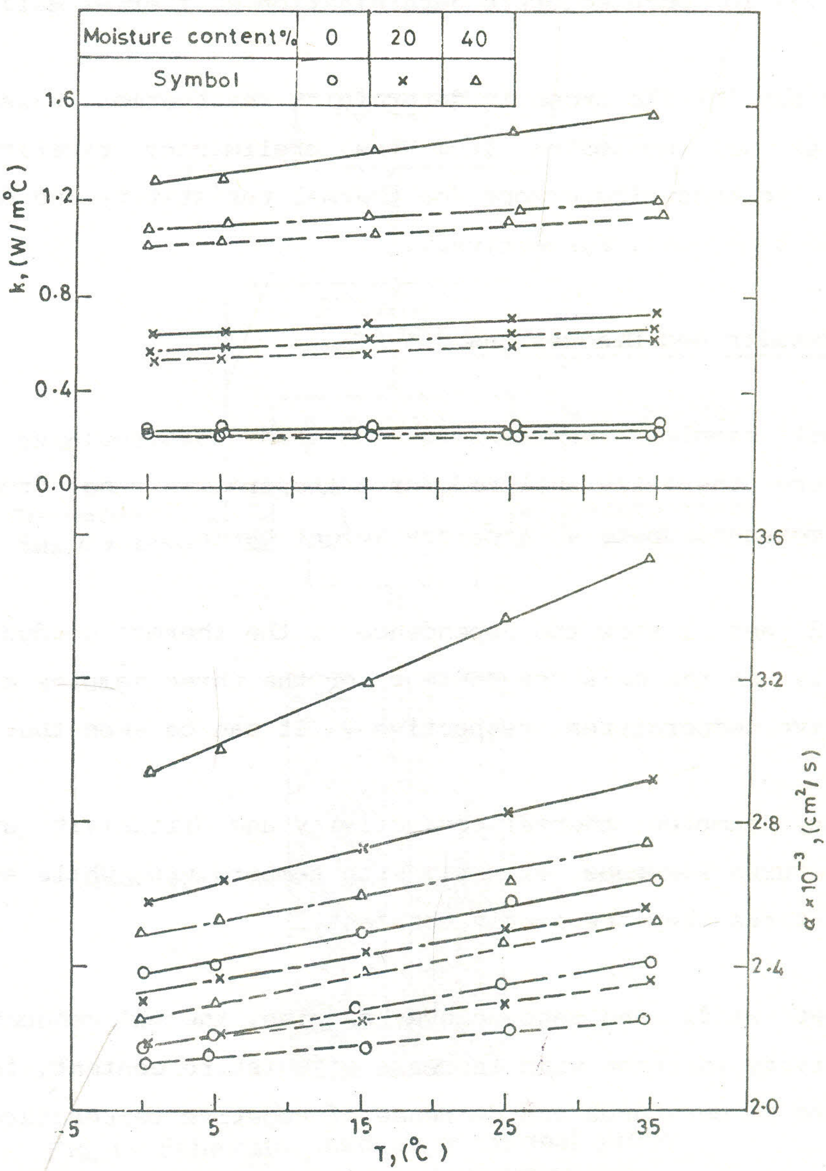


Fig.2 - Dependence of thermal conductivity and diffusivity on moisture content and positive temperatures for sandy (——), sandy clayey (—·—) and clayey (– – –) soils.

