JOURNAL OF CURRENT RESEARCH IN SCIENCE (ISSN 2322-5009)
CODEN (USA): JCRSDJ
2014, Vol. 2, No. 1, pp:63-66
Available at www.jcrs010.com

ORIGINAL ARTICLE

DETERMINATION OF THERMAL CONDUCTIVITY OF SOME MATERIALS USING SEARLE'S BAR AND INGEN HOUSZ EXPERIMENTAL METHODS

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ABSTRACT: The characteristic properties of metals like high strength and heat conductivity make them adaptable for different purposes. Heat sink in electronics, heat exhaust in cars and sophisticated machines, soldering irons, roofing sheets, metal doors, bridges, bullets etc. If a metal is used for any of the purposes without properly taken into consideration its Thermal Conductivity (TC), the material may fail in short time. Thermal conductivity (TC) of six different metals were determined using Searle's Bar Method (SBM) and Ingen Housz Experimental Method (IHEM). SBM was used for copper, aluminum and iron while IHEM was used for copper, aluminum, lead, Zink, brass, and iron. The metals were collected from North Bank Modern Market Area of Makurdi in Benue state. In SBM, the TC were calculated as 389.3Wm^{-1}k^{-1} for copper, 273.0 Wm^{-1}k^{-1} for aluminum and 75.8 Wm^{-1}k^{-1} for Iron while in IHEM, the TC were 407.7 Wm^{-1}k^{-1} for copper, 260.0 Wm^{-1}k^{-1} for aluminum, 90.4 Wm^{-1}k^{-1} for zinc, 111.8 Wm^{-1}k^{-1} for Brass, 28.9 Wm^{-1}k^{-1} for Lead and 42.3 Wm^{-1}k^{-1} for Iron. The SMB values are in remarkable agreement with their theoretical values within $\pm$ 0.1 degree of tolerance. Meanwhile the values gotten from IHEM when compared with their theoretical values fell slightly outside the theoretical value range. Hence, SBM is recommended for industries rather than IHEM for determination of TC of materials. Both SBM and IHEM show that copper has the highest TC value and thus should be used as soldering iron tips, and aluminum which is next to copper could be used as heat sink in electronics. The value of TC for iron is obtained low and with property of high strength, it is recommended to be used as silencer and heat exhauster.

KEYWORDS: Thermal conductivity, Aluminum, copper, Iron, Lead, Zink, Brass, SBM and IHEM.

INTRODUCTION

Conduction is the most significant means of heat transfer in solids (Hans, 2007). All materials have ability to conduct both heat and electricity. This conducting ability varies from one metal to another and the variation may be due to the state of the material i.e solid, liquid and gaseous states. For instance, solid metals such as copper, aluminum, silver etc, are known as good conductors whereas solid insulators like wool, plastics, rubber etc, most liquid and all gasses are poor conductors (Krane, 2013). This variation among materials is as a result of electrons arrangement around the nucleus of the material (Nelkan and Parker, 1995). Conduction is said to be the transmission of heat through a material from a region of high temperature to that of low temperature or /and electricity through a material under the influence of electric field, without possible movement of the material (Hans, 2007; Nelkan and Parker, 1995). Within the last decade there has been a consistent growth in the use of composite materials and layer-coated metals. Excellent chemical and wear resistance, a wide range of electrical and thermal properties, and high service temperatures have made these materials extremely valuable to industry. Due to their increasing importance, and the wide range of shapes, sizes, and composition in which these materials are produced, it is essential to have reliable methods available to measure their thermal conductivity and diffusivity (Altun *et al.*, 2008).

The measure of the ability of a material to transmit heat energy through it, is its thermal conductivity (TC) represented as K, with S.I unit of Js^{-1}m^{-1}k^{-1} (Giancoli, 2007; Vasudeva, 2009). The properties of metals such as high strength and high conductivity of heat etc allow for their application for different purpose (Vasudeva, 2009; Utah, 2008; Halliday *et al.*, 2010; Cengel and Yunilus, 2003). Some of the applications are on heat sinks in electronics, heat exhausts in cars and sophisticated machines, soldering irons, roofing sheets, metal doors, bridges, bullets etc. If a metal is used for any of the listed purposes without properly taking into

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consideration its TC, the material may fail within a short time. But, if the TC of the metal is correctly determined with the best methods (i.e method with minimal error), it will help in making better choice of materials for use. Reducing failure faced by metals in construction in terms of heat is the main drive of this research work, and this work is aims to determine the TC of metals with two (2) methods as well as recommending the best method for the determination of TC.

