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DETERMINATION OF THERMAL CONDUCTIVITY AND DIFFUSIVITY OF DIFFERENT SOIL SAMPLES IN HADEJIA METROPOLIS, JIGAWA STATE NIGERIA

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Abstract

This research was conducted to determine the thermal conductivity and diffusivity of four different soil samples (sandy, loamy, clay and silt soil) and the method used was Seale's bar method. The values obtained were arranged in form of two equations and solved simultaneously in order to obtain the thermal conductivity and diffusivity of all the soil samples in consideration. The results obtained led to the production of number of graphs and tables from which conclusions were drawn. The survey was carried out on four different soil samples. The graph of all the soil samples shows that temperature gradients are all having negative results. This is because longest depths were subtracted from the shortest depths (x_2-x_1) cm. The entire practical work was done separately. Thirty minutes were spent on each soil sample analysis. Interpretation of data obtained shows that all the four soil samples are having different results with sandy soil having the highest value of thermal conductivity and diffusivity of $6.68\times10^{-4}Wm^{-1}k^{-1}$ and $1.2\times10^{-3}m^2/s$ respectively. Furthermore, clay soil has the lowest value of thermal conductivity and diffusivity of $2.30\times10^{-4}Wm^{-1}k^{-1}$ and $4.99\times10^{-4}m^2/s$ respectively. Hence all the samples have unique nature and therefore they will definitely have different uses.

Key words: *conductivity, diffusivity, soil, Seale's bar method, temperature, gradient*

INTRODUCTION

Soil is defined as a disposed poly-phase system consisting of solid, liquid and gaseous phases. Each phase is physically or chemically different and separable. Soil physics is a branch of soil sciences dealing with a state and transport of matter and energy in the soil. It exhibits exceedingly complex interaction among its constitutions (Steven, Nurit, William, Paul, & Robert, 2012). Soil physics principles developed by the pioneers in the field are articulated in several papers. Soil physics have three main parts which are: Soil Solids, Soil Liquids and Soil gas (Braudeau & Mohtar, 2009).

Soil temperature, its value at any moment and the manner with which it varies in time and space, is a factor of determining the rates and directions of soil physical process and of energy and mass exchange with atmosphere- including evaporation and aeration(Jury *et al.*, 2011). Temperature also governs the types and rates of chemical reactions which take place in the soil. Finally, soil temperature strongly influences biological process (Nimmo & Landa, 2005). Such as seed germination, seed emergence and growth, root development, and some microbial activity(Hillel, 2013). Knowledge of the thermal properties of the soil top layer is of great importance in agricultural meteorology,(Evett, Agam, Kustas, Colaizzi, & Schwartz, 2012) where problems of the heat exchange at the soil surface are encountered(Hadas, 1974). Perhaps, thermal properties such as thermal conductivity, diffusivity and heat capacity are the key components that determine the agricultural opportunity of the soil samples (Sorour, Saleh, & Mahmoud, 1990).

Soil heat is the most important factor that controls the intensity of biophysical, biochemical and microbiological processes that take place in the soil. The rate of mineralization of organic matter, the physical processes of diffusion and viscous flow, and the germination of seeds, roots growth and its activities in terms of water and nutrient absorption and reparation are strongly temperature dependent(Fontana, Wacker, Campbell, & Campbell, 2001). The main source of soil heat is solar radiation, in the day and nighttime heat use to exchange at the surface of the ground. The rate at which the radiant energy reaches the earth's atmosphere from the sun per unit time and per unit area is called solar constant (Hepokoski, 2013).

This research paper explores the idea of dynamic equilibrium and characteristics of heat flow. Based on these considerations it follows that in order to measure the thermal conductivity of a certain material, heat input, dimensions of the material and the temperature difference need to be known. Thermal conductivities and diffusivities of four different soil samples were examined in this work.

THEORY

The thermal conductivity of a material, k, is the fundamental property of a material that indicates its ability to conduct heat(Parker, Jenkins, Butler, & Abbott, 1961). Conduction will take place if there exists a temperature gradient in a solid (or stationary fluid) medium. Concerning the temperature dependence of thermal conductivity, a numerous effect of mineralogical composition and temperature result that thermal resistivity is a linear function of temperature whose slope increases at 0^oc (Vosteen & Schellschmidt, 2003). Energy is transferred from more energetic to less energetic molecules when neighboring molecules collide (Mottaghy, Vosteen, & Schellschmidt, 2008). Conductive heat flow occurs in direction of the decreasing temperature because higher temperature is associated with higher molecular energy. However, heat conduction is not only determined by the material, but also by its shape, and by the temperature difference between the two ends. Fourier's Law expresses conductive heat transfer as (Owate, Abumere, & Avwiri, 2007).

