CHAPTER – 3

PREPARATION AND ESTIMATION OF NANOFLUID PROPERTIES

3.1 INTRODUCTION

The idea behind development of nanofluids is to use them as thermo fluids in heat exchangers for enhancement of heat transfer coefficient and thus to minimize the size of heat transfer equipments. Nanofluids help in conserving heat energy and heat exchanger material. The important parameters which influence the heat transfer characteristics of nanofluids are its properties which include thermal conductivity, viscosity, specific heat and density. The thermo physical properties of nanofluids also depend on operating temperature of nanofluids. Hence, the accurate measurement of temperature dependent properties of nanofluids is essential. Thermo physical properties of nanofluids are pre requisites for estimation of heat transfer coefficient and the Nusselt number.

Lee et al (1998), Das et al. (2000), Xuan and Roetzel (2003), and Choi et al. (2003) have investigated on properties of nanofluids containing metals and metal oxides nanoparticles. They have studied the parameters which influence nanofluid properties.

3.2 ESTIMATION OF NANOPARTICLE VOLUME CONCENTRATION

The amount of CuO nanoparticles required for preparation of nanofluids is calculated using the law of mixture formula. A sensitive
balance with a 0.1mg resolution is used to weigh the CuO nanoparticles very accurately. The weight of the nanoparticles required for preparation of 100 ml CuO nanofluid of a particular volume concentration, using water-propylene glycol base fluid is calculated by using the following relation

\[
\% \text{ volume concentration} = \frac{\frac{W_{\text{CuO}}}{\rho_{\text{CuO}}}}{\frac{W_{\text{CuO}}}{\rho_{\text{CuO}}} + \frac{W_{\text{bf}}}{\rho_{\text{bf}}}} = \frac{W_{\text{CuO}}}{6300} + \frac{100}{1036}
\]  \hspace{1cm} (3.1)

The amount of CuO nanoparticles required to prepare nanofluids of different percentage volume concentration in a 100 ml of base fluid is summarized in the Table 3.1 shown below.

Table: 3.1 Volume concentrations of CuO nanoparticle with corresponding weight

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Volume concentration, (\varphi) (%)</th>
<th>Weight of nanoparticles (W_{\text{CuO}}), Grams</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td>0.60872</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>1.21865</td>
</tr>
<tr>
<td>3</td>
<td>0.3</td>
<td>1.82981</td>
</tr>
<tr>
<td>4</td>
<td>0.4</td>
<td>2.44220</td>
</tr>
<tr>
<td>5</td>
<td>0.5</td>
<td>3.05582</td>
</tr>
<tr>
<td>6</td>
<td>0.6</td>
<td>3.6706</td>
</tr>
<tr>
<td>7</td>
<td>0.7</td>
<td>4.28676</td>
</tr>
<tr>
<td>8</td>
<td>0.8</td>
<td>4.90409</td>
</tr>
</tbody>
</table>
3.3 NANOFLUID PREPARATION USING CuO NANOPARTICLES

The CuO nano particles having an average size of 50 nm and density of 6.3 gm/cm³ is procured from a USA based company (Sigma-Aldrich Chemicals Private Ltd) and is used for investigation in the present experimental work. The photographic view of the nanoparticles as seen by the naked eyes is shown in the plate.3.1.

Plate: 3.1 Photographic view of CuO nanoparticles

The distribution of CuO nanoparticles at nano scale can be observed under a Scanning electron microscope (SEM). The SEM images of CuO nanoparticles at 1 μm magnifications is shown in Plate.3.2(a) and SEM image of CuO nanoparticle on a 500 nm scale is shown in Plate.3.2(b). Preparation of nanofluids is an important stage
and nanofluids are prepared in a systematic and careful manner. A stable nanofluid with uniform particle dispersion is required and the same is used for measuring the thermo physical properties of nanofluids.

![Images of CuO nanoparticles](Plate: 3.2(a) Plate: 3.2(b))

SEM images of CuO nanoparticles on 1 μm and 500 nm scales

In the present work, water-Propylene glycol mixture (70:30 by volume) is taken as the base fluid for preparation CuO nanofluids. Basically three different methods are available for preparation of stable nanofluids and are listed below.

### 3.3.1 By mixing of nano powder in the base liquid

In this method, the nanoparticles are directly mixed in the base liquid and thoroughly stirred. Nanofluids prepared in this method give poor suspension stability, because the nanoparticles settle down due to gravity, after a few minutes of nanofluid preparation. The time
of particle settlement depends on the type of nanoparticles used, density and viscosity properties of the host fluids.

