Structural Engineering and Mechanics, *Vol. 58, No. 1 (2016) 93-102*
DOI: http://dx.doi.org/10.12989/sem.2016.58.1.093

An experimental study and new correlations of viscosity of ethylene glycol-water based nanofluid at various temperatures and different solid concentrations

Mahmood Rabani Bidgoli*[1], Reza Kolahchi[1] and Mohammad Saeed Karimi[2]

[1]*Department of Civil Engineering, Jasb Branch, Islamic Azad University, Jasb, Iran*
[2]*Faculty of Civil Engineering, Semnan University, Semnan, Iran*

(Received May 3, 2015, Revised January 16, 2016, Accepted January 20, 2016)

Abstract. This article presents an experimental study on the effect of temperature and solid volume fraction of nanoparticles on the dynamic viscosity for the CuO/EG-water nanofluid. Nanoparticles with diameter of 40 nm are used in the present study to prepare nanofluid by two-step method. A "Brookfield viscometer" has been used to measure the dynamic viscosity of nanofluid with solid volume fraction up to 2% at the temperature range between 20 to 60°C. The findings have shown that dynamic viscosity of nanofluid increases with increasing particle volume fraction and decreasing temperature. Nine different correlations are developed on experimental data point to predict the relative dynamic viscosity of nanofluid at different temperatures. To make sure of accuracy of the proposed correlations, margin of deviation is presented at the end of this study. The results show excellent agreement between experimental data and those obtained through the correlations.

Keywords: dynamic viscosity; Ethylene glycol-water based nanofluid; newtonian fluid

1. Introduction

In recent years, study of nano-structures has been interested by researchers (Ghorbanpour Arani *et al*. 2014, 2015, Rabani Bidgoli *et al*. 2015). A suspension of nano-sized particles in based fluids is called 'nanofluid'. It has been found that nanofluids are capable of providing a significant amount of heat transfer in comparison with conventional fluids such as water and ethylene glycol (Heydari *et al*. 2014). In the recent decades, nanofluids have grabbed the attention of many researchers as well as industrial consumersbecause of their use in different thermal engineering systems such as nuclear reactors, solar energy, etc. An experimental investigation on Al_2O_3-water and TiO_2-water nanofluids containing nanoparticles with mean diameters of 13 and 27 nm respectively, were conducted by Pak and Cho (1998). They carried out these investigations for solid volume fractions of up to 10% in order to measure the viscosity of nanofluids and observed that with increasing solid volume fraction, the viscosity of the nanofluids increased significantly. In another experimental study, the viscosity of CuO-ethylene glycol and water was measured by

*Corresponding author, Ph.D., E-mail: m.rabanibidgoli@gmail.com

http://www.techno-press.org/?journal=sem&subpage=8 ISSN: 1225-4568 (Print), 1598-6217 (Online)

Namburu *et al*. (2007). They observed that Cuonanofluid showed Newtonian behavior in a mixture of EG-water for solid volume fraction differing up to 0.0612. A study on the CuO-water nanofluid with solid volume fractions between 0.05 and 0.15 was conducted experimentally by Kulkarni *et al*. (2006). They observed that the nanofluids behave as non-Newtonian fluids in various temperatures, ranging from 5 to 50^{o}C. The effects of temperature, size of the particles, shear rate and solid volume fraction on the viscosity of Al_2O_3 based nanofluids have been published by Prasher *et al*. (2006). Their results indicated that viscosity was not dependent on shear rate,therefore it proves that nanofluids are Newtonian in nature. The influences of the solid volume fraction and shear rate on the viscosity of Fe_2O_3 nanoparticles in diluted water as a base fluid were measured by Phuocand massoudi (2009). They indicated that the fluid shows non-Newtonian behavior at higher solid volume fraction (>0.02). The viscosity of the water based nanofluids containing Al_2O_3 nano-sized particles (ranging from 0.01 to 0.3 volume fraction) was measured by Lee *et al*. (2008). They reported considerable decrease in the viscosity of Al_2O_3-waternanofluids with increasing temperature and also nonlinear increasein the viscosity with increasing solid volume fraction. The effects of the solid volume fraction and the shear rates on the viscosity of magnetic-deionized water nanofluids were studied by Kwon *et al*. (1998). There are some other investigations on the viscosity of nanofluids which show the effect of the solid volume fraction and temperature on the viscosity (Murshed *et al*. 2008, Kwak and Kim 2005, Wang *et al*. 2004, Choi*et al*. 2000, Yang *et al*. 1986, Avsec and Oblaq 2007, Nguyen *et al*. 2008, Chen *et al*. 2007).

