Determination of Thermal Conductivities of Some Selected Materials

Abstract

This work was carried out to determine the thermal conductivities of some selected metals (copper, brass, steel and aluminium) using silver parameters as standard values to calculate for other four metals. The thermal conductivity of local material (clay) was also determined after verifying that the method has worked for the materials of known thermal conductivities. This was done by calculating the heat supplied to silver metal rod with a known thermal conductivity of 428 W/m.K. By increasing the temperature at various heat supply (2.5 W, 4.0 W, 6.0 W and 8.0 W), corresponding thermal conductivities was calculated for each metal and the local material. The results showed that with the small range of quantity of heat used in this work (2.5 – 8.0 W), Brass, Copper and Clay showed linear increase in thermal conductivity as the quantity of heat increases, while Aluminium and Steel showed a linear decrease in value of thermal conductivity. Also, thermal conductivity of the local clay was determined to be 9.38 $\frac{W}{m}K$.

Keywords: Metals, Thermal Conductivity, Clay, Heat, Temperature

1.0 Introduction

Thermal conductivity is a physical property of materials of great importance. Unlike some physical properties, however, thermal conductivity cannot be directly measured. In order to determine a material thermal conductivity, intermediate quantities must be determined from which the conductivity may be ultimately calculated [1].

Thermal conductivity is the ability of material to conduct the heat. It provides the base to differentiate the materials as conductors, insulators etc. This differentiation forms one of the bases to select the material for particular application. Hence determination of thermal conductivity is very essential. Various methods have been developed in the recent past for this.

Thermal conduction is the transfer of heat from one part of a body to another with which it is in contact. Thermal conductivity k is defined as ability of material to transmit heat and it is measured in watts per square metre of surface area for a temperature gradient of 1 K per unit thickness of 1 m.

The thermal conductivity is not always constant. The main factors affected the thermal conductivity are the density of material, moisture of material and ambient temperature. With increasing density, moisture and temperature the thermal conductivity increases too.
Important is inner structure of materials. Metals and other dense solid materials tend to have high levels of conductivity, whereas materials with very small amount of solid matter and large proportion of voids (gas or air bubbles, not large enough to carry heat by convection) have the lowest thermal conductivities. Thermal conductivity of some building materials is given in Tab

The rational design of equipment such as shaft coolers, heaters, and rotary kilns for the heating and cooling of solids requires that the thermal properties of the solids be known. Thermal conductivity and interfacial thermal conductance play crucial roles in the design of engineering systems where temperature and thermal stress are of concerns. To date, a variety of measurement techniques are available for both bulk and thin film solid-state materials with a broad temperature range [2]. Thermal conductivity (denoted as k, κ or λ) measures the heat conducting capability of a material. Thermal conductivity can be defined as the thermal energy (heat) Q transmitted through a length or thickness L, in the direction normal to a surface area A, under a steady-state temperature difference $T_{□} - T_c$. Knowledge of thermal conductivity and interfacial thermal conductance and their variation with temperature are critical for the design of thermal systems [3].

In physics, thermal conductivity, *k*, is the property of a material's ability to conduct heat. It appears primarily in Fourier's Law for heat conduction. Thermal conductivity is measured in watts per kelvin-meter ($W \cdot K^{-1} \cdot m^{-1}$, i.e. W/(K·m). Multiplied by a temperature difference (in kelvins, K) and an area (in square meters, m^2), and divided by a thickness (in meters, m), the thermal conductivity predicts the rate of energy loss (in watts, W) through a piece of material. In the window building industry "thermal conductivity" is expressed as the U-Factor [4], which measures the rate of heat transfer and tells you how well the window insulates. U-factor values are generally recorded in IP units (Btu/(hr·ft·F)) and usually range from 0.15 to 1.25. The lower the U-factor, the better the window insulates. The reciprocal of thermal conductivity is thermal resistivity.

Thermal conductivity depends on many properties of a material, notably its structure and temperature. For instance, pure crystalline substances exhibit very different thermal conductivities along different crystal axes, due to differences in phonon coupling along a given crystal axis. Sapphire is a notable example of variable thermal conductivity based on orientation and temperature, with 35 W/(m·K) along the c-axis and 32 W/(m·K) along the a-axis [5].

