On Prediction Of Viscosity Of Nanofluids For Low Volume Fractions Of Nanoparticles

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ABSTRACT

Nanofluid which is consisting of nanoparticles in base fluid has high performance of heating and cooling in an industrial process and may create a saving in energy. The flow behavior of nanofluid plays a vital role in designing of Heat transfer equipment. Therefore, the prediction of viscosity of nanofluid which depends on base fluid properties, type of nanoparticles, temperature and particle volume fraction is now a challenging task.

In the present paper, the literature review on viscosity models have been made and presented briefly. The viscosity of nano fluids made with SiO_2 (35nm), ZnO (40nm) and Al_2O_3 (27& 45nm) in base fluid of 70wt% Glycerol and water mixture were measured using Rheometer. The volume fraction(0.001 to 0.1) effect, temperature(30 – 80^oC) and particle diameter effect on variations of viscosity of nano fluids analyzed and found that the viscosity increases with volume fraction and exponentially decreases with increasing temperature. Finally, the regression analysis was done to correlate a suitable an equation for estimation of viscosity.

Keywords: Nano fluid, Volume fraction, Base fluid, 70wt% glycerol and water solution, Viscosity, Rheometer, Correlation

1.0 INTRODUCTION

The enhancement of heating or cooling in an industrial process may create a saving in energy, reduce process time, raise thermal rating and lengthen the working life of equipment. Some processes are even affected qualitatively by the action of enhanced heat transfer. The development of high performance thermal systems for heat transfer enhancement has become popular nowadays. Heat transfer can be enhanced using nanofluids, which consisting nanoparticles in base fluid instead of the original pure fluid because the suspended ultrafine particles significantly increase the thermal conductivity of the mixture and improve its capability of energy exchange. The enhancement mainly depends upon factors such as the shape of particles, the particles size, the volume fractions of particles in the suspensions and the thermal properties of particle materials.

Flow behaviour of nanofluids is one of the new challenges for thermo-science provided by the nanotechnology. The nanoparticles Al_2O_3, CuO, TiO_2, ZnO and SiO_2 are in commonly use for the major research. The base fluid is normally water, mixture of water with ethylene glycol and engine oil as cooling agent, but it is depend on the type of application and use. The viscosity is one of the very important properties of nanofluids which are essential for the evaluation of heat transfer coefficient. This may vary with volume fraction & size of the nanoparticles and temperature of the nanofluid.

In order to find the variation of viscosity, many theoretical models were available in the literature [1, 2, 3]. The liquid layering, particle size,particle shape, particles interaction, and dispersion techniques are the depending factors for determining the nanofluids viscosity. The classical model equation [4, 5,6, 7]is based on the assumption of dilute, suspended, spherical particles and no interaction between the nanoparticles. It is valid for relatively low particle volume fractions of nanoparticles. Maiga et al [8] proposed a viscosity model equation based on theparticle volume fraction for Al_2O_3 /water nanofluids and reported the effective viscosity increases when particlevolume fraction is increased.The temperature variation in viscosity for the range of particle volumefraction of 1% - 4%, reported by [4,7,9,10] for mono particle size (36 nm).Chung et al [11] developed an exponential equation based onkinetic gas theories and correlated with the experimentaldata. They considered the base fluid viscosity and particle volume fraction into account and the particle size and interaction between the particles were not considered. This model found to be more useful for two phase flow having with particles size larger than 100nm.

Kulkarni et al [12] proposed an equation for CuO/water nanofluid and for a temperature range of 5-50^{o}C. It shows the exponential decrease of viscosity when temperature is increased. Namburu et al [13] developed another equation for various particle volume fractions of Al_2O_3, for a temperature range of 5-50^{o}C and for 60:40 ethylene glycol & water as base fluids. It is also found that the exponential decreases of viscosity when temperature is raised.Tseng and Lin [14] also suggested an exponential model equation based on the particle volume fraction for TiO_2 / water nanofluids. Drew and Passman [15] introduced the well known Einstein model for dilute suspension, small size spherical particles and for two phase mixture at low particle volume fraction. Further, Graham [10] presented a generalized equation by considering the particle radius and inter-particle space for small particle volume fraction. Masoumi et al [15] formulated an equation based on the Brownian motion of the particles and reported that it is applicable for Al_2O_3/water nanofluids. White [16] developed an equation for Al_2O_3 / water and ethylene glycol based nanofluids. Many of the investigators ([17], [18], [19] and [20]) used different equations and they underestimate the effective viscosity of the nanofluids.

