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Experimental Determination of Thermal Conductivity of Selected Nigeria Woods

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Abstract— **The thermal conductivity of some selected tropical wood samples were experimentally studied using modified Lee's apparatus. The specimens were prepared from three (3) species of both hard and soft wood widely available and used in Nigeria. The samples were oven dried and analyzed to record the density and to determine the thermal conductivities of the woods along the longitudinal axis parallel to the grain direction and normal to the growth rings. It was discovered that hardwood milicia excelsa (iroko) has the highest heat conductive strength with thermal conductivity of 0.0938W/mK while, Ricinodendro heudelotii (okwe) has the least conductive strength among the selected samples with thermal conductivity of 0.0805W/mK. This indicated that the woods are generally good insulators of heat. Results showed that, the thermal conductivity varied directly with density. Hard woods with high densities and thermal conductive power are suitable for places where strength is needed like construction of bridges, seats etc, while, soft woods with low thermal conductive should find application where cool temperature is required, such as construction of fridge, ceilings, building walls, etc.**

Index Terms— **conductivity, hardwood, softwood.**

I. Introduction

General Background of Study.

Wood is a natural organic composite material that consists of cellulose fibers and lignin. It has a long history of use both as solid fuel and as a construction material. A need exists, however, to understand and model heat transfer processes in wood and wood. Based material. For instances, the energy design and evaluation of energy performance of wood-frame buildings partially rely on the thermal properties of wood and wood products [1].

The wood and wood based materials have many applications. In areas that requires good insulating properties. Their low thermal conductivity and good strength make them of special interest for building construction, refrigerators, cars and beer barrels etc. [2] and [3].

A. *CONDUCTION HEAT TRANSFER*

Heat is a form of energy which flow as a result of temperature gradient. While conduction is a medium of heat transfer from one part of a substance to another part of the same substance. or from one substance to another in physical contact with it. Without appreciable displacement of the molecules forming the substance

Experience has shown that there is an energy transfer from the high –temperature region to the low- temperature region. When a temperature gradient exist in a body. We say that the energy is transferred by conduction and the heat transfer rate as put together by Fourier is proportional to the temperature gradient and the cross sectional area of the substance.

$$Q = -KA\left(dT/dx\right) \quad (1.1)$$

$$\frac{q}{A} \alpha \frac{\partial T}{\partial x}$$

Where Q = quantity of heat applied.
A = cross –sectional area
dT = change in temperature
dx = the distance traveled by heat and
K = the thermal conductivity of the substance.

B. *THERMAL CONDUCTIVITY OF WOOD*

Wood is generally regarded as poor conductors of heat and therefore is used as heat insulators.

This poor heat conductance of wood is due to the paucity of free electrons which are media for energy transmission and due to the porosity of wood. Wood is a typical porous material, its structure is complicated. Which makes it a strongly anisotropic material in the area of drying shrinkage and mechanical application.

The thermal conductivity of wood varies with the direction of heat –flow with respect to the grain, with specific gravity, with defect, with extractive and also with the moisture content in wood and temperature [4].

The thermal conductivity of wood is usually measured by the steady state method which usually requires some time for wood samples to reach equilibrium. If the wood sample contains high moisture content, it will take a fairly long time for the moisture distribution in wood to reach the equilibrium state it is not quite realistic to do the test, so with the help of theoretical understanding of the wood thermal conductivity, it will be possible to predict the change of this property with the extended range of moisture content.

Theoretical models can be set up on dry wood samples. Then experimental results on these dry samples can be used as a comparison to evaluate the model after the model is validated. It can be used for prediction in an extended range. Thermal conductivity referred to as a transport property, provides a 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 [5]

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The knowledge of thermal conductivity of wood in a large range is important in Kiln drying operations. Pressing of wood based composites, wood thermal degradation and others process in which wood is subjected to a temperature change.

Thermal insulators are these materials that are poor conductors of heat; wood is a typical example of a heat insulator.

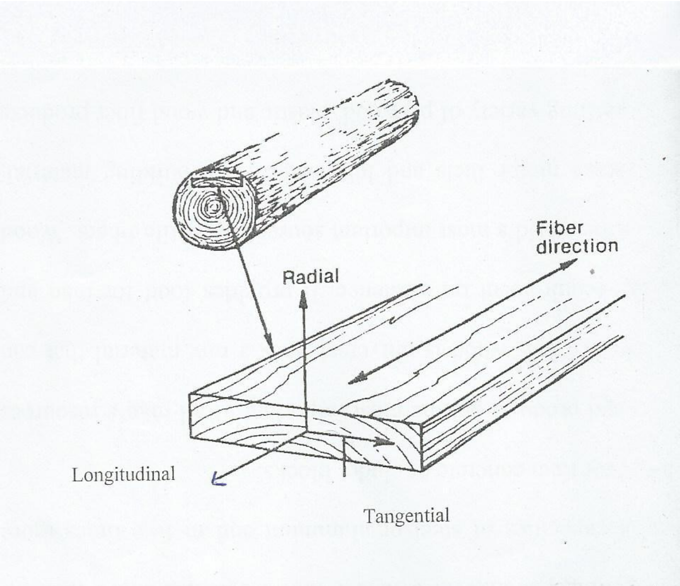


Fig.1.1: Three main direction of wood with respect to gram direction of growth rings.

