EXPERIMENTAL INVESTIGATION INTO RHEOLOGICAL PROPERTY OF COPPER OXIDE NANOPARTICLES SUSPENDED IN PROPYLENE GLYCOL-WATER BASED FLUIDS

M. T. Naik[1], G. Ranga Janardhana[2], K. Vijaya Kumar Reddy[3], B. Subba Reddy[1]
[1]Centre for Energy studies, Department of Mechanical Engineering, JNTUH College of Engineering, Kukatpaly, Hyderabad, A.P., India
[2]Department of Mechanical Engineering, JNTUH Kakinada, India
[3]Department of Mechanical Engineering, JNTUH, Hyderabad, India
E-Mail: mtnaik@rediffmail.com

ABSTRACT

Nanofluids are new generation heat transfer fluids and have opened a new horizon in the areas of heat transfer applications. Nanofluids are prepared by dispersing nano-sized metallic particles in conventional fluids of heat transfer. Heat transfer performance of nanofluid depends primarily on its thermo physical properties like viscosity, thermal conductivity, specific heat and density. Viscosity property assumes importance as it affects the pressure drop and hence the pumping power when nanofluids are circulated in a closed loop for transfer of heat in heat exchangers. In the present research, propylene glycol and water (60:40 by weight) is used as base fluid and viscosity of Cuo nanofluid with different particle volume concentration of 0.025, 0.1, 0.4, 0.8 and 1.2 percent is measured. Experimental results thus obtained revealed that temperature and nanoparticle concentration parameters influence the viscosity of nanofluids considerably. The experimental results obtained in the present experiment found to be in closer agreement with those available in the literature.

Keywords: heat transfer, nanofluids, volume fraction, viscosity, temperature, shear rate, shear train.

Nomenclature

Wp	Weight of CuO nanparticles
ρ p	Density of CuO nanparticles
Wbf	Weight of base fluid
ρ bf	Density of base fluid
ϕ	Volume fraction of CuO nanopowder
μ_s	Nanofluid viscosity
μ_{bf}	Base fluid viscosity
T	Temperature in Kelvin
τ	Shear stress
γ	Shear strain

1. INTRODUCTION

The modern nanotechnology provides fertile grounds for scientific advances and the development of novel devices and materials which will affect the well-being of all. Among the various novelties scientists and engineers have introduced over the recent years are nanofluids which are stable suspensions of nanoparticles into host base fluids. Nanofluids show great promises and are being extensively studied for the heat transfer properties and could potentially enhance the efficiency of large-scale heat exchangers used in chemical processing plants as well as smaller scale heat exchangers used in the automotive and computer cooling sectors. Nanofluids have opened a new chapter in the field of thermal engineering and are considered to be new generation fluids for transport of heat in diverse industries which include micro electronics, chemical engineering and process industries. Conventional fluids have limited heat transfer capabilities. The nanofluids have attracted much interest in heat transfer applications in recent past. A need to development new kinds of fluids with improved heat transfer capabilities is felt by different research groups across the globe to day. The idea behind development of nanofluids is to improve the heat transfer coefficient and to minimize the size of heat transfer equipments for conservation of material and energy. It is well known that the important parameters which influence the heat transfer characteristics of nanofluids are their thermo physical properties like thermal conductivity, viscosity, specific heat and density. Very often micro sized solid particles are suspended in the conventional fluids to augment their thermal conductivity of conventional heat transfer fluids.

Nanofluids fluids exhibit different thermo physical properties and accurate measurement of these properties is essential for engineering applications of these fluids.

Different researchers worked on heat transfer characteristics of nanofluids and presented their findings in the form of research works. Eastman *et al.*, [1] investigated on Cu nanoparticles which are suspended in ethylene glycol and reported about 40% increase in the thermal conductivity of Cu nanofluids of 0.3 volume%. Pak and Cho [2] worked on Al_2O_3/water nanofluids and observed a 75% enhancement in the convective heat transfer coefficient for 2.7%. Das *et al.*, [3] and Putra *et al.*, [4] measure the viscosity of water based nanofluids containing Al_2O_3 and CuO nanoparticles in the particle volume concentration range of 1% to 4%. Their findings revealed an increase in the viscosity of these nanofluids with particle volume concentration. Prasher *et al.*, [5] reported rheological properties of alumina based nanofluids and found that the viscosity is independent of nanofluid temperature and the nanofluids are Newtonian in nature. Paveen K Namburu *et al.*, [6] has studied the viscosity property of Cuo/ethylene glycol nanofluids in the temperatures ranging from -35 to 50°C and observed a four fold increase in the viscosity of Cuo nanofluids of 6.12% volume fraction and an exponential decrease of viscosity with temperature.

