FABRICATION OF APPARATUS FOR MEASURING OF THERMAL CONDUCTIVITY OF LIQUIDS

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ABSTRACT

Determining the physical properties is an important subject in many advanced engineering applications. The physical properties of liquids, such as thermal conductivity play an important role in the design of a wide variety of engineering applications, such as heat exchangers. In this project, importance is given to apparatus designing and a particular design is selected for determining the thermal conductivity of various liquids. Details of the experimental apparatus, testing procedure, data reduction, and sample results are presented. One of the objectives of this project is to strengthen and reinforce some of the heat transfer concepts, such as conduction, convection, and radiation.

The thermal conductivity of liquids is an important energy transport property the value, which is required in the solution of most heat transfer correlations. The results of an extensive literature survey the published. Data and methods of measurement reveal until recently, that the available data were scanty and their accuracy in considerable doubt.

In this project, considerable effort has been expended in the experimental determination of the thermal conductivity of various liquids, but little progress has been made towards developing an apparatus that yields results of high dependability. Therefore, a study of factors affecting the design of a thermal conductivity apparatus for liquids was made, and a new apparatus, based on the results of this study, was developed and tested extensively.

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CHAPTER 1

1 INTRODUCTION

1.1 Heat Transfer

Heat transfer is a basic and very important topic that deals with energy and has long been an essential part of mechanical engineering curricula all over the world. Heat transfer processes are encountered in a large number of engineering applications. It is essential for thermal engineers to understand the principles of thermodynamics and heat transfer and be able to employ the rate equations that govern the amount of energy being transferred.

Heat transfer is the process of the movement of energy due to a temperature difference. The calculations we are interested in typically include determining the final temperatures of materials or how long it takes for these materials to reach these temperatures. This can help inform the level of insulation required to ensure heat is not lost from a system. Typically, heat loss is proportional to a temperature gradient (driving force or potential). Heat transfer can be achieved by conduction, convection, or radiation.

The thermal conductivity of liquids is an important physical property the value of which is required in the solution of most heat transfer correlations. The accuracy of the various correlations predicting these heat transfer coefficients cannot be better than the accuracy with which the thermal conductivity is known. At a given temperature, the thermal conductivity of common liquids varies considerably, and an average value picked at random is not satisfactory.

Despite its importance, and until recently, the available data were scanty and their accuracy in considerable doubt. In recent years, considerable effort has been expended in the experimental determination of the thermal conductivity of various liquids, but little progress has been made towards developing an apparatus that yields results of high dependability. For this reason, an exclusive literature survey of the published data and methods of measurement has been made, followed by a study of factors affecting the design of a thermal conductivity apparatus for liquids.

1.1.1 Conduction

Conduction heat transfer is the transfer of heat through matter i.e., solids, liquids, or gases without bulk motion of the matter. In another ward, conduction is the transfer of energy from the more energetic to less energetic particles of a substance due to interaction between the particles. Conduction heat transfer in gases and liquids is due to the collisions and diffusion of the molecules during their random motion. On the other hand, heat transfer in solids is due to the combination of lattice vibrations of the molecules and the energy transport by free electrons. Thermal conduction is the transfer of internal energy by microscopic collisions of particles and the movement of electrons within a body. The colliding particles, which include molecules, atoms, and electrons, transfer disorganized microscopic kinetic and potential energy, when joined known as internal energy. Conduction takes place in most phases: solid, liquid, and plasma.

Heat spontaneously flows from a hotter to a colder body.

For example, heat is conducted from the hotplate of an electric stove to the bottom of a saucepan in contact with it. In the absence of an opposing external driving energy source, within a body or between bodies, temperature differences decay over time, and thermal equilibrium is approached, temperature becoming more uniform. Heat Conduction can occur through the wall of a vein in the human body. The inside surface, which is exposed to blood, is at a higher temperature than the outside surface.

Ironing of clothes is an example of conduction where the heat is conducted from the iron to the clothes.

Heat is transferred from hands to ice cubes resulting in the melting of an ice cube when held in hands.

Heat conduction through the sand at the beaches. This can be experienced during summers. Sand is a good conductor of heat.

The coefficient of thermal conductivity shows that a metal body conducts heat better when it comes to conduction. The rate of conduction can be calculated by the following equation:

$$Q = [K.A.(Thot-Tcold)]/d$$

Where,

- Q is the transfer of heat per unit time
- K is the thermal conductivity of the body
- A is the area of heat transfer
- T_{hot} is the temperature of the hot region
- T_{cold} is the temperature of the cold region
- d is the thickness of the body

1.1.2 Convection

Convection is the transfer of heat due to the bulk movement of fluids. As such convection only applies to heat transfer within a fluid or between a solid and fluid but not the heat transfer within a solid.

This heat transfer is achieved by the movement of molecules within the fluid. The term convection can refer to either mass transfer and/or heat transfer.

The convection heat transfer mode comprises one mechanism. In addition to energy transfer due to specific molecular motion (diffusion), energy is transferred by bulk, or macroscopic, the motion of the fluid.

This motion is associated with the fact that, at any instant, large numbers of molecules are moving collectively or as aggregates. Such motion, in the presence of a temperature gradient, contributes to heat transfer. Because the molecules in aggregate retain their random motion, the total heat transfer is then due to the superposition of energy transport by the random motion of the molecules and by the bulk motion of the fluid.

It is customary to use the term convection when referring to this cumulative transport and the term advection when referring to the transport due to bulk fluid motion. Convection is the sum of advection and diffusion:

Advection is the heat transported by the large-scale movement of current in the fluid.

Diffusion is the random Brownian motion of individual particles in the fluid.

Examples of convection include the effect of hot air rising and falling or the large-scale convection currents of the atmosphere and oceans.

The draft in a chimney or around any fire. In natural convection, an increase in temperature produces a reduction in density, which in turn causes fluid motion due to pressures and forces when fluids of different densities are affected by gravity.

When water is heated on a stove, hot water from the bottom of the pan is displaced by the colder denser liquid, which falls.

After heating has stopped, mixing and conduction from this natural convection eventually result in a nearly homogeneous density and even temperature. Without the presence of gravity, natural convection does not occur, and only forced-convection modes operate.

The effect of hot air rising and falling (convection currents) or the large-scale convection currents of the atmosphere and oceans.

In the boiling of water, that is molecules that are denser move at the bottom while the molecules which are less dense move upwards resulting in the circular motion of the molecules so that water gets heated.

Warm water around the equator moves towards the poles while cooler water at the poles moves towards the equator.

Blood circulation in warm-blooded animals takes place with the help of convection, thereby regulating the body temperature.

1.1.2.1 Types Of Convection

Two types of convective heat transfer may be distinguished:

1.1.2.1.1 Natural Convection

When fluid motion is caused by buoyancy forces that result from the density variations due to variations of thermal temperature in the fluid. In the absence of an internal source, when the fluid is in contact with a hot surface, its molecules separate and scatter, causing the fluid to be less dense.

