

MEASUREMENT OF THERMAL CONDUCTIVITY AND SPECIFIC HEAT CAPACITY OF THREE MAJOR GEOMORPHOLOGICAL UNITS IN AKWA IBOM STATE, NIGERIA.

ABSTRACT

The thermal conductivity (K) and specific heat capacity (c) of some samples collected from three major landforms in Akwa Ibom State, Nigeria; namely Beach Ridge Sand (BRS), Coastal Plane Sand (CPS), Sandstone/Shale Hill Ridges (SHR) were measured. Results show that an increase in Specific Heat Capacity (SHC) of the samples gives rise to a decrease in K. The SHC of the area under study falls within the range 1813.64jkg⁻¹k⁻¹ to 3313.24jkg⁻¹k⁻¹ while the soil thermal conductivity per unit depth K was between the range 0.272w/mk to 0.451w/mk. The SHC of the soil samples has great effect on crop and construction works.

Key Words: Thermal conductivity, Specific heat Capacity, Soil and Coastal Plane Sand.

INTRODUCTION

The study of soil properties is very important and useful to determine the soil thermal conductivity. Soil the uppermost layer of the earth's crust which provides support and nutrients for plant growth. The conduction process takes place at the molecular level and involves the transfer of energy from the more energetic molecules to those with lower energy level. Heat conduction in many materials can be visualized as the result of molecular collision (Douglas, 1991). The conduction of heat occurs only if there is a difference in temperature between two parts of the conducting medium (Raymond and Jerry, 1992). Heat flow through any soil depends on the thermal properties of the soil. Variation in temperature with thickness of the soil determines whether the soil can be used as heat source. The prediction of temperature at various thicknesses at any given time of the day throughout the year is an important tool in the design of a construction works. Thermal properties of soil samples involve many variables which may be complicated. Such variable include the soil texture, structure and composition parameter.

Similar studies of soil properties in recent time include: comparison of the thermal properties of brick samples for a passively cooled building design (Akpabio and Ekpe, 1998); thermal response of different rock samples for a passively cooled building design (Akpabio *et al*, 2004).

THEORY

Soil temperatures are determined by a number of factors, some of which include the location characteristics and thermal physical properties of the soil samples. The amount of radiant energy absorbed or reflected depends on the material coloration. The proportion of energy absorbed causes changes in temperature of the soil samples.

The heat budget equation in one dimension, can be rewritten as:

$$-k \left(\frac{\partial T}{\partial x} \right)_{x=0} = h(T_{atm} - T_{(x=0)}) + \alpha I - \epsilon \Delta R \dots\dots\dots 1$$

Where k = thermal conductivity of the soil sample; T = soil temperature, h = heat transfer coefficient at the surface; T_{atm} = atmospheric air temperature, α = solar radiation absorptivity, I = intensity of solar radiation, ϵ = long-wave emissivity of the surface, and ΔR = difference between the incident long wave radiation and the radiation emitted from the surface; but solar temperature is given be:

$$T_s = T_{\text{atm}} + \left(\alpha \frac{I}{h} \right) - \left(\epsilon \Delta R \right) \dots\dots\dots 2$$

With this, (Moustafa et al, 1981) assumed a general solution of the form:

$$T_{(x,t)} = a_0 + \sum_{m=1}^{\infty} \{ a_m \exp[i(m\omega t + \alpha mx)] \} \dots\dots\dots 3$$

But, $\alpha m = (m\omega \rho c / 2k)^{1/2} (1-i)$; where C = specific heat capacity of the soil sample, ρ = density of the sample, and $\omega = 2\pi/\text{period } T$. Show the dependence of material temperature with thickness of the periodic variation of temperature at the surface. The real part of the equation (3) can be expressed as:

$$T_{(x,t)} = a_0 + \sum \{ a_m \exp(-\alpha mx) \cos (m\omega t - \alpha mx) \} \dots\dots\dots 4$$

Equation (4) can be modified as:

$$T_{(x,t)} = T_m - A_s \exp(-\alpha x) \cos \{ \omega(t - t_0 - \alpha x/\omega) \} \dots\dots\dots 5$$

Where, A_s = daily temperature amplitude at $x = 0^0\text{C}$; t = time of the day in hours, and t_0 = time of maximum temperature at the surface. The temperature T_m can be calculated from the hourly material surface temperature average $T_{\text{hss}}^0\text{C}$ as:

$$T_m = \sum_{m=1}^{24} (T_{\text{hss}} / 24) \dots\dots\dots 6$$

On 24 hour period, equation (5) can be written as:

$$T_{(x,t)} = T_m - A_s \exp(-\alpha x) \cos \{ (2\pi/24)(t - t_0 - 12 \alpha x/\pi) \} \dots\dots\dots 7$$

