International Journal of Innovation and Scientific Research
ISSN 2351-8014 Vol. 9 No. 2 Sep. 2014, pp. 335-343

http://www.ijisr.issr-journals.org/

DESIGN OF LEE'S DISC ELECTRICAL METHOD FOR DETERMINING THERMAL CONDUCTIVITY OF A POOR CONDUCTOR IN THE FORM OF A FLAT DISC

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ABSTRACT: This experiment was carried out to design modified Lee's disc method of measuring the thermal conductivity of a poor conductor in the form of a flat disc. The modified Lee's disc set-up is equipped with various types of electrical device and probes. The components used to implement the design were chosen because of their ability to withstand high voltage and temperature levels. Most of these instruments are utilized in industrial settings. The designed instrument was used to test the thermal conductivity of some low insulating materials. The value of *k* which is the rate of flow of heat through a material per unit area per unit temperature gradient was determined. The units of *k* are $Wm^{-1}K^{-1}$ (from $Js^{-1}m^{-1}K^{-1}$).The thermal conductivity of the selected materials was tested to validate the effectiveness of the modified design.

KEYWORDS: Conductor, heat transfer, Lee disc, temperature and thermal conductivity.

1 INTRODUCTION

Thermal conductivity is defined as the property of a material's ability to conduct heat as a result of temperature difference under steady state boundary condition. It appears primarily in Fourier's Law for heat conduction [1].Thermal properties depends solely on the temperature gradient which much occur for heat to be transferred [2].Thermal conductivity, referred to as a transport property, provides an indication of the rate at which energy is transferred by the diffusion process. It depends on the physical structure of matter, atomic and molecular, which is related to the state of the matter [3].Considering the importance of thermal conductivity in The analysis of combustion and pyrolysis of wood exposed to fire [4-5], the energy design and evaluation of energy performance of wood-frame buildings [6],Increase in the conversion rate and provision of more electricity for on-board controls and creature comforts since it is an important properties of thermoelectric materials[7] and in the design of insulator for refrigerators, coolers and food flask[8].The knowledge of thermal conductivity is therefore vital in understanding and modelling heat transfer processes in materials. For example, Thermal conductivity that represents quantitatively the ability of wood to conduct heat is of great significance in heat transfer modeling [9]. Design and development engineers continually demand thermal and electrical property data of technically important materials. Often these data are not in the published literature and immediately measurements must be performed. Since only a handful of laboratories have the proven expertise to make such measurements, usually they are performed by inexperienced personnel using unproven apparatus [10]. Therefore there is need to develop a suitable reproducible method for the estimation of thermal conductivity of materials in a developing economy such as that of Nigeria[11].Although development has been registered over the years in the design of thermal conductivity measuring instruments, these technology has not really benefited the developing countries like Nigeria where these instruments still remains out of reach to researchers either because of the price or it accessibility. Various articles have been published on the thermal conductivity measurements of various insulating materials here in Nigeria [11-19]. This publication suggests the design, construction and testing of models for a quick estimation of thermal conductivity of materials based on lee's disc apparatus[20-22]. Hence, this research work sought to chart her course in that same direction but with a better design that minimizes errors in measurement.

2 MATERIALS AND METHODS

2.1 BASIC WORKING PRINCIPLE OF LEE'S DISC APPARATUS

The experimental set up is shown in Figure 1. The brass disc B is hung from the stand with the help of three strings. On the brass disc, the bad conductor sample disc 'S' is placed and over that a metallic disc M is placed. On the metallic disc, a heating chamber, H with facility for steam-in and steam-out is placed.

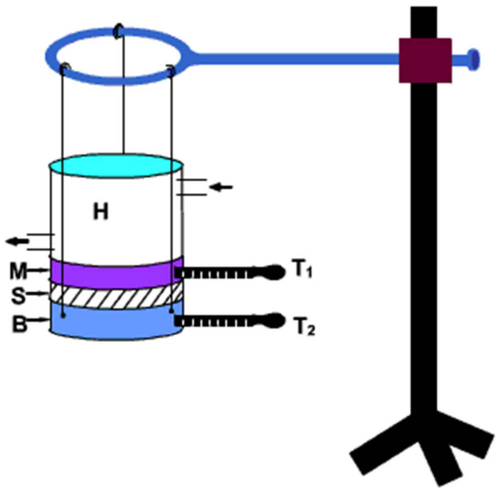

Fig 1 Lee's disc set-up Ref [23]