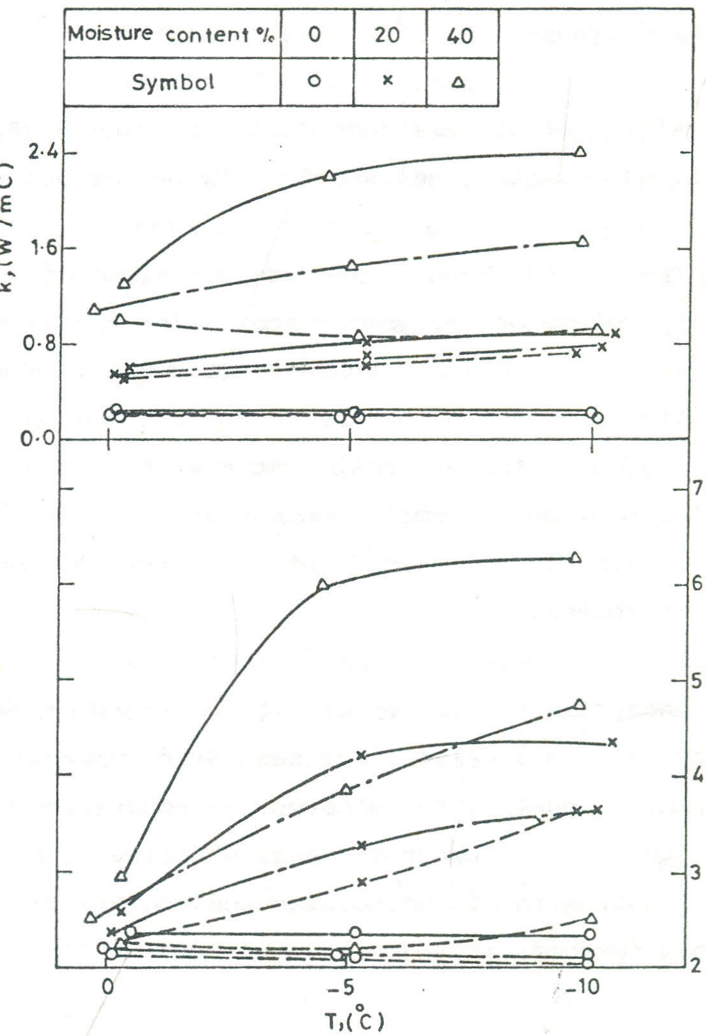


Fig. 3 - Dependence of thermal conductivity and diffusivity on moisture content and negative temperatures for sandy (——), sandy - clayey (—·—) and clayey (- - -) soils.

and diffusivity increase with increase of moisture content and temperature.

d. For wet clayey sample at negative temperatures, thermal conductivity and diffusivity increase with increasing moisture content up to 20% water. With higher moisture contents, the thermal conductivity and diffusivity decrease.

e. Highest values of thermal conductivity and diffusivity are for sandy soil and lowest values are for clayey soil.

The obtained results can be explained as follows: Soil particles touch each other at points or very small areas. The pores between them are filled with air, of a so small conductivity (0.0249 W/m^{o}C at 10^{o}C [11]) that its effect up on the conduction can be neglected. When moisture is added to the dry soil, water will form a contact between soil particles. Since thermal conductivity of water is much bigger than that of air (0.575 W/m^{o}C at 10^{o}C [11]) soil thermal conductivity increases.

As thermal conductivity increases with moisture content, volumetric heat capacity of soil also increases. Since thermal diffusivity is directly proportional to thermal conductivity and inversely proportional to the volumetric heat capacity, the rise of thermal diffusivity of soil with rising moisture content is much less than the rise of thermal conductivity.

When the wet soil temperature is lowered below 0^{o}C, the water changes into ice of a four times thermal conductivity greater than that of water. Therfore, it may be expected that thermal conductivity of the soil will increase with freezing. This result was obtained for sandy and sandy-clayey samples. For clayey samples with high moisture content an inverse result was obtained. This astonishing result may be explained as follows [12]:

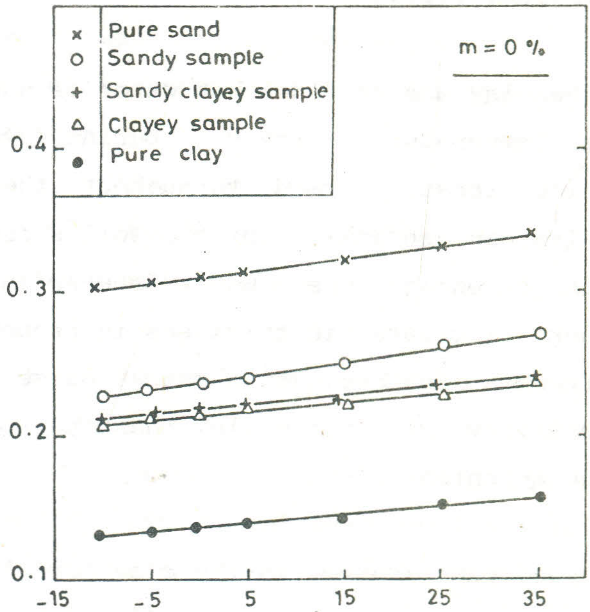
The pores in the clay are so fine that water is under high tension and freezes at a temperature below $0^{\circ}C$. During freezing, water moves towards the ice lenses formed throughout the clay matrix. This movement results in shrinking of the soil substance. The resulting cracks are large enough that water freezes in them at very nearly $0^{\circ}C$. The cracks increase in thickness in proportion to the added water that freezes in them. These cracks cause the decrease in the thermal conductivity of frozen clay than that of unfrozen clay with the same moisture content.

Existance of unfrozen water in the clay more than in the sand [12] results in less increase in thermal conductivity of the clay than the sand when freezing occurs.

