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Experimental Investigation of Thermal Conductivity of the Liquids by Guarded Hot Plate Method

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ABSTRACT: In the present scenario determining the thermal properties of the materials is an important subject in many advanced engineering applications. The thermal properties of fluids, such as thermal conductivity, play an important role in the design of a wide variety of engineering applications. In the present study wedescribed the heat transfer equipment designed and developed to determine the thermal conductivity of liquids by guarded hot plate method. The apparatus will create the nominal one-dimensional heat flow through a liquid by placing it between two isothermal plates at different temperatures. Experiment is carried out for Low viscous liquids like water and distilled water and it is observed that thermal conductivity increases as temperature increases optimum value of 0.609W/m°c recorded for distilled water and 0.573W/m°c is recorded for normal water. For heavy viscous liquids like ethanol, toluene and spent wash a byproduct from the distillery waste, thermal conductivity decreases as temperature increases.For ethanol a value of 0.201W/m°c is recorded, for toluene 0.192W/m°c and for spent wash 0.457 W/°c has been recorded.

KEYWORDS: Thermal conductivity, spent wash, toluene, heat transfer and temperature

I. INTRODUCTION

Heat transfer is a basic and very important topic that deals with energy. Heat transfer processes are encountered in a large number of engineering applications. It is essential for thermal engineers to understand the principle of thermodynamics and heat transfer and be able to employ the rate equation that govern the amount of energy being transferred.

Heat can be transported in two ways, electronic contribution and vibrational (phonon) contribution. The dependence of thermal conductivity of a material on temperature depends on the degree with the molecules of material are strongly bound to. Thermal conductivity of gases increases with temperature due to increase in thermal energy that increases the molecular velocity. In liquids, the temperature dependence of thermal conductivity depends on the viscosity also. The physical properties of fluids, such as thermal conductivity, play an important role in the design of a wide variety of engineering applications, including heat exchangers and electronic cooling. [1-3]. Also, in many cooling applications ranging from microelectronicsto automotive or aero-spatial industries, one of the key elements is the use of advanced fluids, with increased thermal conductivity beside to classical cooling fluids. In such situations, the measurement of the thermal conductivity of fluids is very important in evaluating the thermal transfer efficiency in thermal equipment and in cooling systems[4-5]. Although thermal conductivity values are often not available with sufficient reliability and sometimes are not



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available at all. This is true for both gaseous and liquids, but in the case of liquids, a peculiar factor must be stressed the absence of a rigorous theory of the liquid state comparable to the ones commonly used for the solid state or for the gaseous state. The theoretical formulation used for the liquid state are poor in terms of there practical use [6].

The apparatus is designed and fabricated according to the guarded hot plate principle [7]. The guarded hot plate method has been recognized by scientists & engineers in U.S.A., West Germany, Scandinavian Countries., and U.S.S.R[8]. In India most of the developers aredependable and reproducible for the measurement of thermal conductivity of insulting material. It is a steady state absolute method suitable for material which can be laid flat between two parallel plates & can be adopted for loose fill materials which can be filled between such plates. Used guarded hot plate method is a steady state techniques perform a measurement when the temperature of the material measured does not change with time. This makes signal analysis straight forward .and it requires well engineered experimental set up. The unsteady state methods or transient methods are very costly and experiments can be carried very quickly since there is no wait for steady state condition and moreover mathematical analysis of the data in general more difficult. Therefore the guarded hot plate method which is very cost effective and absolute method. In the present study the work undertaken to measure the thermal conductivity of low and heavy viscous locally available liquids.

II. EXPERIMENTAL SET UP

The essential parts – the hot plate, the cold plates, the heater assembly, thermocouples & the specimens in position are shown in the Fig 1.For the measurement of thermal conductivity (k) what is required is to have a one dimensional heat flow through the liquid, an arrangement has been made to maintain the faces at constant temperature & some metering methods are applied to measure the heat flow through a known area. To eliminate the distortion caused by edge losses in unidirectional heat flow, the central plate is surrounded by guard ring which is separately heated [9]. Temperatures are measured by calibrated thermocouples either attached to the plates or to the hot & cold faces liquid.

The heater plate is surrounded by a heating ring for stabilizing the temperature of the primary heater & prevents heat loss readily around its edges [10]. The primary & guard heater are made up of mice sheets in which is wound closely spaced Nichrome wire & packed with upper &lower mica sheets. These heaters together form flat together with upper & lower brass (or any other good conducting material) plate & rings from the heater plate forming the heater plate assembly. Thermocouples no 1&2 measures the hot face temperature at the upper & lower central heater assembly copper plates. Two more thermocouples are used to check balance in both the heater inputs. Testing liquid is held in between the heater & cooling unit of the apparatus. Thermocouples No. 5 & 6 measures the inlet and outlet temperature of the cooling jacket. (Fig 1) shows The heater plate assembly together with cooling plate & the testing liquid held in the plate on which circular grooves has been made. The whole assembly held in position by three vertical stands & nuts on a base plate are as shown in the assembly. The cooling chamber is a composite assembly of grooved aluminum casting & aluminum cover with entry & exit adapters for water inlet & outlet.