3.3.2: By acid treatment of base fluids

The PH value of the base fluid can be lowered by adding a suitable acid to it. A stable Nanofluid with uniform particle dispersion can be prepared by mixing nanoparticles in an acid treated base fluid. But acid treated nanofluids may cause corrosion on the pipe wall material with prolonged usage of nanofluids. Hence acid treated base fluids are not preferred for preparation of Nanofluids even though formation of stable nanofluids is possible with such base fluids.

3.3.3: By adding surfactants to the base fluid

In this method a small amount of suitable surfactant, generally one tenth of mass of nanoparticles, is added to the base fluid and stirred continuously for few hours. Nanofluids prepared using surfactants will give a stable suspension with uniform particle dispersion in the host liquid. The nanoparticles remain in suspension state for a long time without settling down at the bottom of the container.

After estimating the amount of nanoparticles required for preparation of CuO Nanofluid for a given volume concentration using Eq. (3.1), nanoparticles are mixed in the base fluid of water-Propylene glycol mixture. In the present investigation, neither surfactants nor acid are added in the CuO nanofluids, because with the addition of
surfactants the thermo physical properties of nanofluids are affected. Addition of acid may damage the tube material because corrosion takes place after a few days with the prolonged usage of such nanofluids in practical applications.

Copper oxide nanofluids of five different volume concentrations in range of 0.025, 0.1, 0.4, 0.8, and 1.25 % are prepared for measuring the temperature dependent thermal conductivity and viscosity of all the nanofluids concentration considered in the present work. Normally agglomeration of nanoparticles takes place when nanoparticles are suspended in the base fluid. All the test samples of CuO nanofluids used subsequently for estimation of their properties were subjected to magnetic stirring process followed by ultrasonic vibration for about 5 hours. The photographic view of CuO nanofluid sonication process using a Ultrasonic Cleaner is shown in the Plate.3.3.

Plate.3.3. Ultrasonic Cleaner apparatus for sonication process of CuO Nanofluids
The CuO nanofluids samples thus prepared are kept for observation and no particle settlement was observed at the bottom of the flask containing CuO nanofluids even after four hours. The photographic view of CuO nanofluid suspension prepared after magnetic stirring and sonication process is as shown in Plate.3.4. In

![CuO Nanofluid Suspension](image)

Plate.3.4 Water-Propylene glycol (70%-30% by volume)/ CuO Sample nanofluid

the present experiments with CuO nanofluids, the time taken to complete the experiment for property estimation is less than the time required for first sedimentation to take place and hence surfactants are not mixed in the CuO nanofluids. The CuO nanofluids prepared are assumed to be an isentropic, Newtonian in behavior and their
thermo physical properties are uniform and constant with time all through the fluid sample.

3.4 DETERMINATION OF CuO NANOFLUID PROPERTIES

The most important properties needed for estimation of convective heat transfer coefficient of nanofluids are its density; thermal conductivity, viscosity, and specific heat. The thermo- properties properties of CuO nanofluids are estimated experimentally for all the concentrations and the results obtained in the experiments are compared with the theoretical equations which predict Nanofluid properties.

3.4.1 Density of CuO nanofluids

The base fluid consists of water- Propylene glycol blend. The density of CuO nanofluids for all the volume concentrations under investigation are measured by using Hygrometer and the density data obtained is compared with the values obtained using the density correlation equation (Eq.3.2) developed by Pak and Cho [1998] for nanofluids, which is stated as follows

\[
\rho_{nf} = \phi \rho_p + (1 - \phi) \rho_{bf}
\]  

(3.2)

Where

\( \rho_{nf} \)  Density of CuO Nanofluids, kg/m^3

\( \phi \)  CuO nanoparticle volume concentration,
\( \rho_p \) Density of CuO nanoparticles, kg/m\(^3\)

\( \rho_{bf} \) Density of the base fluid, kg/m\(^3\)

The density data for water-propylene glycol (70:30 by volume percent) blend as a function of temperature is taken from ASHRAE (2009) Hand Book. The density of base fluid and density of CuO Nanofluids for different volume fractions are calculated using the density correlations available for nanofluids and the values are presented in the table 3.2. The error between experimental results and the results obtained from the Eq. (3.2) shows that the correlations results are very close to the experimental results. Hence the same Eq. (3.2) is used in the rest of the work to calculate the density.