$$K = -\frac{\Delta Q \times \Delta x}{A \Delta T} \qquad (1)$$

Where ΔQ is the steady state rate of heat transfer, K is the thermal conductivity of the sample, A is the cross sectional area and ΔT is the temperature difference across the sample thickness Δx(Nelkon & Parker, 1995). The steady state rate of heat transfer, ΔQ can be represented by the specific heat capacity at constant volume and temperature difference(Hugh, Roger, & A. Lewis, 2012). From equation (1) the gradient value in kelvin per meter or degree Celsius per meter is

$$\frac{\Delta T}{\Delta x} = \frac{T_2 - T_1}{x_2 - x_1} \qquad (2)$$

$$\Delta Q = C_v \Delta T \qquad (3)$$

But thermal diffusivity (α) as defined by(Borner & Thern, 1962) states that

$$\alpha = \frac{K}{C_v} \qquad (4)$$

Where K is the thermal conductivity and C_v is the specific heat capacity at constant volume of the sample.

MATERIALS AND METHOD

Materials

The material used in determining thermal conductivity and diffusivity of different soil samples are as follows: Soil Samples (collected in Hadejia metropolis), heat source, head sink, 50cm plastic pipe, lagging Material, Vanier caliper, Ruler, Mercury-in-glass Thermometer.

Method

Searle's method was adopted due to availability of the apparatus (see figure1). The hollow plastic pipe is filled with the soil sample and then heated using steam at one end while the other end is cooled using ice block or very cold water in order to prevent heat from reversing. Four thermometers are set up along the length of the plastic pipe at equal distances, and the pipe is heated for 30 minutes. Using the collected temperature, the elapsed period of time, the distance between the thermometers and several physical constant, the thermal conductivity can be calculated directly.

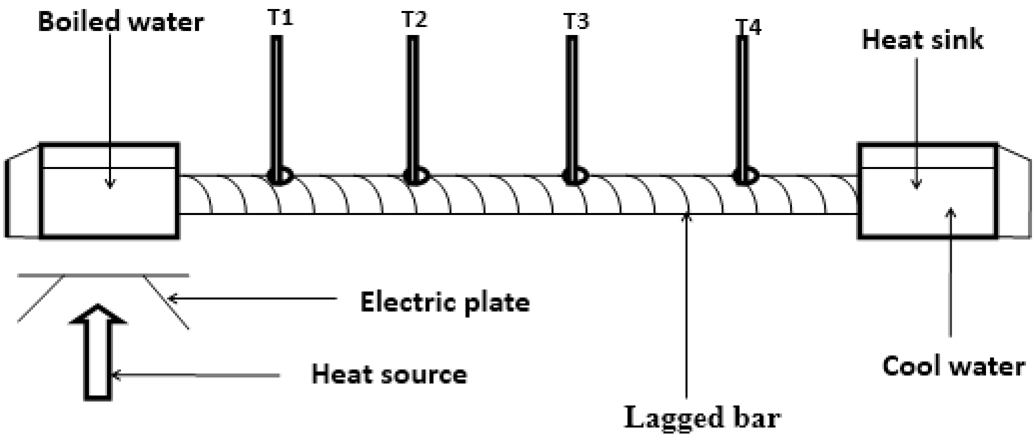

Figure 1: Experimental set up for the experiment

The quantity of soil should be small of about (760g) to avoid error due to the mercury-in-glass thermometer not in good contact with the soil sample and error due to the escaping of thermal heat through the air gap between the soil sample and the bar.

Measurement

The thermometers measurements of all the four soil samples was recorded accordingly and presented in ***Table 1***. Experimental results of thermal conductivity and diffusivity, temperature gradients of each soil sample are evaluated according to Equations (1), (4) and (2) respectively.

RESULTS AND DISCUSSION

The result obtained shows that, the temperature of all the soil sample is decreasing with increase in depth (Figure 2) and it can be seen that sandy soil conducts more heat than all other soil samples because sandy particles have pore spaces between them that will enable a considerable amount of thermal heat to pass through (Table 2). However, clay soil is the soil sample that conducts least amount of thermal heat because clay particles are compacted together and as a result will hinder the passage of thermal heat through the soil sample (Table 2).

Table 1: Soil temperature at different depth soil sample.

		Temperature			
Depth (cm)		Sandy soil (°C)	Loamy soil(°C)	Clay soil(°C)	Silt soil(°C)
10	T_1	86.00	83.2	54.8	71.3
20	T_2	74.00	81.7	40.0	41.3
30	T_3	62.50	80.2	39.0	38.3
40	T_4	50.10	74.6	34.3	30.0

Table 2: Summary of evaluated results available in this experiment.