Wood is an autotrophic and anisotropic material. Because of the orientation of the wood fibers and the manner in which a tree increases in diameter as it grows, properties vary along three mutually perpendicular axes: longitudinal, radial, and tangential. The longitudinal axis is parallel to the fiber (grain) direction, the radial is perpendicular to the grain direction and normal to the growth rings, and the tangential axis is perpendicular to the grain direction and tangential to the growth rings. Although most wood properties differ in each of these axis direction differences between the radial and tangential axis are relatively minor when compared to differences between the radial and tangential axis are relatively minor when compared to difference between the radial or tangential axis and the longitudinal axis.

C. *STATEMENT OF PROBLEM*

The anisotropic nature of wood has made it interesting for researchers to investigate the behavior of wood with regard to heat conduction. This research experiment is to find out the heat conductive capacities of some selected Nigeria woods with regard to the three major direction (viz radial, longitudinal and tangential).

Many studies have been centered on other engineering materials like Iron, plastics etc. but a shift is needed for the development of technology in Nigeria.

The study of the thermal conductivity of wood is as important as the study of the conductivity of every other engineering material hence. The study of wood thermal conductivity will provide values that will guarantee material specification in the technological sector, which will help Nigerian economy and reduce the rush for other materials. Housing is a problem in Nigeria because we have not found other alternatives like wood to concretes and blocks.

Though, some researchers have dealt with the study of other properties of wood. They are yet to study in detail especially in Nigeria to give a data base of thermal conductivity of Nigeria wood for effective specification and application.

This research will serve as an eye opener for other researchers to venture into the determination or sturdy of other thermal properties of Nigeria wood as required in a standard data base

The experimental rig (modified lee's apparatus) used here could as well be used to study other species of wood.

D. *OBJECTIVE OF THE STUDY*

The goal of this research is to characterize the thermal properties of three different species of wood available in Nigeria and to determine the effect of density, temperature, moisture and particularly with respect to the grain directions and application as insulators.

To do this, the following objectives were pursued.

- ✓ To investigate the thermal conductivity values of the selected species of the common woods in Nigeria.
- ✓ To investigate the thermal anisotropic properties of the selected woods samples
- ✓ To build a data base from the results obtained

E. *SCOPE AND LIMITATION OF THE STUDY*

- This research is limited to only three selected types (species) of Nigeria woods, viz, *elaeis guineensis* (palm tree), *miliciaexcelsa* (iroko), *ricinodendron heudelotii* (okwe). Therefore, the outcome of this cannot be generalized to all woods.
- The result of this research is purely on the anisotropic thermal behavior of wood and as such has no detailed information on the effect of moisture, density and defects on the thermal conductivity

II. LITERATURE REVIEW

A. *OVER VIEW*

So many works done by scholars were reviewed in order to know the basic background of the work and as well to know where to improve on. This chapter reviewed some of the investigations of the thermal conductivity of wood at the interfaces, examining both theoretical models and illuminates the relevant phenomena. And experimental studies that provide results for comparison. This chapter is divided into three main study parts, the property studies, the theoretical studies and the instrumental studies.

The first deals with studies that are based on the effects of wood properties like moisture content, density, contact conductance, defect etc. the second is the theoretical studies that deals with the various theories that have been applied in determining the thermal conductivity of wood, like steady state, unsteady state, transient etc. the third is the instrumental studies that deals with the instrument which was used. In the course of evaluation of thermal conductivity of wood.

B. THEORIES AND EXPERIMENTAL METHODS STUDY

There are a lot of theories and methods of experiment that can be used in determining thermal conductivity of a solid material like wood. The type to use depends on the research work that is been pursued.

[6], worked on the thermal conductivity of particular wood specie called *cocos nucifera* trunk (coconut plant). In their work they used one dimensional unsteady state theory and lee disc method of experiment. Their theory was that temperature variation with thickness of solid materials, a factor which depends on thermal conductivity, specific heat capacity, density, thermal absorptive and diffusivity. Unsteady state conduction equation of the form below was used by them.

$$\delta^2 T/_{\delta^2} = {PC}/_{K}\ {\delta T}/_{\delta t} \qquad (2.1)$$

Thermal conductivity were determined by using lee disc apparatus ,dry coconut trunks were used to avoid redistribution of water under the influence of temperature gradients as a result of moisture content in the sample. They knock off the heat conducted at the steady state conditions because they assumed it equals the rate at which it's emitted from the exposed surface. The coconut trunks were used to avoid redistribution of water under the influence of temperature gradients as a result of moisture content in the sample. They knock off the heat conducted at the steady state foundations because they assumed it equals the rate at which it's emitted from the exposed surface. The coconut trunks were all Nigerian wood samples, from Akwa-Ibom State. But, the reason for their using unsteady state equation in their theory and determining their thermal conductivity working values with steady state method was unclear. But this work likened it to the experimental rig they used, lee disc apparatus meant for steady state experiments. Meanwhile, they used the cooling correlation for [7] laboratory manual. Density was measured in bulk and they used weighing displacement method [6] and [8]. Thermal diffusivity and absorptive were calculated using equations below;