As a consequence, the fluid is displaced while the cooler fluid gets denser and the fluid sinks. Thus, the hotter volume transfers heat towards the cooler volume of that fluid. Familiar examples are the upward flow of air due to a fire or hot object and the circulation of water in a pot that is heated from below.

1.1.2.1.2 Forced Convection

When a fluid is forced to flow over the surface by an internal source such as fans, by stirring, and pumps, creating an artificially induced convection current.

Internal and external flow can also classify convection. Internal flow occurs when a fluid is enclosed by a solid boundary such as when flowing through a pipe. An external flow occurs when a fluid extends indefinitely without encountering a solid surface.

Both of these types of convection, either natural or forced, can be internal or external because they are independent of each other. The bulk temperature, or the average fluid temperature, is a convenient reference point for evaluating properties related to convective heat transfer, particularly in applications related to flow in pipes and ducts.

Further classification can be made depending on the smoothness and undulations of the solid surfaces. Not all surfaces are smooth, though a bulk of the available information deals with smooth surfaces. Wavy irregular surfaces are commonly encountered in heat transfer devices which include solar collectors, regenerative heat exchangers, and underground energy storage systems

As the temperature of the liquid increases, the liquid's volume also has to increase by the same factor and this effect is known as displacement. The equation to calculate the rate of convection is as follows:

$$Q = h_c \cdot A \cdot (T_s - T_f)$$

Where,

- Q is the heat transferred per unit time
- H_c is the coefficient of convective heat transfer
- A is the area of heat transfer
- T_s is the surface temperature
- T_f is the fluid temperature

1.1.3 Radiation

Radiant heat is present in some or other form in our daily lives. Thermal radiations are referred to as radiant heat. Thermal radiation is generated by the emission of electromagnetic waves. These waves carry away the energy from the emitting body.

Radiation takes place through a vacuum or transparent medium which can be either solid or liquid. Thermal radiation is the result of the random motion of molecules in matter.

The movement of charged electrons and protons is responsible for the emission of electromagnetic radiation. Let us know more about radiation heat transfer.

Radiation heat transfer is measured by a device known as a thermocouple. A thermocouple is used for measuring the temperature. In this device sometimes, error takes place while measuring the temperature through radiation heat transfer.

Microwave radiation emitted in the oven is an example of radiation.

UV rays coming from the sun are an example of radiation.

The release of alpha particles during the decaying of Uranium-238 into Thorium-234 is an example of radiation.

As temperature rises, the wavelengths in the spectra of the radiation emitted decrease, and shorter wavelengths of radiation are emitted. Thermal radiation can be calculated by the Stefan-Boltzmann law:

$$P = e \cdot \sigma \cdot A \cdot (Tr - Tc)^4$$

Where,

- P is the net power of radiation
- A is the area of radiation
- Tr is the radiator temperature
- Tc is the surrounding temperature

1.2 Thermal Conductivity

Thermal conductivity (often denoted by k, λ, or κ) refers to the intrinsic ability of a material to transfer or conduct heat. It is one of the three methods of heat transfer, the other two being convection and radiation. Heat transfer processes can be quantified in terms of appropriate rate equations. The rate equation in this heat transfer mode is based on Fourier's law of heat conduction.

It is also defined as the amount of heat per unit time per unit area that can be conducted through a plate of unit thickness of a given material, the faces of the plate differing by one unit of temperature.

Thermal conductivity occurs through molecular agitation and contact and does not result in the bulk movement of the solid itself.

Heat moves along a temperature gradient, from an area of high temperature and high molecular energy to an area with a lower temperature and lower molecular energy.

This transfer will continue until thermal equilibrium is reached. The rate at which heat is transferred is dependent upon the magnitude of the temperature gradient, and the specific thermal characteristics of the material.

In physics, a fluid is a substance that continually deforms (flows) under applied shear stress. Fluids are a subset of the phases of matter and include liquids**,** gases**,** plasmas, and, to some extent, plastic solids. Because the intermolecular spacing is much larger and the motion of the molecules is more random for the fluid state than for the solid-state, thermal energy transport is less effective. The thermal conductivity of gases and liquids is generally smaller than that of solids. In liquids, thermal conduction is caused by atomic or molecular diffusion. In gases, thermal conduction is caused by the diffusion of molecules from a higher energy level to lower energy.

Before analyzing thermal conductivity for different phases, let us look at the phenomena which govern heat conduction through solids, liquids, and gases.In solids, heat can be conducted through two mechanisms. First is lattice vibrations and the second is Flow of free electrons. Increased lattice vibrations facilitate the transport heat energy through the medium. The flow of free electrons increases electrical conductivity.

In liquids and gases, heat conduction occurs mainly through two mechanisms. First is the collision between atoms, molecules or ions, and second is molecular diffusion. As the number of collisions increases, the exchange of energy among molecules increases. This helps in the transport of heat energy through the medium. Molecular diffusion is the random movement of molecules in a medium. As the random movement of molecules increases, it obstructs the transport of heat energy in a particular direction.

1.2.1 Fourier's Law Of Conduction

States that the rate at which heat is transferred through a material is proportional to the negative of the temperature gradient and is also proportional to the area through which the heat flows. The differential form of this law can be expressed through the following equation:

$$\mathbf{q = -k.\nabla T}$$

Where ∇T refers to the temperature gradient, q denotes the thermal flux or heat flux, and k refers to the thermal conductivity of the material in question.

Every substance has its capacity to conduct heat. The thermal conductivity of a material is described by the following formula:

$$\mathbf{K = (QL)/ (A\Delta T)}$$

Where,

- K is the thermal conductivity in W/m.K.
- Q is the amount of heat transferred through the material in Joules/second or Watts.
- L is the distance between the two isothermal planes.
- A is the area of the surface in square meters.
- ΔT is the difference in temperature in Kelvin.

1.2.2 Units

Thermal conductivity is expressed in terms of the following dimensions: Temperature, Length, Mass, and Time

The SI unit of this quantity is watts per meter-Kelvin or $Wm^{-1}K^{-1}$.

It is generally expressed in terms of power/ (length * temperature).

These units describe the rate of conduction of heat through a material of unit thickness and for each Kelvin of temperature difference.

Figure 1.1 Thermal Conductivity of Solids and Metals

SOLIDS	THERMAL CONDUCTIVITY(W/mK)
Aluminum	235
Brass	109
Gold	314
Iron	67
Lead	35
Nickel	91
Silver	428
Zirconium	22.6
Stainless Steel	14

1.2.3 Thermal Conductivity Of Liquids

As was written, in liquids, the thermal conduction is caused by atomic or molecular diffusion, but physical mechanisms for explaining the thermal conductivity of liquids are not well understood. Liquids tend to have better thermal conductivity than gases, and the ability to flow makes a liquid suitable for removing excess heat from mechanical components. The heat can be removed by channeling the liquid through a heat exchanger. The coolants used in nuclear reactors include water or liquid metals, such as sodium or lead.

