EXPERIMENTAL STUDY OF THERMO-PHYSICAL PROPERTIES OF GRAPHENE WATER NANOFLUID BELOW BOILING TEMPERATURE

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ABSTRACT

In this paper thermo-physical properties of Graphene nanoparticles dispersed in water was presented. The graphene nanofluid was prepared by two step method. The thermo-physical properties such as thermal conductivity, surface tension and viscosity were studied using transient hot wire apparatus, tensiometer and viscometer respectively. The concentrations of the graphene nanoparticle in the base fluid was varied from 0.2% to 0.8% and the temperature varied from 30 to 80°C. The viscosity increased by 4.48 times the base fluid at the average concentration of 0.5% for graphene water nanofluid. But the surface tension decreases, with increase in concentration of nanoparticle with surfactant. At the particle concentration of 0.5% and temperature of 80°C the thermal conductivity has the maximum increase of 1.17 times the base fluid is observed for graphene water. This drastic increase in the thermal conductivity of nanofluid will have the great scope of application in electronic cooling.

Key words: Nanofluid, thermal conductivity, viscosity and surface tension.


1. INTRODUCTION

Nanofluids are dispersing a Nanometer sized particles (1-100nm) in a base heat transfer fluids. Nanofluids have novel properties that make them potentially useful in many heat transfer applications. Due to the increase in surface area to volume ratio and also solids have higher thermal conductivity than liquids, the thermal performance of nanofluids significantly improved. The nanofluids are prepared by two methods namely, one-step and two-step method. In the two-step method, nanoparticles are produced separately first and dispersed in the base fluid. In one-step method, the nanoparticles production and dispersion in a base fluid combines in a single step. Haddad et al., reviewed the nanofluids preparation methods. Making a stable homogeneous
nanofluid with long-term stability and insignificant agglomeration remains a challenge [1]. One of the property of nanofluid, such as viscosity are significantly affected by temperature, nanoparticle size, shape and volume fractions[2-3]. The relative viscosity of the nanofluids depends on volume percentage and decreases substantially with the temperature for higher concentrations[4]. Fluid viscosity plays an important role in the design of pumps or piping systems because a high viscosity liquid requires more power to pump than a low viscosity liquid. There is no theoretical correlation to predict the viscosity precisely with respect to the volume fractions[5-6]. Rudyak et al., examined the viscosity coefficient of SiO$_2$ particles of different nanometer size suspended in ethylene glycol base fluid. It is observed that the viscosity of nanofluids heavily depends on particle size; the smaller the particles, the higher the viscosity[7].

The next most attractive property of nanofluids is the enhancement of the thermal conductivity. Wang et al. studied the thermo-physical properties of ionic based nanofluids (Ionanofluids) without using surfactants[8]. Lee et al., introduced the new method to track the temporal changes of the particle volume fraction and size distribution, and the effects of the change of the nanofluid thermal conductivity are scrutinized[9].

The thermal conductivity of nanofluids depend on factors like volume fraction ($\phi$), nanoparticle size (d), morphology, additives, pH, temperature, nature of base fluid, nanoparticle material etc. Even small temperature gradients in the sample leads to large errors in thermal conductivity results. Novel strategies to produce stable nanofluids using cost effective techniques, adoption of response stimuli nanofluids, carbon nanotubes and graphene for miniature cooling applications will have to be developed[10].

Thermal conductivity behavior of nanofluids has features that cannot be explained by the classical effective medium theories alone. They are inherently unable to predict the size and temperature dependent thermal conductivity of nanofluids. New models based on a combination of static and dynamic mechanisms appear to predict not only the magnitude of the enhanced thermal conductivity, but also other features of the thermal conduction behavior of nanofluids. Brownian motion induced nano convection is the key mechanism to explain the temperature and size dependent thermal conductivity of nanofluids. The inconsistency in the reported thermal conductivity is due to difference in sample quantity, differences in measurement uncertainties. The sample should be produced with high-quality having suspension stability, without any dispersants or stabilizer[11].