Table: 3.2 Comparison of density of CuO nanofluid

<table>
<thead>
<tr>
<th>S.No</th>
<th>% Volume fraction, (( \varphi ))</th>
<th>Experimental density, (( \rho ))kg/m(^3)</th>
<th>Pak and Cho Density correlation(1998)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.025</td>
<td>1025.21</td>
<td>1024.96</td>
</tr>
<tr>
<td>2</td>
<td>0.1</td>
<td>1029.96.</td>
<td>1028.93</td>
</tr>
<tr>
<td>3</td>
<td>0.2</td>
<td>1036.28</td>
<td>1034.21</td>
</tr>
<tr>
<td>4</td>
<td>0.3</td>
<td>1042.6</td>
<td>1039.5</td>
</tr>
<tr>
<td>5</td>
<td>0.4</td>
<td>1048.98</td>
<td>1044.79</td>
</tr>
<tr>
<td>6</td>
<td>0.5</td>
<td>1055.3</td>
<td>1050.08</td>
</tr>
<tr>
<td>7</td>
<td>0.6</td>
<td>1061.62</td>
<td>1055.36</td>
</tr>
<tr>
<td>8</td>
<td>0.7</td>
<td>1067.94</td>
<td>1060.65</td>
</tr>
<tr>
<td>9</td>
<td>0.8</td>
<td>1074.53</td>
<td>1065.93</td>
</tr>
</tbody>
</table>
3.4.2 Specific heat of CuO nanofluids

The specific heat is one of the important properties and plays an important role in influencing heat transfer rate of nanofluids. Specific heat is the amount of heat required to raise the temperature of one gram of nanofluids by one degree centigrade. For a given volume concentration of nanoparticles in the base liquid, the specific heat can be calculated using the mixture formula. This formula is valid for homogeneous mixtures and is given by the Eq. (3.3).

$$C_{p,nf} = \frac{(1-\phi)\left(\rho C_p\right)_{bf} + \phi\left(\rho C_p\right)_{p}}{(1-\phi)\rho_{bf} + \phi\rho_p}$$ \hspace{1cm} (3.3)

The specific heat of CuO Nanofluids at different temperatures are estimated for all the volume concentrations considered in the present work, using the Eq. (3.4) of Pak and Cho (1998).

$$C_{p,nf} = \phi C_p + (1-\phi)C_{bf}$$ \hspace{1cm} (3.4)

In the present work the specific heat property of the base fluid is taken from the ASHRAE hand book (2009). Variation of specific heat of CuO Nanofluids with nanofluid temperature for all the CuO particle volume concentrations is shown in Fig. 3.1 and compared with the specific heat correlation considering the specific heat properties of the base from. The specific heat of CuO nanofluids decreases with increase in the volume concentration of nanofluids. Specific heat of nanofluids also increases with increase in the nanofluid temperature and the same can be observed from Fig. 3.1.
3.4.3 Thermal conductivity of CuO nanofluids

The nanofluids possess unique features with regard to their thermal performances. The properties of nanofluids are different from the properties of conventional heat transfer fluids. The nanoparticles offer large total surface area as a result of which higher thermal conductivities are expected in nanofluids. Many research findings
reveal that traditional thermo fluids in the presence of nanoparticles exhibit better thermo physical properties.  

The experimental studies on nanofluids confirm that fluids containing nanoparticles are expected to give more thermal conductivity and lower specific heats over conventional fluids. Normally particles of millimeter or micro meter dimension when suspended in fluids will cause erosion of pipe materials, clogging of flow passages and sedimentation due to gravity. Studies on effective thermal conductivities of Nanofluid were investigated under macroscopically in stationery conditions by S.U.S. Choi (1995), Masuda et al. (1993), Eastman et al. (1996), Wang et al. (1999), Lee et al. (1999) Xuan and Li (2000), Eastman et al. (2001), Keblinski et al. (2002), Xie et al (2002), Wang et al. (2003).  