METHOD

Sample Collection and Preparation:

Soil samples used for the experiments were collected from three landforms in Akwa Ibom State. The landforms are: Beach Ridge Sand (BRS), Coastal Plane Sand (CPS) and Sandstone/Shale Hill Ridges (SHR) the soil samples were collected at depths of 0 – 15cm beneath the earth surface and put in different labeled containers. They were then air dried in the Physics laboratory, University of Uyo, Nigeria to drive away the moisture content. With some water, the soil samples were made wet such that they could be molded into the desired shape. Each of the samples was molded into a disc shape using a plastic ring designed for that purpose. The samples were afterwards dried in the soil to solidify and then were stored in their respective containers rightly labeled. Six different soil samples were collected; locations and sources of collection are as shown in the table 1

Table 1: Landforms and sources of soil samples.

Landforms	Location
Beach Ridge Sand (BRS 1)	Ikot Ibok, Eket LGA
Beach Ridge Sand (BRS 2)	Ikot Akpan Mkpe, Onna LGA
Coastal Plain Sand (CPS 1)	Ikot Akan, Nsit Ubium LGA
Coastal Plain Sand (CPS 2)	Uniuoyo Annex, Uyo LGA
Sandstone/Shale Hill Ridges (SHR 1)	Ikpe Ikot Nkon, Ini LGA
Sandstone/Shale Hill Ridges (SHR 2)	Ntak Inyang, Itu LGA.

Measurement of specific heat capacity

The following were used during the analysis: weighing balance, thermometer, calorimeter, heat source, beaker, water, stop clock, soil samples (solid), thread, and logging material (Tyler, 2005). The calorimeter with stirrer was weighed and its mass recorded as M_c . The solid was put into the calorimeter and weighed as M_1 then the calorimeter was half filled with water. The calorimeter and the mixture were weighed and the mass recorded as M_2 . The initial temperature of the mixture was taken as θ_1 ; the final temperature of the boiling water was taken as θ_2 , the hot water was poured into the calorimeter with the mixture and the change in temperature with change in time was recorded. The highest temperature of the mixture was recorded as θ_m . Then, the specific heat capacity can be calculated for each of the soil samples by using

$$C_s = \frac{M_{nw} C_w (\theta_2 - \theta_3) - [M_c C_c + M_{cw} C_w] (\theta_3 - \theta_1)}{M_s (\theta_3 - \theta_1)} \dots\dots\dots 8$$

Table 2: Experimental values of each sample for the determination of specific heat capacity.

Samples	M_c (kg)	M_s (kg)	M_{cw} (kg)	M_{nw} (kg)	θ_1 °C	θ_2 °C	θ_3 °C
BRS 1	0.0545	0.02556	0.02731	0.06238	29.0	98.5	69.58
BRS 3	0.0545	0.04294	0.02587	0.05985	29.5	98.5	67.23
CPS 1	0.0545	0.02964	0.02326	0.06850	29.5	98.5	71.55
CPS 3	0.0545	0.02980	0.02021	0.07919	29.5	98.5	61.14
SHR 1	0.0545	0.03322	0.02766	0.04254	29.5	98.5	61.14
SHR 3	0.0545	0.03810	0.02834	0.05230	29.5	98.5	60.64

Also, $C_w = 4200 \text{ J kg}^{-1} \text{ K}^{-1}$ and $C_c = 400 \text{ J kg}^{-1} \text{ K}^{-1}$ while θ is in $^{\circ}\text{K}$; by putting the above data in table 2 into equation 8 we have the results in table 3. We find that different materials require different quantities of heat to raise the temperature of a given mass of the material through a specified number of degrees. Different materials absorb energy in different ways (Hewitt, 1985).

Measurement of thermal conductivity

The following were used during the experiment: Lee's disc apparatus, thermometer, steam can, vernier caliper, strings, and retort stand with clamp, heat source and rubber tubing's. The specimen in the form of a thin disc B and of the same diameter is placed between A and C

(Tyler, 2005). Thermal conductivity were determined for each of the samples using the steady state method, lee's disc apparatus for a bad conductor was modified and adapted for used; dry samples were used to avoid the problems of redistribution of water under the influence of a temperature gradient. Heat conduction takes place only if there is a difference in temperature. Indeed, it is found experimentally that the rate of heat flow through a substance is proportional to the difference in temperature between its ends (Douglas, 1991). At steady state the heat conducted across the soil sample is equal to the rate at which it is emitted from the exposed surface (Ekpe et al, 1996). In general, the thermal conductivity of a solid is larger than that of a liquid, which is larger than that of a gas (Frank and David, 1996).