Thermal conductivity is the ability of a material to conduct heat. Different materials conduct heat differently and so, it is essential to know about the conductivity power of a material.
Let us consider a cubic section of a material whose face A is at a higher temperature Θ_1 (say) and let the opposite parallel face B be a temperature Θ_2. Now heat will flow from face A to face B depending on the following factors. It will be directly proportional to the area of cross section, since more is the area of the face of a cube more heat will flow i.e.

$$Q \; \alpha \; A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

It will be directly proportional to the time of flow of heat, i.e

Q α t ……………………………………….. (2)

It will directly proportional to the difference of temperature of the two faces of the cube. The more the difference of the temperature (Θ_1- Θ_2),the more rapid is the flow of heat i.e

Q α (Θ_1- Θ_2) …………………………………. (3)

It will be inversely proportional to the thickness of the cube i.e more is the distance between the two faces of the cube, less is the flow of heat i.e

Q α 1/d ………………………………………. (4)

Combining the above equations we have $Q \ \alpha \ \frac{A(\theta_1-\theta_2)}{d}$

Introducing the proportionality constant *k*, we have,

$$Q = \frac{kA(\theta_1-\theta_2)}{d} \qquad (5)$$

Where *k* depends on the material in which the heat is flowing.

From equation (5) this constant *k* is known as coefficient of thermal conductivity.

If A = $1cm^2$, Θ_1- Θ_2 =1^0C, t = 1second, d=1cm.

Thus K can be defined as the quantity of heat that flows for one second through a cube whose opposite faces are maintained at a difference of temperature of 1^0C [1].

This study is aimed to determine thermal conductivity of five different metals by varying the amount of heat supply and compare it with their standard (Experimental) value. To do so, it is necessary to examine the flow of heat through metal samples by determining the rate of heat flow through a material and using Silver parameters as a case study with thermal conductivity of 428W/m.k to calculate the quantity of heat per time flowing through Silver metal rod in order to calculate the thermal conductivity of other four metals. Thermal conductivity of local material (clay) with unknown existing value was also determined.

2.0 Materials and Method

This work was carried out in the laboratory of Physics Department of the Federal University of Agriculture, Abeokuta, Nigeria. The apparatus used in this work include retort stand, metal rods of different materials, burner and thermometers.

The following procedures were employed in this work. A retort stand was placed on a table. A rod was hanged at one end of the retort stand which was insulated to prevent heat transfer from the rod to the retort stand. Heat was applied at one end of the rod using a burner as heater while the other end was kept at a constant temperature.

Figure 1: Experimental setup.

Holes were made on the rod at 10 cm interval away from the heating point and the thermometer was inserted on the holes to measure the final and initial temperature. This was repeated four times using different quantities of heat which was calculated for each case. The experiment was repeated for the four other rods.

To interpret the recorded data and determine the experimental thermal conductivities, the most stable range of temperature measurements was selected from the recorded values. The averages were determined for each of the thermocouples on each sample rod. From these values and the physical measurements taken during the setup, the rate of heat flow through the silver rod was calculated using the equation

$$\frac{Q}{t} = \frac{k.A(T_{hot} - T_{cold})}{d} \qquad 1$$

In this equation, the ratio $\frac{Q}{t}$ represents the rate of heat flow i.e. power, K is the thermal conductivity, A is the cross-sectional area of the sample rod, T_{hot} and T_{cold} are the temperatures at two adjacent thermocouples points, and d is the separation between these two points.

To determine $\frac{Q}{t}$ for silver, its known thermal conductivity of 428W/mK was used. From this heat flow rate, which for this experiment was assumed to be same for all five materials, the other four thermal conductivity values were calculated from equation (1) [6].

3.0 Results and Discussion

3.1 Results

The quantities of heat passed to the rods were calculated using silver of known thermal conductivity of 428W/mK and applying to equation 1. The experiments were therefore repeated for other rods to determine their thermal conductivities. The results of the thermal conductivities determined are presented in table 1.

Table 1: Result of the experiments.

	Heat Supply (W)	Silver (W/mK)	Brass (W/mK)	Aluminium (W/mK)	Steel (W/mK)	Copper (W/mK)
	Standard Value	428.00	109.00	235.00	14.00	401.00
1	2.5	428.00	106.10	244.86	20.00	397.90
2	4.0	428.00	107.22	239.50	18.90	402.00
3	6.0	428.00	108.50	238.00	17.30	404.00
4	8.0	428.00	109.80	237.20	16.50	405.20

3.2 Determination of Thermal Conductivity of Clay

Having determined the thermal conductivities of the different metals stated in table 1 and found that the results obtained were in agreement with standard values obtained from textbooks, the method was now applied to determine the thermal conductivity of local clay obtained within the premises of College of Natural Sciences, Federal University of Agriculture, Abeokuta, Nigeria.

The experiment was setup as described in section 3.0. Clayey soil was moulded in form of rod and it was dried for a period of two (2) hours. The same quantities of heat used for the other metals were used for the clay rod. The diameter of the clay rod was also 10 cm. Thermal conductivity of clay was calculated using equation 1 as was done previously. Table 2 shows the results obtained.

