COMPARATIVE STUDY OF THE THERMO-PHYSICAL PROPERTIES OF RAPHIA PALM, OIL PALM AND PINEAPPLE LEAVES AS ALTERNATIVE CEILING SHEETS

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CERTIFICATION

This is to certify that this research work entitled "Comparative Study of The Thermo-physical Properties of Raphia Palm, Oil Palm and Pineapple leaves as Alternative Ceiling Sheets" was carried out by Anonaba Armstrong Udochukwu (20144913698) in partial fulfilment of the requirement for the award of the Degree of M.Sc in Physics (Solid State Physics), in the Department of Physics, Federal University of Technology, Owerri.

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DEDICATION

This work is dedicated to God Almighty and to my beloved parents, Elder and Deaconess J.O. Anonaba

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ABSTRACT

An investigation of the thermal properties of some selected leaves, some of which have been used traditionally as roofing sheets in different forms have been carried out. We prepared sample sheets from oil palm, pineapple and raffia palm leaves specific heat capacities and thermal diffusivities were then determined. All samples were prepared by drying and grinding of the leaves and then forming into compact sheets for measurements. The major parameter, the thermal conductivity, К was measured with the Lee's disc apparatus. The measurement showed that К is 0.072$Wm^{-1}K^{-1}$ for pineapple leaves, 0.126$Wm^{-1}K^{-1}$ for raffia palm leaves and 0.118 for oil palm leaves. To check how good our method (Lee's disc) is, we measured К for commercial asbestos ceiling sheet and found it to be 0.195$Wm^{-1}K^{-1}$. This value is about 85% in agreement with the known (textbook) value of 0.17$Wm^{-1}K^{-1}$. Other parameters determined here – the specific heat capacities, the thermal diffusivity, etc. confirmed that investigated materials can be engineered to good materials for passive "cool roof" building designs.

Key Words: Thermal conductivity, Density, Specific heat capacity, Roof ceiling.

CHAPTER ONE

INTRODUCTION

1.0 Background of the Study

The terrestrial environment serves as man's abode and is replete with all types of materials. These materials that are either in solid, liquid or gaseous state are considered important, in respect to their utility and our interactions with them as sources of energy transfer in our environment. The concept of heat flow and of course thermal transport within a system is a matter of concern to all in the society: scientist and non scientist alike, especially when it has to do with the basic needs of life: food, shelter and clothing. Heating process involves basically a conversion of thermal energy from one point to another (Etuk, *et al*, 2005). Heat transfer is basically governed by thermal conductivity of the materials that make up a system. This transfer can take place in three ways namely: conduction, convection and radiation. It is therefore important, for the purpose of clarity and refreshing the memory, to discuss briefly these three primary methods of heat transmission.

Conduction involves thermal excitation of molecules passed along within a substance. Here, the average positions of the molecules remain the same, while they respectively and successively impart their energies to their nearest neighbours. Convection involves the motion of current (heat) from one place to another by a physical agent such as fluid (liquid or gas). Thus, conduction and convection require material medium such as solid, liquid or gas for heat transmission. Radiation is a wavelike mode of heat transfer that requires no material medium for heat transmission; instead they are transmitted as electromagnetic waves.

Some materials have a greater ability to conduct, convect and radiate heat, and this ability is dependent on the thermo-physical properties of these materials. The thermal properties of any material influence the temperature around it. Once heated, the rate at which a material transfers the absorbed heat to the surrounding is determined by the thermal effusivity (or thermal inertia) of the material, and this depends on the thermal conductivity and specific heat capacity. (Jayalakshmy and Philip, 2010). An investigation of these parameters in solid state materials can be beneficial to the scientific body in harnessing some natural resources such as raffia palm, oil palm, and pineapple leaves, for effective heat protective purposes.

Raffia palms *(Raphia hookeri),* is a solid straight monocotyledonous plant belonging to the family Palmae, and with trunk covered with an attractive unusual coils, and occasionally producing suckers. On maturation typical full-grown *R. hookeri* of the forest zone in South-western Nigeria can be taller than 15 m with large green shining fronds and curved spaced branching to form numerous hanging partial inflorescences. Trunk of *R. hookeri* is a very useful source of building material and the local people in Nigeria tap wine from the living trunks (Hutchinson and Dalziel, 1963).

The oil palm belongs to the palmae family, originated in tropical West Africa and given the name Elaeis guineasesis. It is a monocotyledonous plant that sometimes grows to a height of over 15 meter. It produces a single trunk which bears a crown of fronds. The crown may consist of between 25 and 40 large plant fronds being a monoecious plant. The male and female inflorescences (flower) are borne at the axile of the fronds. These are produced in alternating cycles; the female inflorescence that gives rise to the palm bunch, bears the fruits, the palm fruit. It is a drupe and consist of leathery exocarp, fleshy mesocarp from which palm oil is extracted and a stony endocarp which encases the kernel.

The scientific name of pineapple plant is *Ananas comosus* L. Pineapple is a longleaf desert plant belonging to the Bromelicea family. The plant is normally grown in nurseries for the first year or so and matures about 12–20 months later. The width of each mature leaf is about 50–75 mm. The fibres are contained in the spiky leaf of plant. Pineapple is a fibrous plant and it was reported that its fibre was as reinforcement or filler in composites. Majority of the research work carried out on pineapple leaf fibre composites were in India and some South East Asian countries like Malaysia and Thailand. This could be due to the fact that the raw material can be obtained there very cheaply. There is a great potential to commercialize this product and to enhance the quality of life of people living in rural areas.

1.1 Statement of the Problem

Heat transmission and absorption by building materials is affected by the absorptivity, the reflectivity, emissitivity and thermal capacity of the materials. These properties of materials determine the characteristics of wall and roof elements and therefore the way they modify the thermal environment. In tropical region, for instance, in Nigeria, materials like zinc, aluminium, asbestos and PVCs (polymerizing vinyl chloride), are commonly used as sheets for roofing in modern building constructions. But these materials have high ability to conduct heat into the interior space of the building, a situation that causes discomfort in the rooms in hot weather. The heat flow through any building material is dependent on the thermal properties of the material (Akpabio, *et al*., 2001). It can therefore be deduced that the heat generated indoors depend solely on the quantity of heat conducted through the building materials used in roof, walls, floor and other sun-exposed parts of the house, that is, the thermal properties able to respond to the state of the climate where the building is located. Also, the materials include synthetic thermoplastic materials; hence the presence of hydrogen chloride, and other dangerous man-made carcinogens that will persist in the environment. Such corrosive, cancergenic materials, can burn the skin and cause severe respiratory problems as well as chemical and thermal degradation of such materials and the environment. Hence, the problem is not what is readily available and economically affordable to the people; rather, it calls for a research for more friendly heat insulating materials, without health hazards.

1.2 Purpose of the Study

The need for safe and self cooling buildings highlights the need for alternative sources of roofing and ceiling materials with suitable conducive properties. “Cool roofs” are roofs covered with a reflective coating that has a high emissivity property that is very effective in reflecting the sun’s energy away from the roof surface. These “cool roofs” are known to stay 10^0C to 16^0C cooler than a normal roof under a hot sun; such quality greatly therefore reduces heat gain inside the building. Hence, the main purpose of this study is to investigate the thermo-physical properties of Raphia fibres (*Piassava*) extracted from species of raphia palm (*Raphia hookeri*), oil palm (*Elaeis guineensis*), pineapple stalk (*Ananas Comosus*), and compare their suitability with standard asbestos ceiling sheet in reducing thermal radiation in buildings.

1.3 Aim and Objectives of Study.

The aim of the study is to devise efficient and alternative roofing and ceiling materials for buildings using local materials. The objectives are to

i) present experimental data on thermal conductivity, thermal diffusivity, specific heat capacity and density of some selected leaves samples,

ii) determine which of these materials can be used for the design of alternative ceiling boards, for the design of passively cool building.

iii) Compare our results with the results determined for standard Asbestos ceiling sheet.

1.4 Significance of the Study

This work is immensely important to the building industry to select the best temperature responsive leave samples, on the basis of experimental data and analysis of results. The thermal and physical properties such as specific heat capacity, density, thermal conductivity, thermal diffusivity and the leaves' flexural and compressive strength are important parameters for determining their temperature response, as well as making good choices of leaves or materials, for a passively cool roof building design in Nigeria.

The application of the findings, from this work will help to augment the status of building technology inputs in Nigeria, and discourage over dependence on foreign and synthetic roofing materials, at the expense of abundant, cheap and environmentally friendly local materials.

1.5 Scope of the Study

The scope of this study borders on, thermal transport of local leaf samples ,raffia palm, oil palm, pineapple leaf and standard Asbestos ceiling sheet with experimental determination of specific heat capacity c, density ρ, thermal conductivity K, thermal resistivity ρ_{th} , thermal diffusivity λ, thermal absorptivity α of the leaves. Cooling curves of the materials will be extracted from the data, to predict the effect of heat and incident solar radiation on the processed leaf samples, to enhance the choice of the best material for cool roof building designs.

CHAPTER TWO

LITERATURE REVIEW

2.1 Heat and Internal Energy

In a simple experiment, where we dip our hands into a bowl of hot water, we will experience an instant change in the sensation of our body from cold to hot, or vice versa when we dip the same hands in a bowl of chilled water. The interaction that causes these sensational changes is fundamentally a transfer of energy from one substance to another, and scientifically, it is measurable. The energy transferred is called heat.

Heat is the energy flowing from a body at a higher temperature to a body at a lower temperature. Thus, heat is internal energy in transit due to temperature difference. A body does not contain heat, it contains internal energy. When the body cools, its internal energy is decreased; when it is heated, its internal energy is increased.

Heat, symbolized as Q, is said to be positive when energy is transferred to a system's internal energy from its environment (we say that heat is absorbed). Heat is negative when energy is transferred from a system's internal energy to its environment (we say that heat is released or lost). (Halliday, *et al*, 2001).

2.2 Heat Transfer Mechanism

In a system where there is no accumulation of energy, the rate of energy received in the system, is equal to the rate of energy sent out of that system.

When this condition is met and heat transfer takes place, it is known as the steady state of heat transfer. There are basically three mechanisms for the transfer of heat: conduction, convection and radiation.

According to Anyakoha (2007), transfer by conduction involves solid materials; convection involves fluids, while radiation takes place as an electromagnetic phenomenon.

2.2.1 Conduction:

When heat is transferred by the energy of motion between adjacent molecules, heat transfer by conduction is said to take place, where the average position of the particles of the material remaining the same. This type of heat transfer takes place to a certain extent in all solids. In metallic solids, energy or heat transfer may also take place by free electrons. Examples of heat conduction are: heat transfer through wall, pipes, freezing of the ground during winter, etc. (Welty, *et al*, 1984).

2.2.2 Convection:

The transfer of heat by convection takes place by bulk transport and the mixing of microscopic parts of hot and cold elements of a fluid. This also includes a transfer of heat between a solid surface and a fluid (Woodall, 1971). Convection heat transfer takes place where a fluid is forced to flow past a surface by any mechanical and natural means or free convection, or where a warmer or cooler fluid next to the surface causes circulation because of density difference due to temperature difference (Thomas, 1992).

2.2.3 Radiation:

Radiation heat transfer differs from conduction and convection heat transfers because no physical medium is required and can take place in a vacuum. It is the mode of heat transfer through electromagnetic waves, and the same laws that govern the transfer of light govern radiation of heat. Solids and liquids have a tendency to absorb the radiation that is being transferred through them. Therefore, radiation is of primary significance in the transfer of heat through gases and space.

