ANALOGY BETWEEN THE THERMAL CONDUCTIVITY AND ELECTRICAL CONDUCTIVITY FOR COMMON LIQUIDS

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ABSTRACT

In the present scenario there is a huge demand for new advanced liquids with improved thermal properties like thermal conductivity for broad ranges of heat transfer applications. The present work describes the analogy of the liquids thermal conductivity and electrical conductivity data measured by using guarded hot plate method which is a steady state method and conductivity meter a transient method. Experiment is carried out for different low viscous samples like normal water, distilled water and it is observed that thermal conductivity increases as temperature increases same trend is observed for electrical conductivity also. An optimum value of 0.609 W/m°c and 22.24 µs /cm is observed for distilled water and for normal water value of 0.573 W /m°c and 1.035 µs /cm is recorded. For heavy viscous liquids it is observed that as temperature increases both thermal conductivity and electrical conductivity decreases. Value of 0.205 W/ m°c and 8.45 µs /cm is documented for ethanol. And for toluene value of 0.192 W/ m°c is and 2.15 µs/cm is recorded. Experiment is carried out at range of temperatures thermal conductivity is measured by both the methods recorded data is analyzed and discussed. Both thermal conductivity and electrical conductivity are undistinguishable.

Key words: *Thermal conductivity, Heat transfer, conductivity meter, guarded hot plate.*