Water and steam are common fluids used for heat exchange in the primary circuit (from the surface of fuel rods to the coolant flow) and in the secondary circuit. It is used due to its availability and high heat capacity**,** both for cooling and heating. It is especially effective to transport heat through vaporization and condensation of water because of its very large latent heat of vaporization.

A disadvantage is that water-moderated reactors have to use a high-pressure primary circuit to keep water in the liquid state and achieve sufficient thermodynamic efficiency. Water and steam also react with metals commonly found in industries such as steel and copper, oxidized faster by untreated water and steam. In almost all thermal power stations (coal, gas, nuclear), water is used as the working fluid (used in a closed-loop between boiler, steam turbine, and condenser), and the coolant (used to exchange the waste heat to a water body or carry it away by evaporation in a cooling tower).

Table 1.2 Thermal Conductivity Of Liquids

LIQUIDS	THERMAL CONDUCTIVITY(W/mK)
Acetic Acid	0.193
Water,Fresh	0.609
Turpentine	0.128
Acetone	0.180
Alcohol,Methanol	0.171
Alcohol,Ethanol	0.204
Castor Oil	0.180
Diesel Oil	0.130
Engine Oil,unused	0.145
Gas Oil	0.150
Kerosene	0.145
Hexane	0.124
Methane	0.215
Petroleum	0.159
Heating Oil	0.120
Dodecane	0.140
Aniline	0.172
Benzene	0.167
Benzine	0.160
Hexane	0.124
n-Heptane	0.140
n-Octane	0.147
n-Pentane	0.136
Nitric Acid	0.260
Phenol	0.190
Trichloro Ethylene	0.160
Toulene	0.151

1.2.4 Thermal Conductivity Of Gases

The effect of temperature, pressure and chemical species on the thermal conductivity of a gas may be explained in terms of the kinetic theory of gases. Air and other gases are generally good insulators in the absence of convection. Therefore, many insulating materials (e.g., polystyrene) function simply by having a large number of gas-filled pockets**,** which prevent large-scale convection**.** Alternation of gas pocket and solid material causes heat to transfer through many interfaces, causing a rapid decrease in heat transfer coefficient.

The thermal conductivity of gases is directly proportional to the density of the gas, the mean molecular speed, and especially to the mean free path of a molecule. The mean free path also depends on the diameter of the molecule, with larger molecules more likely to experience collisions than small molecules, which is the average distance traveled by an energy carrier (a molecule) before experiencing a collision. Light gases, such as hydrogen and helium**,** typically have high thermal conductivity, and dense gases such as xenon and dichlorodifluoromethane have low thermal conductivity.

In general, the thermal conductivity of gases increases with increasing temperature.

Table 1.3 Thermal Conductivity of Gases

GASES	THERMAL CONDUCTIVITY(W/mK)
Air	0.026
Xenon	0.005
Nitrogen	0.024
Argon	0.016
Carbon Dioxide	0.014
Hydrogen	0.180

1.2.5 Thermal Conductivity Variation

The thermal conductivity of a specific material is highly dependent on several factors. These include the temperature gradient, the properties of the material, and the path length that the heat follows.

The thermal conductivity of the materials around us varies substantially, from those with low conductivities such as air with a value of 0.024 W/m•K at 0°C to highly conductive metals like copper (385 W/m•K).

The thermal conductivity of materials determines how we use them, for example, those with low thermal conductivities are excellent at insulating our homes and businesses while high thermal conductivity materials are ideal for applications where heat needs to be moved quickly and efficiently from one area to another, as in cooking utensils and cooling systems in electronic devices.

By selecting materials with the thermal conductivity appropriate for the application, we can achieve the best performance.

1.2.5.1 Variation Of Thermal Conductivity With Temperature

Because molecular movement is the basis of thermal conductance temperature of a material has a large influence on thermal conductivity.

Molecules will move more quickly at higher temperatures, and therefore heat will be transferred through the material at a higher rate. This means that the thermal conductivity of the same sample has the potential to change drastically as the temperature increases or decreases.

The ability to understand the effect that temperature has on thermal conduction is critical to ensuring that products behave as expected when subjected to thermal stress.

To generate heat, such as electronics, and develop fire and heat protection materials This is especially important when working with products.

In the case of pure metals and alloys, the thermal conductivity predominantly depends on electronic effect. As temperature increases, both number of free electrons and lattice vibrations increase. Thus the thermal conductivity of the metal is expected to increase. However, increased lattice vibrations obstruct the flow of free electrons through the medium. The combined effect of this phenomena, in most cases, results into decreased thermal conductivity with the increase in temperature, for the metals and alloys. There are some exceptions to this rule. For Iron, the thermal conductivity initially decreases and then increases slightly with an increase in temperature. For Platinum, the thermal conductivity increases with increase in temperature.

In gases, molecular collisions increase with the increase in temperature. Thus, the thermal conductivity of a gas increases with increase in temperature.

In liquids, as we have seen earlier, thermal conductivity depends predominantly on molecular diffusion effect. As temperature increases, the randomness of molecular movements increases. This obstructs transport of heat through liquids. Thus, the thermal conductivity of liquids decreases with increase in temperature. However, there is one exception, pure water. In the case of pure water, thermal conductivity first increases with increase in temperature and then starts decreasing.

1.2.5.2 Variation Of Thermal Conductivity With Pressure

As most solids and liquids are incompressible in nature, thermal conductivity does not vary with pressure.

In case of gases, the kinetic theory of gases predicts and experiments confirm that the thermal conductivity of gases is proportional to the square root of the temperature T, and inversely proportional to the square root of the molar mass M. However, the thermal conductivity of gases is independent of pressure in a wide range of pressures encountered in practice.

1.2.5.3 Variation Of Thermal Conductivity In Metals , Non-Metals, Alloys

Temperature affects the thermal conductivities of metals and non-metals differently.

The heat conductivity of metals is attributed to the presence of free electrons. It is somewhat proportional to the product of the absolute temperature and the electrical conductivity, as per the Wiedemann-Franz law.

With an increase in temperature, the electrical conductivity of a pure metal decreases.

This implies that the thermal conductivity of the pure metal shows little variance with an increase in temperature. However, a sharp decrease is observed when temperatures approach 0K.

Alloys of metals do not show significant changes in electrical conductivity when the temperature is increased, implying that their heat conductivities increase with the increase in temperature.

The peak value of heat conductivity in many pure metals can be found at temperatures ranging from 2K to 10K.

The thermal conductivities of non-metals are primarily attributed to lattice vibrations.

The mean free path of the phonons does not reduce significantly when the temperatures are high, implying that the thermal conductivity of non-metals does not show significant change at higher temperatures.

When the temperature is decreased to a point below the Debye temperature, the heat conductivity of a non-metal decrease along with its heat capacity.

the conduction of heat through solids is dependent on two effects, namely lattice vibrations and flow of free electrons. The thermal conductivity is obtained by adding lattice and electronic components.

K=Kl+Ke;

where,

Kl= the thermal conductivity due to lattice vibrations

Ke= the thermal conductivity due to electronic effect

In Pure metals, the electronic effect plays a dominant role. Thus, they have relatively higher values of thermal conductivity. For Pure metals, k ~ ke.