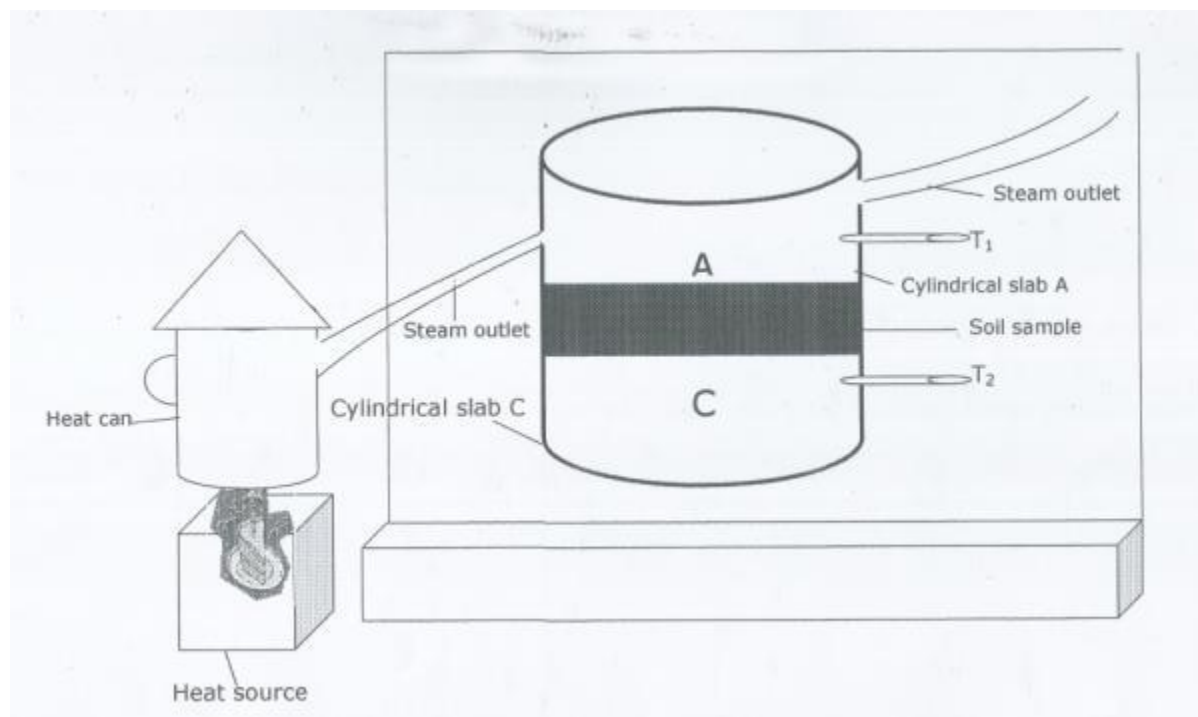


Figure 1: Determination of thermal conductivity of soil samples by Less' Disc method

Results and Discussion

Table 3: Specific Heat Capacity and Thermal Conductivity of soil Samples.

Landforms	Specific Heat Capacity ($\text{Jkg}^{-1}\text{K}^{-1}$)	Thermal Conductivity (W/mK)
BRS 1	1964.54	0.333
BRS 2	1813.64	0.451
CPS 1	2323.42	0.272
CPS 2	2380.21	0.331
SHR 1	2197.36	0.409
SHR 2	3313.24	0.404

Table 4: Showing Results of the Calculated $C_R - K_R$ for each soil Sample.

Landforms	C (jkg ⁻¹ k ⁻¹)	k (/mk)	C_R	K_R	$d=C_R-K_R$	d^2
BRS 1	1964.54	0.333	2.00	3.00	-1.00	1.00
BRS 2	1813.64	0.451	1.00	6.00	-5.00	25.00
CPS 1	2323.42	0.272	4.00	1.00	3.00	9.00
CPS 2	2380.21	0.331	5.00	2.00	3.00	9.00
SHR 1	2197.36	0.409	3.00	5.00	-2.00	4.00
SHR 2	3313.24	0.404	6.00	4.00	2.00	4.00

$$\sum d^2 = 52.00$$

Using the value of specific heat capacity C and thermal conductivity k, to obtained Pearson's correlation coefficient $\gamma = 1 - \frac{6\sum d^2}{n(n^2-1)}$ (Dass, H. k; 2006); where n = 6 (number of soil samples), $d^2 = 52$, but $C_R - K_R$ are correlation coefficient of specific heat capacity (C) and thermal conductivity (K), read from correlation table respectively.

