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Measure of Heat Conduction through Copper

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ABSTRACT: Whenever the term 'Thermal Conductivity Materials' occurs, the two main names that strikes our mind are 'copper' and secondly the 'aluminium' as they are best and highly used metals for thermal management not only for mechanical systems but also for cooling of electronics and electrical systems/devices. This research paper demonstrates the practical test done on Copper strip to test for its thermal conductivity and its validity in terms of mathematical proof.

KEYWORDS: Thermal Conductivity (k), Thermal Resistivity (R_{TH}), Heat Flux (HF), Watts per meter Kelvin (W/m_K) ,Copper (Cu)

I.INTRODUCTION

Simplest definition of Thermal conductivity is the transfer of heat from one location/point/place to other location/point/place with which it is in contact. It has been already proved that copper conductivity (k) is 400W/m_K. Some experiments also indicate a value of 380 W /m_K. Even though standard value is 400 W /m_K, we obtain such variation in values is only because of the fact that thermal conductivity is not always constant. It varies depending on the density of the material, temperature of the surrounding air (ambient temperature), thickness of the material, moisture content in the surrounding, level of purity of the material and the amount of pressure applied (not needed in this experiment).

Searle's apparatus setup and Dr.Bock's apparatus setup are two highly used 'k of Copper' measuring technique. But the setup complexity is the main disadvantage. Guarded Hot Plate uses the infinite slab as heat transfer model. Since sample dimensions are finite, guard heaters are used to facilitate uni-directional heat flow. The sample is sandwiched between a heat source and a heat sink. Guarded Hot Plate technique needs steady state condition to arise. Since steady state conditions may take several hours to develop, this method is unsuitable for use. Radial Heat Flow technique is used to test thermal conductivity of materials which are basically in the powdered form. A cylindrical test device employs a central line (or cylindrical) heat source. End effects are assumed negligible due to either the large length to diameter ratio of the test apparatus or the use of end guard heaters. After steady state has been established, the thermal conductivity can be calculated from the heating power. This technique also relies on steady state achievement. Hence it is time consuming technique. This research paper provides simple innovative technique for testing Copper's thermal conductivity.

II.THERMAL CONDUCTIVITY: SIMPLEST DERIVATION

The below figure 1 illustrates two necessary cases/conditions for heat transfer to take place. The point p1 is at higher temperature T1 than pint p2 which is at lower temperature T2 than T1. The flow of heat (Q) will always happen from higher temperature location to lowest temperature location which is in contact to it.

Thus Q = f1(T1, T2, strip geometry, material) (1)

The relation between T1 and T2 is in the form of temperature difference (T1-T2)

Q = f2 (T1-T2, strip geometry, material) (2)

Case 1:

If (T1-T2) = 0 (i.e.: when T1 = T2)

Then Q = 0 (means no heat/ thermal transfer rate is being taking place between p1 and p2 points)

Case 2 :

If T1>T2

Then Q>0 (means heat transfer rate increases)

$$Q \, \alpha \, \frac{A.(T1-T2)}{L}$$

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$Q = \frac{K.A.(T1-T2)}{L}$

$Q = -\frac{K.A.(T2-T1)}{L}$ (unit: watts)

$Q_x = -\ K.A\frac{dT}{dx}$ (3)

This is the heat transfer at x direction.

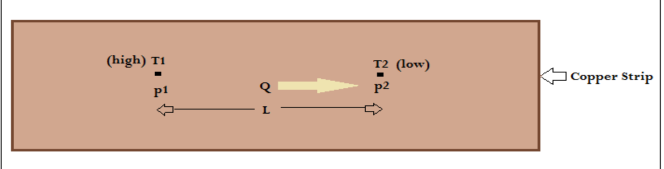

Fig1. Simple diagram of Copper strip heat conductivity

Figure 2 given below shows how heat transfer will happen for a 3D representation. For y and z direction (in 3D representation), Q is given as:

$Q_y = -\ K.A\frac{dT}{dy}$ (4)

$Q_z = -\ K.A\frac{dT}{dz}$ (5)

Note: for a very thin copper strip, heat conduction in 3D form can be neglected. Heat flow in any 1 direction can be considered for simplicity.