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Fig.1. Guarded hot plate method experimental set up

Thermal conductivity of liquid has to be computed using Fourier law of conduction $Q = -KA_m \times (dT / dX)$

 $K = Q/A_m \times (T_h - T_c)$ Watts/m- °c

Where,

K = Thermal Conductivity of sample watts/m-°c

Q = Heat flow rate in the specimen, Watt

 A_m = Mean area for heat flow, m^2 .

 $T_h = Hot plate temperature °c.$

 $T_c = Cold plate temperature, °c.$

III.RESULTS AND DISCUSSION

In the present experiment total five liquid were taken. First water was measured at normal temperature and pressure condition. Fig.2.1 shows the variation of thermal conductivity with time interval of 30, 60, 90,120 minutes. Fig.2.2 shows the variation of thermal conductivity with heat flux ranging from 6.4 to 6.8 watt thermal conductivity increases due to increases heating rate. Fig.2.3 shows the variation of thermal conductivity with respect hot and cold plate temperatures. It is noticed that thermal conductivity increases with increasing the hot plate and cold plate temperature. This is due to the fact that as water is heated it contrasts and causes free convection and conductivity is deceptively increases which is a unique property of water. An average of thermal conductivity of 0.609 W/m°c has been obtained which shows same trends were



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observed by Mostafa H Sharqawy with the theoretical value [11].Fig.3.1, 3.2 and 3.3 indicates the same trend was observed in the case of normal water and for the distilled water [13].



Fig. 2.1. Thermal conductivity vs. time for distilled water



Fig.2.3. Temperature vs. thermal conductivity for distilled water



Fig.2.2. Thermal conductivity vs. heat supplied for distilled water



Fig.3.1. Thermal conductivity vs. time for water



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Fig.4.1. Thermal conductivity vs. time for ethanol



Fig.3.3. Temperature vs. thermal conductivity for water



Fig.4.2. Thermal conductivity vs. heat supplied for ethanol



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Fig.4.3. Temperature vs. thermal conductivity for ethanol

In ethanol thermal conductivity value0.206 W/m^oc which is nearer to the theoretical value0.201 W/m^oc has been observed [12]. And shows that as time elapses between 90-120 min steady state has been reached (Fig 4.1). Fig.4.2. illustrates that as heating rate increases thermal conductivity decrease this due to the fact that there is increase in the disorderness and also the mean free path increases. Optimum heating range for ethanol is around 3-4 watt. Fig.4.3. shows that as temperature of the hot plate and cold plate increases thermal conductivity decreases due to the fact that ethanol evaporates rapidly.



Fig.5.1. Thermal conductivity vs. time for toluene



Fig.5.2. Thermal conductivity vs. heat supplied for toluene



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Fig.5.3. Temperature vs. thermal conductivity for toluene

Fig.6.1.Thermal conductivity vs. time for spent wash

Fig.5.1 shows the variation of thermal conductivity vs. time for toluene which is an aromatic hydrocarbon[14]. It is observed that time for reaching the steady state is between 120-150 minutes. In this time interval optimum value has been observed. Fig.5.2 shows the variation of thermal conductivity with the heat supplied and it is observed that as heat flux going to increases thermal conductivity is going to be decreases due to the disorderness of the system. Fig 5.3 shows the same variation as that of ethanol.







Fig.6.3.Temperature vs. thermal conductivity for spent wash

The study conducted for spent wash Fig.6. Shows the details for thermal conductivity of spent wash distillery by product as spent wash is heavy viscous liquid thermal conductivity is going to be decreases with increasing the temperature. Due to the



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fact that spent wash contains some alcohol around10-15% as heating proceeds it evaporates. Thermal conductivity around 0.4 W/m°c is recorded.

For low viscous liquids the thermal conductivity increases with temperature due to the fact that as temperature increases liquid will contrast causes free convection leads to increase in the thermal conductivity and also it's a unique property of waterand itexchanges easy proton between the molecules. As in the case of heavy viscous liquids thermal conductivity decreases as temperature increases due to the fact that density gradient will exists, this will create a buoyancy force that will opposes by viscous resistance of the fluid and thermal non equilibrium will results leading to decrease in thermal conductivity.

IV. CONCLUSION

Thermal conductivity was measured for different locally available liquids by choosing low viscous and heavy viscous samples at atmospheric temperature and pressure. The apparatus represents a flexible tool for measuring the thermal conductivity of liquids with good accuracy. The results obtained highlight an interesting point that for low viscous liquids like water, distilled water thermal conductivity increases with increasing the temperature which is the unique property of the water. Value of 0.609 W/m°c for distilled water and 0.573W/m°c for normal water has been obtained which matches well with the theoretical value. For heavy viscous liquids it is observed that by increasing the temperature thermal conductivity decreases due to the disorderness and behavior of ions in the molecular structure of the liquid. Value of 0.205 W/m°c for ethanol, 0.192 W/m°c for toluene and 0.457 W/m°c for spent wash has been recorded which matches well with the theoretical value.

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