Based on the review, nanofluid viscosity significantly increases when particle volume fraction is increased anddecreases when temperature increases. Also, viscosity of nanofluid depends on many parameters such as base fluids,nanoparticle volume fraction, particle size, particle shape,temperature, surface charge, pH value, base fluid and dispersion techniques. However no theoretical formula is currently available to predict the nanofluid viscosity with good accuracy.

2.0 EXPERIMENTAL WORK

2.1 Methods of nanofluid preparation

SiO_2 (35 nm), ZnO (40 nm) and Al_2O_3 (27 & 45nm) nanoparticlessupplied by Sigma-Aldrich Chemicals Ltd, Germany have been used to prepare the nanofluid with 70wt% glycerol and water solution as the base fluid. One of the major limitations for commercial application of nanofluid is the difficulty of uniform dispersion in the base fluid and the sedimentation of nanoparticles with time. To avoid the sedimentation of nanoparticles with time, small quantities of surfactants are to be added to the base fluid and it helps sustain dispersion of nanoparticles. To achieve uniform dispersion of nanoparticles and sustain the fluid for longer duration from sedimentation, stirring the mixture for 12 to 16 hour duration was adopted. Sodium Dodecyl Benzene Sulfonate (SDBS) was used as surfactant in the preparation of nanofluid.

Nanofluid at different volume fractions in the range of 0.001 - 0.01 was prepared for property evaluation. Nanofluid samples were prepared using 70 wt% of Glycerol and water solution as base fluid. To prepare nanofluid of specific volume fraction, samples were first prepared by adding SDBS surfactant in different proportions to Glycerol + water solution and the mixtures stirred in a magnetic bath for 10 minutes. The nanoparticles were then added and stirred continuously for 16 hours and the samples observed for dispersion and stability.It is observed that SDBS weighing one tenth the weight of nanoparticles added to base fluid gives uniform dispersion without sedimentation.

$$\text{Volume fraction } (\Phi) = \frac{\frac{Wp}{\rho_p}}{\frac{Wp}{\rho_p} + \frac{W_{bf}}{\rho_{bf}}} \qquad (1)$$

2.2 Evaluation of nanofluid properties

The properties of nanofluid such as density, absolute viscosity, were estimated experimentally and compared with relevant equations available in literature.

2.2.1 Density

The density of nanofluid at different volume concentrations and temperatures were measured. The values were compared with the calculated values using the equation (2).

$$\rho_{nf} = \phi\rho_P + (1-\phi)\rho_{bf} \qquad (2)$$

2.2.2 Absolute viscosity

The experimental setup for measurement of viscosity of nanofluids using SiO_2 (35 nm), ZnO (40 nm) and Al_2O_3 (27, 45nm) with 70 wt% Glycerol and water as the base fluid is as shown in Figure1 and it consists of a programmable R/S+ cylindrical rheometer with temperature controlled bath. The rheometer 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% to100% and accordingly the spindle is chosen. Spindle CC45 DIN is used in the rheometer. The nanofluids under test are poured in the sample chamber of the rheometer.

The spindle immersed and rotated in the nanofluids in the speed ranging from 387 to 540 rpm in steps of 12 seconds. 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 Rheometer is having accuracy within ±1% of the full scale range of the spindle /speed combination. The reproducibility of test data is found to be within ±.2%.