Another property which plays the important role in stability of nanofluid is surface tension. It is the term that is normally used only when the surface of the liquid is in contact with gas (such as the air). The surface tension of a liquid results from an imbalance of the intermolecular attractive forces. This is the tendency of the surface of the liquid that allows external force to resist. If chemicals, surfactants or any another substance that can alter the molecular behavior of the fluid is added, its surface tension changes. Hence surface tension measurement is a direct indicator of the quality of any chemical or surfactant. Surface tension increases with particle concentration and particle size in all cases, because Vanderwaals force between the particles in the liquid/gas interface increases the free energy from the surface and increases the surface tension[12]. At low particle concentrations, the addition of particles has little influence on surface tension due to the large distance between the particles.

Khaleduzzaman et al., mentioned that by adding the surfactants, forms the layer between the surrounding particles and the fluid molecules due to the long-chain, surfactant molecule adheres to the solid particle. These layers impart a repulsive force between them and increase the potential force between the particles. This in turn can reduce the surface energy, so the surface tension decreases [13]. In recent years graphene has attracted much interest due to its distinctive and incomparable properties.
2. PREPARATION AND CHARACTERIZATION OF NANOFLUID

Graphene nanoparticles purchased from SkySpring Nanomaterials, Inc., USA is used for preparing the nanofluid by two step method. The SEM image of nanopowder is shown in Figure 1. The graphene are randomly distributed as a flake-like structure with less than 100 nm in thickness is clearly observed from Figure 1.

![SEM image of graphene nanopowder](image1.png)

Figure 1 SEM image of graphene nanopowder

The shape, size and phase distribution of graphene nanoparticles are characterized by x-ray powder diffractometer (XRD 6000, Japan). The XRD Spectra of the Graphene nanoparticle is shown in Figure 2. The Crystal Size, D is calculated from Scherrer’s formula and mention in equation 1. The average size of the graphene nanoparticle was 18 nm.

\[ D_{\text{vol}} = \frac{k\lambda}{\beta \cos \theta} \]  

(1)

Where, \(D_{\text{vol}}\) denotes crystallite size of the particles, \(\lambda\) is the wavelength of the x-ray source, \(k\) is sherrer constant, \(\beta\) is full width at half maximum (radian) and \(\theta\) is half of the diffraction angle.

![XRD spectra of graphene nanopowder](image2.png)

Figure 2 XRD spectra of graphene nanopowder
De-Ionized water is used as base fluid. Surfactant, Sodium dodecyl Benzene Sulfonate (SDBS) is added to keep the nanoparticles stable in the base fluid. Nanofluids with 0.2%, 0.4%, 0.6% and 0.8% volume of graphene nanoparticles are prepared. The dispersant (SDBS) was first added to the DI water and sonicated for about 15min. Sonication is continued when nanoparticles were added at a very slow rate. After the desired amount of particles, the mixture is sonicated for 45 minutes. The nanofluid prepared by this method is found to be stable without sedimentation.

![Figure 3 Visual observation study of graphene-water after 24, 48 and 72 hours](image)

The visual observation study is conducted in the prepared graphene-water nanofluid at 0.8% concentration to check the stability of nanoparticles. Surfactants are also used in nanofluids to enhance the stability of nanofluids. The prepared Nanofluid at 24, 48 and 72hrs is shown in Figure 3. The first test tube has graphene nanofluid and second one has pure distilled water.

### 3. MEASUREMENT OF THERMOPHYSICAL PROPERTIES

#### 3.1 Thermal Conductivity

The experimental layout for measuring thermal conductivity of nanofluids by the transient hot-wire method is shown in Figure 4. The experimental setup shown in Figure 4 has the DC power supply, Wheatstone bridge, Data logger and computer. Wheatstone bridge has two resistors of 10 Ω (R₁), 12kΩ (R₂), a variable resistor (R₃) and a test section between the junction J₂, J₃. The test section has isonel insulated platinum wire [resistivity=1.06×10⁻⁷ Ω·m (at 20°C)] of length 14.5 cm and 25 μm diameter (Goodfellow Cambridge Limited, UK) is fixed in line with the axis of the test tube cell, this will be surrounded by the liquid whose thermal conductivity is to be measured.