2.3 Heat Flow

Imagine a wall of uniform material such as, plasterboard that separates a warm room from a cold one. A steady temperature difference occurs across the wall and a steady flow of heat goes from warmer room to the cooler one (Etuk, *et al*., 2005).

Experiments show that the rate at which heat flows through the wall is directly proportional to its area A, and the temperature difference ($T_2 - T_1$), while inversely proportional to the thickness (x) of the wall. This is expressed by the heat flow equation:

$$\frac{\mathrm{dQ}}{\mathrm{dt}} = \mathrm{K}A \, \frac{T2 - T1}{x} \tag{2.1}$$

Where,

K = Conductivity of the poor conductor (Sample)

A (area of the disc) = πr^2

T_2 = Mean steady state temperature of upper disc

T_1 = Mean steady state temperature of lower disc

x = Thickness of the sample

$\frac{\mathrm{dQ}}{\mathrm{dt}}$ = Rate of heat flow

The S.I unit for heat flow is J/s or watts.

2.4 Thermal Conductivity

Thermal conductivity (K) of a material is the intrinsic property of a material which relates its ability to conduct heat (Alam, *et al*, 2012). It appears primarily in Fourier's law for heat conduction, and measured in watts per Kelvin meter (W/Km). Thus thermal conductivity predicts the rate of energy loss in watts through a piece of material. It is the property of a material that indicates its ability to conduct heat. Conduction will take place if there exists a temperature difference in a solid or stationary fluid medium. Energy is transferred from more energetic to less energetic molecules, when neighbouring molecules collide. Conductive heat flow occurs in the direction of decreasing temperature because higher temperature is associated with higher molecular energy.

Thermal conductivity can be affected by some factors such as moisture content, temperature, density, porosity and particle size (Ajibola and Onabanjo, 1995; Ekpe and Akpabio, 1994; Van Struaten, 1961; Zemanusky and Dittman, 1981).

The thermal conductivities of some materials are shown in Table 2.1.

Table 2.1 Thermal conductivity of some materials at room temperature. (Giambasttista, *et al*, 2007).

MATERIAL	**Κ –VALUE**	**MATERIAL**	**Κ-VALUE**
Air	0.023	Stainless steel	14
Rock wool	0.038	Lead	35
Cork	0.046	Steel	46
Wood	0.13	Nickel	60
Soil (dry)	0.14	Tin	66.8
Asbestos	0.17	Platinum	71.6
Snow	0.25	Iron	80.2
Sand	0.39	Brass	122
Water	0.6	Zinc	116
Window glass	0.63	Tungsten	173
Pyrex glass	1.13	Aluminium	237
Vycor	1.13	Gold	318
Concrete	1.7	Marble	401
Ice	1.7	Silver	429

2.4.1 Determination of thermal conductivity

There are several ways of determining the thermal conductivity of materials: the guarded hot plate method, the double disk method, the Searl's method, the Stanton Redcroft method and the Lee's disc method. (Alam, *et al*., 2012). For the purpose of this research, the Lee's disc method was used to determine the thermal conductivity of the samples, because it is a well known method. The apparatus is easy to set up and it has been used by so many researchers and confirmed suitable for determining the thermal conductivity K, of bad conductors and porous solids. Various other methods used in determining thermal conductivity are described in the following sub-sections.

(a) GUARDED HOT PLATE METHOD

The apparatus consists of material placed between two plates. One hot plate and the other is cooled or heated to lesser extent. Temperature of the plates is monitored until they are constant. The steady state temperatures, the thickness of the sample and the heat input to the hot plate are used to calculate thermal conductivity. The scheme of guarded hot plate is shown in Fig 2.1.

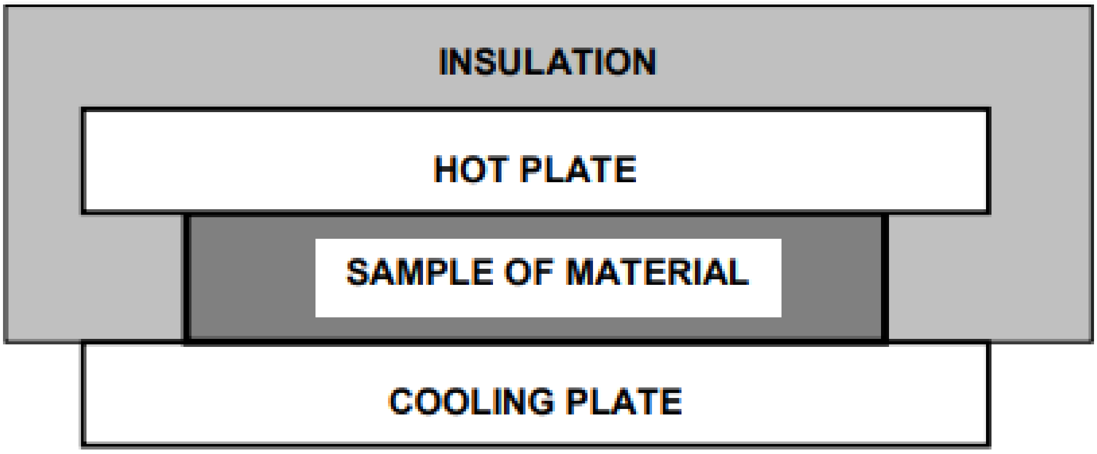


Fig. 2.1: *Schematic Diagram of Guarded Hot Plate method*

(*http://tpm.fsv.cvut.cz/student/documents/files/BUM1/Chapter16.pdf*)

(b) DR. BOCK’S APPARATUS

The apparatus consists of a circular hot plate with diameter 160 mm and is heated electrically. Hot plate is embedded by the compensation plate, which serves as insulation of the hot plate and has the same temperature as the hot plate. Temperaature in compensation and cooling plates is kept by water, running through two thermoststs. For different materials, it is necessary to adjust proper intensity of heating to obtain steady state. The scheme of Dr. Bock’s apparatus is shown in Fig 2.2.

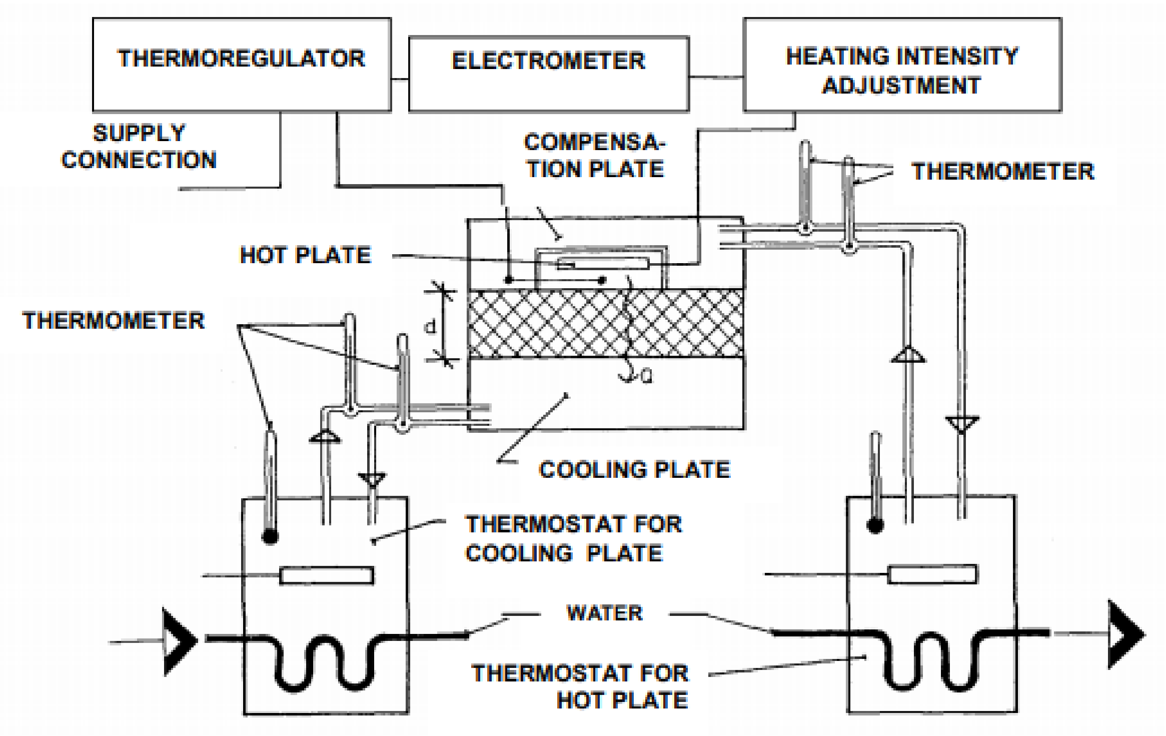


Fig. 2.2: *Schematic Diagram of Dr. Bock's Apparatus*

(http://tpm.fsv.cvut.cz/student/documents/files/BUM1/Chapter16.pdf)

(c) LEE’S DISC APPARATUS.

The apparatus consists of two circular brass discs (upper and lower disc), with the sample usually placed between the two discs during the experiment. The diameter of the sample is made equal to that of the discs and the thicknes of the sample is uniform throughout. A steam chamber is connected to the upper disc,a hollow disc with two side tubes provided for inflow and outflow of steam. Two thermometers T_1 and T_2 are inserted into the discs for temperature measurement, respectively. The complete setup is suspended from a clamp stand by attaching threads to the hooks on the lower disc. The scheme of Lee’s Disc apparatus is shown in Fig 2.3a.

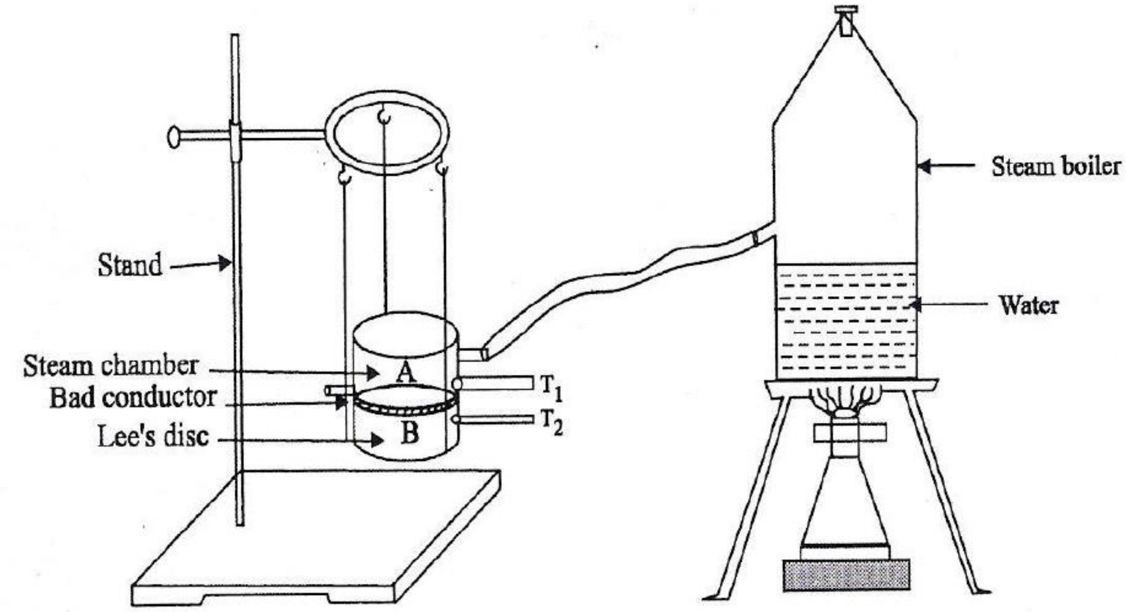


Fig. 2.3a: Lee's Disk apparatus setup (lecture notes from www. arunkumard.yolasite.com/resourcesExp_I_Lees_Disc_Apparatus.pdf).