2.2 THEORY

When a steady state is reached with T_1 and T_2 the temperatures of metallic disc M and brass disc B. The temperature difference between the two ends of bad conductor is $(T_1 - T_2)$. The rate of heat conducted through the bad conductor is:

$$\mathbf{Q_1} = \frac{\mathbf{KA(T_1 - T_2)}}{\mathbf{d}} \quad (1)$$

Where, 'd' is thickness of the bad conductor and 'A' is the cross sectional area. The rate of heat lost by the brass disc to the surrounding under steady state is,

$$\boldsymbol{Q_2} = \mathrm{mc}\left(\frac{dT}{dt}\right)_{T_2} \quad (2)$$

Where m-mass of the brass disc, C is the heat capacity of brass disc and dT/dt is its rate of cooling at T_2
From equation (1) and (2),

$$\mathbf{K} = \frac{\mathrm{m\,c\,d}\left(\frac{\mathrm{dT}}{\mathrm{dt}}\right)_{\mathrm{T_2}}}{\mathrm{A(T_1 - T_2)}} \quad (3)$$

By measuring, $(dT/dt)_{T_2}$ and (T_1-T_2) using Lee's apparatus the thermal conductivity K can be determined.

2.3 THE MODIFIED DESIGN OF LEE'S DISC METHOD FOR DETERMING THERMAL CONDUCTIVITY OF SOLID

2.3.1 BASIC COMPONENT

Temperature Controller: Controllers receive sensor signals and control heaters or other devices to maintain a preset temperature.

Contactor: a contactor is a machine that is used to switch on a power or control circuit remotely within a motor. The activation of the contactor happens when a current or voltage lower than the required amount is sent to the control input on the contactor. The contactor is active when current passes through the electromagnet on the contactor which causes an electromagnetic field to be produced drawing the moving and fixed contacts together. When the coil in the contactor has no electrical charge the core of the electromagnet is moved by gravity back to its starting position [24].

Thermocouple: The temperature sensor is the "Nervous system'' of the temperature controller .Just as one rely on his/her sense of touch, so a temperature controller relies completely on the sensor. The controller uses the sensor signal to decide whether to turn the heater on or off to maintain the desired set point temperature. It consists of two dissimilar conductors that contact each other at one or more spots. It produces a voltage when the temperature of one of the spots differs from the reference temperature at other parts of the circuit [25]. Thermocouples are a widely used type of temperature sensor for measurement and control, and can also convert a temperature gradient into electricity. Commercial thermocouples are inexpensive, interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures.

Advantages of thermocouple sensor

- Simple and rugged
- High temperature operation
- Low cost
- No resistance lead wire problem
- Point temperature sensing
- Fastest response to temperature changes

Nozzle Heater: This material offers much higher thermal conductivity than mica and hard ceramic insulators used in conventional heaters. A thin layer of the high thermal conductive material electrically insulates the element wire from the inside diameter of the heater sheath. A thicker, low thermal conductivity layer backs up the element wire, directing the heat inward toward the heated part. The result is more efficient heat transfer—a performance solution that lowers element wire temperatures and increases heater life [26]. These heaters can be controlled accurately while dealing with sensitive material such as Nylon 66 with 40% glass filled. These are energy efficient durable and can withstand high temperatures [27]. Heater operating temperatures up to 1400°F (760°C). Watt densities up to 230 W/in^2 (35.6 W/cm^2) are available on small diameter nozzle and Maximum voltage up to 240V.

Brass Disc: Brass is an alloy of copper and zinc of historical and enduring importance because of its hardness and workability. The metal was chosen because of it good electrical conductivity. The size of the brass was machined to 50 mm in diameter and 13mm thick. The specific heat capacity of brass is 0.38 KJ/W℃ the faces were also smoothen for good thermal contact.