$\lambda = k/\rho C$ (2.2)

This diffusivity which they used in calculating the absorptive from the equation below;

$\varpi = (\varpi/2\ \lambda)^{1/2}$ (2.3)

To predict the thickness of their sample at any time of the day, they developed an equation as follows;

$T_{(X,t)} = T_m - A_s \exp(-14.701x) \cos(t - t_0) - 14.701x)$ (2.4)

Where;

$T_{(x,t)}$ – temperature at a particular thickness and at a particular time of the day.

A_s – daily temperature amplitude at the surface of the sample

T_0 – time minimum temperature at the surface in hours

Tm – is calculated from the hourly temperature average T_{hss} (^{0}c) as

$Tm = \Sigma(T_{hss}/24)$ (2.5)

Coconut trunk is a good thermal insulating material since thermal diffusivity depends on the thermal conductivity, density, specific heat and absorptivity depends on diffusivity,

Finally, their recommendation was that coconut trunk can be used in the tropical regions of Nigeria. The mere fact that this specie of wood is only used in the rural areas of southern Nigeria commonly for rafter, purlin, window and door frames attest to its suitability and durability.

[9] had another method of finding their thermal conductivity, they used what is called cut-bar thermal conductivity facility. The main aim was not to get the thermal conductivity, rather to get the contact conductance of cylindrically shape inner and outer interfaces. The same Fourier's law was used, with known temperature distribution in the inner and outer cylinders, contact conductance equation of Wikipedia encyclopedia was modified by this research, they tried to get the heat that is transfer though the joint as the sum of heat through the interstitial spaces and the heat through the contacting spot, as thus;

$Qj = qc + qgap + qrad$ (2.6)

The radioactive heat flux across the interface may be neglected if the interstitial material is opaque to infrared radiation or if the interface temperature level is less than 573k [10]. This is justified since even moderate temperature differences at that temperature level yield radiation heat rates that are much smaller than the total heat transfer through the joint.

Neglecting the contribution of thermal radiation, the heat transfer rates in Equation 1.1 can be linked to the temperature difference between the two surfaces by means of proportionality constants, or conductance:

$Hj = qj/\ Aapp\ \Delta Tj,\ hc = qc/Aapp\ \Delta Tj,\ hgap = qgap/Aapp\ \Delta Tj$ (2.7)

Thus, the total heat transfer across the junction (Equation (2.2) can be expressed as: $Qj = hjAapp\ \Delta Tj = (hc + hgap)\ Aapp\ \Delta Tj$ (2.8)

All the values were taken at steady state condition.

The thermal conductivity of the test specimen is obtained by dividing the average heat flux by the average temperature gradient through the specimen.

III. METHOLOGY

In order to determine the thermal conductivities of some tropical woods, a known thermal conductivity apparatus known as Lee's disc was used to obtain data over a temperature range and under some certain thermal condition.

A Lee's Disc as used in [11] is not easily available, because of that, an apparatus working on the same principle as Lee's Disc was used. It was named modified Lee's Disc Apparatus.

The apparatus consist of;

- A heater with heat jacket (experimental rig)
- Thermocouple with probe (K -type)
- Digital thermometer
- Two metallic discs
- A wooden disc (poor conductor)
- A tripod stand
- A vernier caliper
- Micrometer screw gauge

- Weighing balance
- Stop watch

A. *EXPERIMENTAL SET UP*

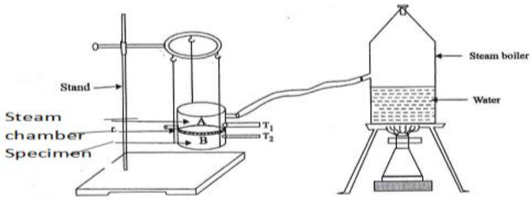
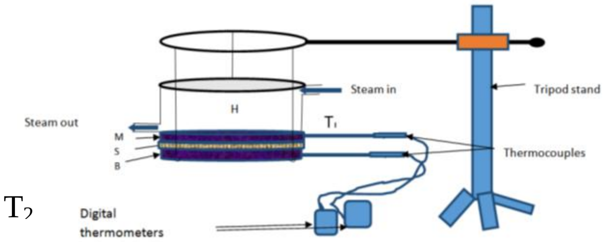


Fig.3.1: Lee's apparatus setup



B. *DESCRIPTION OF LEE'S APPARATUS*

The apparatus shown in Fig. 3.3 consists of two parts. The disc part and the steam part. The disc part consists of two metal discs and a sample (wooden) disc. B is a circular

metal (mild steel) disc placed at the bottom, while M is another metallic disc of uniform size and weight and thickness with the disc "B". The experimental specimen (wooden disc) "S" is placed in between the upper and the lower discs M and B. The diameter of S is equal to that of B and the thickness is uniform throughout. A steam chamber "H" with two tubes for inflow and outflow of steam is placed on M. The inlet tube is connected to a steam generator. Two thermometers for the measurement of T_1 and T_2 are inserted into two holes in M and B, respectively. Three hooks are attached to B. The complete setup is suspended

- $= \delta T / \delta t$. (diagram)

Thermal conductivity measurement.