When steam flows for some time, the temperatures T_1 and T_2 are recorded and when steady, this is the steady state. The rate of heat flowing through the sample per second is given by Eq. 2.1. When the apparatus is in steady state, that is, when temperatures T_1 and T_2 are constant, the rate of heat conduction into the lower disc (B) is equal to the rate of heat lost from the sample (Bad conductor). The rate of heat loss can be determined by measuring how fast the lower disc (B) cools at steady state, with the top of the disc covered with the sample for insulation. If mass and specific heat of the lower disc are m and c respectively, and the rate of cooling at steady state is $\frac{dQ}{dt}$, then the amount of heat radiated per second is:

$$\frac{dQ}{dt} = mc\frac{d\theta}{dt} \qquad (2.2)$$

Equating (2.1) and (2.2) and can be simplified, the thermal conductivity K can be determined as,

$$K = \frac{Mc(d\theta/dt)x}{A\,(T_2 - T_1)} \qquad (2.3)$$

Where:

K = Conductivity of the bad conductor (Sample).

A (area of the disc) = πr^2

T_2 = Mean steady state temperature of upper disc.

T_1 = Mean steady state temperature of lower disc

M = Mass of disc.

c = Specific heat capacity of lower disc.

x = Thickness of the sample

$\frac{d\theta}{dt}$ = temperature gradient from the graph.

Density can be measured for the samples using weighing and displacement method (Archimedes' principle). Thermal diffusivity and thermal resistivity, thermal absorptivity and specific heat capacity for the samples were equally calculated. The procedure was repeated for the other three test samples viz: Raphia palm, oil palm, pineapple stalk, and asbestos for average values. A table of values is gotten from the temperature variation readings taken and the calculations made for the thermal properties using the data from the table. The cooling curve (temperature vs time) was plotted and the slope $d\theta/dt = \Delta\theta/\Delta t$ determined at the steady temperature T_1 from the graph shown in Fig. 2.3b.

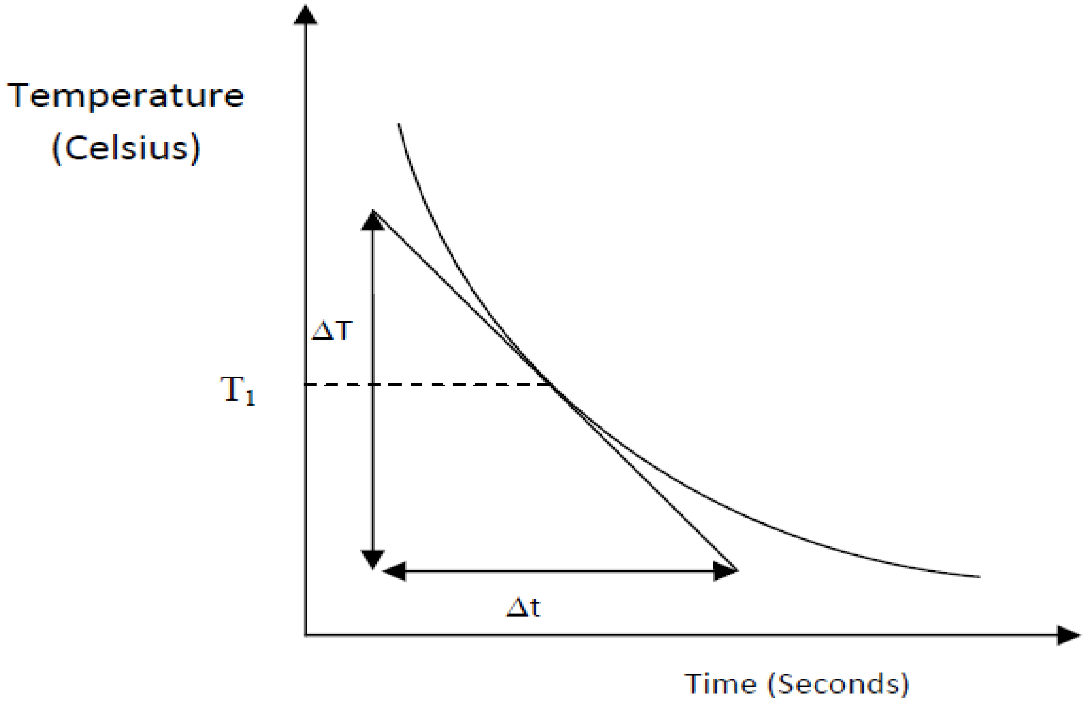


Fig 2.3b A Typical Cooling Curve (lecture notes from

www.iiserpune.ac.in/~bhasbapat/phy221_files/Lee's_Method.pdf)

In carrying out the experiment, some conditions that could introduce error in the results include: uncertainty in measurement of diameter and thickness; uncertainty in measurements of temperatures; heat loss by the sample from its sides; and forced cooling of the sample/ disc by the environment. In view of the errors: the following precautions were taken during the experiment to minimize the errors. The experiment environment attained steady state before commencement of the recordings, the experiment was conducted in drought free environment with fans put at off positions to prevent a forced cooling of the disc; and thermometer readings were carefully taken to avoid error due to parallax.

2.5 Thermal Resistivity

The reciprocal of thermal conductivity is referred to as thermal resistivity, which indicates the ability of a material irrespective of its thickness, to resist the passage of heat and the unit is mkw^{-1}. Equation (2.4) gives the mathematical expression for thermal resistivity

$$\rho_{th} = \frac{1}{K} \tag{2.4}$$

Where: ρ_{th} = thermal resistivity in mkw^{-1} and K = thermal conductivity. A construction layer with a high thermal resistance is a good insulator,while one with a low thermal resistance is a bad insulator.

2.6 Thermal Diffusivity

Another property closely related to the thermal conductivity is thermal diffusivity λ, which is the quantity of heat passing normally through a unit time divided by the product of specific heat capacity, density and temperature gradient. It indicates how quickly changes in temperature diffuse through a material. It is mathematically represented thus:

$$\lambda = K/\rho c \qquad (2.5)$$

Where: ρ is the density of the material in kgm^{-3} and c is the specific heat capacity at constant pressure. The unit of measurement for thermal diffusivity is m^2s^{-1}. Thermal diffusivity measures the ability of a material, to conduct thermal energy, relative to its ability to store thermal energy. Example, metals transmit thermal energy (cold to touch) whereas wood is a slow transmitters. Insulators have low thermal diffusivity. Examples are, Copper($\lambda = 9.88\ m^2s^{-1}$) and wood ($\lambda = 0.0082\ m^2s^{-1}$).

2.7 Thermal Absorptivity

Thermal absorptivity α, of a material is another thermal property associated with insulation of a material. it is defined by the expression

$$\alpha = (\omega/2\lambda)^{1/2} \qquad (2.6)$$

Where: ω = angular frequency. The more heat that a material absorbs, the less it reflects and vice versa.

According to Ekpe, *et al* (1994), variation in temperature with thickness of solid sample at any time depends on the thermal properties of the solid sample.

2.8 Density

The density of a substance is its mass per unit volume. It is known that in general, a given volume of material has a mass different from that of the same volume of some other material. For instance, we say that any given volume of iron is heavier than the same volume of wood. To make this comparison exact, we measure 1m^3 each of iron and wood respectively. Mathematically;

$$\text{Density, } \rho = \frac{mass\ (m)}{Volume\ (v)} \qquad (2.7)$$

Density measurement is an important analytical technique in a wide variety of circumstances. For an irregular shaped solid (e.g. a piece of stone) the mass is obtained as for regular solids but its volume is measured by immersing the object completely in a measuring cylinder containing water. The difference in the level of water before and after the immersion of the solid, gives the volume of the solid. (Anyakoha, 2016). The density of some materials is shown in Table 2.2.

Table 2.2 Density of some materials (Anyakaoha, 2016)

MATERIALS	DENSITY (g/cm^3)	MATERIAL	DENSITY (g/cm^3)
Aluminium	2.7	Silver	10.5
Brass	8.6	Steel	7.8
Copper	8.9	Mercury	13.6
Gold	19.3	Ethyl alcohol	0.81
Ice (at 0^{oc})	0.92	Benzene	0.90
Iron	7.8	Glycerin	1.26
Lead	11.3	Water (at 4^{oc})	1.00
Zinc	7.1	Bamboo wood	0.4

2.9 Specific Heat Capacity

The specific heat capacity of a material is the amount of heat, needed to raise the temperature of 1kg of the material, by 1K (or by$1^{o}C$). A good insulator has a higher specific heat capacity, because it takes time to absorb more heat before it actually heats up (temperature rising) to transfer the heat.

Experimentally, the quantity of the heat Q received by a body is proportional to its mass m and the temperature change ($T_2 - T_1$) and depends on the nature of the material.

Mathematically:

$$Q = mc(T_2 - T_1) \qquad (2.8)$$

Where m is the mass of a body in kg and $(T_2 - T_1)$ is the change in temperature in ^oC or K, c is a constant of proportionality which depends on the nature of the body, it is called, the specific heat capacity of the body. By rearranging Equation (2.8), we obtained:

$$c = \frac{Q}{m(T_2 - T_1)} \qquad (2.9)$$

Therefore by definition, specific heat capacity is the quantity of heat required to raise the temperature of unit mass of a substance by 1K or 1^oC. The specific heat capacity of some materials is shown in Table 2.3.

Table 2.3 Specific heat capacity of some materials: (Anyakoha, 2016).

MATERIAL	SPECIFIC HEAT CAPACITY c in J/kgK.
Aluminium	900
Brass	380
Glass	670
Ice	2100
Iron	460
Lead	129
Mercury	2400
Sea-water	3900
Water	4200
Zinc	384

2.10 Other Empirical Studies

Thermal properties of different materials have been determined by various researchers. Alausa *et al*., (2011)**,** studied the thermal properties of Rattan palm, Raphia palm and synthetic board as alternative sources of roofing and ceiling materials in building design in southwestern Nigeria by using the Lees' disc apparatus. Their results showed that Rattan palm sheet had lower thermal conductivity, and a higher resistivity, compared with Raffia palm sheet, while both palms showed lower thermal conductivity, and higher resistivity, than asbestos sheet. The results indicated that Rattan palm has a higher potential for heat resistivity than many other wood based heat-insulating materials and are recommended for ceiling in modern building designs**.**

Ndukwe (2008) studied the Production of materials from raffia palm leaves,their characterization and applications. In this work, raffia palm leaves, served as raw material, was processed into a refined, relevant form and produced into specimens which were then subjected to some characterizations which include thickness, density, and hardness. They were found suitable for possible applications as roofing and ceiling materials.

Onyeaju, *et al*. (2012) compared the thermal properties of asbestos and polyvinylchloride (PVC) ceiling sheets. The thermal properties of these materials were studied in terms of the thermal conductivity (TC), thermal resistivity (TR), thermal diffusivity, and specific heat capacity (SHC) with the aim of establishing their suitability as ceiling materials in building designs for tropical regions. The steady state Lees’ disc method was used to determine the thermal conductivity of the samples. The results, however, showed that thermal conductivity, thermal resistivity, thermal absorptivity, thermal diffusivity and specific heat capacity values of PVC and asbestos ceiling sheets falls within the range of good insulating materials like pine fibre-board and oak wood. With these properties and further improvement, the latter materials possess properties that can be harnessed for possible usage as ceiling materials.

