Journal of Natural Sciences Research
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.6, No.21, 2016

Thermal Properties of Clay Soil from Uruan River Bank in Akwa Ibom State, Nigeria

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Abstract
Clay soils are widely used in Akwa Ibom State for various purposes that require cooling. It is made into pots for storage of drinking water and as walling material. Clay soils are used as a potential thermal insulator for shelters and there is need for the thermal properties of the clay sample to be investigated. The thermal properties of clay soils from selected parts of Akwa Ibom State have previously been investigated but clay from other parts are yet to be investigated; hence this study investigates the thermal properties of clay soil from Uruan local government area of the state. The result shows that the clay has a mean thermal conductivity of 0.393 $Wm^{-1}K^{-1}$; mean bulk density of 1.69 $\times 10^{-3}$ kg/m^3; mean thermal diffusivity of $1.98m^2s^{-1}$ and mean thermal resistivity is 2.55 mkW^{-1}. The results show that the clay from Uruan, Nigeria has the lowest absorptivity compared to the clay samples from the areas studied so far. The temperature predictor model also shows that the clay presents the least temperature value during the highest daytime of between 13 hours and 14 hours. The resistivity and thermal conductivity compares better with the values for kaolin obtained elsewhere showing that the clay sample from Uruan local government area, Nigeria contains kaolin.
Keywords: Clay, thermal properties, Uruan, conductivity, resistivity

1.0 INTRODUCTION

Information on the rate of heat flow through materials whether through conduction (solid), convection (liquid) or through the process of radiation (space) is necessary in civil engineering and in building industry for comfort of home seekers. In an event that many building materials such as concrete, zinc, glass etc, which are heat conductors are so expensive there is need for naturally locally sourced materials to be used as alternative building materials. Common local materials that could be used as building materials found in this part includes clay soils, *Musa paradisiaca, Thaumatococus danielli, Cocos Nucifera, Macaranga barteri,* and oil and raffia palms etc. These materials could be sourced from river banks and in the forest at no financial. Their effectiveness as thermal insulators especially in the day time determines the choice of any of the materials as used in buildings. Clay is natural and very fine grained, unconsolidated rock material, which develops plasticity when mixed with limited water. Clay soils are formed through natural processes such as weathering of rocks within geological formation. Clay is composed of oxides of silica, alumina, iron, alkali and alkaline earth, and some crystalline substances known as clay minerals (Folaranmi, 2009). The mineral contents of these clays are known to affect some physical properties of the material such as thermal conductivity, plasticity, colour and liquid limit, Clay soils are grouped according to their colors as red, gray, white and yellow (Bamigbala, 2001). For the purpose of considering clay for building houses and the need to enhance its civil engineering potential it is burnt to form bricks as it is hard and strong when fired.

Thermal properties of any material that determine its suitability as a thermal insulator are thermal conductivity, specific heat capacity, thermal diffusivity, thermal absorptivity and bulk density. Thermal conductivity of a body is the property of the body which describes the rate of transport of heat energy through the body as a result of temperature gradient. This property of the body could explain why earthen pots are used to store drinking water and as walling material in Akwa Ibom State.

Various studies have been conducted to investigate the thermal properties of different locally sourced materials in Akwa Ibom State, Nigeria. These include thermal conductivity of *musa paradisiaca* and t*haumatococus danielli* (Essien *et al.*, 2016), *Cocos Nucifera* (Etuk, *et al*., 2005) and *macaranga barteri* (Etuk *et al*., 2009) etc. Thermal conductivity of clay soils from Salta, Ntewa and Kigombya show values ranged from 0.13 $Wm^{-1}k^{-1}$ and 0.30 $Wm^{-1}k^{-1}$ at room temperature (Mukwasibwe 2007), thermal conductivity of Koalin have been investigated and value obtained as range between 0.3 $Wm^{-1}k^{-1}$ to 1.5 $Wm^{-1}k^{-1}$ (Owalu, 2008).

The comparison of the thermal properties of different clay materials in Akwa Ibom State, Nigeria, as potential thermal insulators was conducted by Etuk *et al.*, (2003), similarly Adekunle *et al*., (2014), Owate and Edike (1986) investigated the characteristic properties of some Nigerian clays from other parts of Nigeria different from those investigated by Etuk *et al*.

This study is aimed at investigating the thermal properties of gray clay soil obtained from a river bank in Akwa Ibom State, Nigeria and compare the result with those obtained from other parts of Akwa Ibom State, Nigeria. The thermal properties investigated in this work are thermal conductivity (k), specific heat capacity (c), thermal diffusivity (D) and bulk density (ρ).

2.0 THEORY

The thermal conductivity of a porous material is obtained as a combination of the contribution of the thermal conductivities of the different phases of the materials which includes solid, liquid and gaseous phases as presented in equation below (Essien *et al.*, 2016)

$$\lambda = \lambda_{solid} + \lambda_{rad} + \lambda_{gas} + \lambda_{couple} \quad (1)$$

The total conductivity is λ, while the first, second, third terms are the thermal conductivities contribution from the respective phases while the coupling term accounts for the gas condition that thermally short circuits the high thermal resistance between the points within the fibres.

The thermal transport equation through a solid material is given as (Ekpe *et al.*, 1996)

$$\frac{\partial^2 T}{\partial X^2} = \frac{\rho c}{\lambda}\frac{\partial T}{\partial t} \quad (2)$$

The general solution of Eq. (2) is given as

$$T(x,t) = A_0 + \sum_{m=1}^{\infty} A_m \exp\{i(m\omega t + \delta_m x)\} \quad (3)$$

where

$$\delta_m = \sqrt{m}\,(\frac{\omega\rho c}{2\lambda})^{1/2}(1-i) \quad (4)$$

Substituting Eq. (4) into Eq. (3) modified the transport equation to obtain

$$T(x,t) = T_m - A_0 \exp(-\alpha x)\cos\{\omega(t - t_0 - \frac{\alpha x}{\omega})\} \quad (5)$$

A_o is the daily temperature amplitude at x=0^0c

t is the time of the day in hours

x is the coordinate through the thickness of the material studied

t_0 is the time of minimum temperature at the surface in hours

α is thermal absorptivity

w is the angular velocity per day, $\omega = 2\pi T^{-1}$

T_m is calculated from the hourly surface temperature average T_{av}(0^0c)

$$T_m = \sum_{n=1}^{24} \frac{T_{av}}{24} \quad (6)$$

Hence Eq. (5) becomes

$$T(x,t) = T_m - A_0 \exp(-\alpha x)\cos\{\frac{\pi}{12}(t - t_0 - \frac{12\alpha x}{\pi})\} \quad (7)$$

This is a temperature predictor model for a particular material in a particular time of the day.

3.0 MATERIALS AND METHOD

3.1 Sample collection

The clay sample used for the study was obtained from the bank of a river at Ifiayong in Uruan, Akwa Ibom State, Nigeria. Uruan situates between latitude 6° 40` and longitude 7° 20` E in the North and West. It is bounded in the East by Odukpani Local, Government Area in Cross River State, in the South by Okobo Local Government Area, in the West by Nsit Atai and Ibesikpo Asutan Local Government Areas and in the North by Itu Local Government Area. The clay samples were taken to the civil engineering laboratory of the University of Uyo, Uyo, Nigeria for drying, crushing and sieving. The clay was then moulded into three circular shapes of 11.0 cm diameter each and 0.59 cm, 0.61 cm, and 0.63 cm thickness respectively. The moulded samples were again subjected to slow drying to avoid the problem of redistribution of water due to temperature gradient.

3.2 Experimental Procedure

The thermal conductivity of the clay material studied was determined using the steady state method using Lee's disc apparatus and according to method of (Essien *et al.*, 2016). This involves the measurement of the flow temperature through the clay materials at steady state. At steady state, the rate of emission of heat at the exposed surface is equal to the heat conducted through the material.

The thermal conductivity (λ) is obtained from a modified Fourier heat equation given as

$$\lambda = \frac{mc_p S_c h}{A(\theta_f - \theta_i)}, \quad 8$$

where A is the area of the sample in m^2, c_p is the specific heat capacity at constant pressure of the disc J $(kgk)^{-1}$, h is the thickness (m) of the fibre board, m is the mass of the disc and S_c is the slope of the cooling curve, θ_f, and θ_i are the upper and lower steady state temperatures measured in k and λ in $Wm^{-1}k^{-1}$. Other thermal properties such as C_p, density (ρ) were determined experimentally using method of (Etuk.,2010) while thermal diffusivity (D) and thermal absorptivity (α) were obtained from Eq. (9) (Khatry *et al.*, 1978) and 10 (Sodha *et al.*,1997) and the thermal resistivity (r) the reciprocal of the thermal conductivity(Ajibola and Onabanjo, 1995).

$$D = \frac{\lambda}{\rho c_p} \quad 9$$

$$\alpha = \sqrt{\frac{\omega}{2D}} \quad 10$$

where ω is the angular frequency.

4.0 RESULT AND DISCUSSION

The thermal properties of the studied clay sample and their mean value are presented in Table 1. . The thermal conductivity of the clay sample ranges between 0.371 -0.405$Wm^{-1}K^{-1}$ with a mean of 0.393 $Wm^{-1}K^{-1}$ for a mean bulk density of 1.69 ×10^{-3} kg/m^3, the thermal diffusivity is ranges between 1.70 -2.1 ×10^{-7} m^2s^{-1} with a mean of 1.98m^2s^{-1} while the mean thermal resistivity is 2.55 mkW^{-1}. The mean values of the thermal properties of the clay sample are substituted into equation 7 to obtained equation 11 as a model to aid in predicting the temperature of the clay sample for a particular thickness and nature of the sample;

$$T(x,t) = T_m - A_0 \exp(-13.60x)\cos\{0.262(t - t_0 - 51.94x)\} \quad 11$$

Table 1: Thermal properties of the clay sample

Sample code	λ ($Wm^{-1}k^{-1}$)	ρx10^3 kgm^{-3}	C_p ×10^3 $Jkg^{-1}k^{-1}$	D x 10^{-7} m^2s^{-1}	α (m^{-1})	r (mkW^{-1})
M_1	0.403	1.678	1.121	2.142	13.02	2.48
M_2	0.405	1.652	1.166	2.103	13.15	2.47
M_3	0.371	1.727	1.264	1.700	14.62	2.70
Mean	0.393	1.686	1.183	1.982	13.60	2.55

The resistivity of this clay sample is within range of kaolin clay (Etuk, *et al.*, 2003) while the thermal conductivity is within the range obtained elsewhere (Owalu 2008) and the comparison of the temperature predictor model of the clay from Uruan local government of Akwa Ibom State with other clays from other parts of the state shows the Uruan clay having lower absorptivity of 13.60 m^{-1}. The clay sample studied has a mean specific heat capacity of 1.18 J/Kgk which is comparable to the 1.19 J/KgK obtained for kaolin from Itu local government area of Akwa Ibom State, Nigeria. (Etuk, *et al.*, 2003)**.**

5.0 CONCLUSION

From the experimental result, it could be seen that the clay sample from Uruan in Akwa Ibom State has a lower absorptivity compared to clay samples from other parts of the State. The resistivity and thermal conductivity compares better with the values for kaolin obtained elsewhere showing that the clay sample from Uruan contains kaolin. The temperature predictor model also show that at the highest temperature period of between 13 hours to 14 hours this clay sample records a low calculated temperature. Therefore the clay sample from Uruan has a better potential as thermal insulator compared to the already investigated clay samples from other parts of the State.

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