The rate of heat conducted through the specimen or sample (wood)

$$Q = \frac{KA(T_1 - T_2)}{X} \qquad (3.1)$$

Where 'X' is the thickness of the sample and A= cross-sectional area of the sample and 'K' the thermal conductivity of the sample. And $(T^1 - T^2)$ is the temperature difference.

The rate of heat lost by the metallic disc (A) to the surrounding under steady state is

$$Q = MC\left(\delta T / \delta t\right) T_2 \qquad (3.2)$$

Where M = mass of the metallic disc gotten with balance.

C = specific heat capacity of mild steel

$\frac{\delta T}{\delta t}$ = rate of cooling at T_2

Comparing equation (1) and (2)

$$Q = MC\left(\delta T / \delta t\right) T_2 = \frac{KA(T_1 - T_2)}{x}$$

$$K = \frac{MCx\left(\delta T / \delta t\right) T_2}{A(T_1 - T_2)} \qquad (3.3)$$

Table I: Details of measurement

S/N	Sample	Average thickness (mm)	Average diameter (mm)	Surface area (m^2)	Mass (kg)	Density (kg/m^3)
1	Milicia excelsa	4.8	169.5	0.02256	0.0567	523.604
2	Elaeis guineneensis	5.0	169	0.02243	0.0553	493.090
3	Ricinodendro heudelotii	5.0	168	0.02217	0.0529	477.221

The experiment will be carried out by an investigation through the various grain arrangement viz. longitudinal, axial and tangential direction.

IV. RESULT ANALYSIS

The experiments were carried out on the aforementioned samples and the results were obtained and analyzed as follows;

Details of the lower disc B

Mass of the disc, m = 2000g

Specific heat of the material, c = 0.502416 J/g°C

Correction of Thermometers

Room temperature recorded for T_2 = 29°CRoom temperature recorded for T_1 = 29°CSo, there was no need for correction ofthermometers as $\theta = T_2 - T_1 = 0$

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A. HARDWOODS

A(i)*MILICIA EXCELSA* (IROKO) WOOD SAMPLE

Table II Temperature table per minute rise in time during metal disc cooling

Avg. Temp (K)	326.2	325.6	325	324.5	324	**323.5**	323	322.4	322	321.5	321
Time (s)	0	60	120	180	240	300	360	420	480	540	600

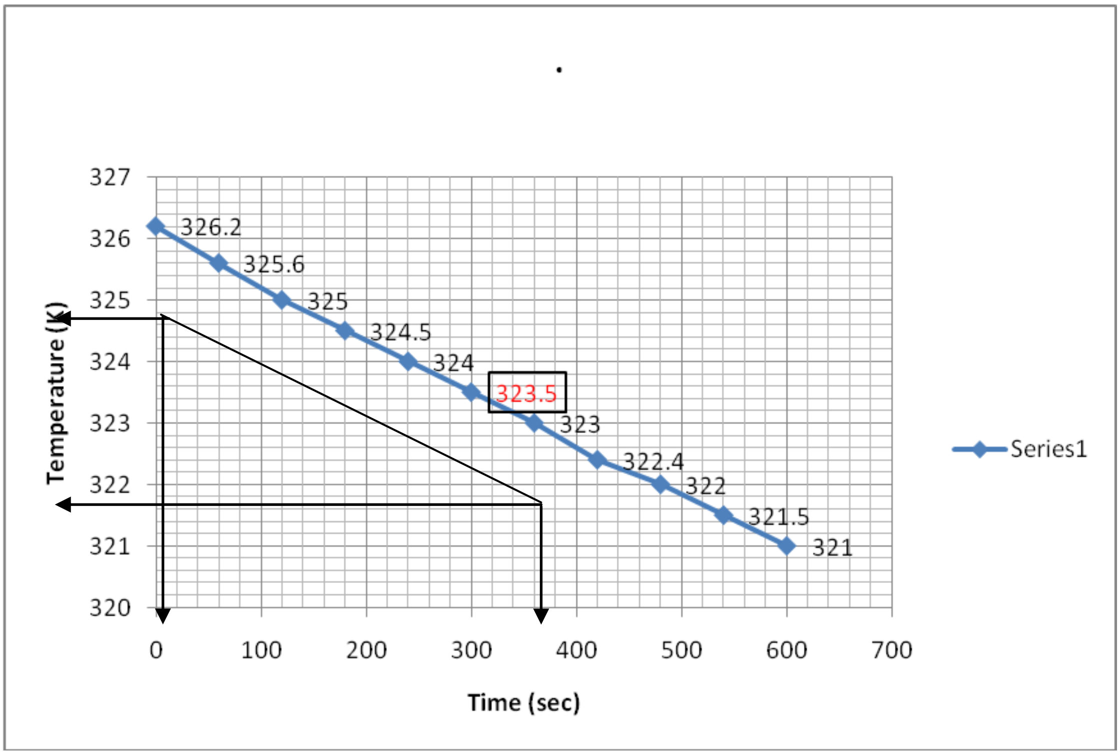


Figure 4.1: Cooling curve (temperature-time graph)of carbon steel disc at a steady temperature T_2.