In Non-metals, the lattice vibrations effect plays a dominant role. Non-metals generally have high electric resistance, which obstructs the flow of electrons. Therefore, for non-metals k ~ kl.

The lattice component of thermal conductivity strongly depends on the way the molecules are arranged. For example, wood, which is an amorphous solid (molecules are arranged in highly disorderly manner), has relatively lower values of thermal conductivity and act as a thermal insulator. Now consider diamond. It is a highly ordered crystalline solid. Thus it has the highest thermal conductivity at room temperature. Beryllium Oxide (BeO), also a non-metal, has relatively higher thermal conductivity due to its crystallinity.

Metals are good electrical and heat conductors because they have free electrons as well as lattice vibrations. On the other hand, non-metals do not have free electrons, meaning they are electrically non-conducting materials. And in general non-metals like wood are thermally non-conducting materials.

However, non-metals like diamond and Beryllium Oxide are good heat conductors. As a result, such materials find widespread use in the electronics industry. E.g. diamond heat sinks used for cooling electronic components.

Pure alloys have high thermal conductivity. One would expect an alloy made of two metals of thermal conductivity k1 and k2 to have a conductivity k between k1 and k2. Surprisingly, this is not the case. The thermal conductivity of an alloy of two metals is usually much lower than that. For example, the thermal conductivities of Copper and Aluminium are 401 W/m°C and 237 W/m°C respectively.

1.2.6 Factors Affecting Thermal Conductivity

Thermal conductivity, also called heat conduction, is the flow of energy from something of a higher temperature to something of a lower temperature. It is different from electrical conductivity, which deals with electrical currents. Several factors affect thermal conductivity and the rate that energy is transferred. As the Physics Info website points out, the flow is not measured by how much energy is transferred, but by the rate it is transferred.

1.2.6.1 Free Electrons

Metals are having more free electrons compared to that of liquids and gases, so metal are good conductors of heat due to the migration of free electrons. Metals are having closely packed lattices compared to liquids and gases.

1.2.6.2 The Chemical Phase

When the phase of a material change, an abrupt change in its heat conductivity may arise. For example, the thermal conductivity of ice changes from 2.18 $Wm^{-1}K^{-1}$ to 0.56 $Wm^{-1}K^{-1}$ when it melts into a liquid phase.

1.2.6.3 Thermal Anisotropy

Some substances, such as non-cubic space can exhibit different thermal conductivities along different crystal axes. 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 with the a-axis wood generally conducts better along the grain than across it.

Other examples of materials where the thermal conductivity varies with direction are metals that have undergone heavy cold pressing, laminated materials, cables, the materials used for the Space Shuttle thermal protection system, and fiber-reinforced composite structures. When anisotropy is present, the direction of heat flow may differ from the direction of the thermal gradient.

1.2.6.4 Electrical Conductivity

In heat via phonons due to its orderly array of atoms. metals, thermal conductivity is approximately correlated with electrical conductivity according to the Wiedemann–Franz law, as freely moving valence electrons transfer not only electric current but also heat energy. However, the general correlation between electrical and thermal conductance does not hold for other materials, due to the increased importance of phonon carriers for heat in non-metals. Highly electrically conductive silver is less thermally conductive than diamond, which is an electrical insulator but conducts via phonons due to its orderly array of atoms.

1.2.6.5 Purity Of Material

Thermal conductivity of the pure material is higher than that of alloy materials. Alloying of metals and the presence of impurities cause a decrease in thermal conductivity. E.g. thermal conductivity of pure copper is 385 W/mK but copper has a content of arsenic, thermal conductivity is 142 W/mK.

1.2.6.6 Effect Of Forming

Treatment of metals like heat treatment and metal forming like bending, drawing, and forging decreases the thermal conductivity of material compared to the material before treatment.

1.2.6.7 Density

Thermal conductivity is highly dependent on density of material. The increase in density increases thermal conductivity.

1.2.6.8 Pressure

Thermal conductivity is weakly dependent on pressure of substance. This means a change in pressure does not affect much in thermal conductivity.

1.2.6.9 Crystalline Structure

Thermal conductivity values vary substantially between materials and are highly dependent on the structure of each specific material. Some materials will have different thermal conductivity values depending on the direction of heat travel; these are anisotropic materials.

In these cases, heat moves more easily in a certain direction due to how the structure is arranged.

When discussing thermal conductivity trends, materials can be divided into three categories; gases, nonmetallic solids, and metallic solids. The differing abilities of these three categories in terms of heat transfer can be attributed to the differences in their structures and molecular movements.

Gases have lower relative thermal conductivities, as their molecules are not as tightly packed as those in solids, and therefore heat transfer is highly dependent on the free movement of molecules and molecular velocity.

Gases are poor thermal transmitters. In contrast, the molecules in nonmetallic solids are bound into a lattice network, and therefore thermal conductivity primarily occurs through vibrations in these lattices.

The proximity of these molecules in comparison to those of gases means that nonmetallic solids have the higher thermal conductivities of the two, however, within this group there is a large variation.

Thermal conductivity in metallic solids differs yet again from the previous examples. Metals have the highest thermal conductivities of any material barring graphene and have the unique combination of possessing both thermal and electrical conductivity.

Both of these attributes are transferred by the same molecules, and the relationship between the two is explained by the Wiedemann-Franz Law.

This law attests that at a certain temperature electrical conductivity will be proportional to thermal conductivity, however, as the temperature increases, the thermal conductivity of the material will grow while the electrical conductivity will shrink.

1.2.6.10 Isotropy Impurity

The thermal conductivity of a crystal can depend strongly on isotopic purity, assuming other lattice defects are negligible.

A notable example is a diamond: at a temperature of around 100 K, the thermal conductivity increases from 10,000 $W \cdot m^{-1} \cdot K^{-1}$ for natural type diamond (98.9% C), to 41,000 for 99.9% enriched synthetic diamond. A value of 200,000 is predicted for 99.999% C at 80 K, assuming an otherwise pure crystal. The thermal conductivity of 99% isotopically enriched cubic boron nitride is ~ 1400 $W \cdot m^{-1} \cdot K^{-1}$, which is 90% higher than that of natural boron nitride.

1.2.6.11 Gaseous State

In the absence of convection, air and other gases are good insulators. Therefore, many insulating materials function simply by having a large number of gas-filled pockets which obstruct heat conduction pathways.

Examples of these include expanded and extruded polystyrene (popularly referred to as tory foam") and silica aerogel, as well as warm clothes. Natural, biological insulators such as fur and feathers achieve similar effects by trapping air in pores, pockets, or voids.

Low-density gases, such as hydrogen and helium typically have high thermal conductivity. Dense gases such as xenon and dichlorodifluoromethane have low thermal conductivity. An exception, is sulfur hexafluoride, a dense gas, which has a relatively high thermal conductivity due to its high heat capacity. Argon and krypton, gases denser than air, are often used in insulated glazing (double-paned windows) to improve their insulation characteristics.