Etuk, *et al*. (2003) investigated *raphia hookeri* trunk as potential ceiling material for passively cooled building designs. The economic situation in most third world countries has made the search for alternative structurally and thermally suitable indigenous building materials necessary. Hence, their work investigated and documented the thermal properties of *raphia hookeri* trunk with a view to establish its suitability as ceiling panels in building design for the tropical region, considering their thermal properties. The results show that the thermal properties of *raphia hookeri* trunk compared favourably with those of other good insulators. If properly harnessed, it could be used as efficient ceiling panel for passively cooled building designs. A model for the estimation of temperature variation with thickness of the sample was developed by them, based on their experimental values and the existing theory on temperature variation with thickness of materials.

The major interest in this work ,is to investigate the thermal properties of three materials (Raphia palm leaves, Oil palm leaves and pineapple stalk) using the steady state method (Lees' disc apparatus), compare the results with other heat insulating devices to ascertain if the natural leaves can serve the same purpose the synthetic roofing and ceiling sheets serve, and perhaps give a better heat insulating result that will encourage us to industrialization with local natural renewable, solid state materials.

CHAPTER THREE

RESEARCH METHODOLOGY

Experimental measurement of bulk density, ρ specific heat capacity, c thermal diffusivity, λ thermal resistivity, ρ_{th} and thermal conductivity, K were carried out and presented in this section.

3.1 Sample Collection / Preparation

The samples for experiment were obtained from three different locations in Apu-na-Ekpu Village in Isiala Ngwa North Local Government Area of Abia State, Nigeria, while the asbestos ceiling sheets were collected at the laboratory premises in the University of Uyo, Nwaniba Campus. In order to prepare these specimens for use, they were stored in a dry atmosphere, at room temperature for weeks to ensure that it was dry. This was done before grinding them into powdery form with infinitesimally small particle size, which was obtained perfectly by sieving the ground leaves. These ground leaves were used to determine the thermal conductivity K, density ρ, specific heat capacity, and thermal diffusivity λ while the specimens were broken into the required sizes before their respective analysis.

The plates of the stages of sample preparation are shown in Plate 3.1 (I-IV).

Stage I: Ground Leaves / Sample

Stage II: Clamping of the Ground Leaves Composite

Stage III: Drying of the Compact Leaves / Samples

Stage IV: Dried Compact Leaves / Samples

Plate 3.1: *Ground leaves/samples, clamping, drying and images of dried compact leaves*

3.2 Sample Analysis

The samples were analyzed in the laboratory at room temperature to determine their density ρ, specific heat capacity c, thermal conductivity K etc, by appropriate methods.

3.2.1 Determination of Density (ρ)

Determination of density of irregular porous sample by weighing and displacement method.

Aim: To determine the value of densities for three different leave samples and Asbestos ceiling sheet.

Apparatus: The apparatus used include a measuring cylinder, narrow test tube, samples, water and weighing balance.

Procedure:

Firstly, the mass of the dried samples were obtained by direct weighing using weighing balance, while the volume was found by immersing a test tube into the measuring cylinder half filled with water, and then placing the sample on the test tube immersed into the measuring cylinder. Before doing this, the reading of the initial water level V_1 of the measuring cylinder was taken, and also the water level after placing the porous sample on the test tube V_2. The difference in the water level V gave the volume of the specimen.

The plate showing the displacement of measuring volume of an irregular solid is shown in Plate 3.2.

(A) **(B)**

Plate 3.2: *Displacement method of measuring volume of an irregular solid*

This procedure was repeated thrice for all the samples and the mean bulk density calculated as shown in Table 3.1:

TABLE 3.1: Experimental Results of Density ρ (kgm^{-3}):

S/N	SPECIMEN	MASS(g)			VOLUME(ml)			Density, ρ (Kgm^{-3})		
		M_1	M_2	M_3	V_1	V_2	V_3	ρ1	ρ2	ρ3
1.	Oil palm leaves.	2.107	0.952	1.831	5.5	2.5	4.8	383.10	380.80	381.46
2.	Pineapple leaves.	1.637	1.940	1.457	4.0	4.7	3.5	409.25	412.77	416.30
3.	Raffia palm leaves.	1.046	1.411	1.046	3.0	4.0	3.0	384.67	352.75	348.67
4.	Asbestos	2.500	2.550	3.250	2.0	2.0	2.5	1250.00	1275.00	1300.00

3.2.2 Density: Measurement of irregular solid, using measuring cylinder

The following results were obtained:

Mass of sample B – pineapple leaves, = 1.940 x 10^{-3}kg.

Volume of sample B – pineapple leaves = 4.7 cm^3

Calculation:

Density of specimen B, $= \dfrac{mass\ of\ sample\ B}{volume\ of\ sample\ B}$

$$= \frac{1.940 \times 10^{-3}\,\text{kg.}}{0.47 \times 10^{-6}\,\text{m}^3}$$

Therefore, p_B = 412.77kg/m^3.

Precautions:

The following precautions were taken during these experiments:

(a) Errors due to parallax while taking readings by ensuring that the eye makes an angle of 80^0 to the water level on the cylinder.

(b) The sample test tube was carefully suspended to avoid the sample falling off and getting in contact with water.

(c) The suspended test tube was very narrow to avoid increasing the water level beyond the volume of the sample, as that would alter the result.

(d) To take care of the air space in the narrow test tube, saw dust was poured inside the tube and the stability of the tube immersed inside the measuring cylinder was ensured.

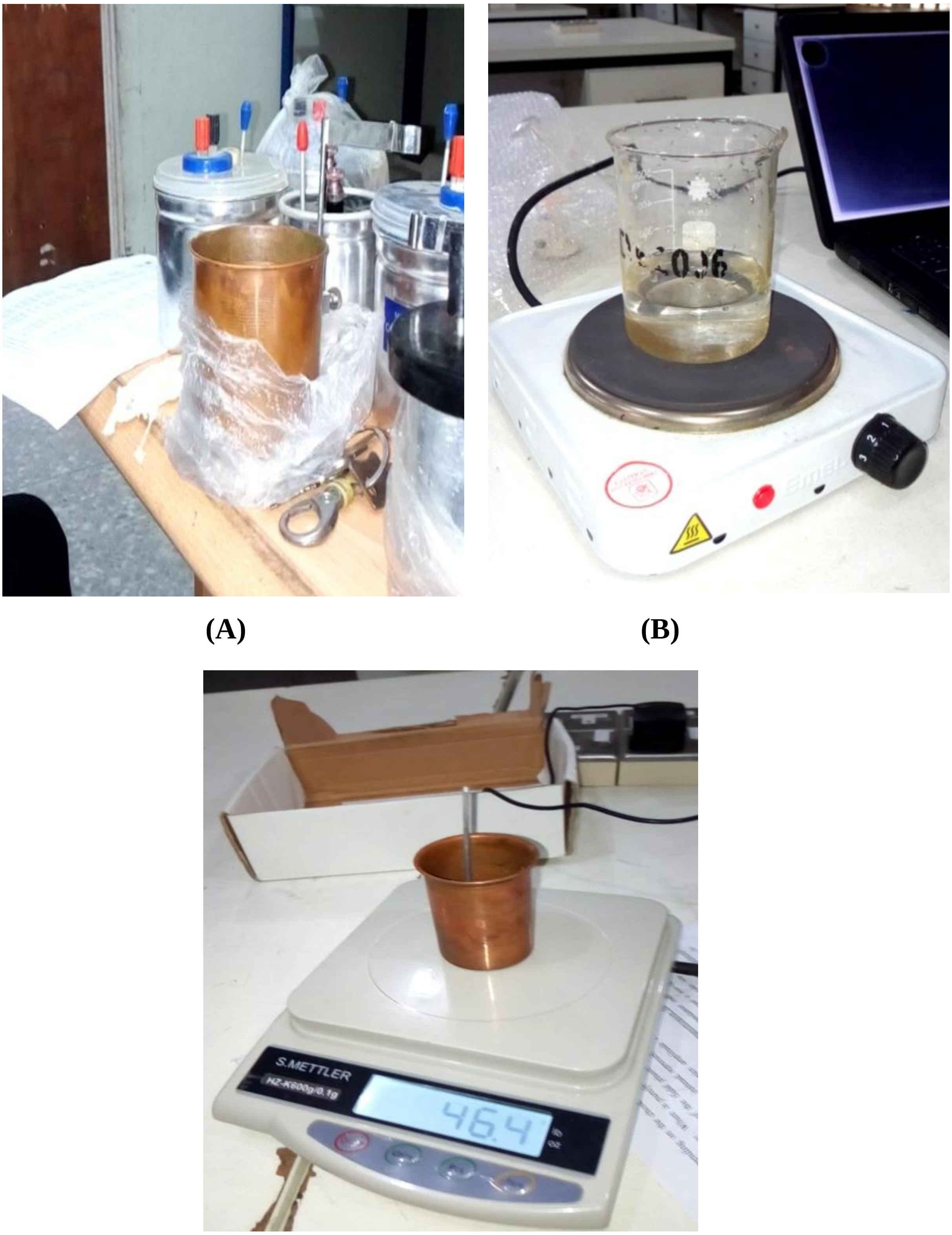
3.2.3 Determination of Specific Heat Capacity (c)

Measurement of specific heat capacity by method of mixtures (modified Calorimetry).

Aim: To determine the value of specific heat capacities of three different leave samples and Asbestos Ceiling sheet.

Apparatus: The apparatus used consists of a lagged copper calorimeter, a porous solid (the three leave samples), polythene as sealer, two thermometers, Bunsen burner/electric heater, a beaker, an inextensible string (thread), and s mettler weighing balance.

The plate showing the apparatus for determination of Specific Heat Capacity is shown in Plate 3.2



(A) (B)

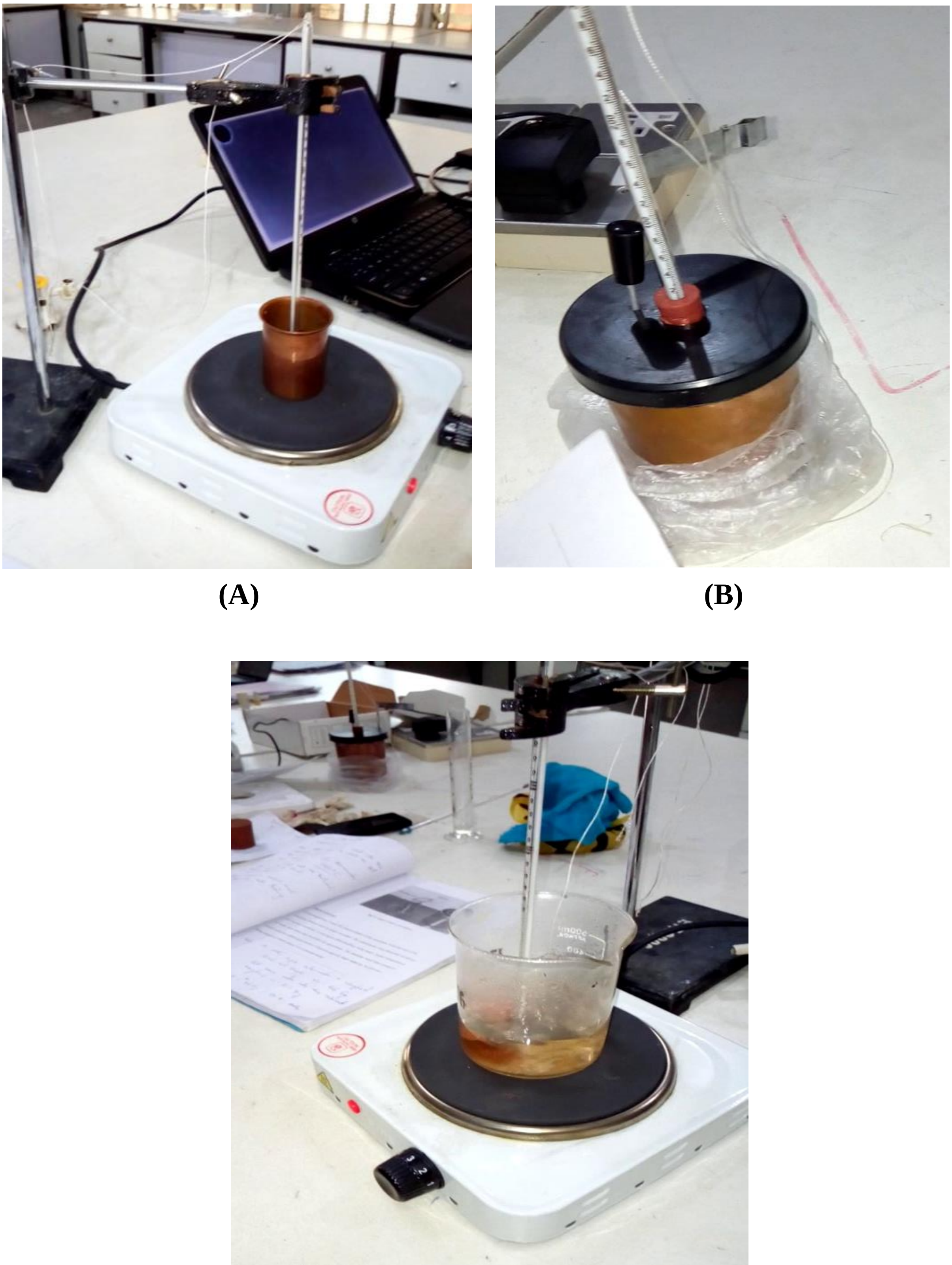
(C)