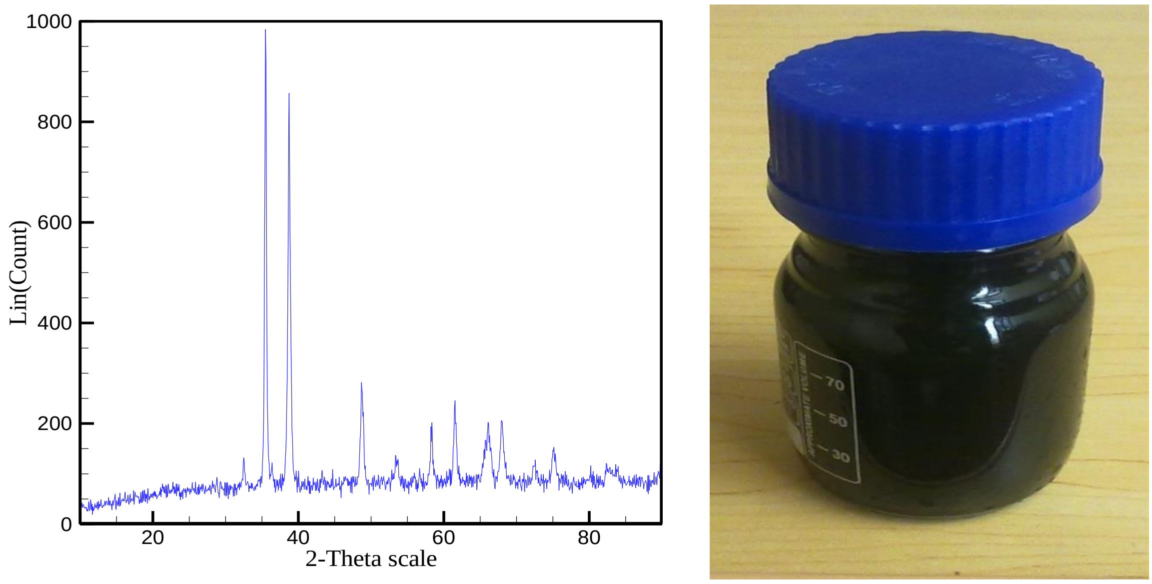
In the present study, the effects of solid volume fraction and temperature on the dynamic viscosity of CuO/ water-EG are investigated. Furthermore, 9 new correlations are proposed to predict the dynamic viscosity of CuO/ water-EG nanofluid with solid volume fraction less than 2%. Based on the authors' Knowledge, no comprehensive researchesis so far done on the changes of the viscosity with the variation of solid volume fraction and temperature for the CuO/ water-EG. Therefore, regarding the importance of this parameter (viscosity) and the necessity to comprehend its effects, the present investigation wasconducted.

2. Nanofluid preparation

The nanofluid, produced by the two-step method, was used without addition of any surfactant. A mechanical mixture was also exploited in order to disperse the nano-sized particles into eight solid volume fractionsof 0.1%, 0.2%, 0.4%, 0.6%, 0.8%, 1%, 1.5% and 2%. For the given solid volume fractions of the nanofluid, a precise amount of CuO with diameter of 40 nanometers was added to the ethylene glycol-water. After primary mixing, a magnetic stirrer is used in order to mix the particles and ethylene glycol for 4 h. In the next step, an ultrasonicprocessor with 600W of powerand frequency of 24 kHz was used and the suspension was inserted inside it for 3 h in order to break down the agglomeration among the particles and also prevent the sedimentation problem. By using this method, the samples remained stable for a long period of time (at least 3days) and no sedimentation was noticed with naked eyes.

3. Measurement of dynamic viscosity

The dynamic viscosity of CuO/ water-EG nanofluid was measured using Brookfield viscometer equipped with a UL adapter and a temperature bath.



(a) (b)

Fig. 1 XRD image of CuO nanoparticles (a) and a sample of the nanofluid (after16 hours) (b)

4. Results and discussion

The present study was focused on dynamic viscosity of CuO/ (40:60) EG- water nanofluid. Dynamic viscosity of the nanofluid was measured experimentally at different solid concentrations and temperatures. With using various solid volume fractions and temperatures, nine separate correlations have been proposed to calculate the dynamic viscosity of CuO/ water-EG nanofluid. Nanofiud samples with solid concentration of 0.1%, 0.2%, 0.4%, 0.6%, 0.8%, 1%, 1.5% and 2% were dispersed and provided utilizing two-step method. The correlations were presented in a temperature range between 20 and 60℃ as a function of the Temperature and solid concentration. The results of current investigation show that the relative dynamic viscosity of nanofluid increases with an increase in the particle concentration and a decrease in temperature. At high solid concentration, temperature has a greater effect on dynamic viscosity of nanofluid.

In order to make sure about the size of CuO nanoparticle and stability of the nanofluid, an XRD image of the nanoparticles, in addition to a sample of the nanofluid (after 16 h) are shown in Fig. 1(a) and Fig. 1(b) respectively.

Fig. 2 presents the effect of temperatureon the relative dynamic viscosityof CuO/ (40:60) EG-water nanofluidin differentparticle volume fractions. As it is observed, with increasing solid concentrationin a particular Temperature, relative dynamic viscosity of nanofluid considerably increases. At higher solid volume fractions, a rise in temperature results in a more severe decrease in the relative dynamic viscosity. Fig. 2 also shows that at solid concentrations lower than 0.6%, addition of the nanoparticles to the nanofluiddoesn't has any significant effect on its relative viscosity. In general, Rheological behavior of CuO/ (40:60) EG-water nanofluid shows that with increasing temperature in a given solid volume fraction, the relative viscosity decreases. Of course, this trend is not correct for all the experimental data points.

Relative viscosity of CuO/ (40:60) EG-water nanofluid versus solid volume fraction in different

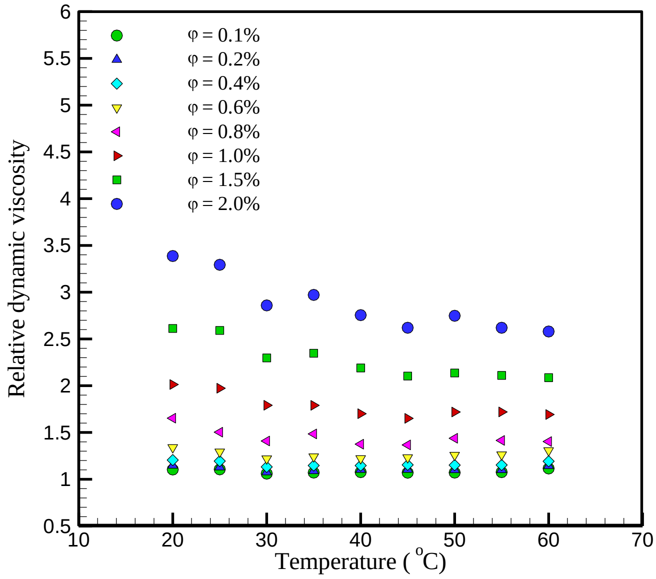


Fig. 2 Relative dynamic viscosity with respect to temperature at different solid volume fraction

