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Investigation on the Electrical Conductivity of Aqueous Glycol based ZnO Nanofluids

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ABSTRACT

Nanotechnology research has proved sustainable results for a wide range of applications from engineering to medical science. Nanotechnology corresponds to the engineering of materials in nanosize (10^{-9}m) whose material properties differ from of bulk properties. Nanofluid is one category of applications reported for its use as thermal management in cooling of electronic devices and fuel cell applications. In most literature, electrical conductivity studies were used as a basis to define the stability of nano-suspensions. In the present paper, the electrical conductivity studies of two glycol based nanofluids dispersed with ZnO nanoparticles of 50nm average diameter in the temperature range of 30-55^{0}C are reported. ZnO nanoparticles are added to the aqueous glycol base fluid prepared with (30 EG: 70 Water) and (30 PG: 70 Water) composition at a low volume concentration of 0.01 to 0.05%. Correlations are developed using experimental results for each volume concentration to predict electrical conductivity (EC) of nanofluids with temperature. From obtained results, the electrical conductivity of aqueous propylene glycol shows a decrement in EC after adding ZnO nanoparticles (except at 0.04% volume concentration) and vice versa for aqueous ethylene glycol. For aqueous propylene and ethylene glycol nanofluids, electrical conductivity enhancement up to 20% and 12% is obtained at a volume concentration of 0.04% and 0.01% at 55^{0}C temperature respectively. The electrical conductivity of both nanofluids increases with increase in temperature at all volume concentrations.

Keywords: Electrical conductivity; ZnO-nanofluids; Aqueous glycol; Volume concentration; Temperature; Ion condensation effect.

1. INTRODUCTION

During the past two decades, exemplary research on the use of Nanotechnology concept for different fields of engineering is being done. The material of nano size is of much importance because of its wide applications in medical, thermal, optical, electrochemical, structural, etc,. Usually, metallic and ceramic nanoparticles show a huge difference in their functional properties when compared to micro size. Dispersing the nanoparticles in base fluids is termed as nanofluids which show enhanced properties compared to their base fluids (Choi *et al.,* 1995).

Research studies conducted by many scientists around the world proved the potential use of nanofluids for thermal management in electrical applications. In Proton exchange membrane fuel cell application, electrical conductivity properties of cooling fluid are required to judge the feasibility of the cooling system. In the electrical appliance, coolant with high electrical conductivity leads to the development of shunt current which will decrease efficiency and not safe for the user. Chip cooling system requires coolant with low electrical conductivity for better performance. Hence the characteristic properties of nanofluids can be analysed to employ them in specific applications. Usually, the stability and thermal conductivity of nanofluids are correlated with their electrical conductivity as reported in the literature (Zawrah *et al.,* 2015). According to Ashrae (2009) the thermal conductivity of aqueous ethylene glycol nanofluids is higher when compared with aqueous propylene glycol. However, both electrical and thermal conductivity are interrelated indirectly because of electron movements. Experimental studies on electrical conductivity property of ZnO based nanofluids are scarce in the literature.

Zinc-Oxide (ZnO) is an inorganic compound with antibacterial, magnetic, catalytic and semiconducting properties. It is also an add-on component for different products such as glass, rubber, paints, inhibitors, pigments, batteries, sealants, etc. (Marsalek, 2014). It is also used as radioactive shielding in electronic devices like mobile phones. Due to the large band gap of ZnO, it can withstand large electric fields with lower electronic noise (Brown, 1957). In nanofluids, suspended nanoparticles gain charge through the formation of electron double layer around the particle. Electrical conductivity increases with a decrease in particle size and an increase of volume fraction of nanofluids (White and Shih, 2010). Opposite charges forms layer of charged ions around the nanoparticle. The electrical conductivity of the ZnO particles increases by adding impurities. Water-glycol mixture is used as coolants in microchannels of electronic devices.

(Zawrah *et al.* 2015) did experiments with Al_2O_3 nanofluids and reported that the electrical conductivity of nanofluid increases for volume concentration till $\phi=0.2\%$, it starts decreasing when volume concentration increases to $\phi=0.5$ and $\phi=0.75\%$. They observed a linear increase in thermal conductivity values of nanofluids for increasing concentration but not electrical conductivity. (Dong *et al.* 2013) investigated the electrical conductivity of Aluminum-nitride-AIN-transformer oil nanofluid at different temperatures and found a nonlinear relation of the electrical conductivity with volumetric fraction and temperature. (Shen *et al.* 2012) observed the electrical conductivity of ZnO-insulated oil nanofluids, and with addition 0.75% volume fraction, they observed an increase of EC by 973 times. They observed the dependence of EC as a non-linear and linear variation for temperature and volume fraction of the nanofluids respectively. They also established a model for electrical conductivity of the nanofluid by considering both the Brownian motion and electrophoresis of the ZnO nanoparticles.

Alina Adriana Minea (2012) carried out the Investigations on electrical conductivity of stabilized water based Al_2O_3 nanofluids. Their experimental results showed the Al_2O_3 nanofluids increased their electrical conductivity with increasing volume fraction as compared to that of the base fluid, as well as with temperature increasing. A stronger influence on volume fraction was noticed. Electrical conductivity measurements for these nanofluids indicate an enormous enhancement (390.11 %) at 60 °C for a volume fraction of 4 %in distilled water.