Ethylene glycol or propylene glycol mixture in water in different proportions is used as heat transfer fluid in cold climatic conditions to lower the aqueous freezing point of heat transfer fluids in automobile radiators. Glycols exhibit better heat transfer performance at low temperatures. Tongfan Sun and Amyn S. Teja [7] experimentally measured density, Viscosity and Thermal Conductivity of aqueous solutions of propylene glycol, Dipropylene glycol from 25 mol% to 100 mol% in the temperature range of 290 K to 460 K. Viscosity of carbon nanotubes [8] and graphite nanotubes [9] and Tio2 nanoparticles in water [10] have been investigated at higher temperatures. Tejpel *et al.*, [11] and W J Tseng *et al.*, [12] investigated viscosity properties of Al2O3 nanoparticles in paraffin oil and water respectively. K. Kwak, C. Kim [13] presented their findings on Viscosity and thermal conductivity of copper oxide nanoparticles dispersed in ethylene glycol at room temperature. Viscosity of nanofluids plays a key role and influences the pumping power requirement and also the convective heat transfer coefficient as Prandtle and Reynolds numbers depend on the viscosity of nanofluids heat transfer.

In the present work Cuo nanoparticles are suspended in the propylene glycol/water mixture (60:40 by weight) and nanofluids is prepared. Propylene glycol is chemically more stable, non-toxic and ensures stability to nanofluids when compared to ethylene glycol. No work is reported on the rheological property of CuO nanofluids using Propylene glycol and water as base fluids. The objective of the present experimental work to study the effects of temperature and nanoparticle volume concentration on the viscosity of PG-Water/Cuo nanofluids.

A few experimental works are reported on the viscosity of nanofluids and viscosity correlations are developed which are as follows.

Einstein [14] has proposed a viscosity correlation in terms of nanoparticle concentration in the base fluid, when the nanoparticle volume concentration is lower than 5%, which is given by

$$\mu_s = \mu_{bf}(1+5/2*\phi) \qquad (1)$$

Brickman [15] presented viscosity correlation as it applies to concentrated particle suspension

$$\mu_s = \mu_{bf}\ [1/(1-\phi)^{2.5}] \qquad (2)$$

Bachelor [16] developed a correlation relating volumetric suspension and viscosity as

$$\mu_s = \mu_{bf}\ (1+2.5\phi+6.2\phi^2) \qquad (3)$$

2. PREPARATION OF NANOFLUIDS

In the present work Cuo nanoparticles with volume weighted average particle diameter less than 50 nm sized and particle density of 6.3 grams/cc is used. The Cuo nanoparticles are supplied by Sigma Aldrich Chemicals Pvt Ltd. The amount of CuO nanoparticles required for a particular volume concentration in the test sample of base fluid is calculated using the law of mixtures in terms percentage of volume fration, density of CuO nanoparticles and density of propylene glycol-water mixture base fluid using the following relationship

% of volume concentration

$$= \frac{(Wp\ /\ \rho p)}{(Wp\ /\ \rho p) + (Wbf\ /\ \rho bf)} \qquad (4)$$

CuO nanoparticle is carefully and accurately weighed by a sensitive balance of 0.1mg resolution. Then the particles are suspended in propylene glycol and water mixture in volume fractions ranging from 0.025, 0.1, 0.4, 0.8, 1.0 and 1.25 %. The test samples were subjected to magnetic stirring for about I hour and then sonication process to break particle agglomeration and to ensure the uniform dispersion of nanoparticles in the base fluids. No surfactant is used as it hampers the properties of nanofluids. No sediment is observed even after 6 hours after sonication process by ultrasonic method.The 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 and the nanofluids behave as Newtonian fluids.

3. EXPERIMENTAL SET UP AND VISCOSITY MEASUREMENT

The experimental setup for measurement of viscosity of the copper oxide nanofluids, with propylene glycol-water mixture as base fluid is as shown in Figure-1. It consists of a programmable R/S+ cylindrical rheometer ver.:9.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 Cuo nanofluid is poured in the sample chamber of the rheometer. The spindle immersed and rotated in the nanofluid in the speed range from 387 to 540 rpm in steps of 12 seconds. 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 guaranteed to be accurate to within ±1% of the full scale range of the spindle /speed combination in use reproducibility is within ±.2%.

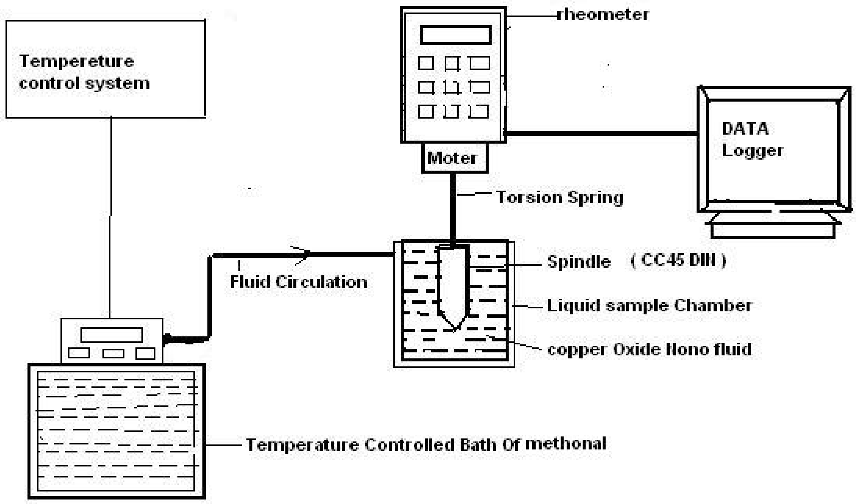

Figure-1. Experimental setup for viscosity measurement of nanofluids.

The experimental setup for measurement of viscosity of the copper oxide nanoparticles suspended in propylene glycol-water mixture consists of an LV DV-II+ Brookfield programmable viscometer [22] and Julabo temperature-controlled bath of methanol with a computer to control temperature. The viscometer drives a spindle immersed in the test fluid. When the spindle is rotated, the viscous drag of the fluid against the spindle is measured by the defection of the calibrated spring. This viscometer has a viscosity measurement range of 1.5-30,000 mPas and can handle the viscosity measurement results within the temperature range of this experiment. A computer controls the temperature of this bath that is used to vary the temperature of the test sample. Spindle SC-18 was used in this viscometer and was calibrated by using Brookfield viscosity standard fluids. The viscometer contains a sample chamber where the fluid is tested. Temperature inside the sample chamber is carefully monitored using a RTD temperature sensor during the viscosity measurements. The spindle type and speed combinations will produce satisfactory results when the applied torque is in between 10% and 100% therefore spindle types and speeds are selected in such a way that the torque values lie in this prescribed range. A wide range of spindle speeds are available in this viscometer (0-200 RPM). Viscosity measurements were started at 60 ºC and temperature was gradually reduced to -15 ºC.

4. RESULTS AND DISCUSSIONS

To ascertain the accuracy measurements in the rheometer, viscosity of the base fluid consisting of propylene glycol-water (60:40 by volume) mixture was measured at different temperatures without adding CuO nanoparticles in the base fluid and the viscosity results obtained are compared with the PG-Water viscosity data available in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) handbook [14] as can be observed in the Figure-2.

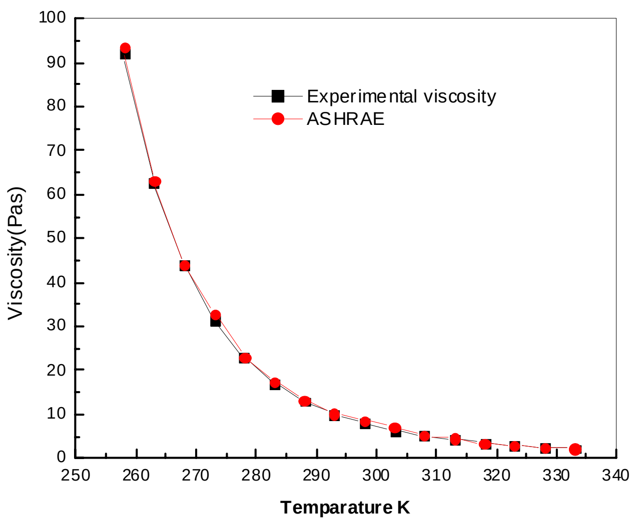

Figure-2. Comparison of ASHRAE viscosity values of 60:40 (by volume) Propylene glycol and water mixture and the experimental data.

The viscosity of propylene glycol- water mixture base fluid is also measured on mole basis (25% mole of Propylene glycol) and compared with the viscosity of PG-Water mixture fluid measured on mole basis, as reported by Tongfan [7] and the results are as shown in the Figure-3. As our experimental viscosity results matched very closely with the viscosity data of Tongfan *et al.* and also with ASHRAE data, we ensured the reliability of the rheometer used for measurement of viscosity of the base fluid in the present experimental investigation.

Kulkarni *et al.*, [17] in his experimental work with CuO nanofluids with water as base has reported that Cuo nanoparticles at volume concentrations of 5-15% in water became non -Newtonian fluids in the temperature range of 5-50 ºC. The Nanofluids in the present investigation assumed to act as Newtonian fluids when the concentration of nanoparticles is low. Newtonian fluids satisfy the equation governing Newtonian behavior of a fluid which is given by

VOL. 5, NO. 6, JUNE 2010 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

$$\tau = \mu\gamma \, . \quad (5)$$

After measuring viscosity of the base fluid and confirming that the present experimental reading are correct, the viscosity of nanofluids with CuO nanoparticles suspension in the propylene glycol/water in the concentration range from 0.025 to 1.2 percentage was measured in the temperature range from 285K-335 K. The measured viscosity of the CuO nanofluids of all the concentrations has shown an exponential decrease with increase in the nanofliud temperatures, as can be observed from the Figure-4. Nanofluids with higher concentration CuO nanoparticles exhibited higher viscosity. It is observed from the results that the trend in the change of viscosity with temperature for all the concentrations of nanofluid is similar. Figure-5 shows that shear stress and shear rate are linearly wearing and CuO oxide nanofluids in the present investigation exhibited Newtonian behavior. Relative viscosity, which is defined as the ratio of the viscosity of the nanofluid to the viscosity of the base fluid, for the entire particle concentrations and shear rate relationship is also studied. The viscosity rario of a particular nanofluids concentration is not altered for different shear rates. The viscosity of the CuO nanofluids of 1.2% volume concentration is increased to 5 percent when compared to base fluid viscosity as shown in the Figure-6. The viscosity results of CuO nanofluids of different volume concentrations considered in the experimental work are compared with different viscosity correlations developed by Einstein, Bachelar and Brinkman models as can be seen the Figure-7. These viscosity models found to be suitable to predict the viscosity of the propylene glycol water based fluid Cu O nanofluids.

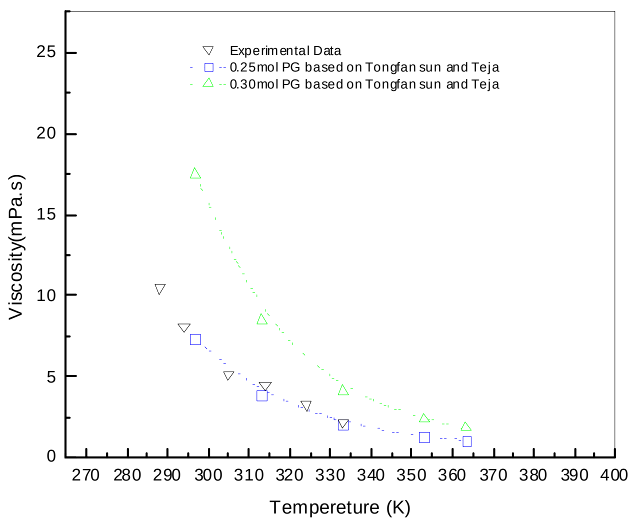

Figure-3. Comparison of experimental viscosity of PG-water base fluid with other experimental data.

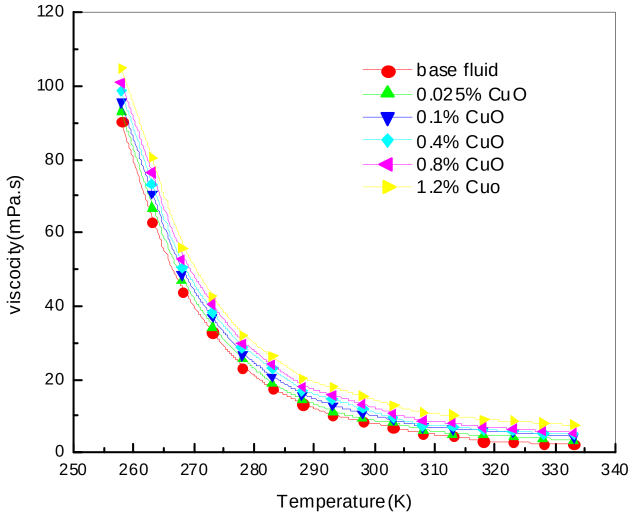

Figure-4. Variation in the viscosity of PG-Water/CuO nanofluid with temperature for different volume concentration of CuO nanofluid.

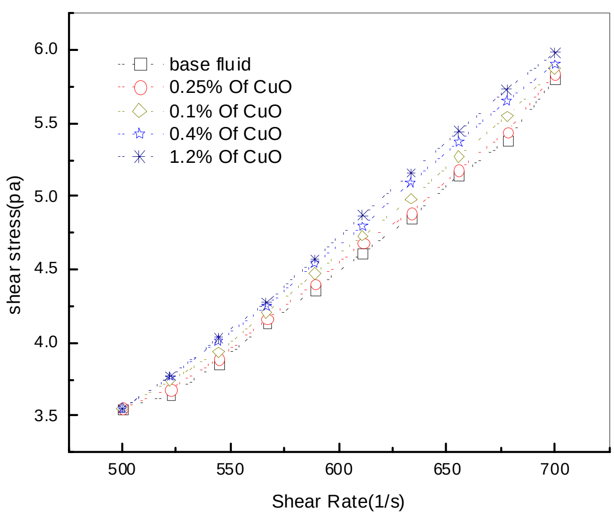

Figure-5. Shear stress and shear strain relations for various volume concentrations of Cuo nano particles in the base fluid.

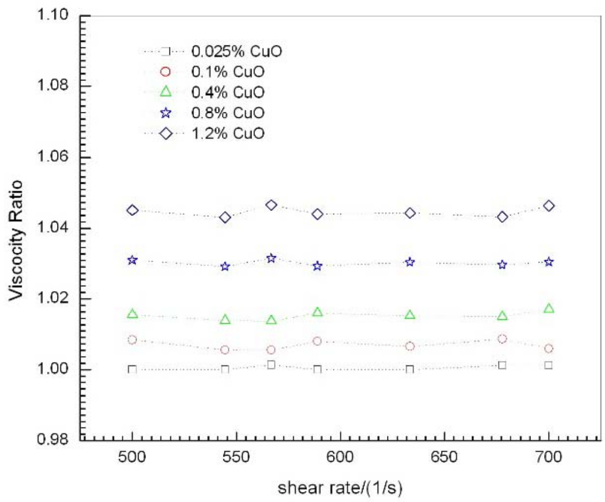

Figure-6. Viscosity ratio vs shear rate for different volume concentration of PG-water/CuO nanofluid.

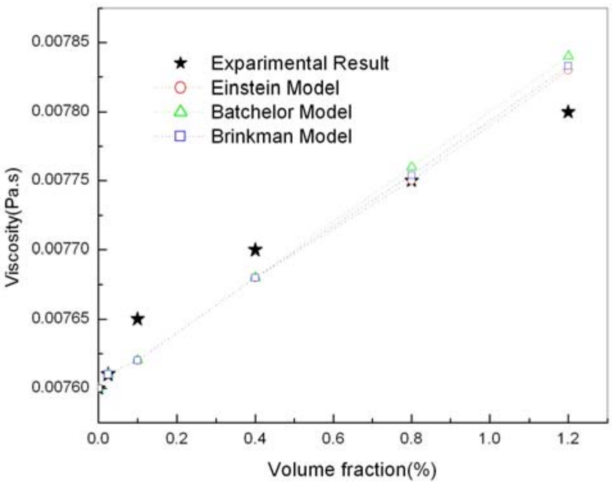

Figure-7. Comparison of viscosity of PG/water- CuO nanofluids with different viscosity models.