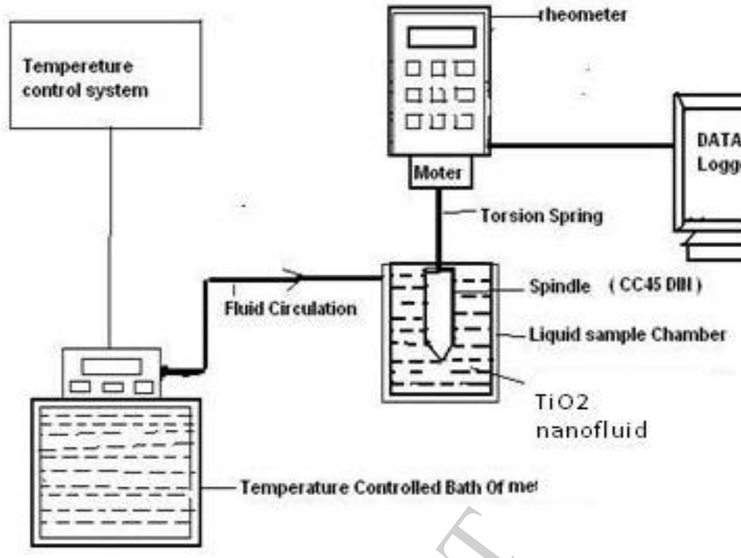

Figure 1 Schematic diagram of the viscosity measurement instrument

The Viscosity of nanofluid was also measured using Redwood-1 viscometer at different volume fractions of nanoparticles and temperatures. The equipment was calibrated with water and the absolute viscosity of the nanofluid was then determined.

3.0 RESULTS AND DISCUSSION

Masoumi et al [15] and Madhusree & Dey [21] evaluated the viscosity using

$$\mu_{nf} = \mu_{bf} + \frac{\rho_p V_B d_p^2}{72 C\delta} \qquad (3)$$

The correction factor (C) is calculated from

$$C = \mu_{bf}^{-1}(a\phi + b) \qquad (4)$$

The a and b experimental parameters are estimated for all the nanofluids used in the present study. Using equation (3), the viscosities are calculated and it is found that the equation (3) predicts the measured viscosity fairly well. Also Madhusree & Dey [21] show that for low loading of nanoparticles, the nanofluid reveals Newtonian behaviour only at high temperatures.

3.1 Effect of Volume fraction of Nanoparticles on Viscosity

Figures 2 and 3show the effect of nanoparticle volume fraction on viscosity of the nanofluid at various temperatures. At all temperatures, nanofluid viscosity increases with increasing nanopartcle volume fraction. Qualitatively, a similar trend has also been observed in all types of nanofluids used in the present study.

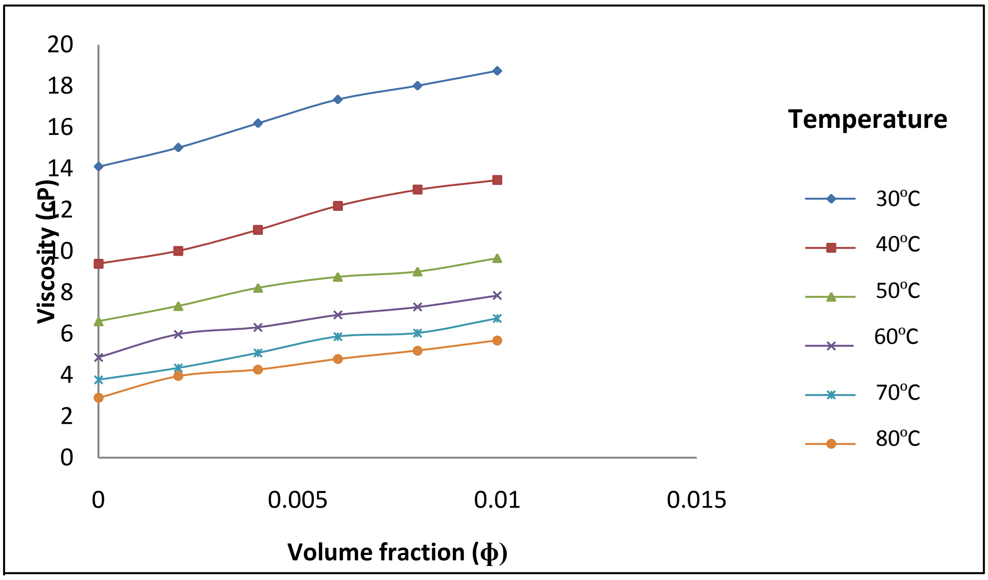

Figure 2: Nanofluid viscosity variation with volume fractions of SiO_2 nanoparticles using Glycerol as base fluid