![Figure 4 Experimental layout of transient hot wire method to measure thermal conductivity of nanofluids](image)
Experimental Study of Thermo-Physical Properties of Graphene Water Nanofluid below Boiling Temperature

The measurement cell is immersed in a constant temperature bath to measure the thermal conductivity. Before starting, the experimental circuit is balanced. The current is passed through the Wheatstone bridge for 5 - 10 seconds to heat the platinum wire. The personal computer connected to the data acquisition system is combined to the electrical circuit. The data acquisition system measures the voltage supplied by the voltage source and the voltage difference across the bridge in a shorter time interval of less than 40 milliseconds and the temperature of the platinum wire and the surrounding liquid path whose thermal conductivity is to be measured. Based on the heat supplied, time interval, temperature difference the thermal conductivity is calculated by using following relation.

\[ k = \frac{q}{4\pi(T_2 - T_1)} \ln \left( \frac{T_2}{T_1} \right) \]  \hspace{1cm} (2)

Where, \( q \) is the heat liberated per unit time per unit length of the line source in W/m and \( k \) is the thermal conductivity of the liquid in W/mK. \( T_1 \) and \( T_2 \) are temperatures of the heat source at time \( t_1 \) and \( t_2 \) respectively.

3.2. Viscosity

Viscosity is the measure of the internal friction of a fluid. The viscosity of the nanofluids decreases exponentially with the increase in temperature. The rotational viscometer (LVDV-E, Programmable DV-II+ Viscometer, USA) is used to measure fluid viscosity. The measuring range of the viscometer is determined by the rotation speed of the spindle, the size and shape of the spindle, the container in which the spindle rotates and the full scale torque of the calibrated spring. The rotational viscometer has the accuracy of ±1% and measure viscosity from 1 mPa.s to 2million mPa.s. The viscosity of graphene-water and graphene-ethylene glycol nanofluids at the volume concentrations of 0.2%, 0.4%, 0.6% and 0.8% for the temperature range of 30°C to 80°C is measured. The spindle S61 is used to measure the viscosity of distilled water and nanofluid. The viscosity of each sample is measured ten times. The average value of the ten readings is taken as viscosity of each sample.

3.2. Surface Tension

Surface tension plays an important part in stabilizing the nanofluid. The bubble tensiometer (SitaMesstechnikGmbh tensiometer), which is used for measuring surface tension of the nanofluids. The resolution of the bubble tensiometer and measuring range are 0.1 mN/m and 15-100. The instrument works on maximum bubble pressure principle. The bubble tensiometer is calibrated by measuring the surface tension of the distilled water. Before starting the surface tension measurement, the capillary tube of the bubble tensiometer is cleaned with distilled water. The measurement of each sample is started by pressing the start button and inserting the capillary tube in to the liquid. The surface tension of each sample is measured ten times. The average value of the ten readings is taken as surface tension of each sample. The readings of surface tension of graphene-water nanofluid at the volume concentrations of 0.2%, 0.4%, 0.6% and 0.8% for the temperature range of 30°C to 80°C is measured.
4. RESULTS AND DISCUSSIONS
The thermal conductivity of the water (base fluid) is measured and the values are compared with the reference values to find the accuracy of the experimental setup.

Figure 5 Validation of thermal Conductivity of water with measured values

Figure 5 shows the thermal conductivity of the base fluid with the standard values at different temperatures. The maximum bias of around ±2% is observed and this may be due to the resistance of platinum wire which is used in the experimental setup is low.

Figure 6 shows the thermal conductivity value of graphene water nanofluid at different concentration and temperature. As the temperature and concentration increases, the thermal conductivity also increases. The maximum increase of 21% has been observed at a concentration of 0.8% of graphene nanoparticle. The enhancement in thermal conductivity of the nanofluid is due to the increase in the random motion of the particle, collision of the nanoparticles at higher temperatures.