The thermal conductivity through bulk materials in porous or granular form is governed by the type of gas in the gaseous phase, and its pressure. At low pressures, the thermal conductivity of a gaseous phase is reduced, with this behavior governed by the Knudsen number, defined as the mean free path of gas molecules and is the typical gap size of the space filled by the gas. A granular material corresponds to the characteristic size of the gaseous phase in the pores or intergranular spaces.

1.2.6.12 Temperature

The effect of temperature on thermal conductivity is different for metals and nonmetals. In metals, heat conductivity is primarily due to free electrons. Following the Wiedemann–Franz law, thermal conductivity of metals is approximately proportional to the absolute temperature (in kelvins) times electrical conductivity. In pure metals the electrical conductivity decreases with increasing temperature and thus the product of the two, the thermal conductivity, stays approximately constant. However, as temperatures approach absolute zero, the thermal conductivity decreases sharply.[21] In alloys the change in electrical conductivity is usually smaller and thus thermal conductivity increases with temperature, often proportionally to temperature. Many pure metals have a peak thermal conductivity between 2 K and 10 K.

On the other hand, heat conductivity in nonmetals is mainly due to lattice vibrations (phonons). Except for high-quality crystals at low temperatures, the phonon mean free path is not reduced significantly at higher temperatures. Thus, the thermal conductivity of nonmetals is approximately constant at high temperatures. At low temperatures well below the Debye temperature, thermal conductivity decreases, as does the heat capacity, due to carrier scattering from defects.

1.2.7 Thermal Conductivity Measurement

Thermal conductivity is a crucial component of the relationship between materials, and the ability to understand it enables us to achieve the best performance out of the materials that we use in all aspects of our lives. Effective thermal conductivity testing and measurement are critical to this endeavour.

Thermal conductivity testing methods can be classified as either steady-state or transient. This delineation is a defining characteristic of how each method works. Steady-state methods require that the sample and reference pieces be at thermal equilibrium before measurements begin.Transient methods do not require this rule to be fulfilled and therefore provide results more quickly.There are several ways to measure thermal conductivity; each is suitable for a limited range of materials. Broadly speaking, there are two categories of measurement techniques: steady-state and transient.

Steady-state techniques infer the thermal conductivity from measurements on the state of a material once a steady-state temperature profile has been reached, whereas transient techniques operate on the instantaneous state of a system during the approach to steady state. Lacking an explicit time component, steady-state techniques do not require complicated signal analysis (steady state implies constant signals). The disadvantage is that a well-engineered experimental setup is usually needed, and the time required to reach steady state precludes rapid measurement.

In comparison with solid materials, the thermal properties of fluids are more difficult to study experimentally. This is because in addition to thermal conduction, convective and radiative energy transport are usually present unless measures are taken to limit these processes. The formation of an insulating boundary layer can also result in an apparent reduction in the thermal conductivity.

1.2.7.1 Steady State Techniques

These methods involve measurements where the temperature of the material in question does not change over some time.

An advantage of these techniques is that the analysis is relatively straightforward since the temperature is constant.

An important disadvantage of steady-state techniques is that they generally require a very well-engineered set up to perform the experiments.

Examples of these techniques are the Searle’s bar method for measuring the thermal conductivity of a good conductor and Lee’s disc method.

1.2.7.2 Transient Techniques

In these methods, the measurements are taken during the heating-up process.

An important advantage of these methods is that the measurements can be taken relatively fast.

One of the disadvantages of transient techniques is the difficulty in mathematically analyzing the data from the measurements.

Some examples of these techniques include the transient plane source method, the transient line source method, and the laser flash method.

Thus, there exist various methods of measuring the thermal conductivity of materials, each with its advantages and disadvantages.

Thermal conduction is a very important and a major topic in the study of heat transfer. Conduction is the transfer of energy from the energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles.

Conduction can take place in solids, liquids, or gases. In gases and liquids, conduction is due to the collision and diffusion of the molecules during their random motion. The rate of heat conduction is proportional to the area and the temperature difference, and inversely proportional to the thickness of the material. The constant of proportionality is the thermal conductivity. thermal conductivity, k, of a material is defined as the rate of heat transfer through a unit thickness of the material per unit area per unit temperature difference. it is a measure of how fast heat will flow in the material.

A large value for thermal conductivity indicates that the material is a good conductor, and a low value indicates that the material is a poor conductor or a good insulator.

The thermal conductivities of materials vary with temperature. This variation, for some materials over certain temperature ranges, is small enough to be neglected; but for many cases, such as liquids and gases, the variation of the thermal conductivity with temperature is significant.

CHAPTER 2

2 LITERATURE SURVEY

Literature review provides help for the present study. It works as helping hand to conduct the analysis. This chapter will play a part to get the information about fabrication of apparatus for measurement of thermal conductivity of liquids and will give idea to operate the test and form the early stage of the projects; various literature studies have been done. Research journals, books, printed or online conference article were the main sources of guidance and used as a supporting material in the project. Literature review section works as reference, to give information and guidance based on journal and other source in the media.

2.1 Measurements and calculations of thermal conductivity for liquid n-octane and n-decane.

Xiong Zheng[1]. The work explored about the hydrocarbons which plays an important role in lots of industrial processes. Thermal conductivity is an important thermophysical property of fluids in energy conversion process, such as the design of the heat transfer system and the evaluation of thermodynamic cycle. Thus, it is of great significance to acquire solid experimental data and develop reliable models for achieving accurate thermal conductivity of hydrocarbons. In this work, thermal conductivity of two common fuels, n-octane and n-decane, were studied by combining experimental and theoretical methods. Using the transient hot wire method, the thermal conductivity is measured with temperature ranging from 303 to 523 K and pressures ranging from 0.1 to 15 MPa. Excellent agreement is achieved by comparing our experimental results with literatures. Furthermore, the mechanism for the influence of temperature and pressure on thermal conductivity of liquid n-octane and n-decane was explored preliminarily based on Bridgman's theory.

2.2 Thermal conductivity measurements for organic liquids at high pressure.

Francisco Yebra [2]. The work explored about measurements of organic liquids at high pressures. A new instrument for determining the thermal conductivity as a function of temperature and pressure for liquids is described.The system is based on the transient hot-wire technique. It is automatized: pressure and temperature are controlled and voltage drop through the wire is acquired using a digital system, which automatically performs all required actions. The instrument calibration can be made using only one reference liquid over the whole temperature and pressure ranges.

2.3 Experimental research on the liquid thermal conductivity of mixtures of methyl caprate and ethyl caprate with n-undecane and n-tridecane.

Jing Fan [3]. The paper investigated about high-pressure thermal conductivity of three ethyl esters in the liquid phase.Recently, biodiesel is considered a biodegradable, renewable, and high-potential fuel that could be used directly in traditional internal combustion engines. Fuel transport properties in high pressure are required to model the process of fuel spray, atomization, and combustion accurately. In this work, three ethyl esters' liquid thermal conductivity (biodiesel compounds) in the liquid phase was measured by an experiment system that is established based on a transient hot-wire method with a bare platinum hot wire. The measurement was conducted at temperatures ranging from 292 K to 372k.