Table 2: Thermal Conductivity of Clay

Heat Supplied (W)	**Thermal Conductivity (W/m K)**
2.5	9.20
4.0	9.35
6.0	9.40
8.0	9.55

From table 2, average thermal conductivity of clay was obtained as 9.38 W/mK.

3.3 Discussion

The values of thermal conductivities of different metal obtained in this work were in agreement with the standard values, this gave the confidence to apply this method to determine the thermal conductivity of local clay. Average value of thermal conductivity of local clay was obtained as 9.38 W/mk. This value is also in agreement with standard value of thermal conductivity of clay with the value of 9.3±0.3W/mk.

Results from table 1 also indicated that increase in value of quantity of heat supplied has no significant effect on the thermal conductivities of these metals. Theory of thermal conductivity of materials indicated that temperature affects thermal conductivity of materials, however, in this work, this is not so because the range of temperature here is very small. Significant increase in thermal conductivities of materials could only be noticeable over a wider range of temperature. With the small range of quantity of heat used in this work (2.5 – 8.0 W), Brass, Copper and Clay showed linear increase in thermal conductivity as the quantity of heat increases, while Aluminium and Steel showed a linear decrease in value of thermal conductivity.

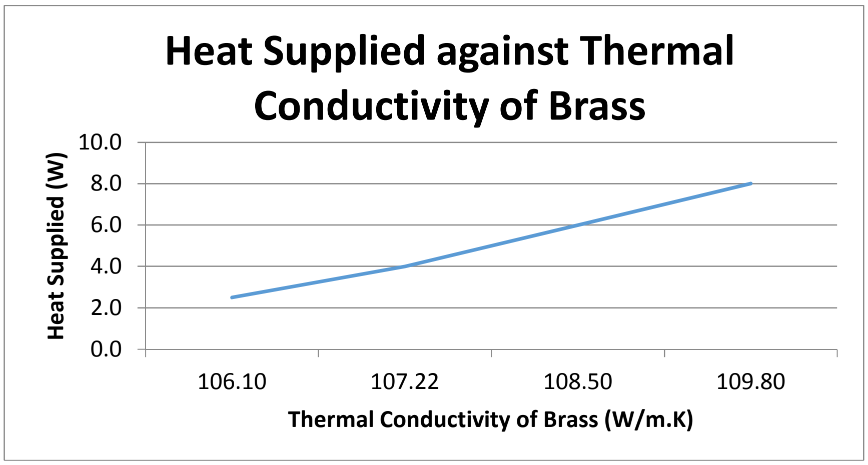