S =0.00811K/s

T_1 = 343K

T_2 = 323.5K

x =5mm =0.005m

A_{iroko} = 0.02217m^2

C = 0.50 kJ/kgK

$$k = \frac{2 \times 0.50 \times 1000 \times 0.005 \times 0.00811}{0.02217\,(343 - 323.5)} \qquad (4.1)$$

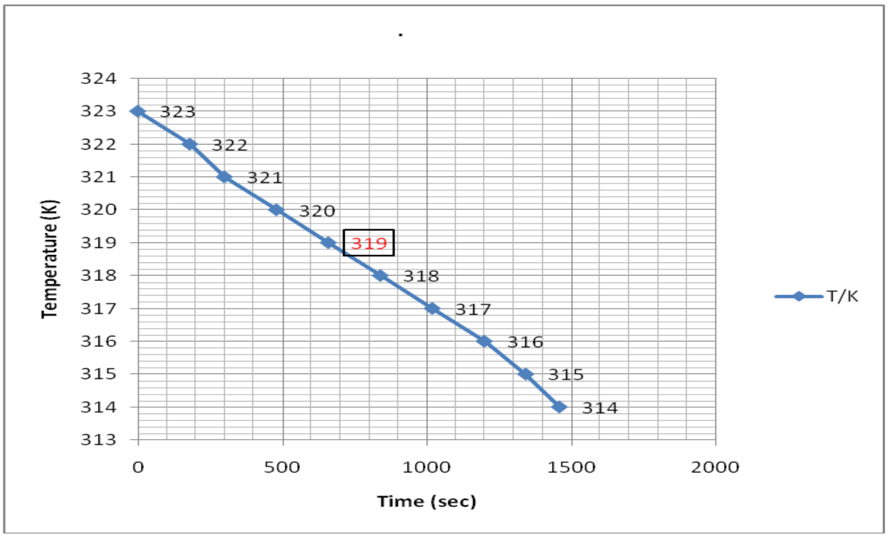
K_{iroko} = 0.0938W/Mk

B. SOFT WOOD

B(i). *ELAEIS GUINEENSIS* (PALM TREE) WOOD SAMPLE

Table III: A table of time for each degree reduction in temperature during metal disc cooling.

Temp (K)	323	322	321	320	**319**	318	317	316	315	314
Avg. Time (s)	0	180	300	480	660	840	1020	1200	1344	1460



1) Figure 4.2: Cooling curve (temperature-time graph) of carbon steel disc at a steady temperature T_2.

S =0.00598K/s

T_1 = 348.4K

T_2 = 319K
x =5mm =0.005m

$A_{palm\ tree}$ = 0.02217m^2

C = 0.50 kJ/kgK

From Equ. (3.3)

$$k = \frac{2 \times 0.50 \times 1000 \times 0.01 \times 0.00598}{0.02217\,(348.4 - 319)} \qquad (4.2)$$

$k_{palm\ tree}$ = 0.09175W/mK

B(ii)RICINODENDDRO HEUDELOTII (OKWE) WOOD SAMPLE

Table IV: A table of time for each degree reduction in temperature during metal disc cooling.

Temp (K)	323	322	321	320	319	**318**	317	316	315	314
Avg. Time (s)	0	125	300	480	660	840	1020	1200	1380	1650

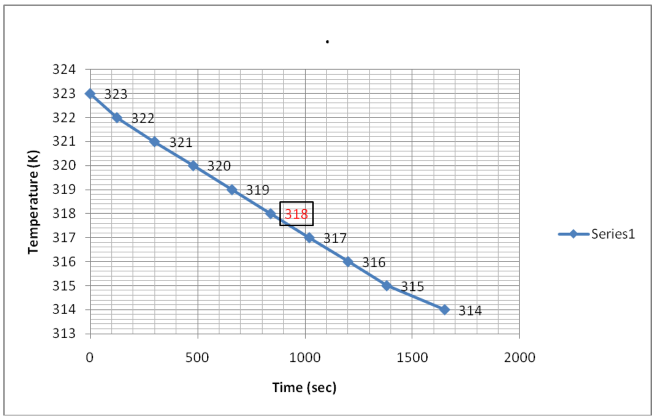


Figure 4.3: Cooling curve (temperature-time graph)of carbon steel disc at a steady temperature T_2.