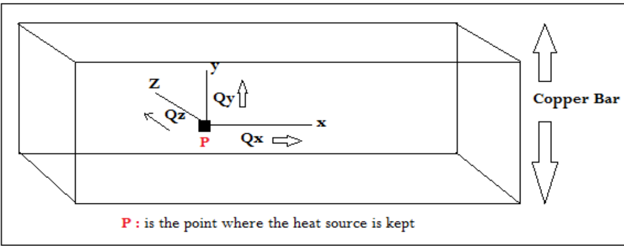

Fig 2. 3D view of heat (Q) flow

Heat Flux (HF) is defined as the 'rate of flow of heat' and Critical heat flux is the 'thermal limit of a phenomenon where a phase change occurs during heating'.

$HF = \frac{Q}{A}$

III.ROLE OF INDIVIDUAL PARAMETERS ON THERMAL CONDUCTIVITY

Thermal Conductivity (K) = $\frac{Q.L}{A.\Delta T}$ (6)

1. Temperature difference (ΔT) :

Greater the temperature difference between the two ends of the bar or the strip, greater will be the rate of heat flow.

$Q \propto \Delta T$ (7)

2. Cross-sectional area (A):

A bar twice as wide conducts twice the amount of heat.

$Q \propto A$ (8)

3. Separation length/ distance (L) :

Rate of heat transfer is always inversely proportional to the length of the bar.

$Q \propto \frac{1}{L}$ (9)

4. Time (t):

Heat flow (Q) directly depends on the amount of time that passes. Twice the time, twice the heat.

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$$Q \alpha t \qquad (10)$$

IV. REQUIREMETS

For the thermal conductivity test conducted, requirements are:

i. Copper Strip.
ii. Temperature sensor to measure the temperature surrounding the setup at initial and final time.
iii. Heat source (solder iron).
iv. 2 Thermometers to measure T1 at P1 and T2 at P2.

V. BLOCK DIAGRAM OF THE EXPERIMENTAL SETUP

Below Figure 3 is the simple diagrammatic representation of the complete experimental setup. Two thermometers T1 and T2 placed at 2 points P1(20mm) and P2 (50mm) respectively. The complete copper strip taken is of 50mm long. Thickness of the copper strip is 0.2mm. Solder iron is placed at the heat source location as marked in below figure.

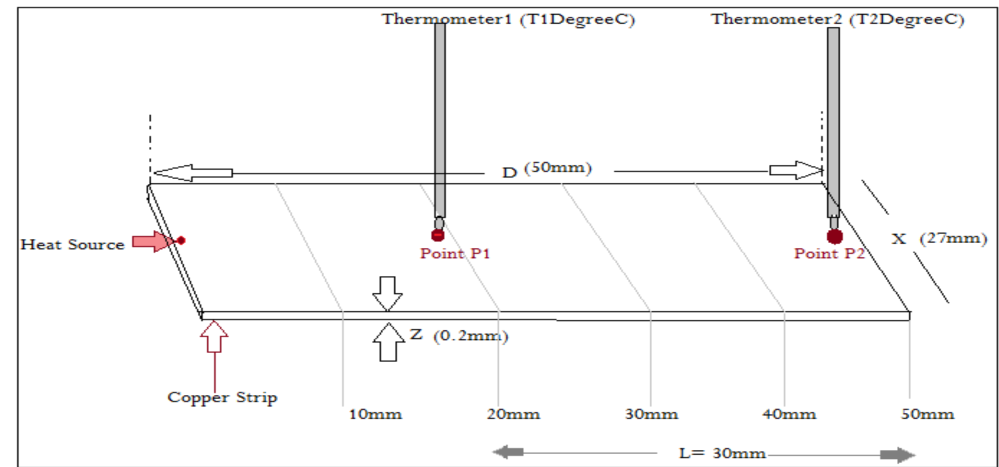

Fig 3. Simplest diagram of the experimental setup

VI. REPRESENTATION OF THE EXPERIMENT THROUGH FLOW DIAGRAM AND PICTURES

1. FLOW DIAGRAM :

Figure 4 illustrates the complete experiment done. This experiment has two sections. First sections also termed as ‘Heating Rate of Cu’ which helps us in knowing how rapidly this copper strip becomes hot i.e. its heat conduction rate. Solder iron is used as a heat source. Measure T1 and T2 at 2mm and 5mm respectively after every 3min. As soon as heat source (placed at the extreme left side of the copper strip) is removed, marks the beginning of second section. This section is termed as ‘Cooling Rate of Cu’ as it will help us to know the rate at which copper cools to its normal temperature. More than 5 reading can be taken but 5 readings are sufficient enough.