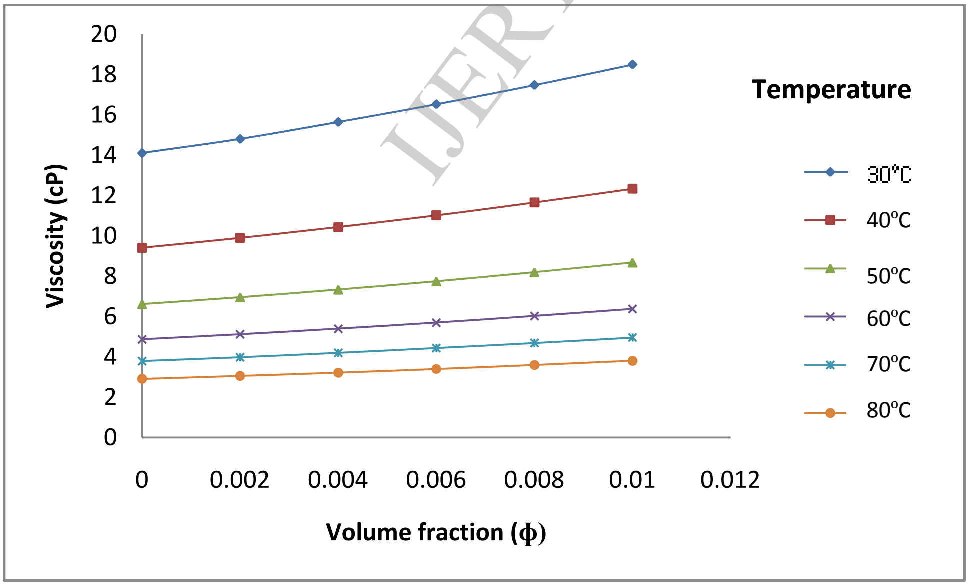

Figure 3: Nanofluid viscosity variation with volume fraction of Al_2O_3 (27nm) Particles: Base fluid as Glycerol

3.2 Effect of Temperature on Viscosity of nanofluid

Figures 4 and 5 show the temperature effect on viscosity of nanofluid with various volume fractions. The viscosity of the nanofluid decreases exponentially with temperatures of the nanofluid and similar trend have also been observed for all the nanofluids used in the present study.