Masuda (1993) reported a 30% increase in the thermal conductivity of water with the addition of 4.3 vol.% Al_2O_3nanoparticles. A subsequent study by Lee (1999) also examined the behaviour of Al_2O_3 nanoparticles in water, but observed only a 15% enhancement in thermal conductivity at the same nanoparticle loading. . These differences in behaviour were attributed to differences in average particle size in the two sets of samples. The Al_2O_3nanoparticles used by Masuda *et al.* had an average diameter of 13 nm, compared with 33 nm in the study by Lee *et al.* In the study conducted by (Faris *et al.* 2013) present new data for the thermal conductivity enhancement in four nanofluids containing 11, 25, 50, and 63 nm diameter Aluminum oxide (Al_2O_3) nanoparticles in distilled water. The thermal conductivity and thermal diffusivity were obtained by fitting the experimental data to the numerical data simulated for Al_2O_3 in distilled water.

The results show that, the thermal conductivity and thermal diffusivity enhancement of nanofluids increases as the particle size increases. Thermal conductivity and thermal diffusivity enhancement of Al_2O_3 nanofluids increase as the volume fraction concentration increases. This enhancement is attributed to the many factors such as, ballistic energy, nature of heat transport in nanoparticle, and interfacial layer between solid/fluids.

2. THEORETICAL MODEL FOR ELECTRICAL CONDUCTIVITY

Maxwell developed a model to predict the effective Conductivity of nanofluids having uniformly sized spherical particles as given below in Eq. (1) (White and Shih, 2010).

$$\frac{\sigma_{nf}}{\sigma_{bf}} = \frac{3(\alpha-1)\varphi}{(\alpha+2)-(\alpha-1)\varphi} \tag{1}$$

Equation (1) has the following three cases based on type of particle added:

a) $\alpha = 1-\frac{3}{2}\varphi$ For insulating particles, ($\sigma_p << \sigma_{bf}$)

b) $\alpha = 1$ For equally conducting particles, ($\sigma_p = \sigma_{bf}$)

c) $\alpha = 1+3\varphi$ For highly conducting particles, ($\sigma_p >> \sigma_{bf}$)

The electrical conductivity of nanofluids depends on several factors such as particle size, temperature, etc.. However, Maxwell model considers only volume fraction for calculating the effective conductivity of nanofluids. Hence, many correlations were developed later to achieve a precise result for the electrical conductivity of both metallic and non-metallic nanofluids using different base fluids. The Maxwell model cannot explain the electrical conductivity enhancement by the nanoparticles since it was developed for solid-liquid emulsions considering micron size particles; hence correlations need to be developed separately for each type of nanofluid (Nabati Shoghl *et al.* 2016). Aqueous Glycol is selected as base fluid and ZnO nanoparticles are dispersed to investigate their electrical conductivity.

3. MATERIALS AND METHODS

The glycol ZnO nanofluid is prepared by dispersing the nanoparticles in the aqueous propylene glycol and ethylene glycol in the ratio of 30:70 (Glycol: water). Zinc oxide nanoparticle of size 50nm was purchased from Anhui Elite Industrial Co., Ltd which is a subsidiary of Hong Kong Elite Industrial Group Limited. The nanoparticle size and shape are observed under High-Resolution Transmission Electron Microscope and the image obtained is shown in Fig. 1. The shape of Zinc Oxide nanoparticle is almost spherical as observed from the TEM images and the average size is found to be 50nm.

The formula used to find volume fraction of the nanoparticle is provided below (Zakaria, 2015).

Volume concentration,ϕ

$$\varphi = \left[\frac{\dfrac{W_{ZnO}}{\rho_{ZnO}}}{\dfrac{W_{ZnO}}{\rho_{ZnO}} + \dfrac{W_{bf}}{\rho_{bf}}} \right] \times 100 \qquad (2)$$

Where,

ϕ is the volume fraction of the nanoparticle.

W_{ZnO} and W_{bf} are the weight of nanoparticle and base fluids respectively.

ρ_{Zno} and ρ_{bf} are the density of nanoparticle and base fluids respectively.

Stabilized nanofluid is achieved with stirring and ultrasonication for 15 minutes and 90 minutes respectively. Initially, the pH of the ethylene and propylene glycol-water mixtures are measured and found to be 7.93 and 7.97 respectively. ZnO nanoparticles were added to 50 ml glycol-water solutions in the volume concentration range of 0.01% to 0.05%. Then, the mixture samples are stirred at higher RPM for 15 minutes using Magnetic Stirrer plus-MLH manufactured by REMI and subjected to ultrasonication (Ultrasonic probe sonicator, DP-120) for 90 minutes. The sonicator operates at a constant wavelength of 20 kHz and can work at a maximum power output of 750 W. Accurate speed control allows smooth variation up to 1200 rpm. MLH Series Magnetic Stirrers have additional stainless steel hot plate. Voltage regulator in the equipment controls the heat energy suppied to the fluid.

This process is controlled by a thermometer with the indicator. A heating plate embedded to the stirrer is used to obtain the required temperature of the fluid sample. The electrical conductivity of nanofluids is measured using EUTECH PC650 conductivity meter. The instrument has an accuracy of ±1% at full-scale accuracy up to the 3-decimal resolution. