DETERMINATION OF THERMAL CONDUCTIVITIES OF SOME AGRO-WASTE MATERIALS.

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ABSTRACT

In our big cities and rural areas, there are many agro-waste materials found littered about. These cause an environmental nuisance and mar the beauty of our landscapes. This work was undertaken to determine the engineering properties of the agro-waste materials, especially their thermal conductivity, in order to be able to utilize these materials in construction and manufacturing industries. Lee's disc apparatus was used to conduct the experiments. The following results were obtained for the thermal conductivity (Wm^{-1} K^{-1}) of such agro-waste materials, coconut shell, 0.0680, cow dung, 0.1587, sponge gourd fibre, 0.1604, groundnut shell, 0.1604, palm kernel shell 0.1630, maize cob, 0.1647 mango seed shell, 0.1656, bean shell 0.1683 and rice husk , 0.1692. the effectiveness of the Lee's disc apparatus was confirmed, by using it on materials whose thermal conductivity values are known. Thermal conductivity values obtained for the agro-waste materials show that they can be used as insulators in building, and preservation of agricultural products.

Key words:- Agro-waste materials, Thermal Conductivity, Lee's disc apparatus, Insulators.

INTRODUCTION

The search for new materials for industrial use is a continuous process in engineering. Fortunately, many agro-waste materials are available in our environment. Attempts to discover their electrical, mechanical and chemical properties can lead to their suitability for use in industries. Thermal conductivity is an important property of a material of medium, that indicates the quantity of heat that will flow across a unit area of the material per unit time if the temperature gradient is unity (Ighodalo and Okoebor, 1996). The value of thermal conductivity determines, to a large extent, the suitability of a material for a given application. If the value of the thermal conductivity is high, such a material makes good conductor of heat. Heat is transfer of energy due to

Temperature difference (Nelkon, 1997). If, however, the thermal conductivity is low such a material makes a good insulator of heat. Heat transfer is a science of spontaneous irreversible processes of heat propagation in space.

By a process of heat propagation, heat is exchanged in internal energy between individual elements and regions of the medium considered (Isachanko et al, 1995). Heat can be transmitted in three ways, by conduction, convection and thermal radiation (Isachanko et al, 1995). The property of thermal conductivity is associated with the conduction of heat, which is the mean concern in this work. Heat energy transfer by conduction is on a molecular scale with no movement of macroscopic portions of matter relative to one another (Rogers and Mayhew, 1980). This also can be translated simply by stating that conduction is the process of molecular transport of heat in bodies (or between them), due to temperature variation in the medium considered (Isachanko et al, 1995).

Fourier's law forms the basis of all calculations of heat transfer by conduction. The law states that the rate of flow of heat through a single homogenous solid is directly proportional to the area, A, of the section at right angle to the direction of heat flow, and to the change of temperature with respect to the length of the path of heat flow dt/dx (Isachanko et al, 1995)

Rate of heat flow, $Q \alpha A \frac{dt}{dx}$

That is,

$$Q = KA \frac{dt}{dx} \quad \text{.....................(1)}$$

In which K in the thermal conductivity ((Isachanko et al, 1995). Therefore Eq. (1) is taken as the mathematical expression of the basic law of heat conduction. In the general case, thermal conduction depends on temperature, pressure and nature of he substance.

Usually, the thermal conductivity of various materials is determined experimentally. Efforts at obtaining the thermal conductivity of some materials have been made locally. Ezeilo (1980 and 1981) worked on the thermal conductivity of building materials, some Nigerian timbers and sand concrete mixtures, respectively. Also, Iloeje and Odukwe (1983) did work on the effective thermal conductivity of materials insulators; the materials tested were raffia palm and roofing grass. Recently, Ighodalo and Okoebor (1996) worked on the thermal conductivity of some local waste materials including: - rice husk, palm- kernel shells and wood shavings.

The procedure of measuring thermal conductivity can be divided into two methods, namely, steady and variable state methods. Each of these ways may be divided further into rod, plate, cylinder and sphere methods. Almost all precise measurements are made using steady state methods, though some of the steady state methods are rather imprecise. The variable state method are generally simpler and more quickly performed though less precise than the steady state ones. Ighodalo and Okoebor (1996) used the principles of

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steady state method to construct the test equipment, which was based on the same principles as that employed by Iloeje and Udokwe (1983). For the present study a standard laboratory's Lee's (Tyler, 1979) disc apparatus was used, based on the principle of steady- state method. According to Tyler (1979), Lee (1908) simplified Eq. (1). Thus,

$$\frac{Q}{A} = \frac{K(t_1 - t_2)}{X} \quad \text{.....................(2)}$$

To determine "K" the thermal conductivity of materials. In Eq (2) where Q is a constant rate, t_1 and t_2 are the temperature of the two thermocouples used to measure the steady-state temperature. "X" is the distance separating the two thermocouples and "A" is the cross section area of the sample.

The aim of the work is to determine the thermal conductivity of some of agro-waste materials, in view of using the materials in construction and manufacturing industries. As a result of the work, small – scale industries may spring up in processing these agro-waste materials for the applications, which they have been determined, and thereby creating opportunities to the people and reducing the cost of the processed materials.

THEORY:

When the steady state has been attained, the rate at which heat is conducted across the specimen disc is equal to the rate at which it is emitted from the exposed surfaces of the metal slab (thin disc). Therefore, heat conducted across is

$$\frac{K\pi D^2}{4} \times \frac{(\theta_1 - \theta_2)}{d} \quad \text{....................(3)}$$

Where K is the thermal conductivity of the specimen disc, D its diameter, and its thickness "d" the readings of the thermometer is T_1 and T_2 in the steady-state θ_1 and θ_2C. If the mass of the slab (thin disc) in "M", its specific heat capacity "S", and the rate of cooling at θ_2 C is $\frac{(d\theta)}{(dt)}$ (Obtained from drawing a tangent to the cooling curve at θ_2). Then the rate of loss of heat from the lower face and the sides of the slab is

$$MS\frac{(d\theta)}{(dt)} \quad \text{.........................(4)}$$

By combining Eqs. (3) and (4),

$$\frac{K\pi D^2}{4} \times \frac{(\theta_1 - \theta_2)}{d} = MS\frac{(d\theta)}{(dt)} \quad \text{........(5)}$$

From which K is determined.

However, since by Newton's Law of cooling the rate of loss of heat is proportional to the excess temperature of a body over that of its surrounding equation (5) may be written in this form:

$$\frac{K\pi D^2}{4} \times \frac{(\theta_1 - \theta_2)}{d} = \text{Constant}\ (\theta_2 - \theta_A)$$

Where θ_2 is the air temperature. Hence is for a specimen of another material of thermal conductivity K* and d* the steady state temperature θ_1 and θ_2 a comparison of the thermal conductivity of the two specimens can be obtained without he necessity of proceeding to the second part of the experiment (cooling curve).

$$\frac{K}{K'} = \frac{d(\theta_2 - \theta A)(\theta_1' - \theta_2'}{d'(\theta'_2 - \theta A)(\theta_1 - \theta_2} \quad \text{..........(6)}$$

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The steady state temperature θ_1 and θ_2 are tested for all the specimens and their values of thermal conductivity were computed in comparison to the calculation value for that of coconut shell (obtained from equation (5), using equation (6)).

MATERIALS AND METHODS

Materials

The materials selected for this study are as follows: Rice husk, bean shell groundnut shell, maize cob, coconut, mango bean shell, palm kernel shell sponge gourd fibre and cow dung.

Preparation of Materials

Each of the materials was collected in various places in a reasonable quantity, cleaned properly and dried thoroughly in the sun for 2 days. Each was later granulated using a mortar and pestle and sieved with a standard 4.25 um. A suitable mould was constructed that produced the specimen in a disc form with a diameter of 85 mm and thickness of 10mm. Each of the materials was then mixed with a suitable binder (Gum Arabic was used for this purpose) and then moulded with a compression of 49N in order to ensure continuity in the particles of the specimens and to remove any trapped air. The specimens were moulded in turns and carefully removed from the pre-lubricated mould and then dried in the sun for two days. Thereafter, they were tested using the Lee's disc apparatus to determine their thermal conductivity.

Description of the Test Apparatus and Procedures:

Test Equipment:

Figure 1, shows standard Laboratory Lee's apparatus. This consists of a cylindrical slab of metal "C" (of brass) suspended by strings from a heavy stand. On this rest a hollow cylinder "A" through which steam from a steam boiler "D" is passed and the specimen in the form of a think disc B of the same diameter (85mm) is placed between "A" and "C". There is a bored hole near the bottom of cylinder "A" and another "C" to take two thermometers and the two metal cylinders which are nickel-plated to give them the same emissive power. A stopwatch and a screw gauge are required

Procedure

The apparatus was suspended by strings from a heavy stand as shown in Fig. 1 and with flat surface of the disc horizontal. Steam was passed through the cylinder A, and the temperature indicated by the two thermometers T_1 and T_2 are read when the steady state has been reached between 30 minutes to 60 minutes. T_1 and T_2 are then interchanged and their temperature again taken when steadies. Cylinder C was then heated directly from A by removing the specimen and T_2 records a temperature up to 5°C higher than that recorded in the steady state. Cylinder A is now removed and the specimen placed on C and allowed to cool, and readings of the temperature are taken at half-minute

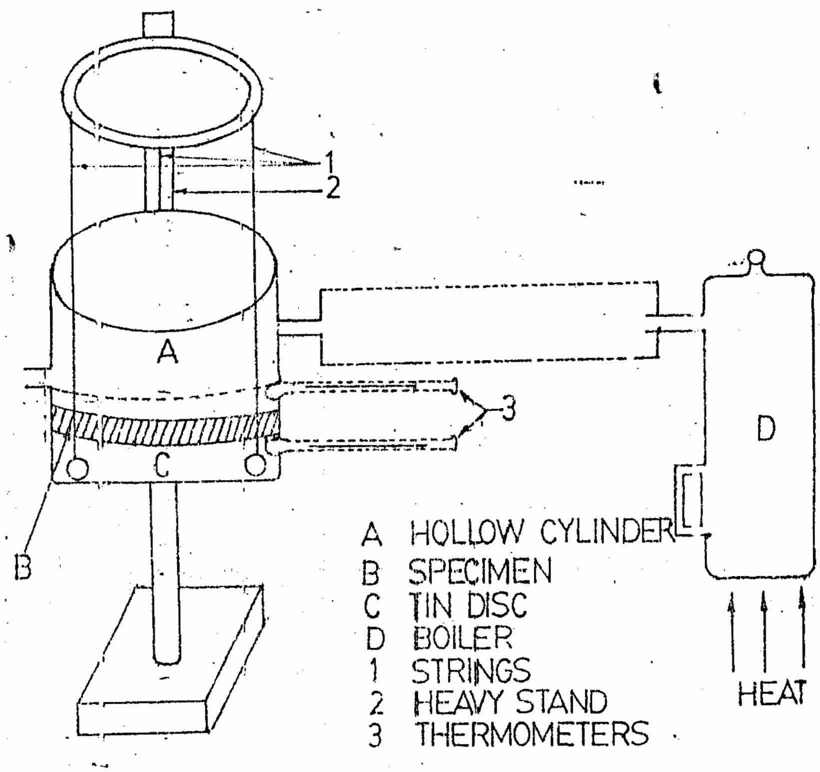

FIG. 1 THE LEES APPARATUS

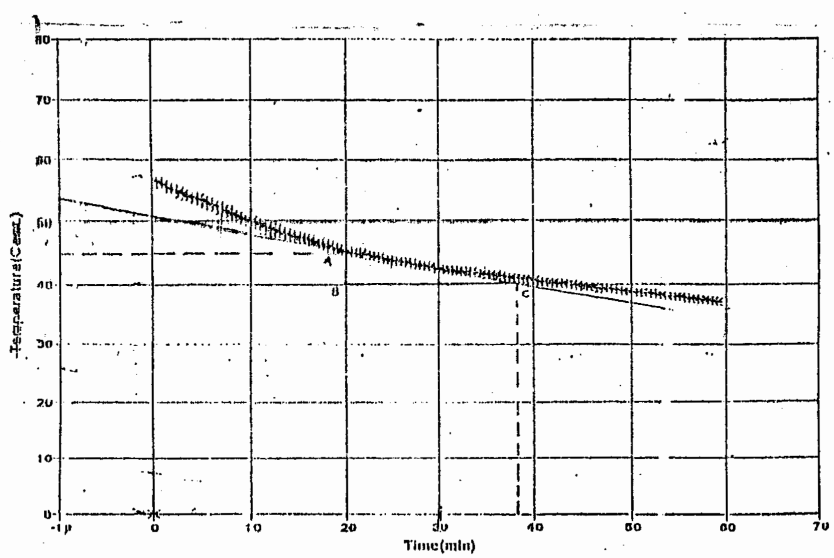

FIG 2 Graph(Cooling Curve) of Temperature and Cooling Time of Coconut Shell

intervals, until the temperature falls to about 10°C below the steady state temperature. The diameter of the specimen is then measured and its thickness is taken by using a screw gauge. Finally, the mass of the slab "C" is measured. Statistical method was used to analyse the results.

Effectiveness Test of the Lee's Disc Apparatus:

The effectiveness test of the Lee's disc apparatus was carried out on the documented thermal conductivity values of known materials, such as clay, asbestos sheet, and cotton wool and window glass.

The deviation from these known values were computed and the mean of the differences of the known values of the thermal conductivity of the materials and their calculated values from Eq. (2), which gives the correction factor.

That is $K = K_s + K_c$ ..... (7)

Where K will be the overall thermal conductivity, K_s the calculated thermal conductivity of the material K_c is the correction factor.

The Results and Discussion:

For the purpose of validating the Lee's disc apparatus thermal conductivity values were determined using the apparatus for some materials with already documented K values. Each material was cut into a diameter of 0.085m. The temperature of steam was maintained at 99°C. The upper and lower thermometer readings were taken twice for each material from which their mean steady temperatures were obtained. Equation (2) was used to calculate their thermal conductivity, using the calculated value of K for coconut shell.

For coconut shell, the following data were obtained from the experiment.

Diameter of the specimen (D) = 0.085m

Thickness of specimen (d) 0.01m

Mass of metal slab (C) 0.65akg

Specific heat of metal (C) =380Jkgk (from table)

Rate of cooling slab $= \frac{(d\theta)}{(dt)}$

(at θ_2°C from graph) (Fig. 2)

Slope of graph

$$= \frac{(A - B)}{B - C}$$

$$= \frac{45 - 40}{37 - 20}$$

$$\frac{(d\theta)}{(dt)} = 0.0049$$

Rate of cooling of slab $= 0.0049 ks^{-1}$

Applying Eq. (5)

K_c for coconut shell is determined to be $0.0465 \ Wm^{-1} K^{-1}$

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Table 1 Comparison between calculated and references values

S/N	Material	Thick in mm	Mean Steady Temp. (°C) 01	02	Room Temp (°C)	Cal (Ks) Thermal Cond. $Wm^{-1} K^{-1}$	Reference (Kr) Thermal Cond. $Wm^{-1} K^{-1}$	Difference (Kr – Ks) $Wm^{-1} K^{-1}$
1	Cotton Wool	10	99	51.5	33	0.04014	0.0603	0.0202
2.	Clay	10	99	54.4	33	0.0510	0.0729	0.0219
3.	Asbestos Sheet	5	99	81.2	33	0.1438	0.1661	0.0223
4.	Window glass	5	99	92.9	33	0.5214	0.519-1.0553	
							Mean K_c	0.0215

values calculated from the test apparatus compare favourably well with the references values obtained from table. The apparatus can thus be said to be effective. From the mean difference Kc that had been calculated can now be added to test apparatus calculations as a correcting factor. Thus, the apparatus equation (7) becomes

$$K = Ks + 0.0215 \qquad (8)$$

Table 2 shows a comparison of corrected values with reference values. A closer correlation can be observed between these values, which establishes the functionality of equation (7).

Table 2: Comparison of corrected values with reference Values.

S/No	Materials	Calculated Ks Thermal Conductivity $Wm^{-1} K^{-1}$	Corrected Kc Values $Wm^{-1} K^{-1}$	Reference Kr Values $Wm^{-1} K^{-1}$
1	Cotton Wool	0.0401± 0.020	0.0202	0.0603
2.	Clay	0.0510±0.026	0.0219	0.0729
3.	Asbestos Sheet	0.1438±0.072	0.0223	0.1661
4.	Window glass	0.5214±0.261		0.519-1.0553

A closer correlation can be observed between corresponding Ks and K_r values which establishes the functionality of equation (7). Tests were

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then conducted for coconut shell, cow dung, sponge gourd fibre, groundnut shell, palm kernel shell, maize cob, mango seed shell, rice husk and shell.

Values obtained for these materials are shown in table 3. Calculated thermal conductivity values for these materials are seen to be quite low when compared with the values for a common insulator such as asbestos sheet (K=0.1616 $Wm^{-1} K^{-1}$).

Table 3: Results obtained for the Thermal Conductivity of selected agro-waste materials.

S/N	Material	Thick. in mm	Mean Steady Temp. (°C) 01	02	Room Temp (°C)	Calculated Thermal Cond. $Wm^{-1} K^{-1}$	Overall values of the determined (K) $Wm^{-1} K^{-1}$
1.	Coconut Shell	10	99	53.1	33	0.046± 0.023	0.0680
2.	Cow dung	10	99	70.2	33	0.1372±0.069	0.1587
3.	Sponge gourd Fibre	10	99	70.4	33	0.1389±0.069	0.1604
4.	Groundnut Shell	10	99	70.6	33	0.1406±0.070	0.1604
5.	Palm Kernel	10	99	70.7	33	0.1415±0.071	0.1630
6.	Maize Cob	10	99	70.9	33	0.1432±0.072	0.1647
7.	Mango Seed Shell	10	99	71.0	33	0.1441±0.072	0.1656
8.	Bean Shell	10	99	71.3	33	0.1468±0.073	0.1683
9.	Rice husk	10	99	71.4	33	0.1477±0.074	0.1692

Table 4: Given Standard values of "K" for insulator for form buildings (Mark, 1978).

S/No.	Materials	Thermal Conductivity $Wm^{-1} K^{-1}$
1.	Asbestos Sheet	0.1661
2.	Particle board (Medium density)	0.115
3.	Hardboard (High density)	0.135
4.	Wood (Maple, Oark)	0.158

Conclusion:

Thermal conductivity values for agro-waste materials have been successfully determined. The values obtained for those materials show that they can be used as insulators such as building and preservation of agricultural products. See table 4 for given standard values for K – values for insulator for farm buildings.

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