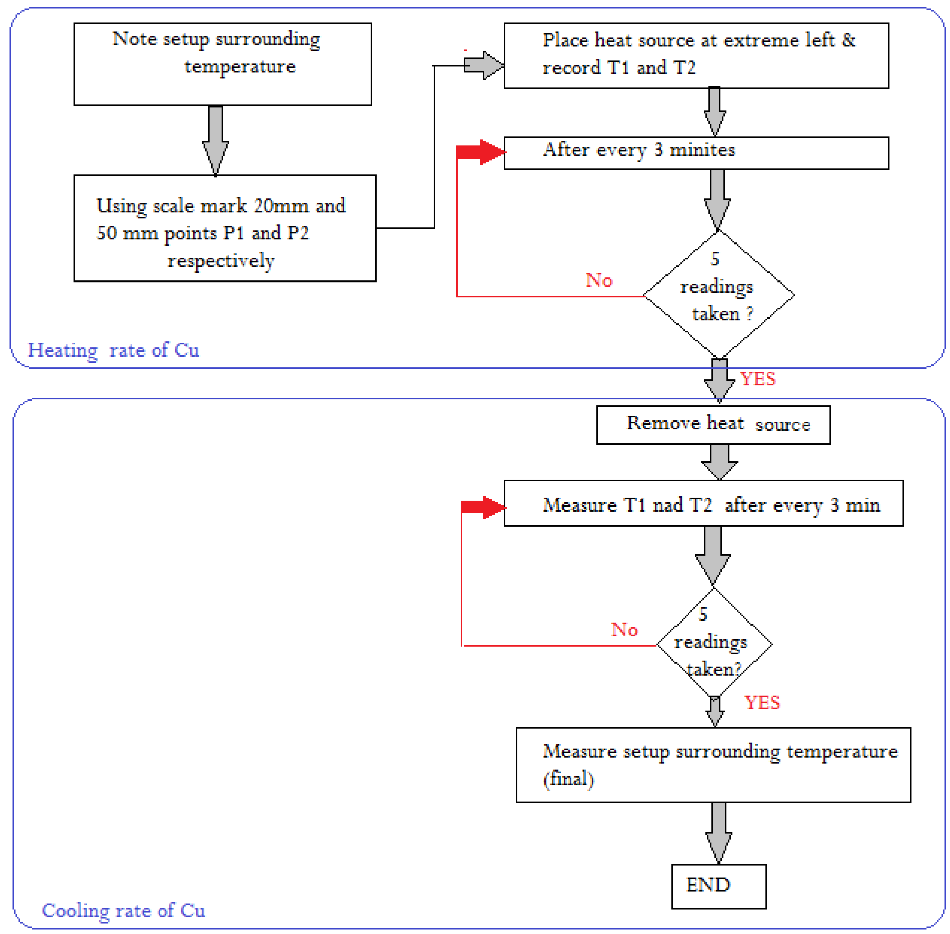

Fig 4. Flow diagram of the experiment performed.

2. PICTORIAL ILLUSTRATION:

1. It explains about measuring initial room temperature near the setup (fig 5).

Fig 5. Initial Temperature near the setup

2. During the experiment, the setup surrounding temperature rises which can be noted from the heat sensor indicator (fig 6).

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Fig 6: Surrounding Temperature rise during the experiment

3. Note down the temperatures T1 and T2 at 20mm and 50mm points respectively. Heat flow happens during the experiment due to the fact that T1 is always at higher temperature than T2 (Fig7).

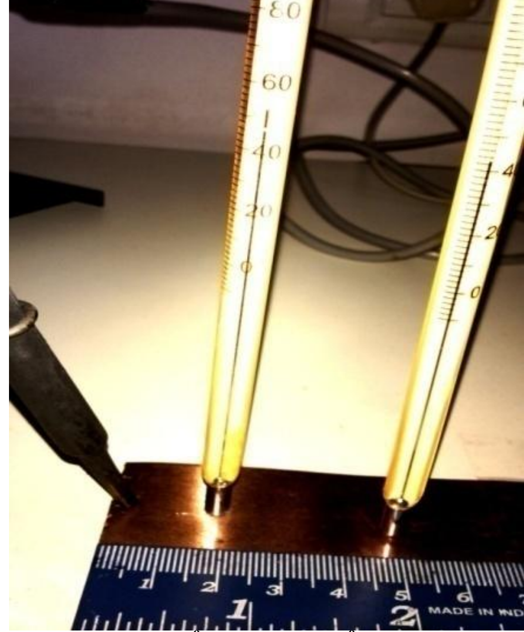

Fig 7: Figure showing T1(high:51^{0}**c**),T2 (low:42^{0}**c**) as mentioned in the table1