2.4 Asphaltenes as novel thermal conductivity enhancers for liquid paraffin: Insight from in silico modelling.

Sergey V.Larin [4] this paper investigated on asphaltenes as novel thermal conductivity for liquid paraffin. The practical use of paraffin and other organic phase-change materials for heat storage is largely limited by their low thermal conductivity.In this paper, we employed 60 microsecond-long atomic-scale computer simulations to explore for the first time whether the asphaltenes, natural polycyclic aromatic hydrocarbons, can be used as thermal conductivity enhancers for paraffin. We focused on a simple model molecule of asphaltene (a polycyclic aromatic core decorated with the peripheral alkane chains) and showed that the asphaltenes of such molecular architecture are not able to improve the thermal conductivity of paraffin.

2.5 Experimental Set-Up for The Measurement of The Thermal Conductivity of Liquids.

C.Codreanu[5] The paper describes a house-made experimental set-up that measures the thermal conductivity of liquids measurement principle is based on the Transient Hot-Wire Method.The theoretical bases of the measurement method are presented, and then our original experimental implementation is described. The hardware, as well as the software design, reveals the simple configuration of the measurement set-up that contains high-performance inexpensive components.It is also simple to use and well-suited for research laboratories, data is stored either in text or graphically.Finally, based on experimental results, the measurement accuracy and sensibility performances are discussed and compared with other instruments in the literature.

2.6 Effective thermal conductivity in thermoelectric materials

Eric S.Toberer[6] this paper discusses recent advances in materials engineering to control thermal conductivity. We begin by presenting theories of heat conduction for general material classes, focusing on common approximations and trends.Next, we discuss characterization techniques for measuring thermal conductivity and the underlying transport properties. Advanced materials at the frontiers of thermal transport, such as rattlers, complex unit cells, nanowires, and nanocomposites, are treated in depth using experimental data and theoretical predictions. The review closes by highlighting several promising areas for further development.Many electronic applications require high thermal conductivity materials to facilitate heat extraction. Excessive heating can lead to poor device performance and decreased lifetimes. Heat generation in electronics can arise from a variety of sources, including Joule heating, solar flux, and even exothermic reactions. Localized Joule heating is prevalent in high power density electronics such as integrated circuits, supercapacitors, LEDs, and lasers. As these devices move to the nanoscale, both the power density rises and the ability to extract heat decrease.A similar challenge is faced by nanostructured and concentrated solar cells, in which increased temperature reduces device efficiency due to dark current. A final example in which heat extraction is critical for performance is that of batteries, where Joule heating and exothermic reactions can lead to undesired chemical reactions and device failure. At the opposite extreme are materials that must minimize heat transfer.

2.7 Measuring Thermal Conductivity of Fluids Containing Oxide Nanoparticles.

S.Lee[7] this paper discusses about Oxide nanofluids were produced and their thermal conductivities were measured by a transient hot-wire method. The experimental results show that these nanofluids, containing a small amount of nanoparticles, have substantially higher thermal conductivities than the same liquids without nanoparticles. Comparisons between experiments and the Hamilton and Crosser model show that the model can predict the thermal conductivity of nanofluids containing large agglomerated Al_2O_3 particles. However, the model appears to be inadequate for nanofluids containing CuO particles. This suggests that not only particle shape but size is considered to be dominant in enhancing the thermal conductivity of nanofluids.

2.8 Studies of thermal conductivity of liquids.

Bryon C.Sakadia[8]this paper discusses The thermal conductivity of liquids is an important energy transport property the value, is required in the solution of most heat transfer correlations. The results of an extensive literature survey the published. data and methods of measurement reveal that, until recently, the available data were scanty and accuracy in considerable doubt.In recent years, considerable effort has been expended in the experimental determination of the thermal conductivity of various liquids, but little progress has been made towards developing an apparatus that yields results of high dependability. Therefore, a study of factors affecting the design of a thermo conduct apparatus for liquids was made, and a new apparatus, based on the results of this study, was developed and tested extensively. The main features of the apparatus are the Steady-state, horizontal, and parallel plane apparatus. Downward heating to eliminate convection effects. b. Variable thickness, to study the presence and effects of convection and radiation, as well as other effects.

Scope of the work from the literature:

From the above literature ,it is understood that various reaseachers considered various apparatus designs to determine the thermal conductivities of various liquids at different parameters.

Here,in this work the authors have fabricated an apparatus of particular suitable design to measure the thermal conductivities of various liquids at same heat input.Further the authors validated the obtained results using suitable fabricated apparatus for finding the accurate values of thermal conductivities of various liquids.

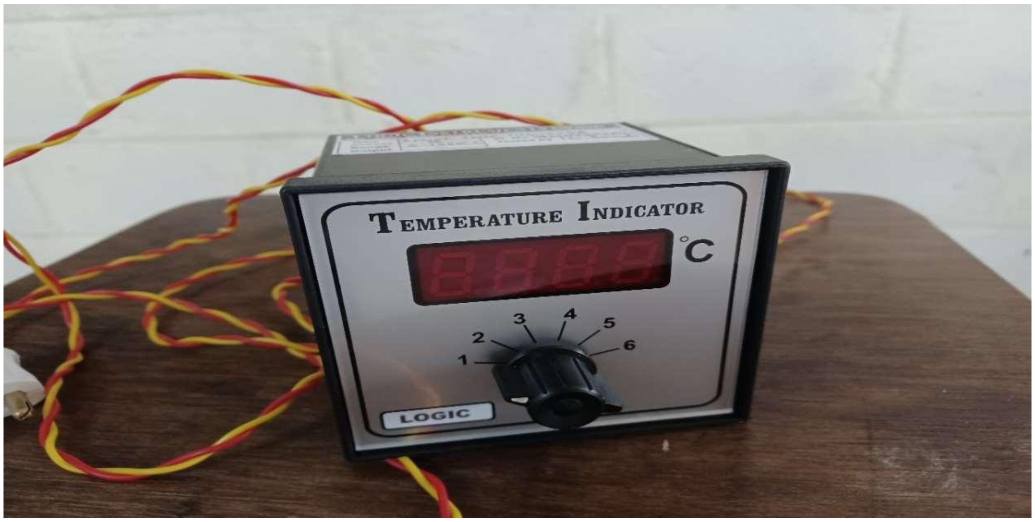
CHAPTER 3

3 EXPERIMENTATION

The experimental setup consists of the following components which are shown below.

Temperature Indicator

Figure 3.1 Six-Point Temperature Indicator



Specifications:

- 6 Point Temperature Indicator
- Range : 0-1000 Celsius
- Sensor Type : K

Features:

- Low Maintenance
- Easy to Operate
- Hassle free performance.

Uses:

It is designed for temperature monitoring and analysis.