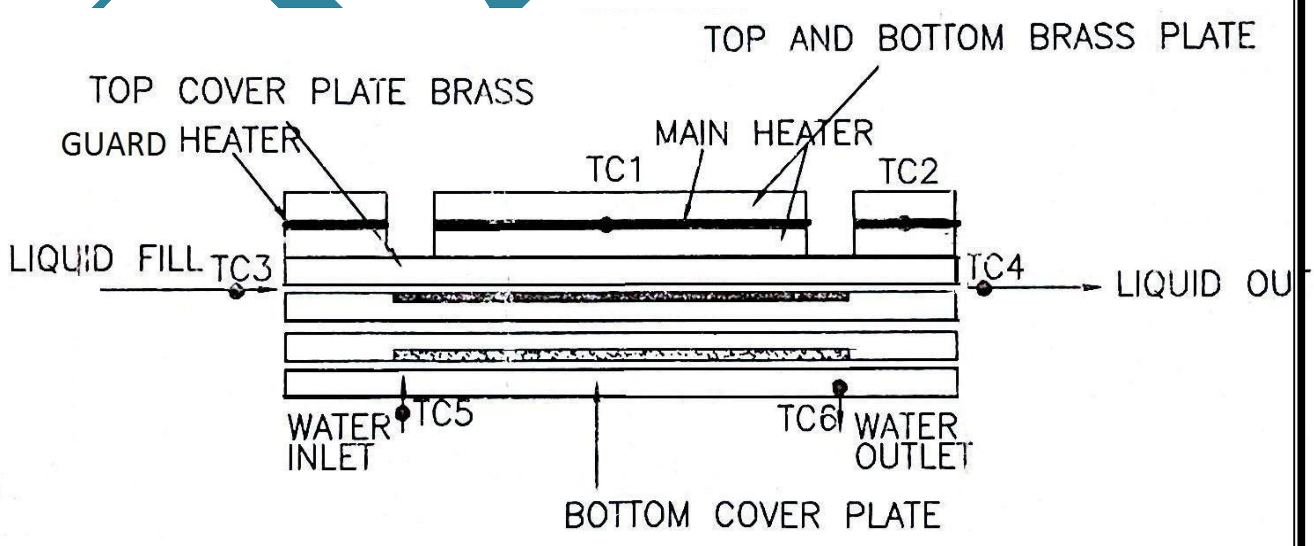
1. INTRODUCTION

In engineering applications liquids properties are required for accurate prediction of their behavior as well for design of components and systems. In the thermal engineering field, great efforts are made to construct high efficient heat transfer equipment, where high thermal conductive liquidsdata are essential to enhance the heat transfer rate (1-3). Also in many of the cooling applications ranging from microelectronics to automotive or aero-spatial industries and machine cooling applications, one of the major fundamentals is the use of advanced liquids, with increased thermal conductivity beside to classical cooling liquids (4-6). In such circumstances, the measurement of the thermal conductivity of liquids is very important in evaluating the heat transfer efficiency in heat transfer equipment also in cooling systems; the temperature gradient will give rise to a density gradient. This will create a buoyancy force that will be opposed by viscous resistance of the fluid, and mechanical non-equilibrium will result. This mechanical instability will cause bulk convective motion, i.e. the bodily motion of whole portions of the fluid. This makes experimental measurements of thermal conductivity for liquids more complicated. In order to measure thethermal conductivity of liquids very few methods are used. In the present work guarded hot plate method which is a steady state method and conductivity meter apparatus which is a transient method are used. Steady state method involves normally very large measurement times because the system should come to the steady state, perhaps starting from initial room temperature to all the components that make up the apparatus. And also for maintaining the steady state requires expensive controllers and uninterrupted power and water supply. Conductivity is measured with a probe and meter a voltage is applied between the two electrodes in probe immerses in the liquid sample. The drop in the voltage caused by the resistance of the liquid is used to measure the conductivity. The electric field applied causes the ions to move creating a current. Because the charge carriers are ions, the current is called an ionic current. The analyzer measures the current and uses Ohm's law to calculate the resistance of the solution (resistance= voltage/current).

2. EXPERIMENTAL SET UP

2.1 Guarded hot plate method

Guarded hot plate method consists of main heater plate is surrounded by a ring type heater which is called guard heater to stabilize the temperature of the main heater and prevents edge losses [7-8]. The main and guard heater are made up of mice sheets in which nichrome wire is wounded closely and packed with upper and lower mica sheets. These heaters organized flat together with upper and lower brass plates. Two thermocouples are used to ensure the hot face temperature at the upper and lower brass plates. Two more thermocouples are used to check balance in main heater and the guard heater inputs. Testing liquid is held between the heater & cooling unit. Two more Thermocouples are used to measure cooling water inlet and outlet temperature. The cooling chamber is assembly of grooved aluminum casting, copper tubes and aluminum cover with entry and exit connectors for water inlet and outlet. The whole set of apparatus is shown in figure.1



(Fig 1.0 Guarded hot plate method experimental set up)

$Q = -KA \times \frac{dT}{dX}$(1)

$K = \frac{Q \times S}{Am \times (Th - Tc)}$ (2)

Where,

K = Thermal Conductivity of sample watts/m- ºc

Q = Heat flow rate in the plates, watts

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

T_h = Hot plate temperature in ºC.

T_c = Cold plate temperature in ºC.

S = Spacer area = 3-8 mm (5mm chosen).