Figure 6 Comparison of thermal conductivity of graphene water nanofluid
The percentage variation of thermal conductivity enhancement with respect to the volume concentration of graphene-water nanofluid at an average temperature of 55 ℃ is shown in Figure 7. As the volume concentration increases the thermal conductivity of the graphene-water nanofluid is also increases [14]. It is observed that for 0.2, 0.4, 0.6 and 0.8% of volume concentrations of graphene-water nanofluid, the thermal conductivity enhanced by 11.92%, 16.12%, 18.28% and 20.61% respectively at an average temperature of 55 ℃. When the volume concentration is increased from 0.2% to 0.4%, 0.6%, 0.8%, there is an enhancement of 4.2%, 6.36%, 8.69% in thermal conductivity of graphene-water nanofluid is observed respectively.

![Figure 7](image1.png)

**Figure 7** Percentage enhancement of thermal conductivity with respect to the volume concentration percentage of graphene

![Figure 8](image2.png)

**Figure 8** Comparison of viscosity of water between experimental and theoretical
The dynamic viscosity of the water is measured for the temperature range of 30°C to 80°C by using Brookfield viscometer. The equipment is validated by comparing the theoretical and experimental values as shown in Figure 8. The experimental viscosity results are well agreed with the standard values up to the maximum deviation of around ±5%.

Figure 9 shows the viscosity of graphene-water nanofluid at different temperature and for various concentration of graphene. The viscosity decreases with increase in temperature and increases with increase in concentration. The viscosity of the nanofluid at 30°C to 80°C are 4.65 and 2.06 mPa.s respectively, for 0.8% volume concentration. The viscosity of the graphene-water nanofluid at 0.8% concentration is nearly four times the base fluid. Adding the graphene sheets increases the friction and ultimately increases the viscosity.

Figure 10 Graphene-water nanofluid viscosity percentage reduction with respect to temperature.
The graphene–water nanofluid viscosity percentage reduction for each 10°C rise from 30°C to 80°C at the constant volume concentration of 0.5% is shown in Figure 10. The viscosity is clearly decreases with an increase in temperature. The average percentage reduction of the viscosity for each 10°C rise from 30°C temperature upto 80°C is 14.93%. The percentage reduction of graphene-water nanofluid for each 10°C is raise from 30°C to 80°C are 18.17%, 16.23%, 14.63%, 13.49%, 12.13% respectively. At lower temperatures the percentage reduction of the viscosity of the graphene-water nanofluids is higher [15].

Surface tension of water was measured using the bubble tensiometer (sitaMessetechnikGmbH tensiometer) and the results are validated against the standard values. The surface tension values of base fluid for the temperature range of 30°C to 80°C are compared with the theoretical values as shown in Figure 11. The surface tension values are found to be in well agreement with the theoretical values with a deviation of ±2%.

![Figure 11](image)

**Figure 11** Comparison of Surface tension between experimental and theoretical values for water

The surface tension values of graphene-water nanofluid is compared with base fluid (water) as shown in Figure 12. Surface tension increases with particle concentration and particle size for all cases, this is because Vanderwaals force between particles at the liquid/gas interface increases the surface free energy and thus increases the surface tension. At low particle concentration this addition of particles has little influence on the surface tension due to large distance between particles. On adding surfactants, the long chain surfactant molecule attach to the solid particle and form a layer between the particles and the surrounding fluid molecules. Such layers increase the potential force between particles and impart a repulsive force between them. This in turn can reduce surface energy, therefore the surface tension decreases.
CONCLUSION

The measurement of thermo-physical properties such as thermal conductivity, viscosity and surface tension, have shown that the thermal conductivity of the nanofluids increase with an increase in particle volume concentration and temperature. The viscosity of the nanofluid decreases with an increase in temperature and increases with increase in the particle volume concentration. For average particle concentration of 0.5% and temperature of 80°C the thermal conductivity has the maximum increase of 1.17 times the base fluid is observed for graphene-water nanofluid. At the average particle concentration of 0.5% and mean temperature of 55°C, the viscosity increased by 4.48 times the base fluid for graphene water nanofluid extra pumping power. The temperature-dependent thermo-physical properties can also be used as a reference to support the thermal equipment and electronic device cooling industries to instantly use nanofluids for various systems.

REFERENCES


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