Plate 3.3: *Apparatus for determination of Specific Heat Capacity*

PROCEDURE:

The empty copper calorimeter was weighed with a copper stirrer, m_1 and then it was filled to about one-half with water and reweighed m_2. The calorimeter was placed with its content in the insulating jacket and the temperature of water in it was recorded (this served as the initial temperature of both water and the calorimeter with water), θ_1. The water was boiled in a 500 cm^3 beaker, the porous sample was sealed with polythene material, and its mass m_3 was weighed. The sample was suspended in the boiling water by means of a light thread for some time. At a constant boiling temperature θ_2 the specimen was quickly transferred from the boiling water into the calorimeter. With the aid of a retort clamp, the thermometer was suspended into the boiling water and sample to take accurate boiling temperature. While stirring the mixture, the temperature of the mixture was recorded at every 30 seconds. The maximum temperature of the mixture was observed θ_3, until it fell 5^oC below the maximum temperature recorded. The room temperature, θ_R was noted also.

The determination of specific head capacity setup is shown in Plate 3.4.



(A) (B)

(B)

Plate 3.4: *Determination of Specific Heat Capacity Setup*

It was observed experimentally that, the quantity of heat Q received by a body is proportional to its mass m and the difference (θ_1 - θ_2) and also the nature of the material making up the body (Eq. 2.8)

Similarly, from conservation law:

Heat gained by cold substance = Heat lost by hot substance.

Therefore;

Heat gain by calorimeter + water = Heat lost by the sample.

Heat gain by calorimeter + water = $m_1c_1(\theta_3 - \theta_1) + (m_2 - m_1)\, c_w\, (\theta_3 - \theta_1)$ (3.1)

Then, heat lost by specimen = $m_sc_s\, (\theta_1 - \theta_2)$ (3.2)

Therefore, $m_1c_1(\theta_3 - \theta_1) + (m_2 - m_1)\, c_w\, (\theta_3 - \theta_1) = m_sc_s\, (\theta_1 - \theta_2)$ (3.3)

making c_s the subject gives;

$$c_s = \frac{m_1c_1(\theta_3 - \theta_1) + (m_2 - m_1)\, c_w\, (\theta_3 - \theta_1)}{m_s\, (\theta_1 - \theta_2)} \qquad (3.4)$$

Hence, equation (3.4) is the relation for the specific heat capacity of the samples. Where: the experimented samples include, oil palm leaves, raffia palm, pineapple and asbestos).

Mass of the sample, $m_s = 4.0g$

Specific heat capacity of water $c_w = 4200 Jkg\, k^{-1}$

Specific heat capacity of the sealer $c_x = 1550\ Jkg\, k^{-1}$

Mass of calorimeter. $m_1 = 25.23g$

Mass of calorimeter + water. $m_2 = 38.90g$

Initial temperature of water. $\theta_1 = 28.0^oC$

Temperature of boiling water. $\theta_2 = 102^oC$

Highest temperature of the mixture. $\theta_3 = 62.0^oC$

$$c_s = \frac{2.52 \times 10^{-2} \times 400 \times (62-28.0) + (38.90 - 25.2) \times 4200 \times (62- 28.0)}{(4.0) \times (102 - 62)}$$

Therefore, cs (pineapple leave sample) – C_x(1550)
$c_s = 1949.95Jkg^{-1}K^{-1}$.

3.2.4 Experimental Results of Specific Heat Capacity (c):

The following values were measured, and kept constant during calculation:

Mass of calorimeter, $m_1 = 25.23g$

Specific heat capacity of calorimeter, $c_1 = 400Jkg^{-1}k^{-1}$

Specific heat capacity of water, $C_w = 4200Jkg\ k^{-1}$

Then other results with variable values are tabulated in Table 3.2.

Table 3.2: Experimental results for specific heat capacity (c)

SAMPLE	**Sample Mass(m_s)g.**			**Initial Temp of water and calorimeter θ_1(^{0}C).**	**Temp of boiling water θ_2 (^{0}C) for**			**Observed Temp of mixture θ_3(^{0}C).**		
					Sample 1	**Sample 2**	**Sample 3**	**Sample 1**	**Sample 2**	**Sample 3**
Oil Palm leaves.	M_1 4.0	M_2 4.0	M_3 4.0	28.0	102.0	101.0	101.0	62.0	61.0	61.0
Raffia Palm Leaves	4.0	3.8	3.6	28.0	99.0	98.9	98.8	59.5	59.0	58.0
Pineapple Leaves.	4.2	4.3	4.1	28.0	98.0	97.9	97.0	61.5	62.0	61.5
Asbestos	4.9	4.7	4.6	28.0	101.0	102.1	101.2	53.0	62.0	61.0

Summary of Specific Heat Capacity, C ($Jkg^{-1}K^{-1}$)		
Sample 1	**Sample 2**	**Sample 3**
1611.30	1611.24	1611.24
1949.16	1948.95	1949.37
1516.38	1516.35	1516.38
1456.21	1456.15	1456.24

Precautions:

The following precautions were taken during this experiment:

(a) The stirrer used was of the same material with the calorimeter.

(b) The calorimeter was well lagged with an insulating material.

(c) The sample was properly sealed to avoid being soaked in water.

(d) The hot materials, (samples) were transferred quickly to the calorimeter.

(e) The mixture was gently stirred to ensure uniform heat distribution from the specimen to water in the calorimeter.

3.3 DETERMINATION OF THERMAL CONDUCTIVITY (Ⲕ)

Title: Measurement of thermal conductivity Ⲕ of porous solids.

Aim: To determine the value of specific heat capacities of three different leave samples (Oil palm leaves, Raffia palm leaves and Pineapple leaves) and compare with Asbestos ceiling sheet.

Apparatus: The apparatus used were a standard laboratory form of Lee’s disc apparatus, two thermometers (-10°C to 110°**C),** heat source (electric stove), steam can, stop watch, three retort stands, steam pipe and the grinded leaf sample.

Plate 3.5: *Photograph of Thermal conductivity measurement setup*

Procedure:

In the experimental setup shown in plate 3.5, steam is allowed to pass through the inlet of the upper brass disc, and it escapes through the outlet. After steady state is reached, there was no further rise in the reading of the thermometers, hence, no change in temperature with time. The steady state temperatures T_1 and T_2 are noted. The sample is removed by gently lifting the upper brass disc and the lower brass disc is allowed to be directly in contact with the upper disc to heat it up to some temperatures above the steady state temperature of the lower brass disc. When the temperature of the lower disc attains a value of about 10^0C above the steady state temperature, the upper disc is removed and the lower disc is allowed to cool on its own with the sample placed on it to prevent forced cooling. A stop watch is started when the temperature is 5^oC above the steady state temperature and time is noted for every 1^oC fall in temperature until the lower disc cools below its steady state temperature. A graph of temperature against time is plotted and the rate of cooling $\frac{d\theta}{dt}$ is calculated from the graph (Fig. 2.3). The mass of the lower disc (M) and the thickness (x) of the sample are measured using the proper instruments.

The following values were measured and kept constant during calculations:

Mean diameter of brass slab = 0.11m, hence: r = 0.055m

Mass of the lower disc = 0.75kg

Specific heat capacity of the steel slab = 448Jkg^{-1}k^{-1}

Mean thickness of the sample = 0.006m

Tables 3.3 – 3.10 show the values of the steady state temperature and data for cooling curve, temperature reduction for samples.

SAMPLE A – OIL PALM LEAVES

Table 3.3: Steady State Temperatures for Sample A.

Reading of Thermometers in Steady State.	T_2(°C)	T_1(°C)
Before interchanging	99.00	48.00
After interchanging	99.50	47.50
Mean temperatures	99.25	47.75

Table 3.4: Data for cooling curve, temperature reduction from 62^0C to 38^0C for sample A.

Time	Temp	Time	Temp.	Time	Temp
00	62.00	660	52.50	1290	44.00
60	61.00	720	52.00	1320	43.50
120	60.00	780	51.00	1380	43.00
180	58.50	840	50.00	1440	42.25
240	58.00	900	49.00	1500	41.75
300	57.00	930	48.50	1560	41.25
360	56.00	990	48.00	1620	41.00
420	55.25	1050	46.75	1680	40.45
480	54.50	1110	46.00	1740	40.00
540	54.00	1170	45.25	1800	39.00
600	53.25	1230	44.50	1920	38.15

SAMPLE B: RAFFIA PALM LEAVES.

Table 3.5: Steady state temperatures for sample B

Reading of Thermometers in Steady State.	T_2(^{0}C)	T_1(^{0}C)
Before interchanging	99.00	66.50
After interchanging	99.50	66.00
Mean temperatures	99.25	66.25

Table 3.6: Data for cooling temperature reduction from 76^0C to 42^0C for sample B.

Time	Temp	Time	Temp	Time	Temp	Time	Temp	Time	Temp
00	76.25	570	65.00	1170	56.75	1860	50.75	2460	46.25
60	75.50	630	64.00	1230	56.00	1920	50.25	2520	46.00
120	74.25	690	63.50	1290	55.50	1980	49.75	2580	45.75
180	73.00	750	62.50	1350	54.50	2040	49.25	2640	45.25
240	71.50	810	61.50	1440	54.25	2100	48.75	2700	45.00
300	70.50	870	60.50	1500	53.50	2160	48.25	2760	44.50
330	69.50	930	59.50	1560	52.75	2220	48.00	2820	44.25
390	68.50	990	59.00	1620	52.50	2280	47.50	2880	44.00
450	67.50	1050	58.25	1680	51.57	2340	47.25	2970	43.50
510	66.25	1110	57.50	1800	51.25	2400	46.75	3030	43.25

SAMPLE C: PINEAPPLE LEAVES.

TABLE 3.7: Steady state temperatures for sample C.