T_1, T_2- Temperature of hot plate

T_3- Main heater temperature

T_4- Guard heater temperature

T_5, T_6- Cold plate temperature

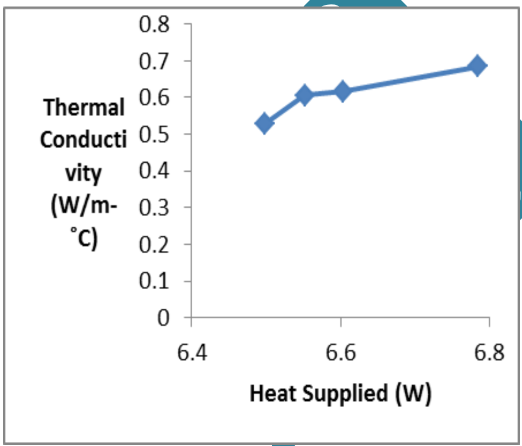
2.2 Conductivity meter

The conductivity meter apparatus consist of two metal electrodes, generally stainless steel or titanium, in contact with the liquid solution. The analyzer applies an alternating voltage to the electrodes. The electric field causes the ions to move producing a current because the charge carriers are ions and conductivity depends on that ion, the current generated is called an ionic current. The analyzer measures the current and uses Ohm's law to calculate the resistance of the solution. The conductance of the solution is defined as the reciprocal of the resistance. The ionic current generated depends on the total concentration of the ions in solution and on the length and area of the liquid through which the current flows. The flow of current is well-defined by the sensorgeometry, or cell constant, which has units of 1/cm (length/area). Multiplying the conductance by the cell constant corrects for the effect of sensor geometry on the measurement. The result is the conductivity, which depends on the concentration of the solution. Shown in fig 2

(Fig 2.0 Conductivity meter apparatus)

Experimental set up contains a tungsten metallic electrode most contacting conductivity sensors consist of two metal electrodes, generally stainless steel or titanium, in contact with the electrolyte solution. See Figure 3. The analyzer applies an alternating voltage to the electrodes. The electric field causes the ions to move back and forth creating a current. Because the charge carriers are ions,the current is called an ionic current.

3. RESULTS AND DISCUSSION



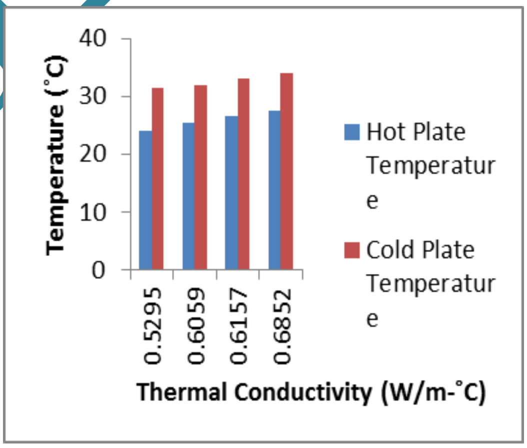
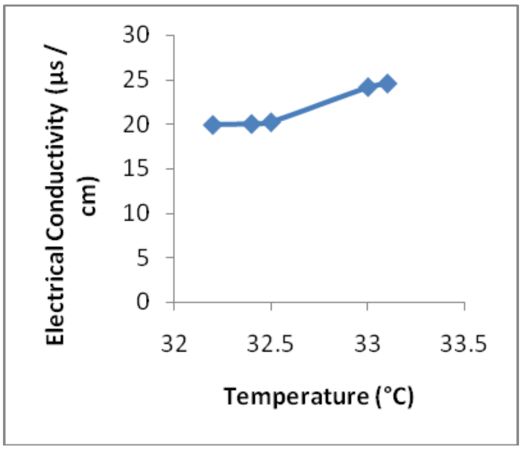
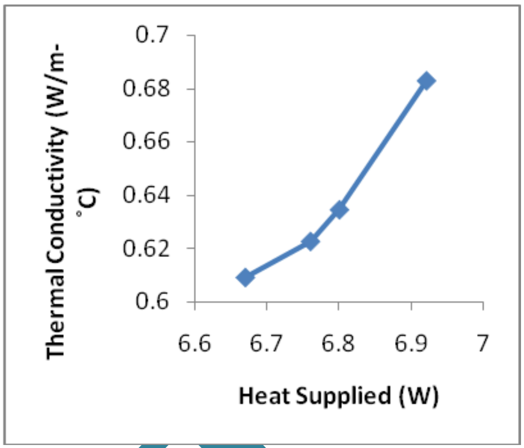


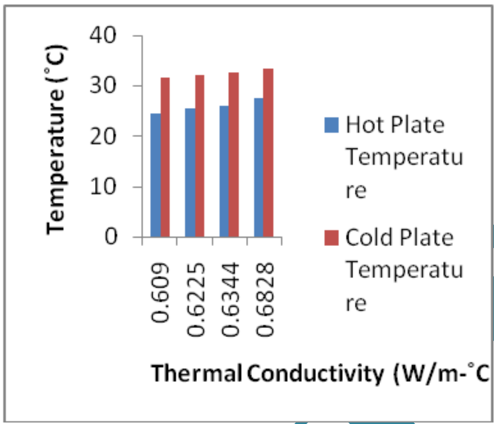
Fig.3.1 Thermal conductivity vs. heat supplied for DW