$$\text{Thus, } \gamma = 1 - \frac{6\sum d^2}{n(n^2-1)} = 1 - \frac{6 \times 52}{6(6^2-1)}$$

$$= 1 - \frac{(312)}{6(35)} = 1 - \frac{(312)}{210} = 1 - 1.4857$$

$$= -0.4857$$

By using the analysis of variance (ANOVA),

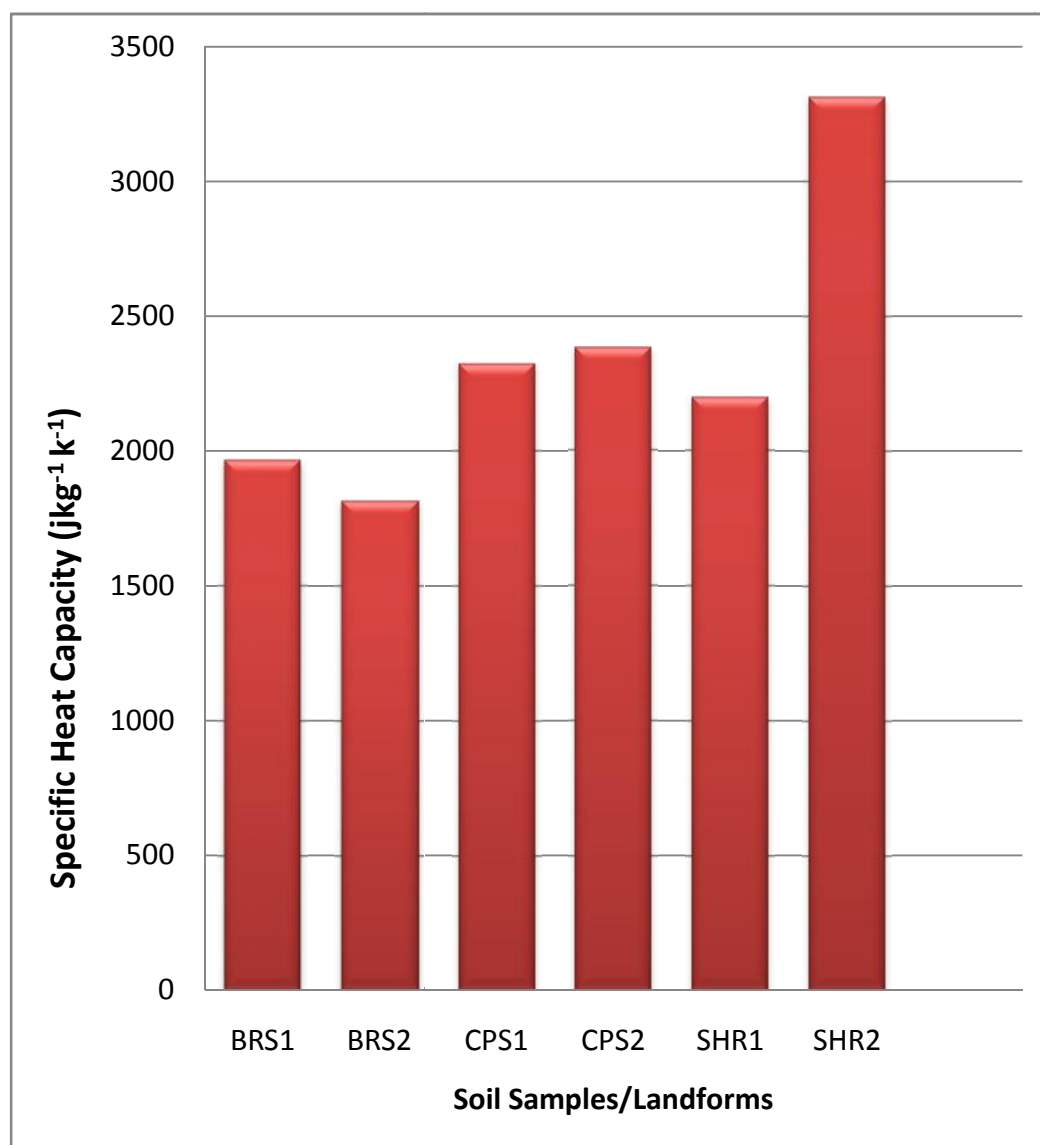
Null hypothesis (H_N): $C = K$; if $\gamma_{cal} > \gamma_{tab}$

Alternative hypothesis (H_A): $C \neq K$; if $\gamma_{cal} < \gamma_{tab}$

Where γ_{cal} = calculated value of γ and γ_{tab} = value of γ from correlation table. From correlation table (Gerald and Brian; 2003); with 6 degree of freedom γ_{tab} at $\alpha = 0.05$ and $\gamma_{tab} = 0.8860$.