MATERIALS AND MATHEMATICAL FORMULATIONS

This research work was conducted with two (2) methods, namely Ingen Housz Experimental Method (IHEM) and Searle's Bar methods (SBM) instead of modeling as done by Bjorn *et al.*, (2013). Prediction method was also done by Poot *et al.*, (2011). The two methods were aimed at measuring the TC of some conductors (metals). For IHEM, the materials collected were six equal sized and polished metal rods, each of 3 X 10^{-3}m in diameter. These metals are copper, aluminum, zinc, lead, brass and iron. The rods were fitted into the apparatus (constant-head device, measuring cylinder, stop watch, steam generator which passed steam through the steam chest and four thermometers) vessel and the outside portion was waxed and the vessel filled with hot water. When steady state was reached, the wax melted up to different lengths in the various rods. Length of the rods were taken to be L_1, L_2, L_3,…,L_n to which the wax was melted and θ^o, the temperature of the hot bath, θ is the melting point of wax, then:

$$\theta = \theta_o e^{-U1L1} = \theta_o e^{-U2L2} = \ldots = \theta_o e^{-UnLn} \qquad (1)$$

which implies that,

$$ln\left(\frac{\theta}{\theta o}\right) = U_1L_1 = U_2L_2 = \ldots.. = U_nL_n \qquad (2)$$

$$\text{But } U = [\frac{EP}{KA}]^{1/2} \qquad (3)$$

Where K = thermal conductivity
E = emissivity of the metals
A = cross sectional area of the rods
P = perimeter of the rods

Substituting equation (3) into (2) for U,

$$[ln\left(\frac{\theta}{\theta o}\right)^2] = \frac{EP}{KA}L^2 \qquad (4)$$

$$\text{Where } K = \frac{EPL^2}{[ln\left(\frac{\theta}{\theta o}\right)^2]\ A} \qquad (5)$$

Equation 2.4 shows that

$$\frac{EPL_1^2}{K_1A} = \frac{EPL_2^2}{K_2A} \qquad (6)$$

$$\frac{L_1^2}{K_1} = \frac{L_2^2}{K_2} \qquad (7)$$

Equation (7), it implies that if the thermal conductivity of one rod was known, that of all others could be found. This showed that this method is an indirect method and does not give very accurate results [5]. As a result, equation (5) is a better alternative for determination of TC of metals.

The second method was SBM, Three metals were used namely copper, aluminum and Iron. The copper rod was obtained alongside the Searle's apparatus, the aluminum rod was collected at North Bank area of Makurdi, and the iron was bought at Modern Market area of Makurdi. Their TC was measured one after the other. A constant-heat device, a measuring cylinder, stop watch, steam generator which passed steam through the steam chest and four thermometers, T_1, T_2, T_3, and T_4 were used. T_1 and T_2 measured the temperatures at a point on the bar, while T_3 & T_4 measure the temperature of water entering and leaving the spiral. Assuming no loss of heat along the bar, it could be shown that:

$$Q = \frac{-KAdT}{dx}t \qquad (8)$$

Where Q is the heat supplied to the bar in time t, A is the cross-sectional area of the bar = $\frac{\pi D^2}{4}$ & D = diameter.

$dT = T_1 - T_2$ where $T_1 > T_2$, and K is the thermal conductivity.