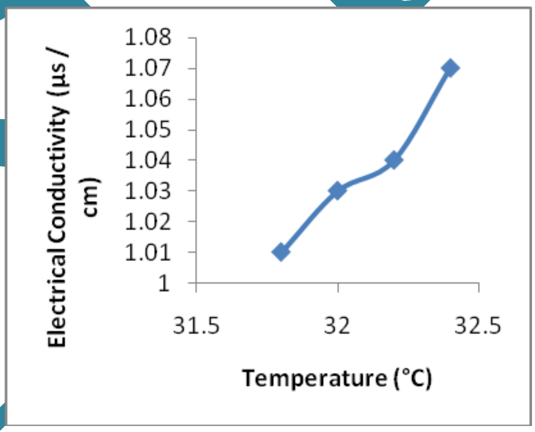
Fig.3.2 Temperature vs. thermal conductivity for DW





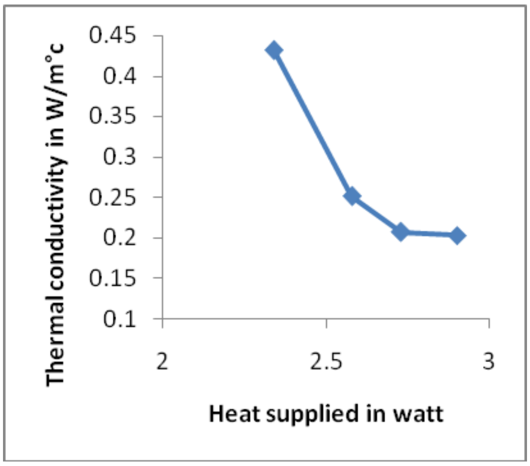
(Fig.3.3 Graph of electrical conductivity vs. temperature) **Fig.3.4 Thermal conductivity vs. heat supplied for water**

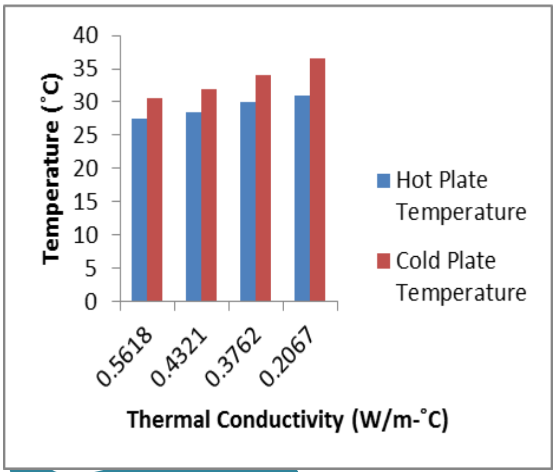




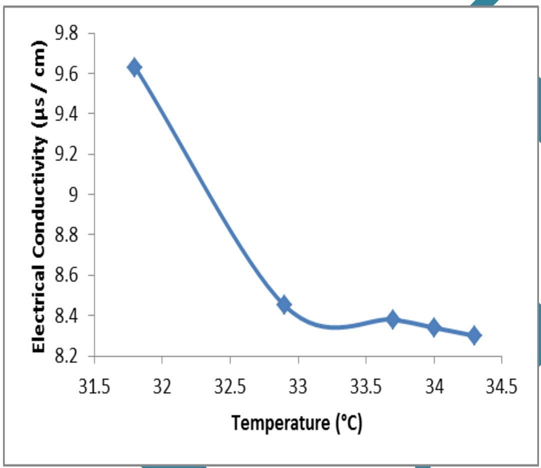
(Fig.3.5 Temperature vs. thermal conductivity for water) **(Fig.3.6 Graph of electrical conductivity vs. Temperature)**