Coil Heater

Figure 3.2 Coil Heater

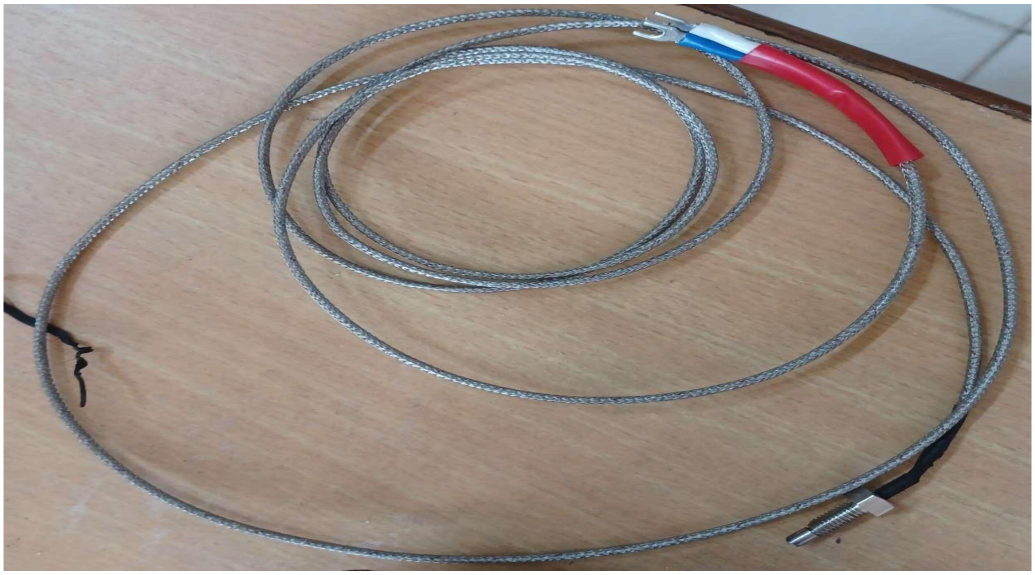
Specifications:

- Capacity: 100 Watts
- Material: Stainless Steel

A heater coil is a device used to heat water or air. Typically electric, the heater coil acts like a large resistor, and as the electric current flows through it, it begins to heat up.

K-Type Thermocouples

Figure 3.3 K-Type Thermocouples



Type K Thermocouple provides widest operating temperature range. It consist of positive leg which is non-magnetic and negative leg which is magnetic. In K Type Thermocouple traditional base metal is used due to which it can work at high temperature and can provide widest operating temperature range. One of the constituent metal in K Type Thermocouple is Nickel, which is magnetic in nature.In K Type Thermocouple positive leg is composed of 90% nickel, 10%chromium and a negative leg is composed of 95% nickel, 2% aluminium , 2% manganese and 1% silicon. One of the major advantage of K type thermocouple over other thermocouple's is it can function in rugged environmental condition & in various atmospheres. Also known as general purpose thermocouple due to its wide range of temperature. They are inexpensive.Have a fast response and small in size and are reliable.

Circular Brass Plates

Figure 3.4 Brass Plates

The above figure depicts about brass plates having thickness of 2mm and in this project we are taking two brass plates .These two brass plates were kept in between coil heater and cylindrical closed chamber.The main purpose of this brass plate is to absorb the some part of heat coming from the coil heater .As a result the whole equipment can't be get damaged due to heat coming from heater and so that equipment works in efficient way. The main reason that we are using brass plate is it is having higher thermal conductivity .

Cylindrical Closed Chamber

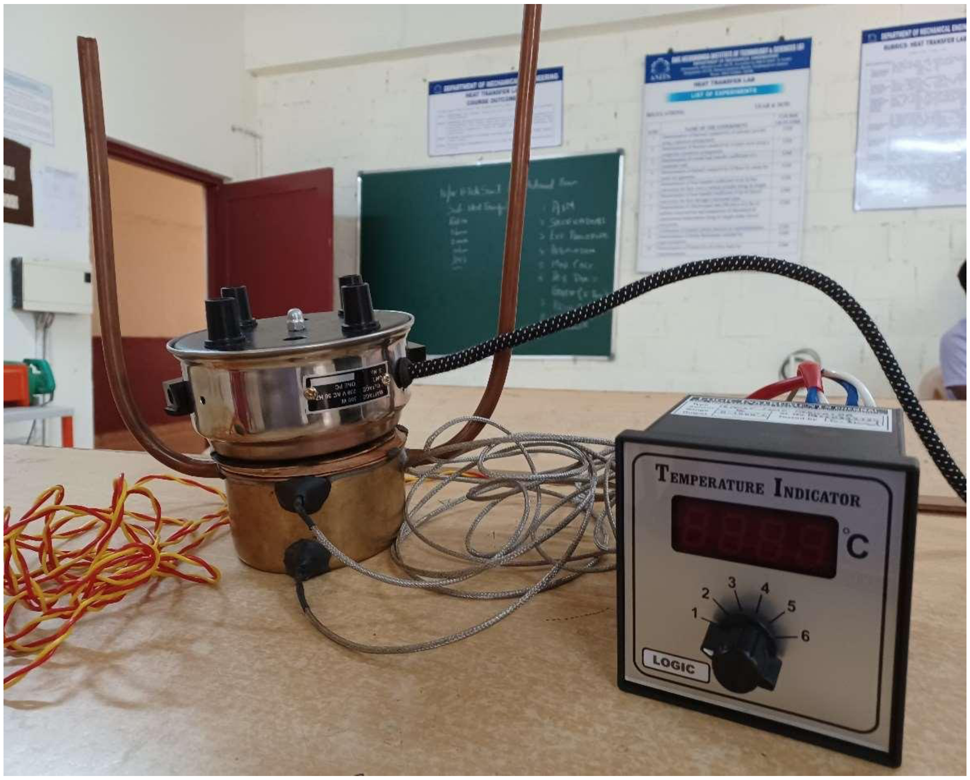
Figure 3.5 Cylindrical Closed Chamber

Specifications:

- Cylindrical Tank Capacity : 460ml
- Material : Copper

In this work, a cylindrical chamber is filled with test sample, distilled water in this case. A coil heater is fitted on the top of the cylinder and K-type thermocouples are fitted at their respective positions as shown in the figure are at top and bottom of closed cylindrical chamber to measure the temperatures at different locations. Constant heat flux is supplied radially inward, towards the center and natural conduction phenomenon is carried out to find out the heat loss to air and it also consists of outlet and inlet pipes.Through the inlet pipe water or any other liquid is entered into cylindrical chamber.

Figure 3.6 Thermal Conductivity of Liquid Apparatus



The above figure depicts the complete arrangement of thermal conductivity of liquids apparatus set up.

Cylindrical closed chamber is made with a copper sheet of thickness 1.5mm as shown in above figure. Fix a two brass plates on the top of the cylinder. Attach thermocouples top and bottom of the cylinder and connect them to the temperature indicator. Arrange the 100W heater on the top of the cylindrical closed chamber. Cover the whole setup with insulating material like foam. Prepare a wooden casing for the whole setup and enclosed in it.