5. CONCLUSIONS

a) Propylene glycol/distilled water mixture base fluid is prepared and its viscosity is measured and the viscosity results thus obtained are compared with the experimental data available in ASHRAE hand book.
b) The present experimental results indicated that viscosity of copper oxide nanofluids decreases exponentially with increase in the temperature.
c) The nanoparticle volume concentration has considerable influence on the viscosity of CuO nanofluids.The nanofluids with higher particle concentrations exhibited more viscosity.
d) The shear stress and shear rate of CuO nanofluids have shown a linear relationship and the nanofluids exhibited Newtonian behavior.
e) The relative viscosity of nanofluids is not altered by a change in the shear rate for a particular viscosity ratio.
f) The experimental viscosity results obtained in the present work are compared with Einstein, Bachelar and Brinkman viscosity models.

REFERENCES

[1] J.A. Eastman, S.U.S. Choi, S. Li, L.J. Thompson. 2001. Anomalously increased effective Thermal Conductivity of Ethylene glycol based nanofluids Containing Copper Nanoparticles. Applied Physics Letters. 78(6): 718-720.

[2] B.C. Pak, Y.L. Cho. 1998. Hydrodynamics and Heat Transfer Study of Dispersed fluids with Submicron Metallic oxide Particles. Experimental Heat Transfer. 11: 151-170.

[3] S.K. Das, N. Putra, W. Roetzel. 2003. Pool boiling characteristics of nano-fluids. International Journal of Heat and Mass Transfer. 46: 851-862.

[4] N. Putra, W. Roetzel, S.K. Das. 2003. Natural Convection of nanofluids. Heat and Mass Transfer. 39: 775-785.

[5] R. Prasher, D. Song, J. Wang, P.E. Phelan. 2006. Measurements of nanofluid viscosity and its implications for thermal applications. Applied Physics Letters. 89: 133108-1-133108-3.

[6] Praveen K Namburu, Devdatta, P. Kulkarni, Debasmita Misra K. 2007. DasViscosity of copper oxide nanoparticles dispersed in ethylene glycol and water mixture. Experimental Thermal and Fluid Sciences. 32: 397-402.

[7] Tongfan Sun and Amyn S. Teja. 2004. Density, Viscosity and Thermal Conductivity of Aqueous Solutions of Propylene Glycol, Dipropylene Glycol, and Tripropylene Glycol between 290 K and 460 K. J. Chem. Eng. Data. 49: 1311-1317.

[8] J. Hilding, E.A. Grulke, Z.G. Zhang, F. Lockwood. 2003. Dispersion of carbon nano tubes in liquids. Journal of Dispersion Science and Technology. 24(1):1-41.

[9] Y. Yang, E.A. Grulke, Z.G. Zhang, G. Wu. 2005. Journal of Nanoscience and Nanotechnology. 5: 571-579.

[10]W.J. Tseng, K.C. Lin. 2003. Rheology and colloidal structure of aqueous TiO2 nanoparticle suspensions. Materials Science and Engineering. 355: 186-192.

[11]U. Teipel, U. Barth. 2001. Rheology of nano-scale aluminum suspensions. Propellants, Explosives, Pyrotechnics. 26: 268-272.

[12]W.J. Tseng, C.H. Wu. 2002. Aggregation, rheology and electrophoretic packing structure of aqueous Al_2O_3 nanoparticle suspensions. Acta Materialia. 50: 3757-3766.

[13]K. Kwak, C. Kim. 2005. Viscosity and thermal conductivity of copper oxide nano. uid dispersed in ethylene glycol. Korea-Australia Rheology Journal. 17(2): 35-40.

[14]A. Einstein. 1956. Investigations on the Theory of the Brownian movement. Dover Publications, New York.

[15]H.C. Brinkman. 1952. The viscosity of concentrated suspensions and solutions. Journal Chemistry Physics. 20: 571-581.

[16]J. Bicerano, J.F. Douglas, D.A. Brune. 1999. Model for the viscosity of particle dispersions. Journal of Macromolecular Science Review. 39: 561-642.

[17]D.P Kulkarni, D.K.Das, G.A Chukwu. 2006. Temperature dependent rheological property of copper oxide nanoparticles suspension. Journal of nanoscience and nanotechnology. 6: 1150-1154.