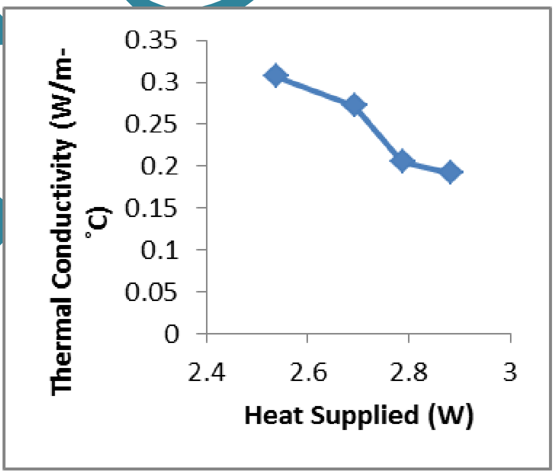
Thermal conductivity of distilled water measured at different heating inputs at atmospheric pressure and temperatures. Fig 3.1shows heating Range from 6.4 watts to 6.8 watts. And it is observed that the thermal conductivity increases by increasing the heating rates which is unique property of water due to the fact that as water is heated it contrast and causes convection current and conductivity is increases. Fig 3.2 shows the graph of temperature vs. thermal conductivity as temperature of hot plate and cold plate increases thermal conductivity increases as water is heated the movement of ions takes place dominant H^+ ions transfers more electrons to the OH^- ions usually the H^+ ions are more dominant and causes ionic current to move[9]. Fig 3.3 shows the graph of electrical conductivity vs. temperature electrical conductivity shows the movement of ions in the liquid concentration. For the distilled water it is observed that the electrical conductivity increases as the temperature increases due to the movement of H^+ ions. H^+ ions will dominantly transfer more number of ions and OH^- ions will receive the ions given by the H^+ ions. In distilled water most of the ionic content is removed therefore the conductivity is high and a optimum value of 22.24 µs/ cmis recorded. The same trend is observed for the normal water fig 3.4 and 3.5 thermal conductivity value of 0.624 W/m °c is recorded. In normal water there is more group of ions fluoride content and iron content and hence the electrical conductivity is dissipative high and optimum value of 1.035 µs /cm is observed which is shown in fig 3.6



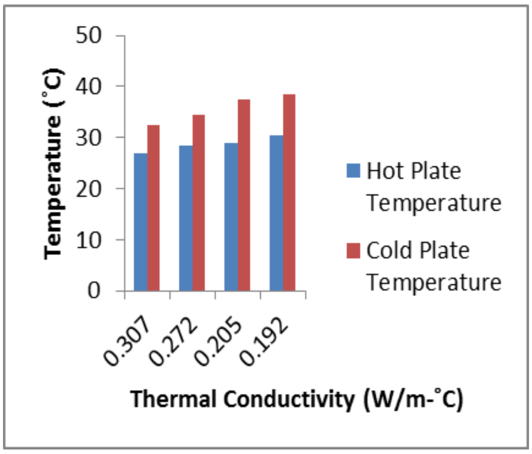


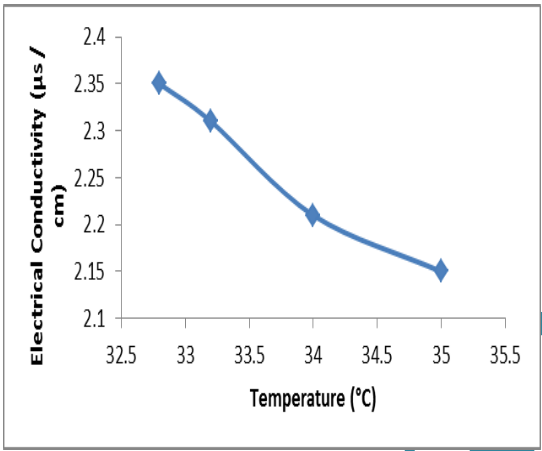
(Fig.3.7 Thermal conductivity vs. heat supplied for ethanol) (Fig.3.8 Temperature vs. thermal conductivity for ethanol)