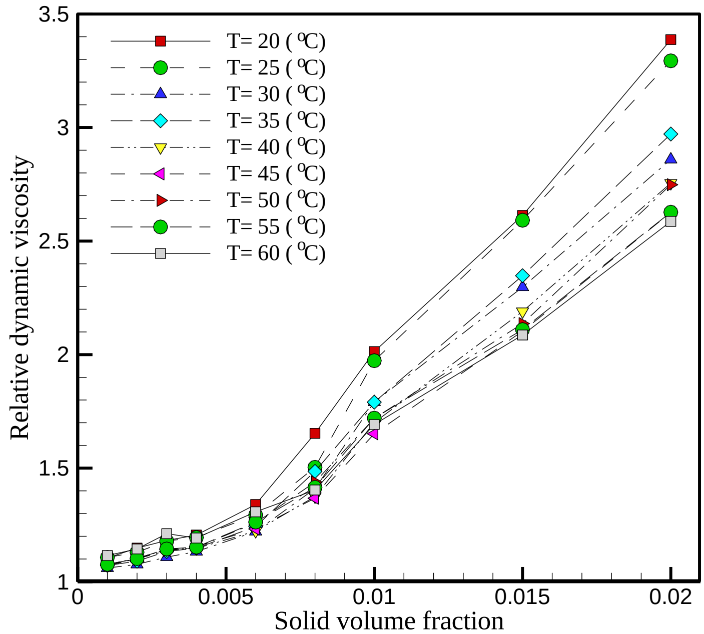
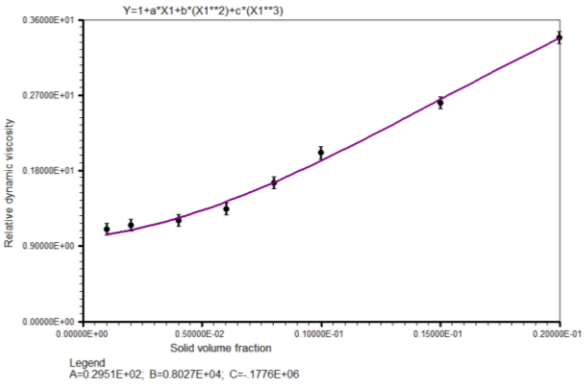


Fig. 3 Relative dynamic viscosity with respect to solid volume fractionat different temperature

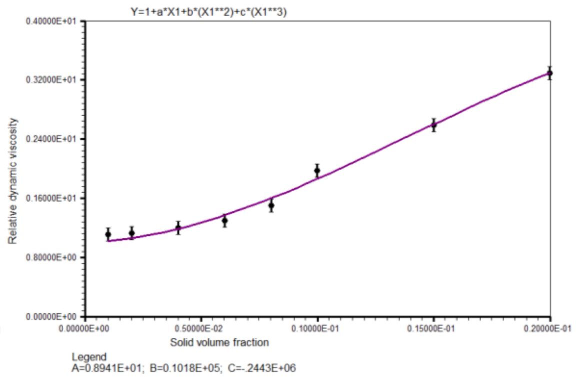
temperatures is shown in Fig. 3. It is obvious that the temperature at a high particle concentration is more effective on the relative viscosity than at low concentrations. The maximum effect of temperature on the relative dynamic viscosity of nanofluid occurs at solid concentration of 2%.On the other hand, it is observed that temperature doesn't have significant effect on relative viscosity at solid concentrations of lower than 0.6%.

Fig. 4 indicates a curve fitting on the experimental data at different solid volume fraction for



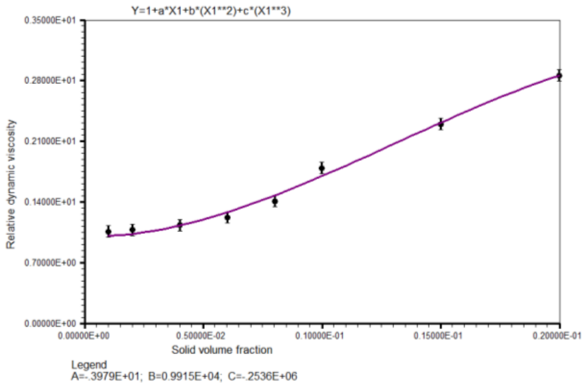
T= 20°C

(a)



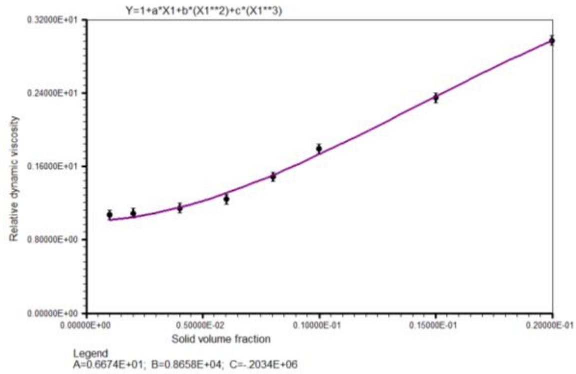
T= 25°C

(b)



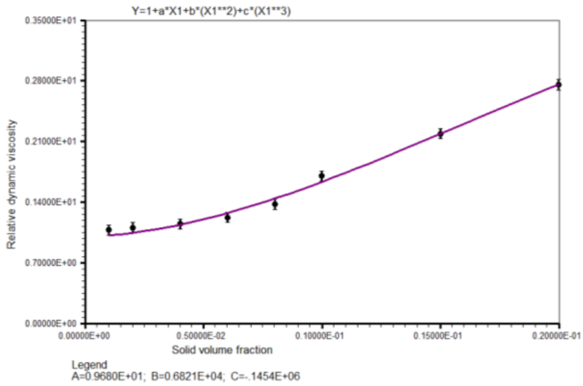
T= 30°C

(c)



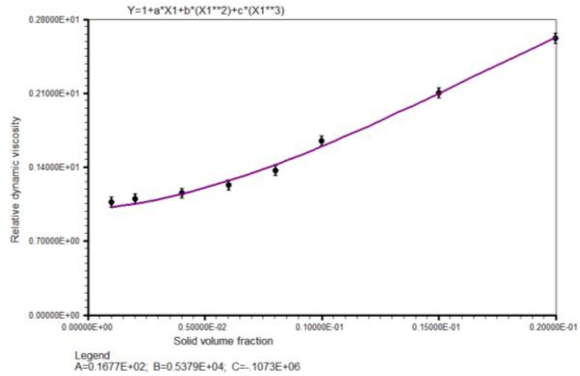
T= 35°C

(d)



T= 40°C

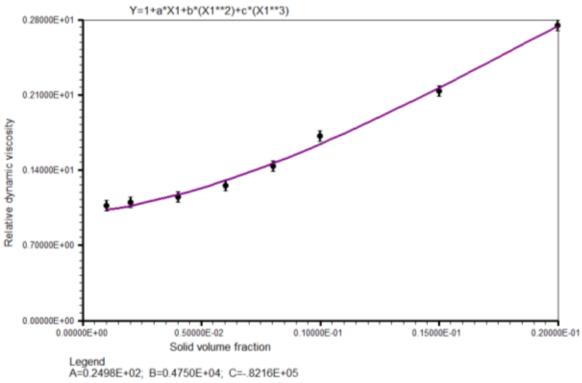
(e)



T= 45°C

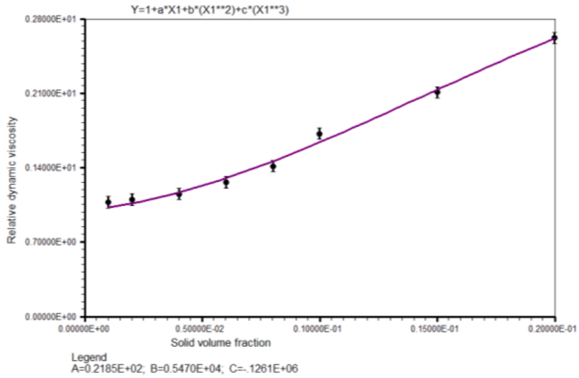
(f)

Fig. 4 Curve fitting of viscosity experimental data at various temperature and different solid volume fractions



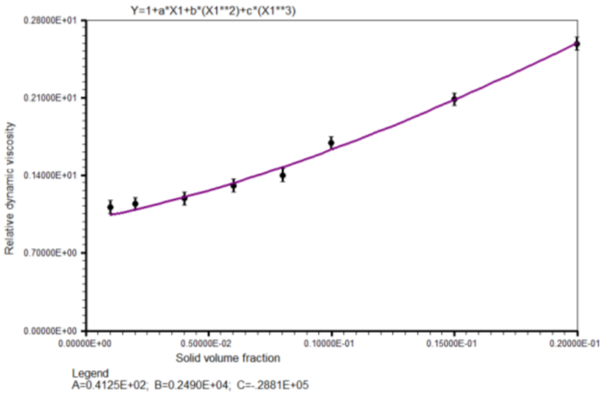
T= 50°C

(g)



T= 55°C

(h)



T=60°C

(i)

Fig. 4 Continued

each studied temperature. As it can be seen, curve fitting of data points in a specific temperature maylead to propose precise correlations for estimating dynamic viscosity.

A comparison between experimental data points and the values of proposed in Fig. 4 (a toi) shows the accuracy of the correlation to determine the relative viscosity of the nanofluid.

In order to develop models to predict effective dynamic viscsosity of nanofluid, some accurate models based on experimental measurements have been proposed in Table 1.

5. Margin of deviation

In the present study, margin of deviation is employed to examine the precision of proposed correlations. Margin of deviation can be calculated as follows

$$\text{Margin of deviation (\%)} = \frac{\mu_{\text{cor}} - \mu_{\text{exp}}}{\mu_{\text{exp}}} \times 100 \qquad (1)$$

Table 1 Proposed models to predict the dynamic viscosity of CuO/ (40:60) EG- water

Temperature	Proposed model
@ T=20	$\frac{\mu_{nf}}{\mu_{bf}}=1+29.51(\varphi)+8027(\varphi^2)-177600(\varphi^3)$
@ T=25	$\frac{\mu_{nf}}{\mu_{bf}}=1+8.941(\varphi)+10180(\varphi^2)-244300(\varphi^3)$
@ T=30	$\frac{\mu_{nf}}{\mu_{bf}}=1-3.98(\varphi)+9915(\varphi^2)-253600(\varphi^3)$
@ T=35	$\frac{\mu_{nf}}{\mu_{bf}}=1+6.67(\varphi)+8658(\varphi^2)-203400(\varphi^3)$
@ T=40	$\frac{\mu_{nf}}{\mu_{bf}}=1+9.96(\varphi)+6821(\varphi^2)-145400(\varphi^3)$
@ T=45	$\frac{\mu_{nf}}{\mu_{bf}}=1+16.77(\varphi)+5379(\varphi^2)-107300(\varphi^3)$
@ T=50	$\frac{\mu_{nf}}{\mu_{bf}}=1+24.98(\varphi)+4750(\varphi^2)-82160(\varphi^3)$
@ T=55	$\frac{\mu_{nf}}{\mu_{bf}}=1+21.85(\varphi)+5470(\varphi^2)-126100(\varphi^3)$
@ T=60	$\frac{\mu_{nf}}{\mu_{bf}}=1+41.25(\varphi)+2490(\varphi^2)-28810(\varphi^3)$

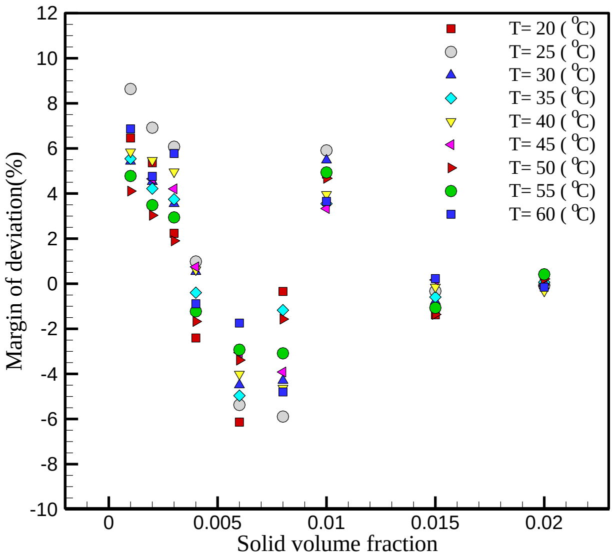


Fig. 5 margin of deviation with respect to solid volume fraction of nanoparticles

Where μ_{cor} is the dynamic viscosity obtained from the correlations, and μ_{exp} is the dynamic viscosity of the nanofluid measured during the experiments.

Table 2 The averagevalues of margins of deviation for each solid volume fraction

φ	Average margin of deviation (%)
0.001	5.828442
0.002	4.714839
0.003	3.932493
0.004	1.053143
0.006	4.009644
0.008	3.299959
0.01	4.484301
0.015	0.672174
0.02	0.181403

Table 3 The average values of margin of deviation for each temperature

Temperature	Average margin of deviation (%)
20	6.460413
25	8.636328
30	5.425134
35	5.546508
40	5.847853
45	4.787089
50	4.107677
55	4.777802
60	6.86717

Fig. 5 illustrates the margin of deviation with respect to solid concentration for all temperatures considered in this work. It is confirmed that the proposed correlations have acceptable accuracy because the margin of deviation doesn't exceed 9%.

To have a better understanding, the average values of the margin of deviation, which are classified based on solid volume fraction and temperature, are provided in Tables 2 and 3.

As the tables show, the average margin of deviation is less than 5% in most solid volume fractions and temperatures.

6. Conclusions

In this study, the dynamic viscosity of CuO/ (40:60) EG-water nanofluid with solid volume fractions of 0.1%, 0.2%, 0.4%, 0.6%, 0.8%, 1%, 1.5% and 2% at a temperature range of 20 to 60^{o}C has been considered experimentally. The results of this investigation can be summarized as follows:

1- Dynamic viscosity of CuO/ (40:60) EG-water nanofluid increases with increase in particle volume fraction and decrease in temperature.

2- 9 different correlations are developed on experimental data points to predict the relative

dynamic viscosity of nanofluid at the different temperatures.
3- Acurve fitting on the experimental data at different solid volume fractions for each studied temperature has been drawn.
4- The margin of deviation with respect to solid concentration for all temperatures is presented and discussed.

References

Avsec, J. and Oblak, M. (2007), "The calculation of thermal conductivity, viscosity and thermodynamic properties for nanofluids on the basis of statistical nanomechanics", *Int. J. Heat Mass Trans*., **50**, 4331-4341.

Chen, H., Ding, Y. and Tan, C. (2007), "Rheological behavior of nanofluids", *New J. Phys*., **9**, 367-382.

Choi, H.J., Kwon, T.M. and Jhon, M.S. (2000), "Effects of shear rate and particle concentration on rheological properties of magnetic particle suspension", *J. Mater. Sci*., **35**, 889-894.

Ghorbanpour Arani, A. and Kolahchi, R. (2014), "Exact solution for nonlocal axial buckling of linear carbon nanotube hetero-junctions", *Proc IMechE Part C: J. Mech. Eng. Sci.*, **228**, 366-377.

Ghorbanpour Arani, A., Kolahchi, R. and Zarei, M.Sh. (2015), "Visco-surface-nonlocal piezoelasticity effects on nonlinear dynamic stability of graphene sheets integrated with ZnO sensors and actuators using refined zigzag theory", *Compos. Struct.*, **132**, 506-526.

HemmatEsfe, M., Abbasian Arani, A.A., Karimipour, A. and MirtalebiEsforjani, S.S. (2014), "Numerical simulation of natural convection around an obstacle placed in an enclosure filled with different type of nanofluid", *Heat Transf. Res*., **45**(3), 279-292.

Kulkarni, D.P., Das, D.K. and Chukwu, G.A. (2006), "Temperature dependent rheologicalproperties of copper oxide nanoparticles suspension", *J. Nanosci. Nanotechnol.*, **6**, 1150-1154.

Kwak, K. and Kim, C. (2005), "Viscosity and thermal conductivity of copper oxide nanofluid dispersed in ethylene glycol", *Korea-Australia Rheology J.*, **17**, 35-40.

Kwon, T.M., Jhon, M.S. and Choi, H.J. (1998), "Viscosity of magnetic particle suspension", *J. Mol. Liq*., **75**, 115-126.

Lee, J.H., Hwang, K.S., Jang, S.P., Lee, B.H., Kim, J.H., Choi, S.U.S. and Choi, C.J. (2008), "Effective viscosities and thermal conductivities of aqueous nanofluids containing low volume concentrations of Al2O3 nanoparticles", *Int. J. Heat Mass Trans*., **51**, 2651-2656.

Murshed, S.M.S., Leong, K.C. and Yang, C. (2008), "Investigations of thermal conductivity and viscosity of nanofluids", *Int. J. Thermal Sci.*, **47**, 560-568.

Namburu, P.K., Kulkarni, D.P., Misra, D. and Das, D.K. (2007), "Viscosity of copper oxidnanoparticles dispersed in ethylene glycol and water mixture", *Exp. Thermal Fluid Sci.*, **32**, 397-402.

Nguyen, C.T., Desgranges, F., Galanis, N., Roy, G., Maré, T., Boucher, S. and Mintsa, H.A. (2008) "Viscosity data for Al_2O_3-water nanofluid-hysteresis: is heat transfer enhancement using nanofluids reliable?", *Int. J. Thermal Sci*., **47**, 103-111.

Pak, B.C. and Cho, Y.I. (1998), "Hydrodynamic and heat transfer study of dispersed fluidswith submicron metallic oxide particles", *Exp. Heat Transfer.*, **11**(2), 151-170.

Phuoc, T.X. and Massoudi, M. (2009), "Experimental observations of the effects of shearrates and particle concentration on the viscosity of Fe2O3-deionized waternanofluids", *Int. J. Thermal Sci*., **48**, 1294-1301.

Prasher, R., Song, D., Wang, J. and Phelan, P. (2006), "Measurements of nanofluid viscosityand its implications for thermal applications", *Appl. Phys. Lett.*, **89**, 108-133.

Rabani Bidgoli, M., Karimi, M.S. and Ghorbanpour Arani, A. (2015), "Viscous fluid induced vibration and instability of FG-CNT- reinforced cylindrical shells integrated with piezoelectric layers", *Steel Compos. Struct.*, **19**, 713-733.

Wang, B.X., Zhou, L.P. and Peng, X.F. (2004), "Viscosity, thermal diffusivity and Prandtl number of nanoparticle suspension", *Prog. Nat. Sci.*, **14**, 922-926.

Yang, M.C., Scriven, L.E.and Macosko, C.W. (1986), “Some rheological measurements on magnetic iron-oxide suspensions in silicon oil”, *J. Rheol.*, **30**, 1015-1029.

CC