Ahuja (1975) and Liu et al. (1988) carried out investigations on practical implication of hydrodynamics and heat transfer of slurries. The present day modern technology facilitates to produce process and characterize materials having average crystalline size below 100nm. Nanofluids were engineered in Argonne National Laboratory and proof test were conducted by Eastman et al (1995). The nanoparticles of Al₂O₃ and CuO materials have exhibited excellent dispersion quality and increased thermal conductivity when suspended in heat transfer fluids like water, oils and glycols mixtures. Brownian motion of the particles and large surface area are supposed to be the responsible factors for enhanced thermal conductivity of nanofluids. A detailed
measurement of thermal conductivity of $\text{Al}_2\text{O}_3$ and CuO particles dispersed in ethylene glycol and water base fluids was taken up by Lee et al. (1999). The thermal conductivity of nanofluids is measured using transient hot wire method. A considerable improvement in thermal conductivities of the nanofluids was noticed and researchers are motivated to undertake investigations on thermal conductivity studies on different nanofluids. Recent study by Xuan and Li (2000) revealed that particles as large as 100nm can also produce a stable fluid with the addition of small amount of laurite salt in the base fluids. But it was also observed in experimental studies that these dispersant affect the desirable properties of nanofluids.

Maxwell (1881) developed a classical theory of thermal conductivity with spherical particles and Hamilton and Crosser (1962) modified Maxwell’s theory applied to liquid suspensions comprising non spherical particles. Lee et al. (2008) later confirmed that the Hamilton and Crosser models are suitable to predict the properties of $\text{Al}_2\text{O}_3$/water or ethylene glycol nanofluids. Copper nanoparticles in water has shown enhancement of thermal conductivity, as reported by Xuan, Y and Li (2004). Eastman et al. (2001) brought out surprising results that nanoparticles less than 10 nm in size can result in about 40% enhancement in the thermal conductivity of a 0.3% volume concentration. The abnormal increase in the effective thermal conductivity of solid-liquid with micro particles was not explained by Maxwell’s and Crosser’s thermal conductivity models. Their thermal
conductivity model did not take into account the surface to volume ratio of particles. Surface to volume ratio for nanoparticles is very high and this ratio increases with decrease in nanoparticle size. Probably this could be one of the reasons for rise in the thermal conductivity of nanofluids.

In all the investigations mentioned above either water or ethylene glycol was used as base fluid and thermal conductivity of nanofluids is measured at room temperatures only. Das et al. (2003) have reported a four fold enhancement in the thermal conductivity of CuO nanofluid. They have measured thermal conductivity of CuO nanofluids, in the temperature range from 21°C to 51°C. Thermal conductivity of propylene glycol-water base fluid was measured by Tongfan Sun et al. (2004) at different temperature for different mole fraction of propylene glycol.

Based on the literature review, the scholar felt that, no previous work is reported on the properties of Copper oxide nanofluids using Propylene glycol as the base fluid. Propylene glycol is chemically more stable, non-toxic and gives a stable suspension when dispersed in the base fluids. In the present experimental work copper oxide nanoparticles are thoroughly mixed in the water-propylene glycol base fluid, then sonicated and a stable fluid is prepared. The effects of parameters like nanoparticle volume concentration and nanofluid temperature on the thermal conductivity of copper oxide nanofluids are studied in the present work.
3.4.4 Thermal conductivity models

Several classical models proposed by Maxwell (1881), Hamilton and Crosser (1962), Wasp (Wasp), Bruggeman (2009), are available in the literature to predict the effective thermal conductivities of Liquid-solid suspension. The Maxwell developed a model to predict the effective thermal conductivity of solid-liquid suspension for low volume concentration of spherical microparticles suspensions. Thermal conductivity studies taken up on nanofluids by different research groups have reported a considerable enhancement in the thermal conductivity over the base fluids. Later other thermal conductivity models for prediction of effective thermal conductivities of nanofluids were developed by Wang et al. (1999), Xuan et al. (2003), Choi et al. (2001). Some of the models used to predict effective thermal conductivity of fluids with fine particle suspensions are listed below.

Maxwell-Eucken (Maxwell 1892) model (Mamut, 2006)

\[
k_{nf} = k_{bf} \left\{ \frac{[(1+2\phi(1-(k_{bf} / k_{CuO}))/((2(k_{bf} / k_{CuO}) + 1))] \cdot [(1-\phi(1-(K_{bf} / k_{CuO}))/((K_{bf} / k_{CuO}) + 1))] \cdot [k_{CuO} + 2k_{bf} - 2\phi(k_{bf} - k_{CuO})]} \cdot [k_{CuO} + 2k_{bf} + 2k_{CuO}(k_{bf} - k_{CuO})] \right\}
\]  

(3.5)