Fig 2. Cutting and Turning of the Metal Brass

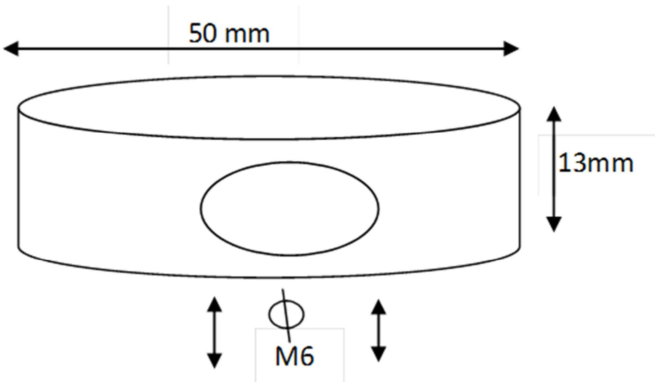

Fig 3. The metal disc with dimension

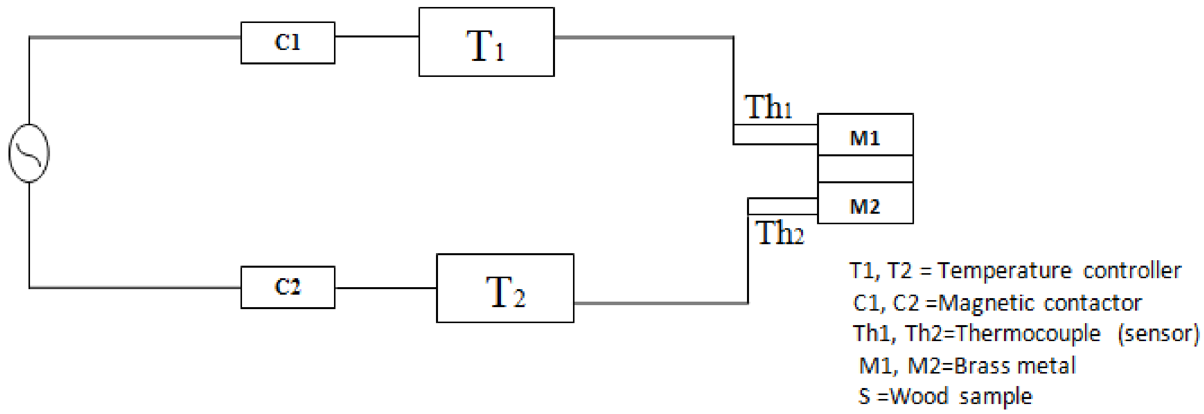

Fig 3 Block Diagram of the electrical set-up

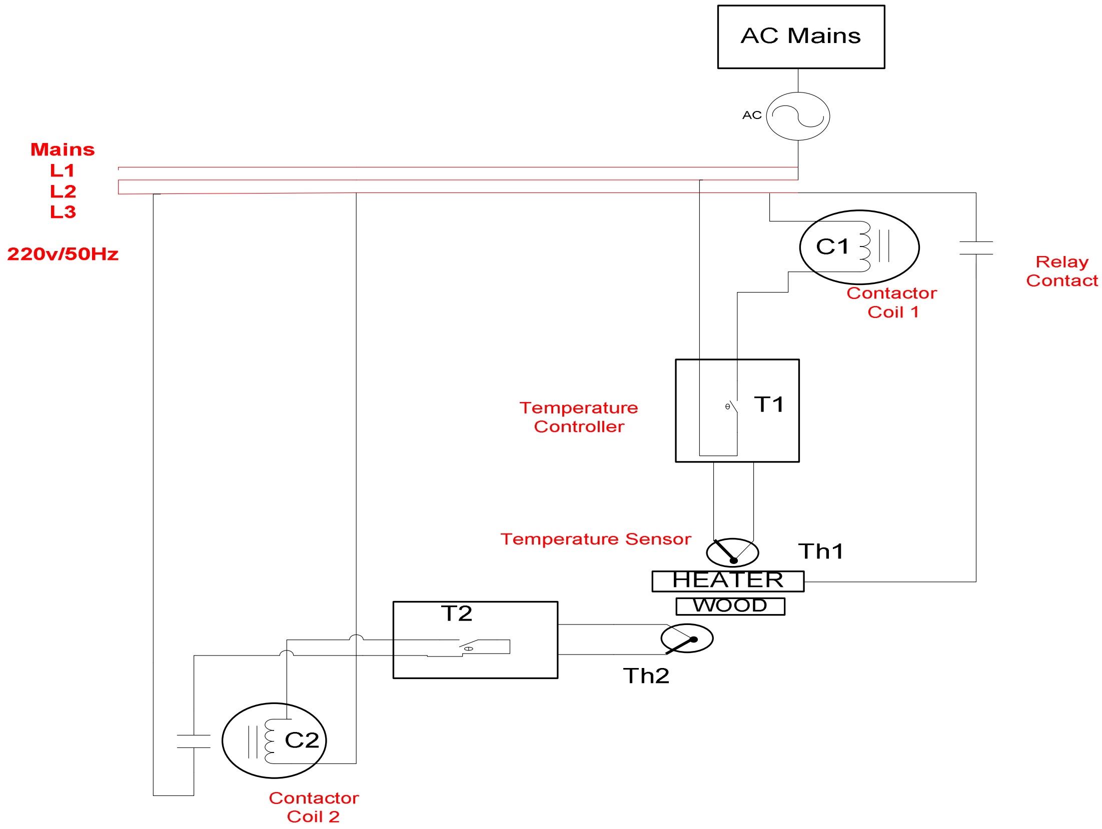

Fig 4 Circuit Diagram of the Electrical set-up

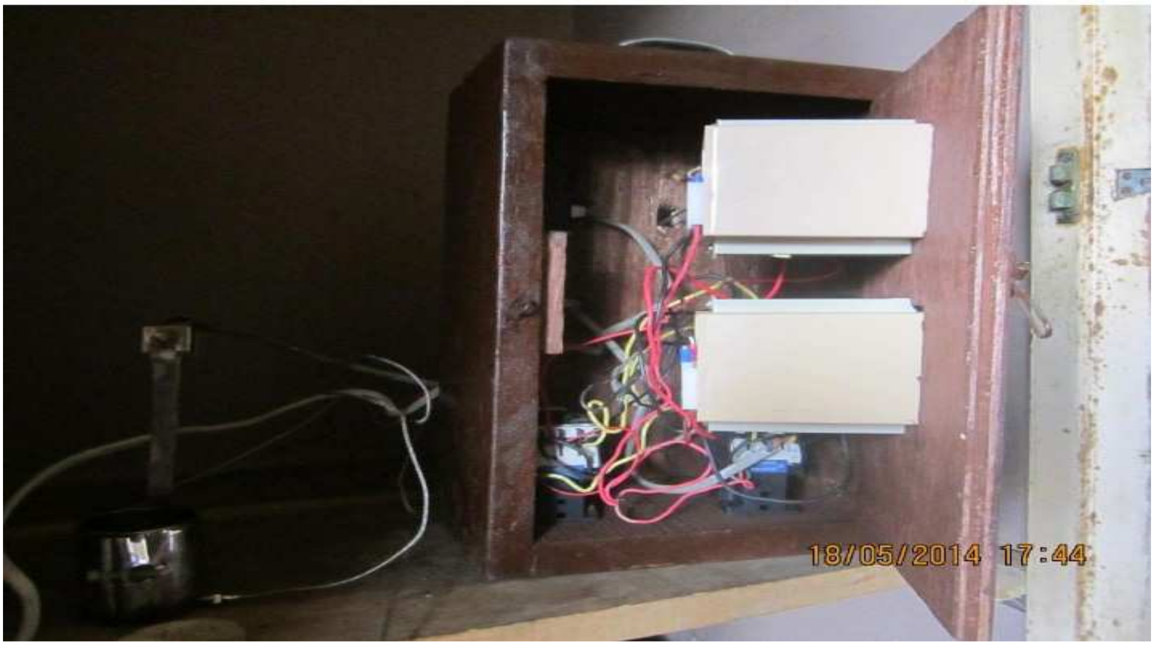

Fig 5 The front and inner components of the Electrical set-up

2.4 MODE OF OPERATION

The Block diagram depicts a Temperature controller for the determination of thermal conductivity of wood. The circuit model comprises of two digital temperature controllers (T1 and T2), two magnetic Contactor switches (C1 and C2), Two Thermo couple sensors (Th1 and Th2) and a nozzle heater H1.In the circuit configuration below, at power ON, the contactor switch C1 is activated by the source lines L2 (220v/50Hz) to supply power to C1 the heater H1. The temperature controller T1 is also activated to a preset temperature value t. The heat from the heater is transferred to the Metal Disc M1. The heat from M1 is then transferred to the material specimen placed in between metal disc M1 and M2.The two sensors Th1 and Th2 connected to the metal discs are used to sense temperature changes in the metal. When the thermocouple sensor Th1 connected to the first metal disc reaches the preset temperature t, the contactor switch c1 breaks power supply to the heater H1.However, the heat from the wood is transferred to second metal disc m2. The temperature of M2 rises till it reaches a steady temperature T2 in the second Temperature controller. The thermal conductivity value is calculated in intervals of 5 minutes until the temperature controller T2 indicates a steady temperature value. The components used to implement the design were chosen because of their ability to withstand high voltage and temperature levels. Most of these instruments are utilized in industrial settings.