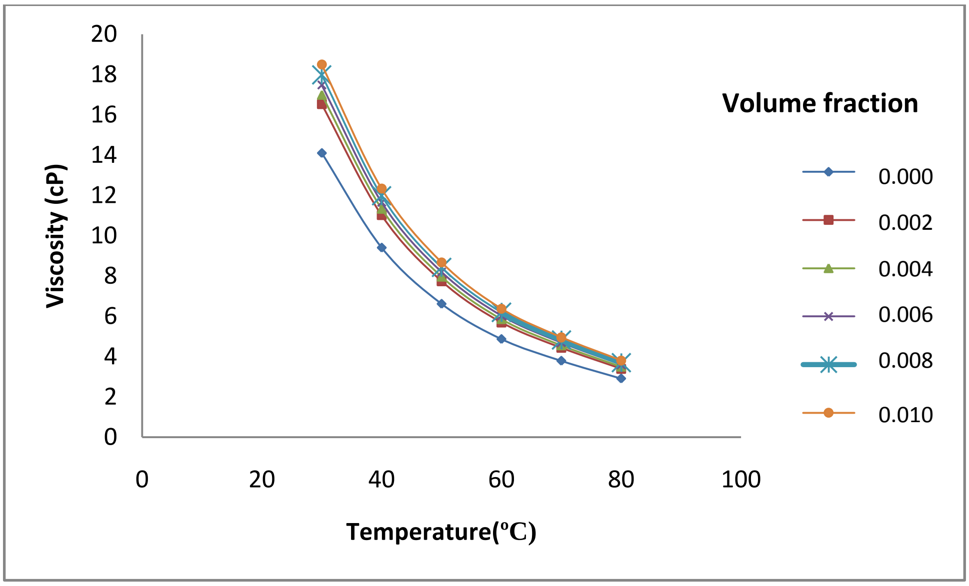

Figure 4: Nanofluid Viscosity variations using ZnO nanoparticles and Glycerol

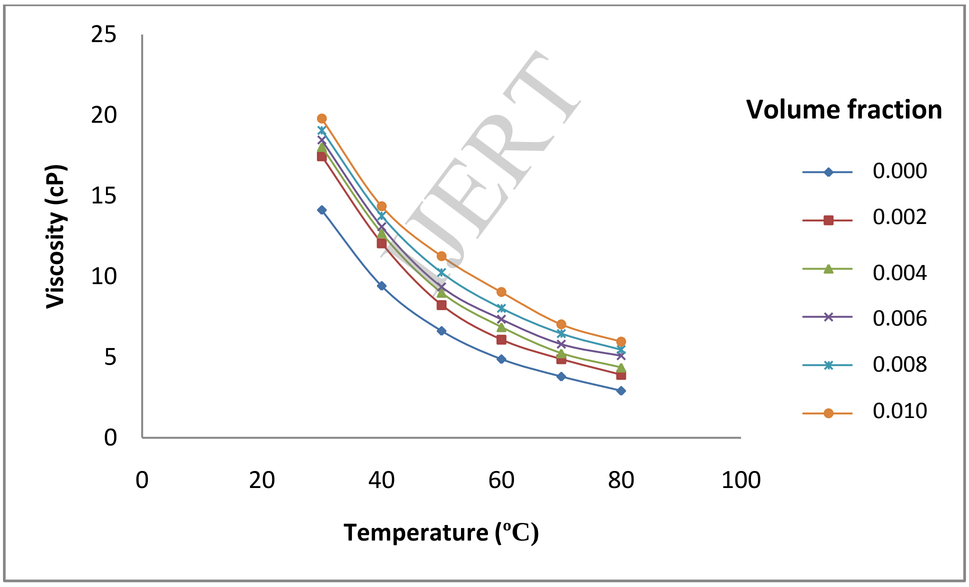

Figure 5: Nanofluid Viscosity Variations using Al_2O_3 nanoparticles and Glycerol

Further, it can be observed from the figure 6 that the nanofluid prepared by Al_2O_3 (27 nm) and base fluid of 70 wt% Glycerol and water solution shows the highest viscosity. Whereas remaining nanofluids prepared by SiO_2 (35 nm), ZnO (40 nm) and Al_2O_3 (45nm) in the base fluid of 70 wt% Glycerol and water solution shows decreasing order of viscosities. Since the particle concentration is considerably low (less than 1 vol%), the formation of aggregates are prevented in the nanofluids. Also, figure 6 depicts the decrease in the viscosity when particle size increases irrespective of the type of the nanoparticle. This indicates there can be generalized equation for low volume fraction of nanoparticles in the nanofluid (less than 1 vol%).

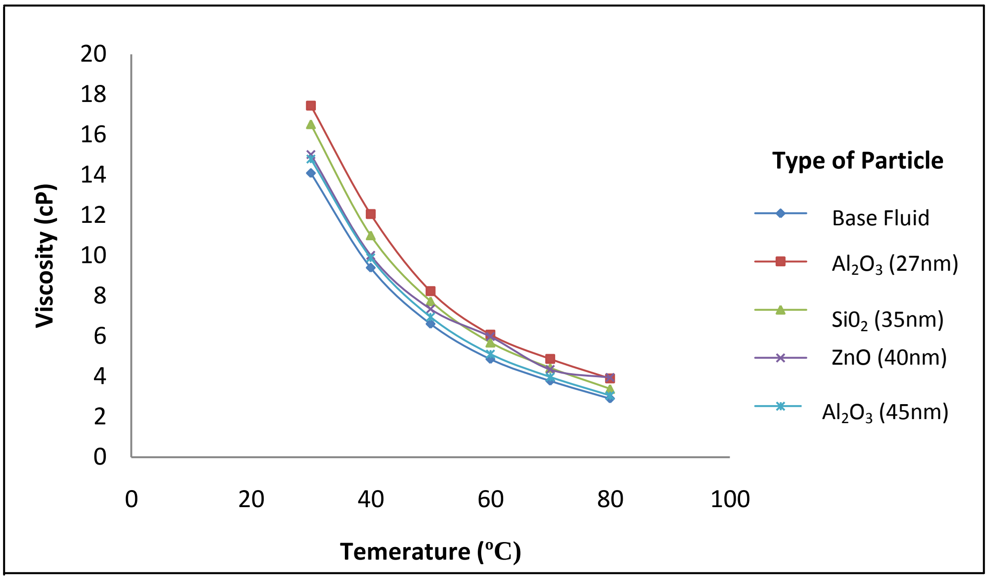

Figure 6: Nanofluid Viscosity variations using various nanoparticels and Glycerol as base fluid