Since $\gamma_{cal} = 0.4857 < \gamma_{tab} = 0.8860$, we upheld the alternative hypothesis and concluded that there is no significant different in the C values of the three landform observed in Akwa Ibom State. The result of the measurement between the specific heat capacity and thermal conductivity is shown in figure 2 and 3.

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130 **Figure 2:** Measurement of Specific Heat Capacity.

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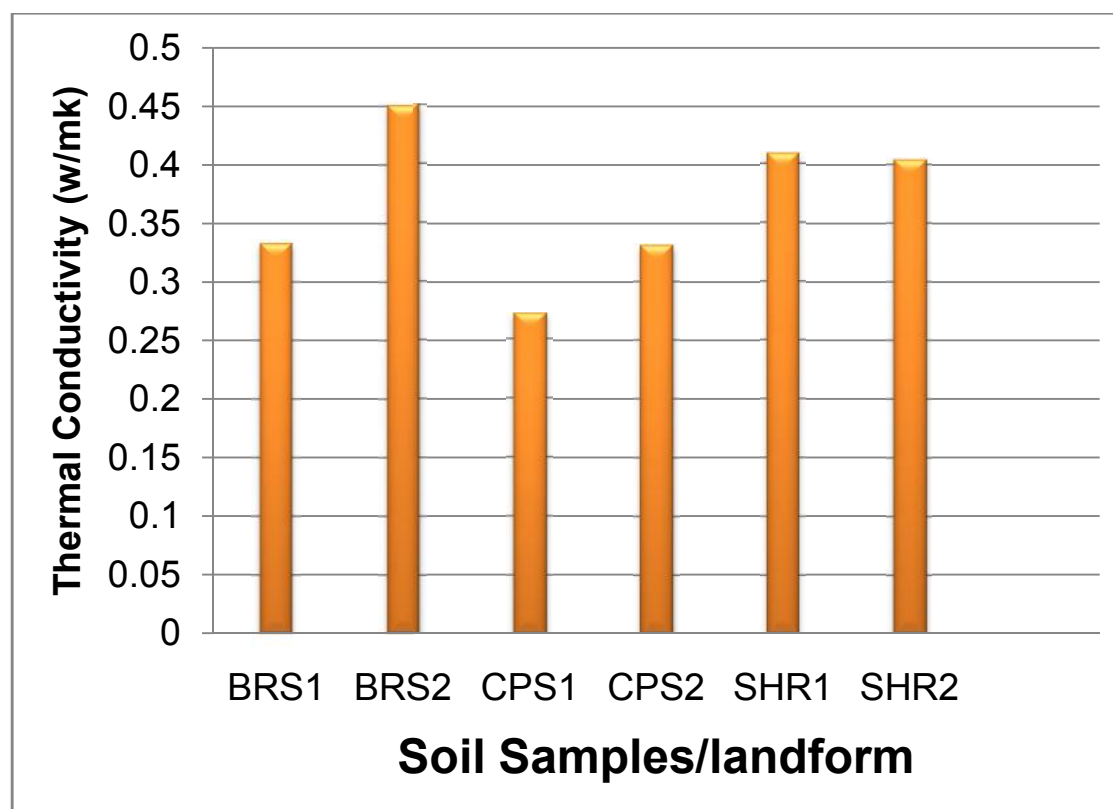


Figure 3: Measurement of Thermal Conductivity.

SUMMARY AND CONCLUSION

Equation 7 reveals that variation in temperature with thickness of soil sample at any time depends on the thermal properties of the soil. Similarly, different amounts of heat are absorbed by blocks of the same material if their mass is different and their temperature change is the same, if their mass is the same and their temperature change is different, or if they have different masses and undergo different temperature changes (Frederick, 1990).

From table 3, sample SHR have the higher thermal conductivity closely followed by BRS and CPS. This shows that samples SHR tend to conduct heat at a higher rate than BRS and CPS. Therefore, it can be said that specific heat capacity of the soil increases with a corresponding increase in thermal conductivity of the soil samples and vice versa as shown in the figures above. The results also reveal that they are an increase in specific heat capacity of SHR2. In order to increase the temperature of an object one must increase the thermal energy of its molecules. We can do this by letting heat flow into the object from hotter object (Frederick, 1977). Evidently, the larger the object to be heated, greater amounts of heat that must be supplied (Frank, 1983).

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