CALCULATION

$$P=I^2R=KA\left(\frac{t_2-t_1}{d}\right) \quad (4)$$

P = electric power (Watts)
R = Resistance of the heating element (Ω)
t_1 , t_2 = temperature indicated by the respective thermocouple
A = area of the flat face of the specimen (m^2)
I = current passed to the heating element (Ampere)
d = thickness of the material

$$A = \frac{\pi d^2}{4} \quad (5)$$

$$P = mc\left(\frac{dT}{dt}\right) \quad (6)$$

Where equation 4 is equal to 6 then K will be equal to

$$K = \frac{m\,c\,d\left(\frac{dT}{dt}\right)}{A(T_1-T_2)} \quad (7)$$

It is assumed that the radiation from the edges M1 and M2 is almost negligible by reason of the thermal insulation provided.

Procedure for Determining the Thermal Conductivity

The materials used in the study include samples of selected materials with low thermal conductivity. Materials of low thermal conductivity are usually those with high insulation i.e. non-metals examples are wood materials, plastics etc. The samples were machined down to the diameter of the Lee disc (i.e. 50 mm) and various thicknesses for convenience depending on the material. The surfaces of the samples were also smoothened for good thermal contacts. The basic apparatus used was modification of the standard Lee's disc method, for the measurement of thermal conductivity by the absolute plane parallel plate technique. This consists of two brass discs A and B drilled to accept thermocouple (Sensor) and 500 W electrical nozzle heater of the same diameter as the discs. Each sample was placed between discs A and B one after the other. The heater was placed on discs A. After tightening the clamp screw to hold all the discs together, the set-up was connected to a power supply. The whole assembly was placed in an enclosure to minimize the effects of draughts. At the beginning of each determination, the temperature of the discs (i.e. the temperatures of plates A and B) was monitored until the temperature of disc A attains a desired value of 20 - 50 ^oC. Readings was then taken at 5 minutes intervals during this period. In order to effectively analyze the thermal agitation in the samples, the thermal conductivity was estimated at every 5 minutes interval up to a point at which the temperatures of the discs would have stabilized to within ±0.1 °C for at least 30 minutes [19]. The value for the thermal conductivity of each sample of thickness d and radius r was then estimated from the appropriate analytical equations governing the heat transfer process along and across the principal conductivity axes. The result was analyzed and graphs were plotted for comparison.

3 RESULT AND DISCUSSION

The thermal conductivity measurements of some selected materials are tabulated below

Materials	Thermal conductivity value ($Wm^{-1}K^{-1}$)
Gmanila wood	0.0914
Oak wood	0.1850
Rubber	0.1720
Asbestos cement sheet	0.3190
nylon	0.2300
Varied PVC	0.04-0.350

The thicknesses used for the materials were varied considering the fact that the thicknesses of all the materials can not be the same. The materials were also oven dried for wood while rubber and nylon were free from every form of moisture. The temperature for the wood materials was also varied although some measureable degree of accuracy was obtained at the 50 ^{0}C temperature. The table above shows the thermal conductivity value obtained for the various materials with asbestos cement sheet having the highest thermal value while Gmanila wood with the lowest thermal value. The experiment was conducted with high degree of accuracy eliminating possible error that could arise in the measurement of thermal conductivity [28].

4 Conclusion And Recommendation

From the experimental results, the value of the thermal conductivity of the materials selected was low; this is because they are all non-metals with high insulating value. Thermal conductivity is regarded as the most important characteristic of a thermal insulator since it affects directly the resistance to transmission of heat that a material offers. The lower the thermal conductivity value, the lower the overall heats transfer. Comparing the result with other thermal insulators as reported by other researchers who have carried out similar experiment [29-32], it was evident that the modified apparatus has some measureable degree of effectiveness considering the fact that the differences in the value obtained was between 1.0-8.0 per cent.

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