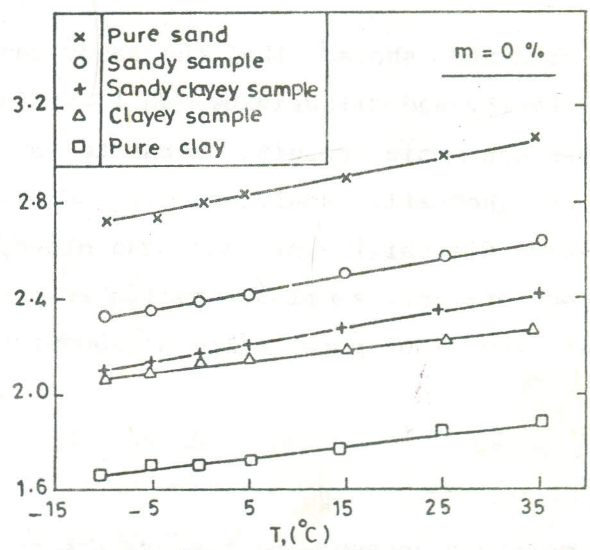
The results obtained showed that the sandy sample has the greatest thermal conductivity and diffusivity, while the clayey sample has the lowest. To declare this result, separate pure sandy and clayey components were thermally analyzed. Figure 4 shows the thermal conductivity and diffusivity of sandy and clayey components together with the three dry soil samples. The figure confirm this result and indicates that the two pure samples sandwitch the three studied samples.

6. Conclusion

The effect of moisture content and temperature on thermal conductivity



a – Thermal conductivity



b – Thermal diffusivity

Fig. 4 – Thermal properties of dry soil samples and components.

and diffusivity for sandy, sandy-clayey and clayey soil samples were experimentally investigated. Generally, thermal conductivity and diffusuivity showed an increase with increase in moisture content, increase in positive temperature and decrease in negative temperature. For wet clayey soil with large moisture content, thermal conductivity and diffusivity decrease as the negative temperature decreases, then increase with more decrease in temperature.

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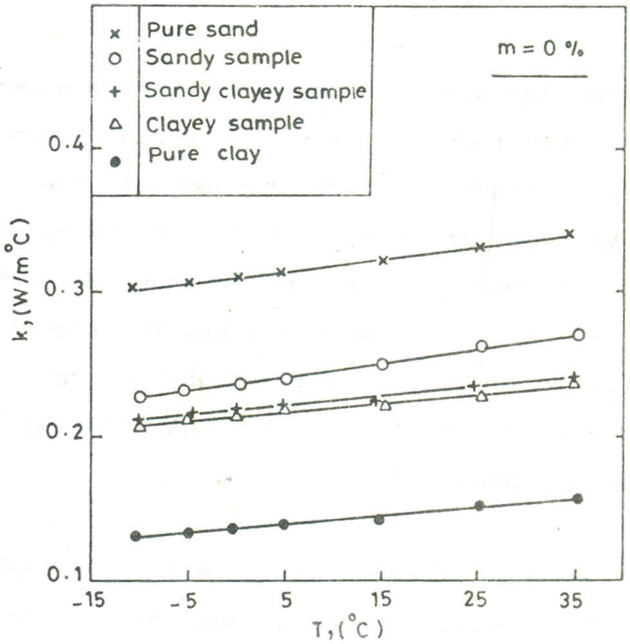

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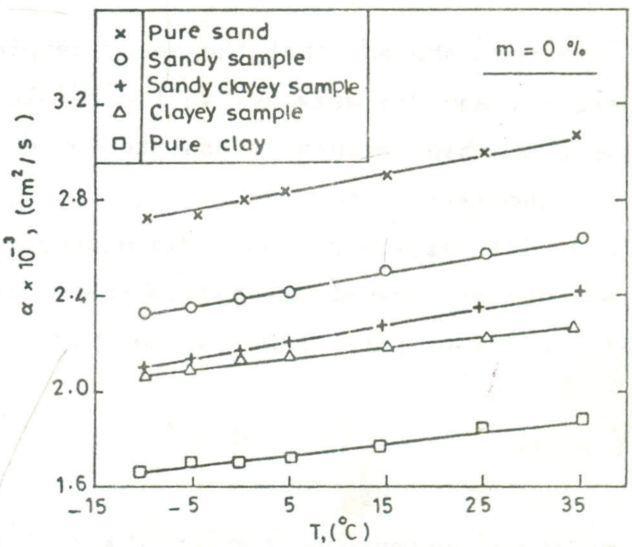

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