4. Remove solder iron and note minimum 5 reading. This will give the cooling rate of Cu (Fig 8).

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Fig 8.Rate of Cu cooling

5. Note the final room temperature (fig.9)

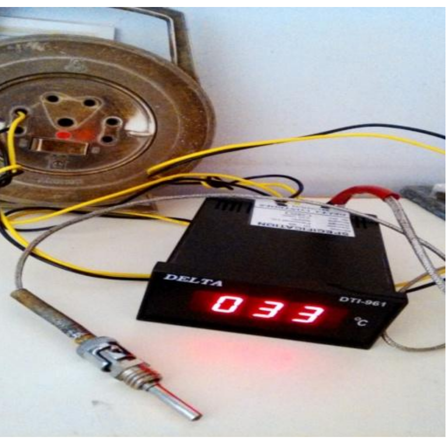

Fig 9: Surrounding Temp at the end of the experiment

VII. TABLES AND CALCULATIONS

Below table1 represents the measurements of T1 and T2 for every 3 seconds for two sections i.e. for 'Heating rate of Cu' and 'Cooling rate of Cu'

TABLE 1. READINGS TAKEN DURING THE EXPERIMENT

TIME (min)	T1 (^{0}C)	T2 (^{0}C)	Temperature around the setup	Nature of Experiment
3	37	35	Initial: 29 ^{0}C	To measure thermal rise of Cu
6	44	37		
9	53	40		
12	55	42		
15	57	43		
18	41	39	Final : 33 ^{0}C	To measure Cooling rate of Cu
21	39	38		
24	37	36		
27	35	33		

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CALCULATIONS

We know that

Thermal Conductivity (K) = $\frac{Q.L}{A.\Delta T}$, Heat flow rate (HF) = $\frac{Q}{A}$ and Thermal resistance (R_{TH}) = $\frac{L}{K.A}$

Now see the measurements from TABLE1.

Q (heat flux) = (VXI) in watts, for solder iron it is 25W

Cross-sectional area A = (0.03 × 0.0002) in m^2

$\Delta T = (37^0C - 35^0C) = (2^0C+273.15) = 275.15$Kelvin

$$k = \frac{25 \times 0.03}{0.03 \times 0.0002 \times 275.15} = 454 \quad W/m_K$$

$R_{TH} = 11.0\ ^0C/W$

For further T1 and T2 readings taken, we need to proceed with the same calculation as illustrated above. Below table2 illustrates that as thermal conductivity increases, thermal resistance decreases and vice versa.

TABLE 2. THERMAL CONDUCTIVITY (K) AND THERMAL RESISTANCE (R_{TH}) WITH RESPECT TO TIME

Time (min)	k(W/m_K)	R_{TH} (^{0}C/W)	Nature of Expt.
3	454	11.0	Thermal rise of Cu
6	446	11.2	
9	437	11.4	
12	437	11.4	
15	435.5	11.7	

VIII. GRAPHS

Below graph is the plot of thermal conductivity of Cu on y axis with respect to time on X axis. As time increases, K decreases. After certain time, K will become constant.