Wasp (1977) model (Eastman et al. 2004)

\[
k_{nf} = k_{bf} \left\{ \frac{[k_{CuO} + 2k_{bf} - 2\phi(k_{bf} - k_{CuO})]}{[k_{CuO} + 2k_{bf} + 2k_{CuO}(k_{bf} - k_{CuO})]} \right\}
\]  

(3.6)

Hamilton and Crasser (1962) presented a model for liquid-solid mixtures when the ratio of conductivity is more than 100 and is given by the flowing relation
\[ k_{nf} = k_{bf} \left[ \frac{k_{CuO} + (n-1)k_{bf} - \phi(n-1)(k_{bf} - k_{CuO})}{k_{CuO} + (n-1)k_{bf} + \phi(k_{bf} - k_{CuO})} \right] \]  

(3.7)

And \( n = 3/\phi \)

Where \( n \) is the shape factor and \( \phi \) is sphericity which is equal to surface area of a sphere with a volume equal to that of the average particle/surface area of the average particle

Bruggeman (Hui et al.) model which is valid for spherical particles and considered interaction between particles

\[ k_{nf} = \frac{1}{4} \left[ (3\phi - 1)k_{CuO} + (2 - 3\phi) - k_{bf} \right] + \frac{k_{bf}}{4} \sqrt{\Delta} \]  

(3.8)

Where \( \Delta = [(3\phi - 1)^2(k_{CuO}/k_{bf})^2 + (2 - 3\phi)^2 + 2(2 + 9\phi - 9\phi^2)(k_{CuO}/k_{bf})] \)

Where \( \phi \) is the particle volume concentration, \( k_{CuO} \) is the thermal conductivity of CuO nanoparticles and \( k_{bf} \) is thermal conductivity of the base fluid.

3.4.5 Experimental set up for thermal conductivity measurement

The experimental setup to measure the thermal conductivity of nanofluids is shown schematically in Fig. 3.2. The photographic view of the experimental set up is shown in the plate 3.3. Syam Sunder et al. (2008) measured the thermal conductivity of the aluminum oxide nanofluids. In the present work thermal conductivity of the CuO nanofluids is measured by using the thermal conductivity apparatus supplied by P A Hilton Ltd, England.
Fig: 3.2 Schematic diagram of thermal conductivity measuring experimental setup

Plate: 3.. Photographic view of thermal conductivity measuring apparatus
The experimental setup consists of test section which is cooled by continuous supply of cooling water at a rate of 3 liters/min. The test section is heated by DC power supply. The temperatures of the fluid in the test section are measured by the thermocouples placed in test fluid and inside surface of the test fluid chamber followed by a filter which is finally fed to the data acquisition system comprising of a card for logging the measured data. The data logger is in turn interfaced to the computer with proper software for online display that is required to assess the recording data. Since, in the present experiments the prime objective is to observe the effect of temperature on the enhancement of thermal conductivity, the control of temperature of the heater is controlled with the dimmer stat. The test

Fig: 3.3 Construction details of test Section
section is a flat cylindrical cell as shown in Fig.3.3. The plunger diameter is 39 mm and effective length of the plunger is 110 mm. Nominal radial clearances between plug and jacket (r) is 0.3 mm. Nominal resistance of heating element is 53.3Ω. Effective area of conducting path through the fluid is 0.0133 m². The voltmeter, variable transformer and digital temperature indicator are part of the console. The heater dimmer is having the flexibility to increase the voltage up to 220 V. All the electrical components are earthed and protected with circuit breakers as part of safety measures.

The fluid whose thermal conductivity is to be measured is filled in the small radial clearance between a heated plug and water cooled jacket. The clearance is small enough to prevent natural convection in the fluid and the fluid is presented as a lamina of face area and the thickness to the heat transfer of heat from the plug to the jacket. The plug is machined from aluminum and contains a cylindrical element whose resistance at the working temperature is accurately measured. A thermocouple is inserted in the plug close to its external surface and the plug also has ports for the introduction and venting of the fluid under test. The plug is held centrally in the water jacket by ‘O’ rings which seal the radial clearance. The jacket is constructed from brass and water inlet and drain connection and thermocouple is carefully fitted in the inner sleeve. A small console is connected by flexible cables to the plug/jacket assembly and provides for the control of the voltage supplied to the heating element. An analogue voltmeter enables the power to be determined and a digital temperature
indicator with 0.1 resolution display the temperature of the plug/jacket surfaces.