Reading of Thermometers in Steady State.	T_2(°C)	T_1(°C)
Before interchanging	98.00	63.00
After interchanging	99.50	62.00
Mean temperatures	98.50	66.25

Table 3.8: Data for cooling temperature reduction from 72^oC to 39^oC

Time	Temp	Time	Temp	Time	Temp	Time	Temp	Time	Temp
00	72.5	540	60.5	1080	52.5	1650	47.0	2160	42.5
60	71.5	600	59.5	1140	52.0	1710	46.5	2220	42.5
120	69.5	660	58.5	1200	51.0	1770	45.5	2280	42.0
180	68.5	720	57.5	1260	50.5	1830	45.5	2340	41.5
240	67.0	780	56.5	1320	49.5	1890	44.5	2400	41.0
300	65.5	840	55.5	1380	49.0	1950	44.5	2460	40.5
360	64.5	900	54.5	1470	48.5	2010	44.0	2520	40.0
420	63.0	960	54.0	1530	48.0	2070	43.5	2580	39.5
480	61.5	1020	53.0	1590	47.5	2100	43.0	2640	39.0

SAMPLE D: ASBESTOS

Table 3.9: Steady state temperatures for sample D.

Reading of Thermometers in Steady State	T_2(^{0}C)	T_1(^{0}C)
Before interchanging	99.5.00	86.00
After interchanging	102.00	83.00
Mean temperatures	100.70	84.5

Table 3.10: Data for cooling temperature reduction from 90^{0}C to 45^{0}C for sample D.

Time	Temp	Time	Temp	Time	Temp	Time	Temp	Time	Temp
00	90.50	540	72.00	1080	61.50	1650	53.50	2100	49.00
60	90.00	600	70.00	1140	60.50	1710	53.00	2160	49.50
120	88.55	660	69.00	1200	59.50	1770	52.25	2220	49.50
180	83.00	720	68.00	1260	58.50	1830	51.50	2280	48.50
240	81.00	780	66.50	1320	57.75	1860	51.50	2340	48.50
300	79.00	840	65.50	1380	57.00	1920	50.25	2400	47.50
360	77.50	900	64.50	1470	56.00	1980	50.00	2490	47.25
420	75.50	960	63.00	1530	55.00	2010	50.00	2640	46.00
480	73.00	1020	62.50	1590	54.25	2070	49.50	2760	45.00

Calculation:

Mean upper temperature in steady state, T_2 = 98.50 ^{0}c

Mean lower temperature in steady state, T_1 = 62.50 ^{0}c

Mean thickness of the sample (pineapple leaves) = 0.006m

Mass of the metal disc = 0.75kg

Radius of metal disc = 0.055

Cross sectional area A = πr^2

$= 3.142 \times (0.055)^2 = 0.0095m^2$.

Recall from the cooling curve,

Gradient from the cooling curve for sample pineapple leaves, $= \frac{\Delta\theta}{\Delta t \times 60}$

$= \frac{56.0 - 39.5}{(34.0 - 11.4) \times 60} = 0.0122^0C/s$.

Therefore, $= 0.0122^0C/s$.

Specific heat capacity of steel slab $= 448Jkg^{-1}k^{-1}$

From the formula,

$$KA\left[\frac{T_2 - T_1}{x}\right] = Mc\,\frac{d\theta}{dt} \qquad (3.5)$$

$$K = \frac{Mc\,\frac{d\theta}{dt}}{A\left[\frac{T_2 - T_1}{x}\right]} \qquad (3.6)$$

$$\frac{0.0095\,(98.50 - 62.50)}{0.006}K = 0.75 \times 448 \times 0.012$$

$57K = 4.0992$

$$K = \frac{4.0992}{57}$$

$K = 0.0719Wm^{-1}K^{-1}$

Therefore, the thermal conductivity K of the sample (pineapple leaves) = $0.0719\ Wm^{-1}K^{-1}$.

The cooling curves for the samples are shown in Figures 3.1 – 3.3

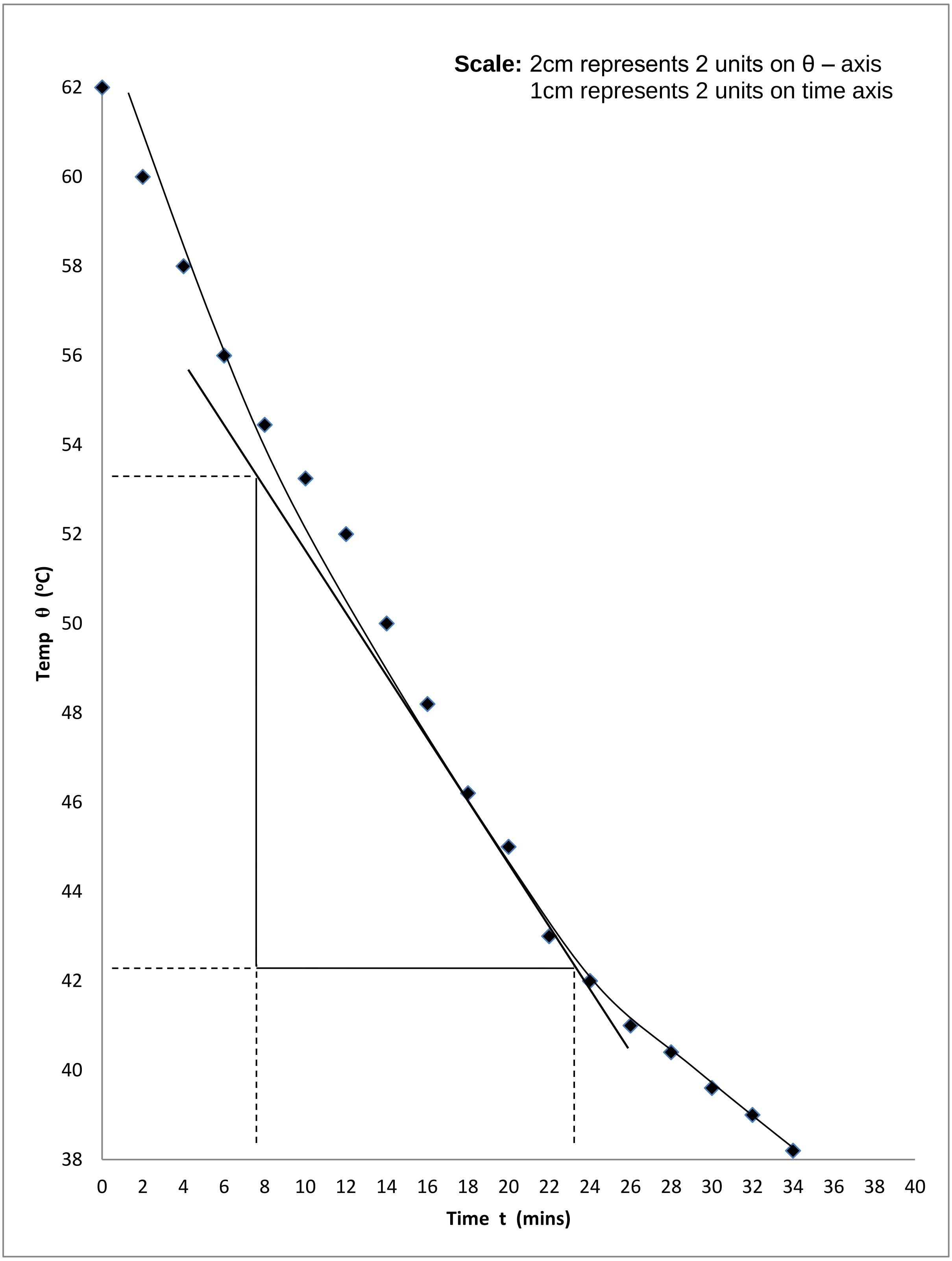


Fig. 3.1: COOLING CURVE FOR SAMPLE A: OIL PALM LEAVES

SLOPE FOR SAMPLE A (OIL PALM LEAVES)

Gradient $= \frac{\Delta\theta}{t(s)}$

$= \frac{\theta_2}{t_2} - \frac{\theta_1}{t_1}$

Where: $\theta_1 = 42.0$, $\theta_2 = 53.4$

$t_1 = 8.0$ $t_2 = 23.0$

Gradient $= \frac{53.4 - 42.0}{(23.0 - 8.0) \times 60}$

$= \frac{11.4}{900}$

$= \underline{0.0126^{o}C/S}$

Gradient for Sample A (Oil Palm Leaves) = 0.0126^{o}C/S.

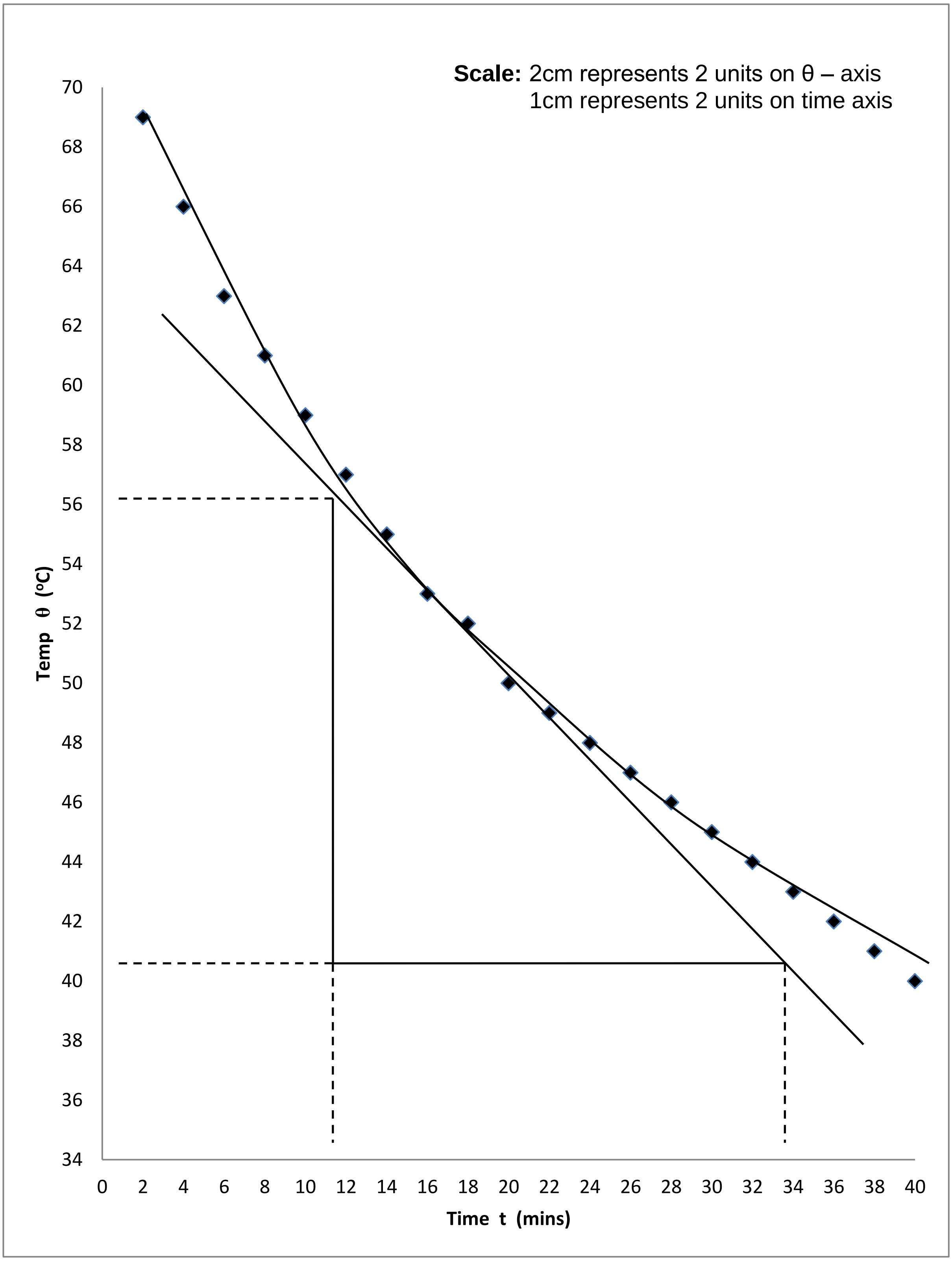


Fig. 3.2: COOLING CURVE FOR SAMPLE B: PINEAPPLE LEAVES

SLOPE FOR SAMPLE B (PINEAPPLE LEAVES)