Also, the heat Q warms up a mass M (in kilograms) of water from temperature T_4 to T_3 according to the formula:

$$Q = mc(T_3 - T_4) \qquad (9)$$

If $dx = d$, then Equation (2.8) becomes

$$Q = K(\frac{\pi D^2}{4})(\frac{T1 - T2}{d})t \qquad (10)$$

Equating equations (2.9) with (2.10)

$$mc(T_3 - T_4) = K(\frac{\pi D^2}{4})(\frac{T1 - T2}{d})t \qquad (11)$$

$$\rightarrow K = \frac{4mcd(T3-T4)}{\pi D^2(T1-T2)t} \qquad (12)$$

Where C is the specific heat capacity of water (4190JKg-1K-1) and unit of K is Wm-1K-1 [7]

RESULTS

The TC of the sampled rods were calculated using equation (6) for IHEM and equation (12) for SBM and the results are presented in Figure 2. These values increased for both methods with respect to the different metals (copper, aluminum, Brass, Iron, Lead and zinc). This agreed with the theoretical values as shown in the Fig 1. In SBM, the TC were calculated as 389.3 Wm^{-1}k^{-1} for copper, 273.0 Wm^{-1}k^{-1} for aluminum and 75.8 Wm^{-1}k^{-1} for Iron while in IHEM, the TC were 407.7 Wm^{-1}k^{-1} for copper, 260.0 Wm^{-1}k^{-1} for aluminum, 90.4 Wm^{-1}k^{-1} for zinc, 111.8 Wm^{-1}k^{-1} for Brass, 28.9 Wm^{-1}k^{-1} for Lead and 42.3 Wm^{-1}k^{-1} for Iron. The SMB values are in remarkable agreement with their theoretical values within ± 0.1 degree of tolerance. Meanwhile the values gotten from IHEM when compared with their theoretical values fell slightly outside the theoretical value range.

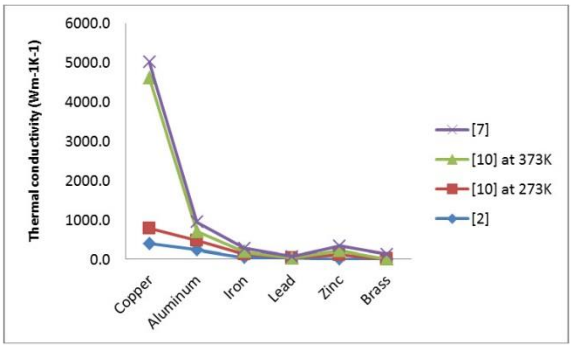

Figure 1: Graph of theoretical Values of K

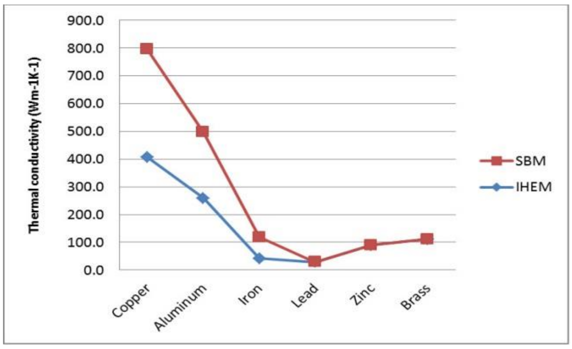

Figure 2: Graph of Experimental Value of K

DISCUSSION

From the theoretical values of the TC of the six metals, a comparison was made between the two methods (SBM and IHEM) and their theoretical values which revealed that the result obtained in SBM is of remarkable agreement with the theoretical values (Halliday *et al.*, 2010; Neil and Mermin, 2007) with degree of tolerance value of ±0.1. Meanwhile, the result in IHEM is slightly outside the theoretical value when compared. This failure experienced in IHEM is as a result of taking readings on the melted wax on the rods.

In the two methods used, copper recorded the highest TC value followed by aluminum, brass, Zinc, iron, and lead respectively. This confirms that both copper and aluminum conduct heat higher than the other used metals. As a result, they should be used in this perspective for either producing or absorbing heat. For instance, copper is recommended to be used as cooking pots, electric heater etc. Meanwhile, iron and lead recorded the lowest TC values among the metals, which meant that they could withstand heat better. They may therefore be used in main body of bridges. Iron is also recommended as heat exhauster or silencer due to its high strength (Emeka, 2006).

In conclusion, all the six metals used produce high values of TC (TC range of 28.9Wm^{-1}K^{-1} to 407.7Wm^{-1}K^{-1}) which shows that all the metals are good conductors of heat. Also, SMB is a better method for determination of TC compared to IHEM which is one of the key objectives of this work (to determine the best method which could be used to determine the TC of Materials) and is therefore recommended for industrial application.

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