3.3Theoretical Models and Correlation for Viscosity

The viscosities at different volume fractions of the nanoparticles are also calculated using equation (3) in comparison with the values of Pak and Cho [19]

$$\mu_{nf} = \mu_{bf}\left(1+39.11\phi+533.9\phi^2\right) \qquad (5)$$

For temperature dependence of viscosity the following equations have been proposed in the literature;

$$\mu_{nf} = Aexp(A/T) \qquad (6)\ [22]$$

$$ln(\mu_{nf}) = AT^{-1} - B \qquad (7)\ [12]$$

$$log(\mu_{nf}) = A\ exp(-BT) \qquad (8)\ [13,23]$$

The present experimental data of nanofluid viscosity show higher deviations with equations (6) and (7). It agrees very closely with equation (8). However, the coefficients of A and B values were evaluated by Namburu et al [23] for each volume fraction of Al_2O_3 nanoparticles in base fluid of engine coolant as

$$A = -225.245(\phi^2) + 18.404(\phi) + 1.749 \qquad (9)$$

$$B = 575.835(\phi^3) - 32.101(\phi^2) + 0.148(\phi) + 0.011 \qquad (10)$$

However, the above equation is not representing the particle size effect on the viscosity of nanofluids. Therefore, generalized regression equation is developed to include the effect of temperature, volume concentration and particle diameter in the estimation of nanofluid absolute viscosity given by

$$\log \mu_{nf} = \left(1.75 + 16.85\phi + 23.5\,\frac{\phi^2}{d_p^2}\right) \exp\left(0.015 + 0.15\phi - 31.3\phi^2 + 5.65\,\frac{\phi}{d_p}\right) T \quad (11)$$

Valid in the range 30<T <80°C, 27<d_p<45 nm, 0.0<ϕ<0.01 and obtained with AD of 1.17% and SD of 1.95%.

4.0 CONCLUSION

Experimental values of viscosity ofSiO_2 (35nm), ZnO (40nm) and $A1_2O_3$ (27, 45nm) nanofluid at various volume fractions (less than 1 vol%) in base fluid of 70wt% Glycerol and Water are measured. The viscosity of nanofluids were observed to increase with volume fractions of nanoparticles and exponential decrease with increase in temperature. Generalized regression equation is developed to include the effect of temperature, volume concentration and particle diameter in the estimation of nanofluid absolute viscosity given

$$\log \mu_{nf} = \left(1.75 + 16.85\phi + 23.5\,\frac{\phi^2}{d_p^2}\right) \exp\left(0.015 + 0.15\phi - 31.3\phi^2 + 5.65\,\frac{\phi}{d_p}\right) T$$

Valid in the range 30°C < T < 80°C, 27 < d_p <45 nm, 0.0 < ϕ < 0.01

5.0 NOMENCLATURE

a : Constant in equation (4)
A : Constant in equations (6), (7) and (8)
b : Constant in equation (4)
B : Constant in equation (7) and (8)
C : Correction factor in equation (3)
d_p : Diameter of the Particle (nm)
T : Temperature (^oC)
V_B : Volume of the Base Fluid, nm^3
W_{bf} : Weight of Base Fluid, g
W_p : Weight of the nanoparticles, g

Greek Letters

δ : Thickness of the nanolayer
ϕ : Volume fraction of the nanoparticles
μ_{bf} : Viscosity of base fluid, cP
μ_{nf} : Viscosity of nanofluid, cP
ρ_{bf} : Density of Base Fluid, g/cc
ρ_{nf} : Density of nanofluid, g/cc
ρ_p : Density of Particles, g/cc

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