S =0.00566K/s

T_1 = 349.7K

T_2 = 318K

x =5mm =0.005m

A_{okwe} = 0.02217m^2

C = 0.50 kJ/kgK

Therefore, from the equation (3.3)

$$k = \frac{2 \times 0.50 \times 1000 \times 0.005 \times 0.00566}{0.02217\,(349.7 - 318)} \qquad (4.3)$$

k_{okwe} = 0.0403W/mK

V. ERROR ANALYSIS

The two major sources of error in this research are;

- The systematic error due to contact between the metal disc and the specimen.
- The random error due to changes in the experimental conditions

A. THE CONTACT ERROR;

According to the handbook of heat and mass transfer by Rohsenow and Hartnett [46], there is an apperent temperature discontinuity in the immediate vicinity of the contact between two dissimilar materials.

B. RANDOM ERROR AND PERSONAL ERROR;

Considering the six samples used for each specimen, the error due to measurement incude; temperature reading error and thermal conductivity calculation error. These errors could be taken care of using the 95% confidence uncertainty calculation, Ellison et al [47] and Kline et al [48]. For uncertainty;

$$U^2 = p^2 + \beta^2 \qquad (4.4)$$

where U = uncertainty, P = precision and $\beta = bias$

Precision $p = \sqrt{\left(\frac{1}{n-1}\Sigma_i^n (x_i - \bar{x})^2\right)}$

In this kind of experiment where the true value cannot be identified, the avarage mean value could be used. Therefore, uncertainty = precision

i.e $U = \sqrt{\left(\frac{1}{n-1}\Sigma_i^n (x_i - \bar{x})^2\right)}$ (4.6)

For instance, the uncertainty in the mass measurements are calculated as shown below;

Considering*milicia Excelsa*

The table below shows the uncertainty in the mass measurement for*Parinari Excelsa*

Table V: uncertainty in the mass measurement

S/N	Mass m (Kg)	$\bar{m}$ (kg)	$m - \bar{m}$ (kg)	$(m - \bar{m})^2$X10^{-4} kg^2
1	0.059	0.059	0.000	0.000
2	0.060	0.059	0.001	0.001
3	0.059	0.059	0.000	0.000
4	0.058	0.059	-0.0001	0.001

5	0.059	0.059	0.000	0.000
6	0.060	0.059	0.0001	0.001
∑	0.355			0.003

$$U = \sqrt{\left(\frac{1}{n-1}\sum_{i}^{n}(m-\bar{m})2\right)}$$

$$U = \sqrt{\left(\frac{3\ X10^{-7}}{6-1}\right)} = 2.45\times10^{-4}$$

Therefore, mass m of milicia*excelsa* with a 95% confidence uncertainty = 0.059 ± 0.000245kg

A. Error Estimation of K

According to Ming-Tsung Sun and Chin-Hsiang Chang [50] in their work "The Error Analysis of a Steady-State Thermal Conductivity Measurement Method with Single Constant Temperature Region" where thermal conductivity k was determined using

$$k = \frac{Q}{A(T_0 - T_{max})} \qquad (4.7)$$

In a bid to analyze the random error of the measurement, they have to consider the error from temperature measurement, temperature control, and the heating power readout that propagate to generate uncertainty in the measured thermal conductivity k_E. The relative uncertainty of the measured thermal conductivity u_{k_E} was expressed as

$$u_{k_E} = \frac{\delta k_E}{k_E} = \left\{\left(\frac{\delta Q}{Q}\right)^2 + \left(\frac{\delta T_0}{T_0 - T_{max}}\right)^2 + \left(\frac{T_{max}}{T_0 - T_{max}} - \frac{\delta T_{max}}{T_{max}}\right)^2\right\}^{1/2} \qquad (4.8)$$

Using Equ. (3.3) the error associated with k can be calculated as follows

$$k = \frac{mCx\left(\frac{dT}{dt}\right)_{T_2}}{A(T_1 - T_2)}$$

$$\ln k = \ln C + \ln x + \ln m + \ln\left(dT/_{dt}\right) + \ln A + \ln\left(T_1 - T_2\right) \qquad (4.9)$$

$$\frac{\Delta k}{k} = \frac{\Delta m}{m} + \frac{\Delta C}{C} + \frac{\Delta x}{x} + \frac{\Delta(dT/dt)}{(dT/dt)} + \frac{\Delta A}{A} + \frac{\Delta(T_1 - T_2)}{(T_1 - T_2)} \qquad (4.1.0)$$

Keeping(T_1-T_2)constant for the six samples, then

$\Delta(T_1 - T_2) = \Delta C = 0$.