Gradient $= \frac{\Delta\theta}{t(s)}$

$= \frac{\theta_2}{t_2} - \frac{\theta_1}{t_1}$

Where: $\theta_1 = 39.5$, $\theta_2 = 56$

$t_1 = 11.4$ $t_2 = 34.0$

Gradient $= \frac{56.0 - 39.5}{(34.0 - 11.4) \times 60}$

$= \frac{16.5}{1356}$

= <u>$0.0122^{o}C/S$</u>

Gradient for Sample B (Pineapple leaves) = $0.0122^{o}C/S$

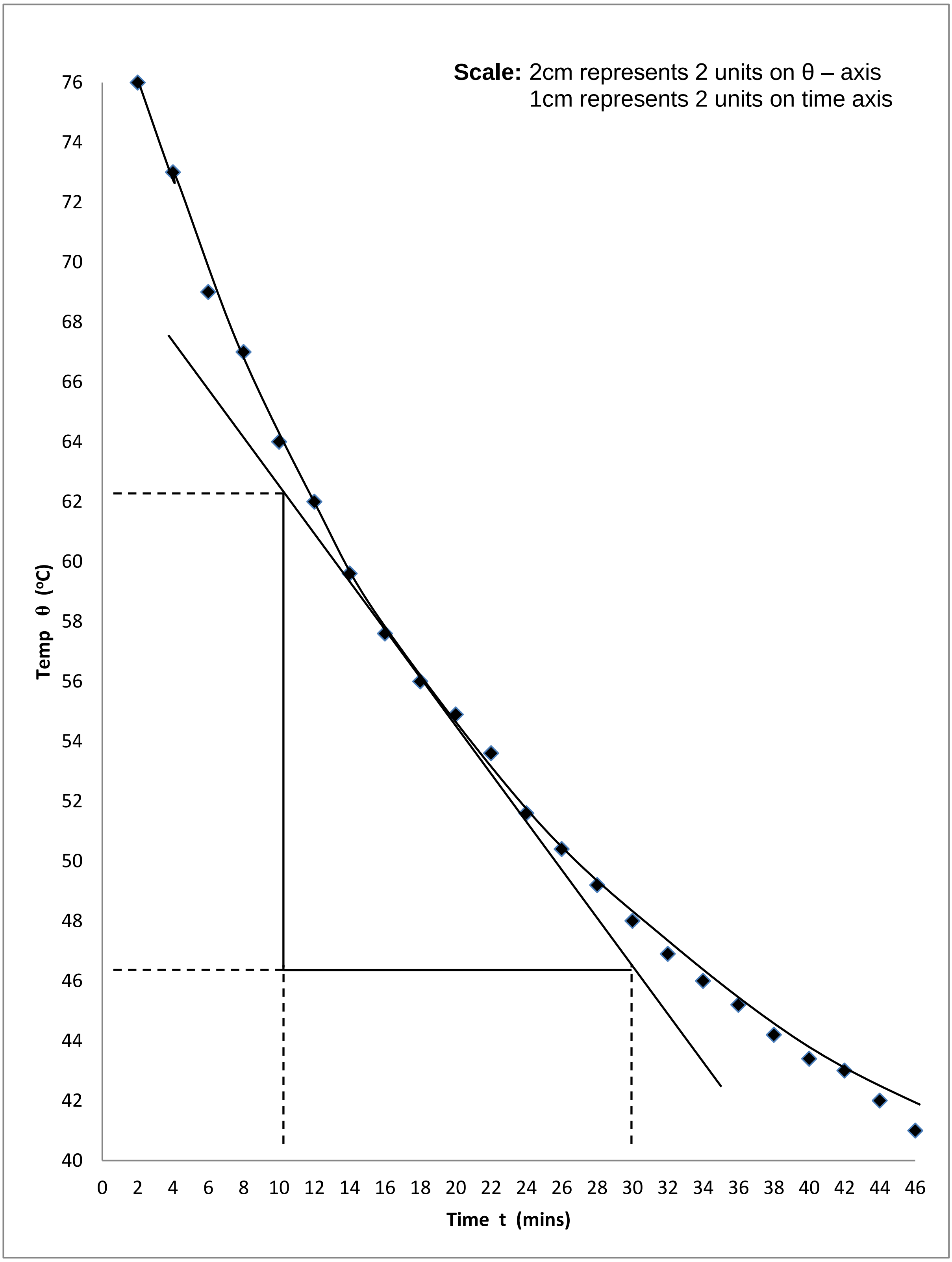


Fig. 3.3 COOLING CURVE FOR SAMPLE C: RAFFIA PALM LEAVES

SLOPE FOR SAMPLE C (RAFFIA PALM LEAVES)

Gradient $= \frac{\Delta\theta}{t(s)}$

$= \frac{\theta_2}{t_2} - \frac{\theta_1}{t_1}$

Where: $\theta_1 = 46.0$, $\theta_2 = 62.0$

$t_1 = 10.0$ $t_2 = 28.8$

Gradient $= \frac{62.0 - 46.0}{(28.8 - 10.0) \times 60}$

$= \frac{16}{1128}$

$= \underline{0.014^{o}C/S}$

Gradient for Sample C (Raffia Palm Leaves) = 0.0142ºC/S.

Precautions:

The following precautions were taken during this experiment;

(a) The sample were heated for long enough to be certain that they reached the steady state temperatures.

(b) The thermometer readings were carefully taken to avoid error due to parallax.

(c) The steam pipe was straightened to avoid condensation.

THERMAL DIFFUSIVITY:

Determination of thermal diffusivity of sample by calculation.

CALCULATION:

Thermal diffusivity λ:

$$\lambda = \frac{K}{\rho c} \quad (3.9)$$

$K = 0.0719 Wm^{-1}K^{-1}$

$c = 1949.95\ Jkg^{-1}K^{-1}$.

$\rho = 412.77 kg/m^3$

$$\lambda = \frac{0.0719}{4.12 \times 10^3 \times 1949.95}$$

Therefore λ = 8.64 x 10-7m^2s^{-1}

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSIONS

4.1 Results

Values for the density, specific heat capacity, thermal conductivity and thermal diffusivity for samples A, B, C and D (Oil palm leaves, Raffia palm leaves, Pineapple leaves and Asbestos) were calculated using equation (3.1), (3.6), (3.8) and (3.9) respectively.

The respective results of these calculations are presented in Table 4.1 below. The results presented would be used later in this chapter for error analysis, discussion of result, summary and as important indices in predicting temperature variation of the different leaf samples as alternative ceiling materials, which is the core subject matter in this research work.

Table 4.1: Summary of results

Samples	**Thermal Conductivity ($Wm^{-1}K^{-1}$)**			**Specific Heat Capacity, C ($Jkg^{-1}K^{-1}$)**			**Density, ρ (Kgm^{-3})**			**Thermal Diffusivity, λ($10^{-7}m^2s^{-1}$)**
Oil Palm Leaves	0.1171	0.1203	0.1177	1611.30	1611.24	1611.24	383.10	380.80	381.46	8.6
Pineapple leaves	0.0719	0.0737	0.0741	1949.16	1948.95	1949.37	409.25	412.77	416.30	9.1
Raffia Palm Leaves	0.1283	0.1249	0.1255	1516.38	1516.35	1516.38	384.67	352.75	348.67	14.1
Asbestos ceiling sheet.	0.182	0.193	0.210	1456.21	1456.15	1456.24	1250.00	1275.00	1300.00	**10.5**

4.2 Error Analysis

Experimental errors are some of the problems physicist find ways of reducing, so that the effect of errors on the final results does not render the experiment unreliable. There are different type of error that could arise in an experiment and can generally, come from several sources such as errors inherent in the apparatus and instruments, errors due to reading of instruments and errors in graphing (Ikeobi el al, 1990).

Whenever, a measurement of physical quantity (i.e.) length, mass, time, velocity is made, there is always an error or uncertainty in measurement and therefore in the result calculated from the reading. This kind of errors is known as experimental error, and is an estimate of how far the result of an experiment differs from the true or standard value of the physical quantity. It is important to note that errors discussed here do not include mistakes made by an observer himself due to using a wrong procedure for the experiment or carelessness in taking and writing down readings. It is assumed that an observer is careful and able to use the measuring instruments correctly. In spite of this, errors cannot be eliminated completely from experimental results. Therefore, there is the need to estimate them and quote them in the final result (Akpan, 2000).

For instance, assuming the force of an object of mass m, travelling at a velocity v is in a circle of radius r is given by:

$$F = \frac{mv^2}{r}$$

Where: v = (v $\pm \Delta v), r =$ (r$\pm\Delta r$),and m =(m $\pm$ Δm), given that $\Delta v, \Delta r\ and\ \Delta w$ represent errors in the respective quantities.

Therefore, the maximum possible (relative) error is given by:

$$F = \frac{mv^2}{r} \qquad (4.1)$$

Where: v = (v ± Δv), r = (r ± Δr), and m = (m ± Δm), given that Δ represents error in the quantity.

Therefore, the maximum possible (relative) error is given by:

$$\frac{\Delta F}{F} = \frac{\Delta m}{m} + \frac{2\Delta v}{v} + \frac{\Delta r}{r}$$

Which implies that:

$$\Delta F = \left(\frac{\Delta m}{m} + \frac{2\Delta v}{v} + \frac{\Delta r}{r}\right) \times F \qquad (4.2)$$

Where, F = standard value of the result.

ΔF = Error in measurement.

Alternatively, it is also noted that the percentage error in a specimen is the sum of errors contributed by the different measured quantities in the experiment. Finally, the total percentage error gives the maximum possible or relative error in any experiment which is similar to the result obtained in equation (4.2) were used. Method of Equation (4.2) is known as differential method (Eno, 2000).

4.2.1 Error Analysis of density

Consider the formula for density ρ which is given by:

$$\rho = \frac{m}{v} \tag{4.3}$$

The least of the measuring instruments are:

Weighing balance, $\Delta m = 0.05g$

Measuring cylinder, Δv = 0.05ml

Using the following conversion in SI unit;

1ml = 10^{-3} m

1g = 10^{-3} kg

Therefore, the actual values with the least count of their respective instruments are:

M = (m $\pm$ Δm) x 10^{-3} kg

V = (v $\pm \Delta v$) x 10^{-6}m^3

In order to calculate maximum possible (relative) error, Equation (4.3) can be expressed as:

$$\frac{\Delta \rho s}{\rho s} = \frac{\Delta ms}{ms} + \frac{\Delta Vs}{Vs}$$

Which reduces to:

$$\Delta p_s = \left[\frac{\Delta m_s}{m_s} + \frac{\Delta v_s}{v_s}\right] x\rho_s \tag{4.4}$$

And the result would be represented as:

$\rho = \rho_s \pm \Delta\rho,$ s represents samples B, A, C, …….. D. Equation (4.4) was used to calculate the values for error in density as presented in Table 4.2.

Table 4.2: Summary of density analysis with errors.