### 3.4.6 Calibration and operation

The incidental heat transfer in the test section unit is determined by using air in the radial space. Once calibrated the results may be carefully preserved and used subsequently. The CuO Nanofluid to be tested is then introduced into the radial space. Sufficient water is passed through the jacket and the heater is adjusted to give a reasonable temperature difference and heat transfer rate. After attaining steady state the rate of heat transfer and plug/jacket temperature may be observed. After deducting the incidental heat transfer at the given temperature difference it is known that the remainder is passing through the fluid lamina. The voltage and temperature are noted after ensuring steady state. The rate of heat transfer $Q$ through the air lamina is then calculated from

$$Q = \frac{K_{air} \pi d_m L \Delta t}{\Delta r}$$

(3.9)

### 3.4.7 Error estimation

The main source of experimental uncertainty in the measurement of thermal conductivity is the accuracy of thermocouples. Thermocouples of 0.1°C were used in the present experimental work. To make the measurements more accurate the experiment is first calibrated by measuring the thermal conductivities
of air and distilled water in the temperature range from 20°C to 65 °C. The maximum deviation of thermal conductivities from standard values is 2.5% over the temperature range considered.

3.5 RESULTS AND DISCUSSION

The thermal conductivity of the base fluid at different temperature is measured and the results obtained in the experiment were compared with the thermal conductivity data of water-Propylene glycol blend available in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) handbook (2009). The present experimental thermal conductivity values obtained for the base fluid matched very closely with the ASHRAE data as shown in Fig.3.4. This indicates accuracy and reliability of the experimental

![Image: Fig: 3.4 Comparison of thermal conductivity of water-Propylene glycol base fluid with ASHRAE Handbook data]
setup for carrying out thermal conductivity measurements for nanofluids. Thermal conductivity of base fluid was determined first before determining the thermal conductivity of CuO Nanofluids. Then five different CuO Nanofluids in percentage volume concentration of 0.025%, 0.1%, 0.4%, 0.8% and 1.2% were prepared and their thermal conductivities were measured.

The thermal conductivity of CuO nanofluids found to be increasing with the increase in the nanofluids temperature. Further thermal conductivity of nanofluids also enhanced with increase in the nanoparticle volume concentration in the base fluid as shown Fig.3.6. For a nanofluid of 0.1% Volume concentration the thermal conductivity is increased from 1.8 % at 25 °C to 15.97% at 65 °C, where as the enhancement in the thermal conductivity for a 1.2% CuO nanofluid is 10.9% at 25 °C and increased to 43.37% at 65 °C. The variation of CuO nanofluid thermal conductivity with temperature is shown in Fig.3.5. It can be inferred from the same results that the enhancement of thermal conductivity is more pronounced at higher temperatures when compared to the thermal conductivities of nanofluids at lower temperatures.

Thermal conductivity ratio is the ratio of nanofluids thermal conductivity to the base fluid thermal conductivity. The relationship between the thermal conductivity ratios and volume concentration of CuO Nanofluids is also studied in the present work and the results
are presented in the Fig. 3.6. It is observed that nanofluid temperature also plays an important role on the thermal conductivity enhancement of CuO Nanofluids.

Fig: 3.5 Variation of thermal conductivity of CuO nanofluids with temperatures for different volume concentrations

The experimental thermal conductivity results of CuO Nanofluids obtained in the experiment are compared with the three conductivity models viz by Maxwell, Wasp and Brugeman. The thermal conductivity of CuO nanofluids conducted by these three models is far less than the experimental thermal conductivity and the same can be observed from the Fig. 3.7. The probable parameters which promote
thermal conductivity enhancement are stochastic and Brownian motion of nanoparticles in the base fluid. The temperature is another factor which is responsible for particle random movements which in turn results in enhanced thermal conductivity. The thermal conductivity property is a surface phenomenon. The increase in the thermal conductivity of nanofluids can also be attributed to the large surface area of CuO nanoparticle. A more comprehensive theory needs to be developed to understand the mechanism behind the enhancement in the effective thermal conductivity of CuO nanofluids.