The error associated with area ($A = \pi\frac{d^2}{4}$) is due to diameter, so, Equ. 4.17 is then reduced to

$$\frac{\Delta k}{k} = \frac{\Delta m}{m} + \frac{\Delta x}{x} + \frac{\Delta(dT/dt)}{(dT/dt)} + 2\frac{\Delta d}{d} \qquad (4.1.1)$$

Using standard deviation to estimate the error

$$\frac{\Delta k}{k} = \sqrt{\left(\frac{\Delta m}{m}\right)^2 + \left(\frac{\Delta x}{x}\right)^2 + \left[\frac{\Delta\left(\frac{dT}{dt}\right)}{\frac{dT}{dt}}\right]^2 + \left(2\frac{\Delta d}{d}\right)^2} \qquad (4.1.2)$$

Where $\left[\frac{\Delta\left(\frac{dT}{dt}\right)}{\frac{dT}{dt}}\right]^2$ is an error term from the slopes

$\left(2\frac{\Delta d}{d}\right)^2$ is an error term from the sample area $A = \pi\frac{d^2}{4}$, but $\frac{\pi}{4} = constant$

$\left(\frac{\Delta x}{x}\right)^2$ is an error term from the thickness x of the metallic disc

$\frac{\Delta(T_1 - T_2)}{(T_1 - T_2)}$ is an error term from the temperature readings T

$\left(\frac{\Delta k}{k}\right)^2$ is an error term from the thermal conductivity k.

$\frac{\Delta C}{C}$ is the error term associated with specific heat capacity of mild steel

$$\frac{\Delta k}{k} = \sum_i^n \sqrt{\left(\frac{m_i - \bar{m}}{\bar{m}}\right)^2 + \left(\frac{S_i - \bar{S}}{\bar{S}}\right)^2 + \left(2\frac{d_i - \bar{d}}{\bar{d}}\right)^2 + \left(\frac{x_i - \bar{x}}{\bar{x}}\right)^2} \qquad (4.1.3)$$

Considering the six experimental results for the six samples of each speciment, the error estimation is thus, for n = 6:

$$\frac{\Delta k}{k} = \sum_1^6 \sqrt{\left(\frac{m_i - \bar{m}}{\bar{m}}\right)^2 + \left(\frac{S_i - \bar{S}}{\bar{S}}\right)^2 + \left(2\frac{d_i - \bar{d}}{\bar{d}}\right)^2 + \left(\frac{x_i - \bar{x}}{\bar{x}}\right)^2} \qquad (4.1.4)$$

For example the error associated with the thermal conductivity of *parinari excelsa* is calculated as;

$$\frac{\Delta k}{k} = \sum_1^6 \sqrt{\left(\frac{m_i - \bar{m}}{\bar{m}}\right)^2 + \left(\frac{S_i - \bar{S}}{\bar{S}}\right)^2 + \left(2\frac{d_i - \bar{d}}{\bar{d}}\right)^2 + \left(\frac{x_i - \bar{x}}{\bar{x}}\right)^2}$$

i.e

$$\frac{\Delta k}{k} = \sqrt{\left(\frac{m_1 - \bar{m}}{\bar{m}}\right)^2 + \left(\frac{S_1 - \bar{S}}{\bar{S}}\right)^2 + \left(2\frac{d_1 - \bar{d}}{\bar{d}}\right)^2 + \left(\frac{x_1 - \bar{x}}{\bar{x}}\right)^2} + \sqrt{\left(\frac{m_2 - \bar{m}}{\bar{m}}\right)^2 + \left(\frac{S_2 - \bar{S}}{\bar{S}}\right)^2 + \left(2\frac{d_2 - \bar{d}}{\bar{d}}\right)^2 + \left(\frac{x_2 - \bar{x}}{\bar{x}}\right)^2} + \sqrt{\left(\frac{m_3 - \bar{m}}{\bar{m}}\right)^2 + \left(\frac{S_3 - \bar{S}}{\bar{S}}\right)^2 + \left(2\frac{d_3 - \bar{d}}{\bar{d}}\right)^2 + \left(\frac{x_3 - \bar{x}}{\bar{x}}\right)^2} + \sqrt{\left(\frac{m_4 - \bar{m}}{\bar{m}}\right)^2 + \left(\frac{S_4 - \bar{S}}{\bar{S}}\right)^2 + \left(2\frac{d_4 - \bar{d}}{\bar{d}}\right)^2 + \left(\frac{x_4 - \bar{x}}{\bar{x}}\right)^2} + \sqrt{\left(\frac{m_5 - \bar{m}}{\bar{m}}\right)^2 + \left(\frac{S_5 - \bar{S}}{\bar{S}}\right)^2 + \left(2\frac{d_5 - \bar{d}}{\bar{d}}\right)^2 + \left(\frac{x_5 - \bar{x}}{\bar{x}}\right)^2} + \sqrt{\left(\frac{m_6 - \bar{m}}{\bar{m}}\right)^2 + \left(\frac{S_6 - \bar{S}}{\bar{S}}\right)^2 + \left(2\frac{d_6 - \bar{d}}{\bar{d}}\right)^2 + \left(\frac{x_6 - \bar{x}}{\bar{x}}\right)^2}$$

$$\left(\frac{\Delta k}{k}\right) = \sqrt{\left(\frac{0.060-0.059}{0.059}\right)^2+\left(2\frac{0.00118-0.0118}{0.0178}\right)^2+\left(\frac{0.0048-0.0048}{0.0048}\right)^2+\left(\frac{169.4-169.5}{169.5}\right)^2}+$$