The heating unit consists of coil heater with an electrically power supply system. Heat was allowed to flow into the vertical cylinder to create a temperature gradient along the test sample.

A Copper cylindrical closed chamber of 110mm diameter was used to hold the test sample. The cylindrical chamber was equally insulated with foam from sides and top to reduce the heat loss.

Two K-type thermocouples were embedded into the cylinder internally at two equal locations, one which is at the top of cylindrical closed chamber and another at the bottom.

The cylinder was filled with distilled water or any other liquid heated by passing heat through coil heater. The temperatures were seemed to be at steady state after one hour but the data was recorded for more than two hour. The temperature are noted down at respective positions by using K-type thermocouples. The experiments were performed at different heat inputs and temperatures of water and other liquids were noted down with above procedure.

So when we switch on the heater the heat will flow from the top of the cylinder. So the upper portion of liquid particles is heated first and the dentity of that particle of these liquid particles will decrease and remain float at the same position.

Because we know that density is inversely proportional to the temperature of fluid particles. So therefore the density of hot liquid particles is low whereas the density of cold liquid particles is high.

As the hot liquid particles remain floating at the same position, we can achieve conduction by eliminating convection to a greater extent.

Therefore, in this design of the apparatus where the circular coil heater is located at top of the cylindrical chamber, we can achieve better thermal conduction through any liquid, and also we can obtain a better value of thermal conductivity of any liquid when compared to a design containing circular constant heater at bottom of the cylindrical chamber.

Experimental Procedure

- Arrange the experimental setup as shown in the above figure and make necessary connections such as connect the two K-type thermocouples at the top and bottom of cylindrical chamber and connect the other ends of thermocouples to the temperature indicator. And also the cylindrical chamber is completely insulated with foam.

- Now through the inlet pipe, water or any other liquid will be entered into the cylindrical chamber.

- Switch on the electrical supply.

- Now let the heat input of about 26watts is given to cylindrical chamber containing liquid from coil heater.

- After waiting for 2-3 minutes, the cylindrical chamber will get heated up without any radiation loses to surroundings.

- Now note down the temperature readings of at top and bottom positions of cylindrical chamber as T1,T2 .These T1,T2 temperatures are obtained by selecting 1 & 2 positions by using temperature selector switch on 6-Temperature indicator.

- Now repeat the above procedure with different liquids at various heat inputs such as 55 watts, 26 watts, etc.

Table 2.1 Experimental results of various liquids

Liquid	Heat Input(Watts)	Temperature at top layer of liquid(T1) (Kelvin)	Temperature at bottom layer of liquid(T2)(Kelvin)	Change in Temperature (dT)(Kelvin)
Water	26	873	696	177
Castor Oil	26	915	380	535
Engine Oil	26	1273	483	790
Diesel Oil	26	1373	473	900

CHAPTER 4

4 CALCULATIONS

The calculations of thermal conductivities of various liquids at same heat input are determined as follows:

Basic Data

DIAMETER OF CYLINDRICAL COPPER TANK (d) = 0.11m
THICKNESS OF CYLINDRICAL COPPER TANK (dX) = 0.045m
TEMPERATURE AT TOP LAYER OF LIQUID=T1 (IN KELVIN)
TEMPERATURE AT TOP LAYER OF LIQUID=T2 (IN KELVIN)
CROSS-SECTIONAL AREA OF CYLINDRICAL CHAMBER (A) = (3.14*d*d) / 4

= (3.14*0.11*0.11) /4
A=0.0094985 meter square.

Model Calculations for Water:

HEAT INPUT (Q) =26W
CHANGE IN TEMPERATURE (dT) =T1-T2 = (600+273)-(423+273)= 177 Kelvin
dT = 177 Kelvin
THERMAL CONDUCTIVITY (k) = (Q*dX) / (A*dT)
k= (26*0.045) / (0.0094985*177)

k=0.695 watt/ (meter-Kelvin)

THERMAL CONDUCTIVITY OF WATER (k) = 0.695 watt / (meter-Kelvin)

Model Calculations for Castor Oil:

HEAT INPUT (Q) =26W

CHANGE IN TEMPERATURE (dT) =T1-T2= (642+273)-(107+273)=535 Kelvin

dT =535 Kelvin

THERMAL CONDUCTIVITY (k) = (Q*dX) / (A*dT)

k= (26*0.045) / (0.0094985*535)

k=0.230 watt/ (meter-Kelvin)

THERMAL CONDUCTIVITY OF CASTOR OIL (k) = 0.230 watt / (meter-Kelvin)

Model Calculations for Engine Oil:

HEAT INPUT (Q) =26W

CHANGE IN TEMPERATURE (dT) =T1-T2= (1000+273)-(210+273)=790 Kelvin

dT =790 Kelvin

THERMAL CONDUCTIVITY (k) = (Q*dX) / (A*dT)

k= (26*0.045) / (0.0094985*790)

k=0.160 watt/ (meter-Kelvin)

THERMAL CONDUCTIVITY OF CASTOR OIL (k) = 0.160 watt / (meter-Kelvin)

Model Calculations for Diesel Oil:

HEAT INPUT (Q) =26W

CHANGE IN TEMPERATURE (dT) =T1-T2= (1100+273)-(200+273)=900 Kelvin

dT =900 Kelvin

THERMAL CONDUCTIVITY (k) = (Q*dX) / (A*dT)

k= (26*0.045) / (0.0094985*900)

k=0.145 watt/ (meter-Kelvin)

THERMAL CONDUCTIVITY OF CASTOR OIL (k) = 0.145 watt / (meter-Kelvin)

CHAPTER 5

5 RESULTS AND DISCUSSIONS

By conducting number of experiments on various liquids at different heat inputs with the help of fabricated apparatus for measuring of thermal conductivity of liquids, we have got the final values for thermal conductivities of various liquids and these values are tabulated which are shown below.

Table 5.1 Experimental results of various liquids

Liquid	Heater Input(Watt)	Temperature at top layer of liquid(T1) (Kelvin)	Temperature at bottom layer of liquid(T2) (Kelvin)	Change in Temperature (dT)(Kelvin)	Thermal Conductivity (k) (watt/meter kelvin)
Water	26	873	696	177	0.695
Castor Oil	26	915	380	535	0.230
Engine Oil	26	1273	483	790	0.160
Diesel Oil	26	1373	473	900	0.145

CHAPTER 6

6 CONCLUSION

The fabrication of apparatus for calibration of thermal conductivity of liquids is done by undergraduate mechanical engineering students so that with help of this fabricated apparatus we can calculate thermal conductivities of various liquids at different heat inputs which is presented in this article and includes the procedures and relevant calculations.

In this experiment, students perform the calibration of the experimental apparatus and then employ the apparatus to determine the thermal conductivity of a liquid . This kind of experience serves to enhance the level of understanding of the transfer of thermal energy by undergraduate mechanical engineering students, while also exposing them to several important concepts involved in heat transfer.

CHAPTER 7

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