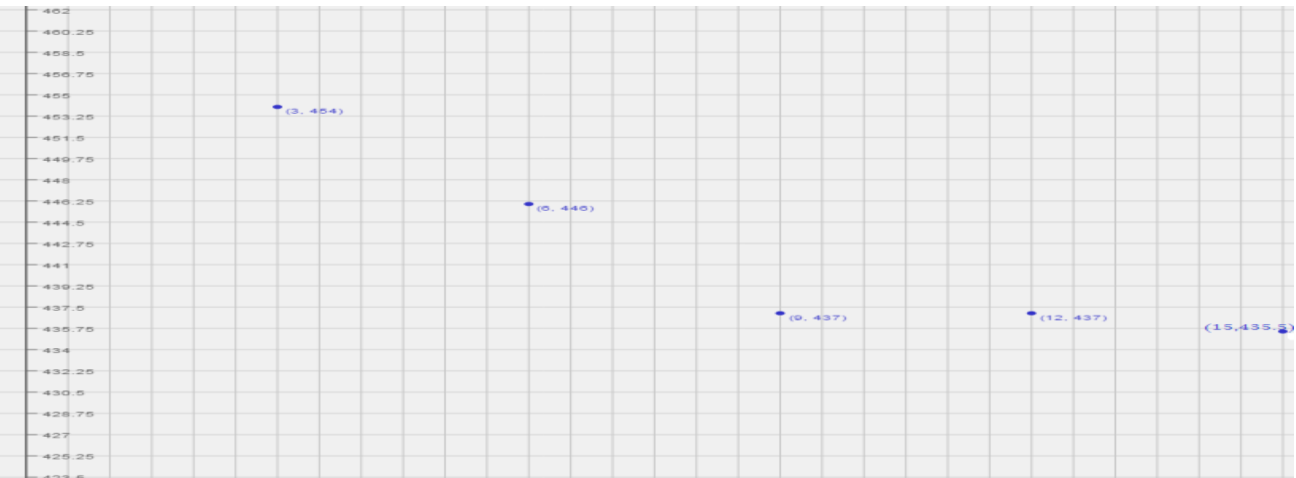

Fig 10. Graph showing thermal conductivity of Cu with respect to time (t in minutes)

Below graph is the plot of thermal resistance delivered by the Cu (y-axis) with respect to time plotted on (X axis). As time increases, R_{TH} increases. After certain time, R_{TH} will become constant.

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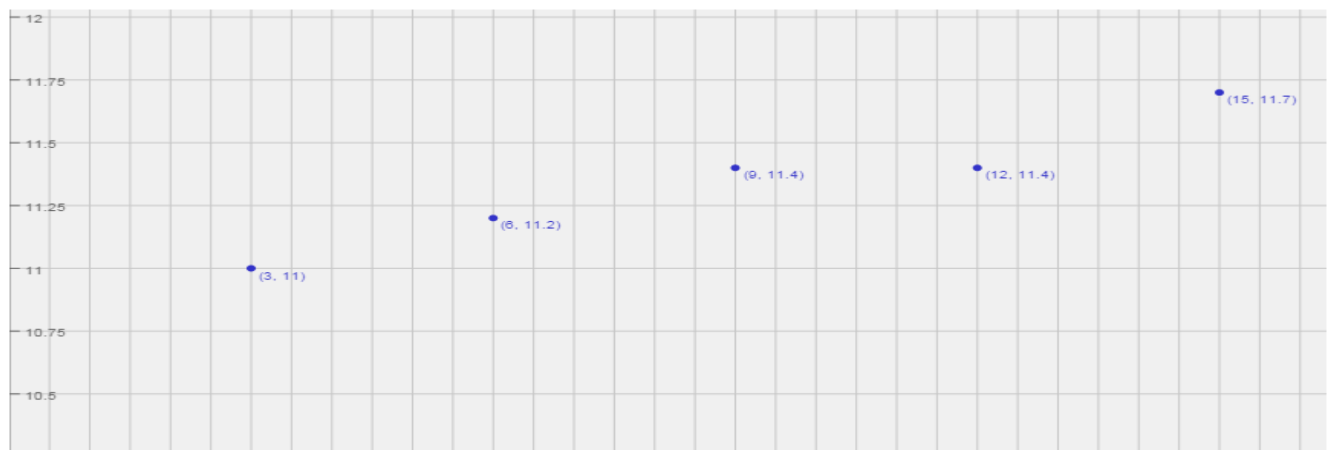

Fig 11.graph showing thermal resistance offered by Cu with respect to time

IX. CONCLUSION

We got the positive result in 'Thermal Conductivity Test of Copper' conducted by us using simple technique and easily available experimental tools. No high cost instrument is used for our experiments but still we have obtained a clear result. Values of R_{TH} from table2 illustrates that at the beginning of this experiment thermal resistance offered by Cu is less when compared with the last reading taken after 15minutes of initial start up. Plot of Graph 10 and 11 proves that there always exist a inversely proportional relation between thermal conductivity and thermal resistivity.

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BIOGRAPHY

	Er. PAL RIYA BIPRADAS SANCHITA received Bachelor Of Engineering in Electronics from PIIT (Pillai Institute Of Information Technology, Engineering, Media Studies & Research) under Mumbai University. Currently pursuing Master of Engineering. Her research areas are Power Electronics and Optical Communication. She is the author of (1) **'Free Space Light Communication'**. (2) '**Negative Role of Atmosphere On Free Space Light Communication**'. (3) **'Heat in Electronic Circuits and Material Selection Criteria for Cooling Solutions'**. She has designed Electronics PCB project for **HPST** POWER **COMPANY** in KBR.
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