$$\sqrt{\left(\frac{0.059-0.059}{0.059}\right)^2+\left(2\frac{0.00118-0.0118}{0.0118}\right)^2+\left(\frac{0.0047-0.0048}{0.0048}\right)^2+\left(\frac{169.6-169.5}{169.5}\right)^2}+$$

$$\sqrt{\left(\frac{0.058-0.059}{0.059}\right)^2+\left(2\frac{0.00118-0.0118}{0.0118}\right)^2+\left(\frac{0.0048-0.0048}{0.0048}\right)^2+\left(\frac{169.5-169.5}{169.5}\right)^2}+$$

$$\sqrt{\left(\frac{0.059-0.059}{0.059}\right)^2+\left(2\frac{0.00117-0.0118}{0.0118}\right)^2+\left(\frac{0.0049-0.0048}{0.0048}\right)^2+\left(\frac{169.5-169.5}{169.5}\right)^2}+$$

$$\sqrt{\left(\frac{0.060-0.059}{0.059}\right)^2+\left(2\frac{0.00118-0.0118}{0.0118}\right)^2+\left(\frac{0.0048-0.0048}{0.0048}\right)^2+\left(\frac{169.6-169.5}{169.5}\right)^2}+$$

$$\sqrt{\left(\frac{0.059-0.059}{0.059}\right)^2+\left(2\frac{0.00118-0.0118}{0.0118}\right)^2+\left(\frac{0.005-0.0048}{0.0048}\right)^2+\left(\frac{169.4-169.5}{169.5}\right)^2}+$$

$$\Delta k = k\sqrt{(0.00265)}$$

Error = 0.0938×0.0806 =±0.0078

From the above analysis the thermal conductivity of the three wood samples could be tabled as shown below in Table 12;

TableVI: Thermal properties of the wood samples in descending order

S/N	Sample	Mass (kg)	Density (kg/m^3)	Thermal conductivity (W/mK)	Error Δk (±)
1	*Milicia excels*$_{(h)}$	0.0590	532.250	0.0938	0.0078
2	*Elaeis guineneensis*$_{(s)}$	0.0553	493.090	0.0459	0.0032
3	*Ricinodendro heudelotii*$_{(s)}$	0.0529	477.221	0.0403	0.0027

(h = hardwood, s = softwood)

The full caculations for the error analysis are detailed at the appendix of this work.

VI. DISCUSSION

From the literatures reviewed, it could be seen that different models on specific heat and thermal conductivity calculation were developed refs. [4][11]. The differences are due to the dependent variables of thermal properties ref.[15] at any given condition. Also observed was that thermal conductivity of wood can be measured with difference techniques, viz; transient heat flow method andLee's apparatus [7] and[11] respectively. This research was carried out with a modified Lee's apparatus and the results are discussed below;

From the analysis of the results, the samples have their thicknesses, diameters, cross-sectional areas, masses and their densities displayed in Table 4.1. The temperature increase with time varies across the different specimens, when heat was passed steadily on the test discs. The values of the temperatures with respect to time were recorded during the experiments and their relationship were represented in an excel graphs (cooling curves: temperature- time graph), while the slopes of the graphs were obtained at a steady state temperature "T_2" indicated boldly on the temperature-time tables and enclosed with a rectangle on the graph of individual samples considering heat transfer along the grain (longitudinal) direction. The slope was represented as in equation (4.1), and was substituted from the energy equation as in equation (3.2).

The thermal conductivity of the wood samples were determined from Equation. (3.3), which was obtained by comparing Eq. 3.1 and Eq. 3.2 applying law of conservation of energy (heat gain = heat loss).

In Fig. 4.1 the slope of the graph was obtained at a steady-state temperature T_2 of 53°C. Considering 2kg of mild steel disc of specific heat capacity 0.502416J/g°C and T_1 as 80°C, the value of thermal conductivity of*milicia excelsa* k was calculated as 0.0938W/mK. Similar things were done for *elaeis guineneensis*,and *ricinodendron heudelotii* at $T_{2;}$ 319 and 318K respectively. And their respective thermal conductivity (k) calculated to be; 0.09175 and0.0403W/mK. The low thermal conductivity values of the samples follows the fact that they are non-metals and poor heat conductors. From table 4.8 and 4.9, you can see that the temperature-time data could be obtained either by recording the temperature rise per second or by recording the time taken per unit rise in temperature. The non-linear nature of the temperature –time graph was due to cooling effect. The rate of cooling is not a constant and as such, the slope varies at different points of the curve. Although, for the purpose of this work the thermal conductivity is determined from a slope taken from the steady state temperature T_2**.**

Table 4.1.3 showed the thermal properties of the wood samples in a decending order, ranging from *milicia excelsa*of thermal conductivity 0.0938W/mK to *ricinodendron heudelotii* of thermal conductivity 0.0403W/mK. This indicates that *milicia excelsa* is better heat conductors than other samples while *ricinodendron heudelotii* is a better heat insulator than other samples. It could also be noted that on average, the thermal conductivities of the samples increases from softwoods to hardwoods. The table equally revealed that as density increases so does the thermal conductivity of wood.

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