(Fig 3.9 Graph of electrical conductivity vs. Temperature for ethanol) (Fig.3.10 Thermal conductivity vs. heat supplied for toluene)





(Fig.3.11 Temperature vs. thermal conductivity for toluene) (Fig 3.12 Graph of electrical conductivity vs. Temperature for toluene)

Fig 3.7 shows the graph of heating rate vs. thermal conductivity for ethanol (95%) which is avolatile and flammable liquid with chemical odors and it is two carbon alcohols attached to the oxygen of hydroxyl group OH^- . Optimum heating range for ethanol is 3-4 watts. The latent heat of vaporization of ethanol is very high as it exposed to atmosphere it evaporates readily. As ethanol is heated there is increase in the disorderness of the system there by increases in the mean effective path [(10)]. As result the thermal conductivity of ethanol decreases with increasing in the temperature as shown in fig 3.8 an optimum value of 0.203 is recorded which matches very well with the theoretical value. Fig 3.9 shows the graph of electrical conductivity vs. temperature for ethanol the same trend is observed as that of thermal conductivity that as temperature increases the electrical conductivity decreases. The reason is that there is carbon bond with hydrogen which opposes the transfer of electrons to the OH^- group resulting in decreases electrical conductivity. In fact, ethanol, like other alcohols, conducts electricity rather poorly because it is a non-electrolyte. Ethanol itself contains virtually no electrolytes besides those that form as an effect of auto-ionization these electrolytes, however, are in so small a number that they're virtually negligible.

Toluene is an aromatic hydrocarbon and weakly absorbing liquid. Fig 3.10 shows that optimum heating range for toluene is 2.8 to 3 watts. Fig 3.11 shows the same that as temperature increases the thermal conductivity decreases due to disorderness of the system an optimum value of 0.192 W/m°c is recorded[10]. Fig.3.12 shows the graph of electrical conductivity vs. temperature for toluene and it is observed that as temperature increases the electrical conductivity decreases sameas that of thermal conductivity. The reason is that toluene is a electrophilic aromatic substitution owing to greater electron releasing capacity of methyl group vs. hydrogen and an optimum value of 2.15 μs/ cm is observed which is slightly less than water.

For low viscosity liquids the thermal conductivity increases with increase in the temperature. As low viscous liquids are heated there is contraction phenomena takes place and causes free convection current to move which leads to increase in thermal conductivity. For low viscous liquids there is easy exchange of protons between the molecules particularly the H^+ ions will easily transfer electrons. For heavy viscous liquids thermal conductivity decreases as temperature increases[11]. As temperature increases the density gradient will going to exist, leading to the formation of buoyancy force which is opposed by the viscous resistance force of the liquid. For heavy viscous liquids as temperature increases thermal non-equilibrium will results leading to decrease in the thermal conductivity.

4. CONCLUSION

Thermal conductivity of various liquids measured at atmospheric temperature and pressure. The apparatus used is guarded hot plate method (steady state method). For electrical conductivity meter set up is used (transient method). Results obtained from both methods show the same trend and behavior of conductivity by analogy of thermal conductivity and electrical conductivity. For low viscous liquids it is observed both thermal conductivity and electrical conductivity increases with increasing the temperature. An optimum value of 0.609 W/m°c and 22.24 μs /cm is observed for distilled water and for normal water value of 0.573 W /m°c and 1.035 μs /cm is recorded. For heavy viscous liquids it is observed that as temperature increases both thermal conductivity and electrical conductivity decreases. Value of 0.205 W/ m°c and 8.45 μs /cm is documented for ethanol. And for toluene value of 0.192 W/ m°c is and 2.15 μs/cm is recorded which matches well with thetheoretical values.

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