S/N	SAMPLE	DENSITY, $\rho(kg/m3)$
1	OIL PALM LEAVES	381.79±0.77
2	PINNEAPPLE LEAVES	412.77± 2.35
3	RAFFIA PALM LEAVES	350.00± 1.36
4	ASBESTOS CEILING SHEET	1275.00 ±16.67

4.2.2 Error Analysis of specific heat capacity

Mathematically, specific heat capacity is given by:

$$C_s = \frac{m_1c_1(\theta_3 - \theta_1) + (m_2 - m_1)\, c_w\, (\theta_3 - \theta_1)}{m_s\,(\theta_1 - \theta_2)}$$

Where the quantities involved were earlier defined in equation (3.6). But in terms of maximum possible or relative error in the experiment, we have:

$$\frac{\Delta c_s}{c_s} = \frac{\Delta m_1}{m_1} + \frac{\Delta m_2}{m_2} + \frac{\Delta \theta_1}{\theta_1} + \frac{\Delta \theta_2}{\theta_2} + \frac{\Delta \theta_3}{\theta_3} + \frac{\Delta m_s}{m_s}$$

$$\Rightarrow\ \Delta c_s = \left[\frac{\Delta m_1}{m_1} + \frac{\Delta m_2}{m_2} + \frac{\Delta \theta_1}{\theta_1} + \frac{\Delta \theta_2}{\theta_2} + \frac{\Delta \theta_3}{\theta_3} + \frac{\Delta m_s}{m_s}\right] \times c_s \qquad (4.5)$$

The values of error in specific heat capacity C_s were calculated using equation (4.5) and their respective results tabulated in Table 4.3.

Table 4.3: Summary of specific heat capacity analysis with errors

S/N	SAMPLE	SPECIFIC HEAT CAPACITY c_s ($Jkg^{-1}K^{-1}$)
1.	OIL PALM LEAVES	1611.26± 0.02
2.	PINEAPPLE LEAVES	1949.16± 0.07
3.	RAFFIA PALM LEAVES	1516.37±0.01
4.	ASBESTOS CEILING SHEET	1456.20± 0.03

4.2.3 Error analysis of thermal conductivity

Consider the relation for thermal conductivity K of a metal slab given by:

$$KA\left[\frac{T_2 - T_1}{x}\right] = Mc\,\frac{d\theta}{dt}$$

Where, c, $\frac{d\theta}{dt}$, and π in A (πr^2) are constants, since they were not directly measured. Then, the maximum possible error in thermal conductivity K is given by:

$$\frac{\Delta k_s}{k_s} = \frac{\Delta m_s}{m_s} + \frac{\Delta t}{t} + \frac{2\Delta r}{r} + \frac{\Delta\theta}{\theta}$$

Where: $\theta = \theta_2 - \theta_1$

Specimen A:

The maximum possible error in specimen A is given by:

$$\Delta k_s = \left[\frac{\Delta m}{m} + \frac{\Delta t}{t} + \frac{2\Delta r}{r} + \frac{\Delta\theta}{\theta}\right] \times k_s \qquad (4.6)$$

The least count of a weighing balance, Δm = 0.05g

The least count of a thermometer, $\Delta\theta$ = 0.5°C

The least count of a meter rule Δt, Δr = 0.05cm

$$\Delta K_A = \left[\frac{0.05}{719.00} + \frac{0.05}{1.6} + \frac{0.05 \times 2}{3.1} + \frac{0.5}{40.7}\right] \times 0.0719$$

ΔK_A = 0.007

Therefore, $K_A = 0.0719 \pm 0.007\ Wm^{-1}K^{-1}$

Table 4.4: Summary of thermal conductivity analysis with error.

S/N	SAMPLE	THERMAL CONDUCTIVITY K($Wm^{-1}K^{-1}$)
1.	OIL PALM LEAVES	0.1184±0.0002
2.	PINEAPPLE LEAVES	0.0719± 0.0007
3.	RAFFIA PALM LEAVES	0.1262± 0.0001
4.	ASBESTOS CEILING SHEETS	0.195± 0.009

4.2.4 Error Analysis in thermal diffusivity λ

Mathematically, thermal diffusivity λ is given by:

$$\lambda_s = \frac{k}{\rho c}$$

The maximum possible (relative) error in thermal diffusivity λ_s is given by:

$$\frac{\Delta\lambda_s}{\lambda_s} = \frac{\Delta k_s}{k_s} + \frac{\Delta\rho_s}{\rho_s} + \frac{\Delta c_s}{c_s} \qquad (4.7)$$

Equation (4.7) was used to calculate for the values of samples A, B, C, … D and the results presented in Table 4.5.

The summary of thermal diffusivity analysis is shown in Table 4.5

Table 4.5: Summary of thermal diffusivity analysis with errors

S/N	SAMPLE	THERMAL DIFFUSIVITY λs (m^2s^{-1})
1.	OIL PALM LEAVES	8.6± 0.3
2.	PINEAPPLE LEAVES	9.1± 0.4
3.	RAFFIA PALM LEAVES	14.1±0.2
4.	ASBESTOS CEILING SHEET	10.5 ±0.5

The summary of the results error analysis is shown in Table 4.6.

4.3 Summary of the results Error Analysis

Table 4.6: Summary of the results with the errors

SAMPLE	THERMAL CONDUCTIVITY $K(Wm^{-1}K^{-1})$.	THERMAL RESISTIVITY ρ_{th} (mkw^{-1})	SPECIFIC HEAT CAPACITY Cs $(Jkg^{-1}K^{-1})$.	DENSITY, $\rho(kg/m3)$	THERMAL DIFFUSIVITY λs (m^2s^{-1}).	THERMAL ABSORPTIVITY (m^{-1})
Oil palm leaves (A)	0.1184±0.0002	08.4459± 0.0002	1611.26± 0.02	381.79±0.77	8.6± 0.3	29.1± 1.0
Pineapple leaves (B)	0.0719± 0.0007	13.908 ± 0.007	1949.16± 0.07	412.77± 2.35	9.1± 0.4	28.3±1.2
Raffia palm leaves (C)	0.1262± 0.0001	07.729 ± 0.001	1516.37±0.01	350.00± 1.36	14.1±0.2	22.7± 0.3
Asbestos ceiling sheet	0.195± 0.009	5.128± 0.009	1456.20± 0.03	1275.00 ±16.67	10.5 ±0.5	9.62± 0.14

4.4 Results and Discussion

The result for the density, ρ; specific heat capacity, c; thermal conductivity, k: and thermal diffusivity for all of the materials are shown. The table (4.6) shows that the Sample B, Pineapple leaves has the lowest thermal conductivity value of $0.0719Wm^{-1}k^{-1}$, with a density ρ; $412.77kg/m^3$, specific heat capacity, c; $1949.16Jkg^{-1}k^{-1}$ and thermal diffusivity λ of $9.1m^2s^{-1}$; followed by Sample A, Oil palm leaves, with thermal conductivity of $0.1184\ Wm^{-1}k^{-1}$, density ρ; $381.79\ kg/m^3$, specific heat capacity, c; $1611.26\ Jkg^{-1}k^{-1}$, thermal diffusivity λ; $8.6m^2s^1$.

The rest are, sample C, Raffia palm leaves with thermal conductivity Ҡ; 0.126 $Wm^{-1}k^{-1}$, and Asbestos with 0.195 $Wm^{-1}k^{-1}$. And their respective values of density ρ, specific heat capacity c, and thermal diffusivity **λ**. Since thermal conductivity of the materials Ҡ is a very important parameter used in measuring temperature variations of different materials, it is observed that the temperature response of these samples varied, and this was dependent on their thermodynamic properties.

The calculation of the rate of cooling (the gradient) from the temperature versus time cooling curves (Fig 3.1b, 3.2b and 3.3b) show that pineapple leaf sample attained steady state at $0.0122^0C/s$, Oil palm leaf attained steady state at $0.0126^0C/s$ while the Raffia palm leaf sample C attained steady state at $0.014^0C/s$. The lower the steady state temperature, the lower the thermal conductivity value, thus pineapple leaf sample with the lowest steady state temperature value has the lowest thermal conductivity value, as a result would record the lowest thermal response from the other samples. Consequently, a material having a lower thermal conductivity value will have a higher thermal resistivity.

It is important to note that a material with the highest specific heat capacity value, would record the lowest thermal conductivity response, with reference to the experimental results. It is observed that pineapple leaf sample recorded the highest thermal conductivity value than oil palm and raffia leaf samples respectively. Another property worth discussing is thermal diffusivity λ, which is a function of thermal conductivity K, density ρ, and specific heat capacity c. Thermal diffusivity is directly proportional to K and inversely proportional to ρ and c. Thus, a material having a low thermal conductivity value, with a high specific heat capacity, is expected to record a lower thermal diffusivity value if it is a bad conductor. Obviously, we can see that pineapple leaf sample recorded the lowest thermal diffusivity value of $8.6m^2s^{-1}$ as a result, would record the lowest temperature response if all are exposed to the same condition.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Thermal transport, which is a key factor in thermal insulation, involves the reduction of heat transfer and the transfer of thermal energy between objects of differing temperature in thermal contact. It involves some parameters, measured and derived physical quantities that were obtained experimentally, thermal conductivity K, thermal resistivity ρ_{th}, specific heat capacity c, density of the material ρ, thermal diffusivity λ, and thermal absorptivity α. The basic results were obtained experimentally and the others derived from them through established equations.

Firstly, thermal conductivity K of these samples were determined using Lee's disc apparatus for measuring bad conductors for each of the samples at steady state, the leaf samples were ground to almost powdery forms. During this preparation, care was taken to ensure that water or other substances never mixed or penetrated, the storage was done in a dry place in the laboratory, to avoid problems of redistribution of water under the influence of temperature gradient. The rates of cooling and thermal conductivity were calculated at steady state and were used in the determination of other properties. The values of the thermal resistivity, absorptivity, diffusivity, density and specific heat capacity for the samples were also calculated.

Since, one hardly does without error in any experimental analysis, the reliability factor of the experiments or errors were calculated and the results presented accordingly in table 4.6.

The table shows that pineapple leaf sample has the lowest thermal conductivity and thermal diffusivity value and the highest specific heat capacity of all the other samples. It is envisaged from these results the oil palm leaves, raffia palm leaves and pineapple leaves will serve as insulating materials since they had better thermal properties compared to asbestos ceiling sheet. However, pineapple leaf sample would make the better ceiling material of all the other samples, for a passively cool building design.

5.2 Recommendations

From this observation, it is recommended that; in the tropical region like west Africa with high level of incident solar radiation and certain zones like Niger Delta region of Nigeria where activities of petroleum industries which generate much heat is prevalent, certain materials like pineapple leaf, raffia palm leaf and oil palm leaf, should be processed and used as ceiling materials.

Proper research support should be granted to enable further investigation of other physical properties; like vapour permeability, percentage water absorption, flexural strength and compressive strength which are highly considered in the making of insulating materials like ceiling boards.

Proper workshops and orientation should be organized for builders and key players in the building industry to be enlightened and made to appreciate more about the physics of materials, solid state physics and thermal transport. The physical effect and economic value of leaves and other raw materials in our environment that are considered as waste or neglected due to ignorance of their utility values in our environment should be looked into.

Both the builders and the regulatory agencies should also encourage proper exploitation of these leaves, as major building materials, for the design of self-cooling building. This development can serve not only as an important source of revenue for the country, but most importantly, as a measure of technological breakthrough to deviate from synthetic high temperature response roofing materials.

5.3 Contribution to Knowledge

It is expected that this work will add to the pool of resources available to researchers in this field of study. It will serve as a reference tool for stakeholders in educational and scientific research on ways of developing better building materials. Improvements on this work will also aid in the development of a better and green environment.

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