Fig: 3.6 Thermal conductivity ratio Vs CuO nanofluids volume concentration at different temperatures
3.6 VISCOSITY MEASUREMENT OF CUO NANOFLOUIDS

3.6.1. Introduction

Glycols are normally mixed in water in different proportions and used as heat transfer fluids in heat exchangers particularly in the cold climatic regions where sub zero temperature conditions prevail. It is essential to lower the aqueous freezing point of heat transfer fluids used in the automobile radiators and other heat exchangers in such regions. Pure glycols have high viscosity and lower freezing points over water. High viscous fluids need high power for pumping of fluid in a loop in heat exchangers. The Prandtl number and Nusselt number of heat transfer fluids also depend on the viscosity property of fluids.
Hence glycols are mixed in water to lower the viscosity of the fluid and at the same time maintaining the required sub zero temperature. Such water based glycols are used as heat transfer fluids when the ambient temperature is below zero degrees Celsius.

Experimental works on the absolute viscosity of various thermo fluids were undertaken by different authors and the results are available in literature. Hilding et al. (2003), studied viscosity and dispersion behavior of carbon nanotubes. Tseng et al. (2003) investigated on rheological properties of aqueous TiO$_2$ particle suspension. Tejpel et al. (2001) and W J Tseng et al. (2002) investigated on the viscosity properties of Al$_2$O$_3$ nanoparticles in paraffin oil and water respectively. Kwak et al. (2005) presented their findings on viscosity and thermal conductivity of copper oxide nanoparticles dispersed in ethylene glycol at room temperature. Das et al. (2003) and Putra et al. (2003) measured the viscosity of water based nanofluids containing Al$_2$O$_3$ and CuO nanoparticles and their findings revealed an increase in the viscosity of nanofluids with increase in the particle volume concentration. Kulkarni et al. (2006) in his experimental work on water based CuO nanofluids in the volume concentrations ranging from 5 to 15%. Namburu et al. (2008) have measured temperatures dependent rheological property of CuO/ethylene glycol Nanofluids and their experimental results shows an exponential decrease in the viscosity with rise in the temperature of the nanofluids.
3.6.2 Viscosity models

A few experimental works are reported on the viscosity of nanofluids and correlations were developed to predict the viscosity of nanofluids in terms of particle volume concentration and density of the base fluid. The following are some of the viscosity models developed by different researchers.

Einstein has developed a viscosity correlation (Drew and Passman-1999) given by Eq.(3.10) in terms of nanoparticle volume concentration in the base fluid, when the nanoparticle volume concentration is lower than 5%, and is given by

\[ \mu_{nf} = \mu_{bf} (1 + 2.5\phi) \]  

(3.10)

Brinkman (1952) presented the following viscosity correlation Equation pertaining to concentrated particle suspension and is given by Eq. (3.11)

\[ \mu_{nf} = \mu_{bf} \left( \frac{1}{(1 - \phi)^{2.5}} \right) \]  

(3.11)

Bachelor (1999) developed a regression equation (Eq.3.12) for viscosity of nanofluids as follows

\[ \mu_{nf} = \mu_{bf} (1 + 2.5\phi + 6.2\phi^2) \]  

(3.12)
3.7 EXPERIMENTAL SET UP AND PROCEEDURE

In the present work water-propylene glycol based CuO Nanofluids of 0.025%, 0.1%, 0.4%, 0.8%, and 1.25% volume concentrations were prepared to measure the absolute viscosity. The CuO nanofluids thus prepared are assumed to be an isentropic and their thermo physical properties are uniform and constant with time all through the fluid sample. The nanofluids are assumed to act as Newtonian fluids as the concentration of nanoparticles is low. A Newtonian fluid satisfies the equation (Eq.3.13) governing Newtonian behavior of fluids and is given by

$$\tau = \mu \dot{\gamma}$$  \hspace{1cm} (3.13)

The objective of the experiment is to study the effects of the temperature and the volume concentration of CuO nanofluid on its absolute viscosity. The experimental setup for measurement of viscosity of CuO nanofluids using water-propylene glycol blend as the base fluid is shown in Fig.3.8. It consists of a programmable Brookfield viscometer with temperature controlled bath. The viscometer is calibrated using the standard fluids. The spindle type and its speed combinations will produce results with accuracy when the applied torque is in the range of 10% to 100% and accordingly the spindle is chosen. Spindle CC45 DIN is used in the present case. The CuO nanofluid under test is poured in the sample chamber of the viscometer. The spindle immersed and rotated in the nanofluid in the speed ranging from 387 to 540 rpm in steps of 12 seconds.
Fig. 3.8 Schematic diagram of experimental setup for measuring CuO nanofluid dynamic viscosity

A temperature control system is activated to vary the temperature of the test sample. The viscous drag of the fluid against the spindle is measured by the deflection of the calibrated spring. The shear rate, shear strain and viscosity data at room temperature is recorded by a data logger. The viscosity of nanofluids of different volume concentrations under test also measured at different temperature by varying the temperature of methanol bath by activating temperature controls system. Viscosity measurements were started at 335 K and temperature was gradually reduced to 260 K. The viscometer is having accuracy within ±0.1% of the full scale range of the spindle /speed combination. The reproducibility of test data is found to be within ±0.2%. The photographic view of the Brookfield viscometer which is
Plate 3.5 Photographic view of Brook field viscometer apparatus used for measuring dynamic viscosity of CuO nanofluids is shown in Plate 3.5.