Figure 2: Graph of Heat Supplied against Thermal Conductivity of Brass

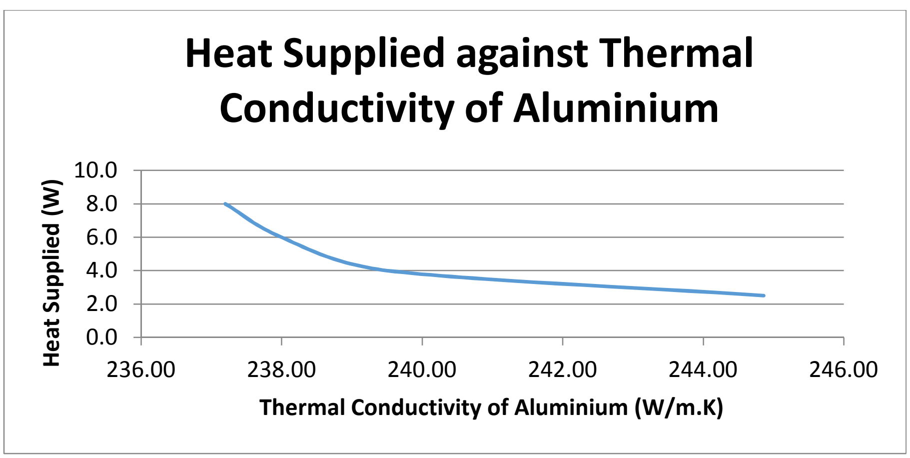

Figure 3: Graph of Heat Supplied against Thermal Conductivity of Aluminium

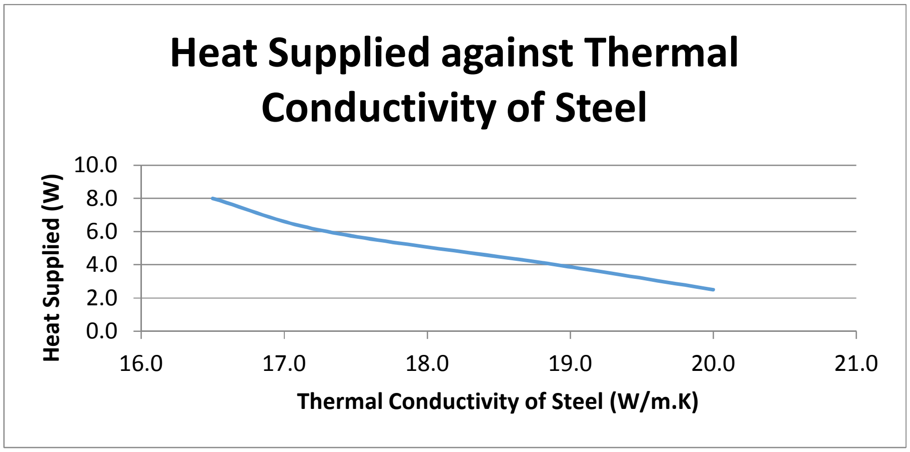

Figure 4: Graph of Heat Supplied against Thermal Conductivity of Steel

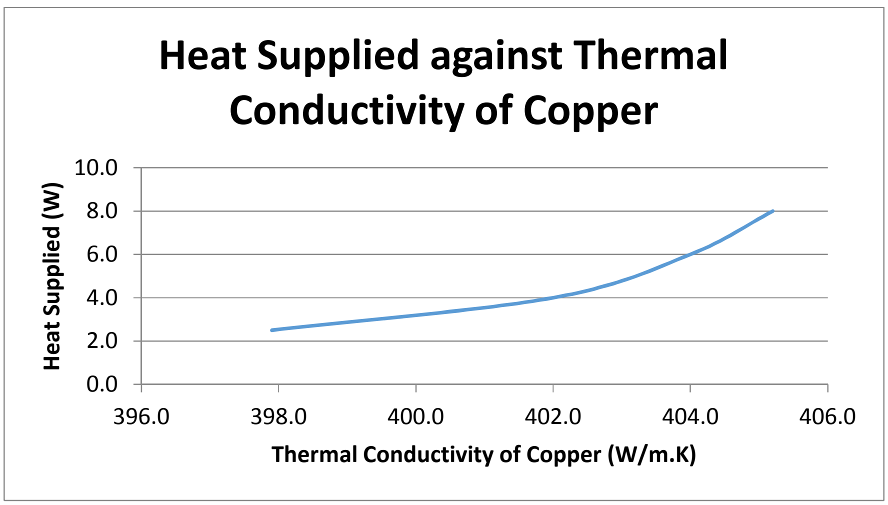

Figure 5: Graph of Heat Supplied against Thermal Conductivity of Copper

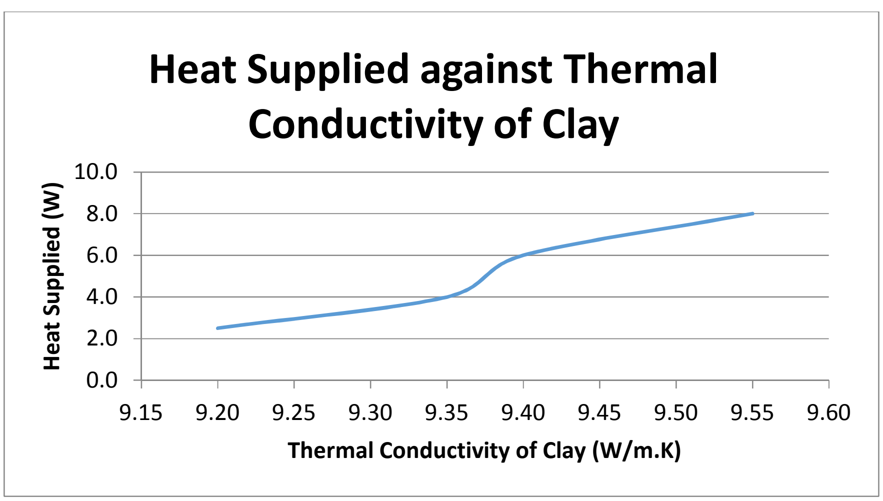

Figure 6: Graph of Heat Supplied against Thermal Conductivity of Clay

4.0 Conclusions

From this work, the thermal conductivity of clay was determined which was confirmed by calculating the thermal conductivity of some selected metals (Copper, Aluminium, Brass and Steel) using Silver parameters and the values obtained were compared with the textbook values which showed no significant difference.

With the small range of quantity of heat used in this work (2.5 – 8.0 W), Brass, Copper and Clay showed linear increase in thermal conductivity as the quantity of heat increases, while Aluminium and Steel showed a linear decrease in value of thermal conductivity.

Thermal conductivity of clay was determined to be 9.38 W/m.K. It was noted that, clay has an experimental thermal conductivity value of 9.3±0.3W/mk.

Clay is of great importance for commercial use. It is used in bakery in order to prevent heat loss because it absorbs heat.

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