Soil sample	Temperature gradient (km^{-1})	Thermal conductivity(k) ($Wm^{-1}k^{-1}$)	Thermal Diffusivity (m^2/s)	Heat Flux (J/s)	Specific heat capacity (JK^{-1})
Sandy Soil	-0.769	6.68×10^{-4}	1.2×10^{-3}	53.77	0.19
Loamy Soil	-987.3	8.32×10^{-4}	2.0×10^{-3}	61.74	0.21
Clay Soil	-980	2.30×10^{-4}	4.99×10^{-3}	49.98	0.17
Silt Soil	-1047.67	1.06×10^{-4}	3.09×10^{-3}	81.72	0.26

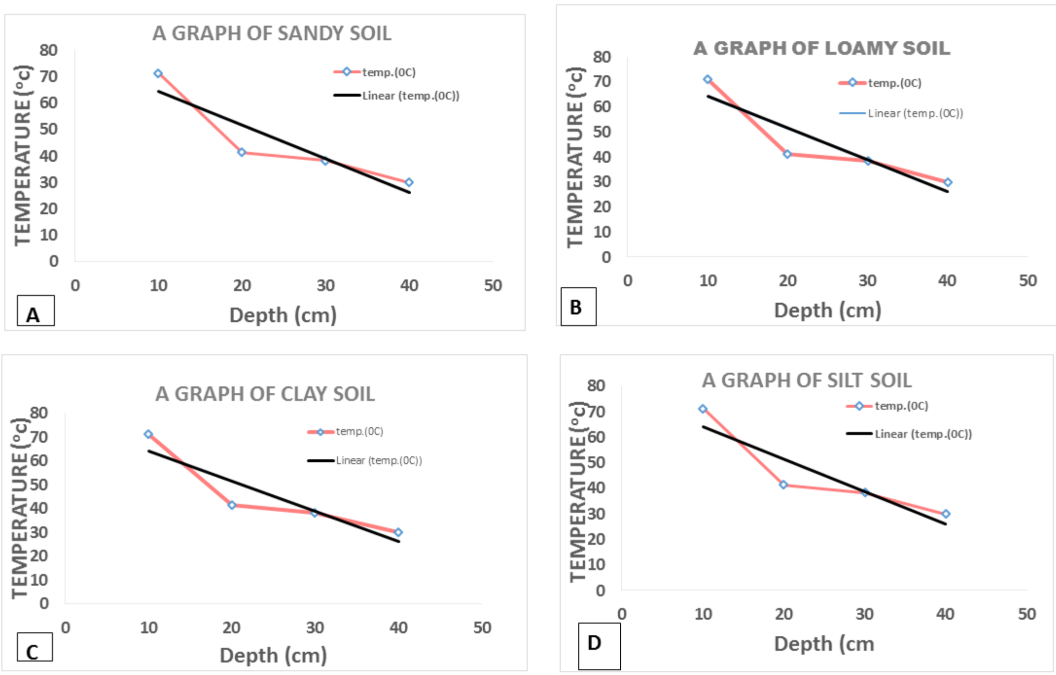

Figure 2: the graph of; A- temperature against spacing for sandy soil, B- temperature against spacing for Loamy soil, C- temperature against spacing for Clay soil, D- temperature against spacing for Silt soil.

CONCLUSION

Results from the interpretation of data shows that the temperature of all soil samples is decreasing with increase in depth as a result of energy concentration from a place with highest energy concentration to a place with lowest energy concentration. It is proved that the thermal conductivity, thermal diffusivity and heat capacity of all the soil samples are different hence, though they are showing similar trends. From the experimental result it can be seen that sandy soil conducts more heat than the other soil samples. This is because sandy particles have pore spaces between them that will enable a considerable amount of thermal heat to pass through. However, clay soil sample conducts least amount of thermal heat because clay particles are compacted together and as a result will hinder the passage of thermal heat through the soil sample.

RECOMMENDATION

From this research work, we can make the following recommendations for future study, any thermometer selected to be used in the survey should be carefully installed at specific soil depth. The sensing element should be in good thermal contact with the soil, more especially in the case of mercury in glass thermometer. All the selected thermometers should be calibrated initially and separately.

The bar to be used should be lagged with cotton to avoid excess heat loss, the bar should be moderately long to ensure that sufficient temperature difference exist between the two ends in order to obtain an accurate measurement. The bar should be poor conductor of heat and electricity e.g. (rubber pipe or cast pipe).

The heat source should be a reliable source of heat e.g. cooker gas, kerosene stove. The practical should be conducted accurately in order to obtain good result.

Finally Government Schools especially Tertiary Institutions and other Private Organization should provide the necessary adequate or relevant materials, tools and apparatus in the field of soil physics or Geophysics.

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