3.8 RESULTS AND DISCUSSION

To check the reliability of the experimental set up, viscosity of the base fluid was measured. The viscosity results of the base fluid obtained in the present work at different temperature are compared with the viscosity data in the ASHRAE hand book (2009). The present experimental viscosity matches very closely with the ASHRAE data of the base fluid and the results are shown in Fig. 3.9. This ensures the accuracy and reliability of the viscometer and the apparatus can be used to measure the viscosity of the CuO nanofluids.
After measuring the viscosity of the base fluid and confirming that the viscometer is generating correct reading, the viscosity of CuO nanofluids of all the concentrations under investigation is measured in the temperature ranging from -13 °C to 60 °C. The measured viscosity of the CuO nanofluids was observed to be decreasing exponentially with an increase in the nanofluid temperature and the same is represented in Fig. 3.10. The nanofluids with higher concentration of CuO nanoparticles exhibited more viscosity over the base fluid. It can be also observed from the results that the trend in the change of viscosity with temperature for all the
concentrations of CuO nanofluid is similar. The Fig. 3.11 shows the relationship between shear stress and shear rate of nanofluids and which are linearly proportional with each other indicating that the low

![Graph showing variation in viscosity of CuO nanofluids with temperature for different volume concentrations](image)

**Fig.3.10** Variation in the viscosity of CuO nanofluids with temperature for different volume concentrations

volume concentrated CuO nanofluids considered in the present experimental work have shown Newtonian behavior.

Relative viscosity is defined as the ratio of the absolute viscosity of the CuO nanofluids to the absolute viscosity of the base fluid. The Fig. 3.12 depicts that no variation in the viscosity ratios
with increase in the shear rates of CuO nanofluids was observed. The viscosity data of CuO nanofluids obtained in the experimental work are compared with various viscosity correlations as shown in Fig. 3.13 and observed that the experimental viscosity of CuO nanofluids are in closer agreement with the viscosity models. The experimental thermo physical properties of CuO nano fluids evaluated at different volume concentrations along with property values estimated by using different property models are shown in the table 3.3.

Fig.3.11 Shear stress and shear rate relations of CuO nanofluids for different volume concentrations
Fig. 3.12 Viscosity ratio Vs shear rate of CuO nanofluids for different Volume concentrations

Fig. 3.13 Comparison of viscosity of CuO Nanofluids with different viscosity model
### Table 3.3 Thermo-physical properties of CuO Nanofluids at different volume concentrations

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Volume fraction, ( \varphi ) in %</th>
<th>Thermal conductivity, W/m K</th>
<th>Density, Kg/m(^3)</th>
<th>Viscosity, Pa-s</th>
<th>Specific heat, J/Kg K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Present Data</td>
<td>Wasp [1977]</td>
<td>Present data</td>
<td>Pak and Cho [1998]</td>
<td>Present data ( \nu \times 10^6 )</td>
</tr>
<tr>
<td>1</td>
<td>0.025</td>
<td>0.3142</td>
<td>0.3120</td>
<td>1025.2</td>
<td>1024.9</td>
</tr>
<tr>
<td>2</td>
<td>0.1</td>
<td>0.3206</td>
<td>0.3161</td>
<td>1029.9</td>
<td>1028.9</td>
</tr>
<tr>
<td>5</td>
<td>0.4</td>
<td>0.3361</td>
<td>0.3276</td>
<td>1048.9</td>
<td>1044.7</td>
</tr>
<tr>
<td>8</td>
<td>0.8</td>
<td>0.3579</td>
<td>0.3434</td>
<td>1074.5</td>
<td>1065.9</td>
</tr>
<tr>
<td>8</td>
<td>1.2</td>
<td>0.3806</td>
<td>0.3597</td>
<td>1074.5</td>
<td>1065.9</td>
</tr>
</tbody>
</table>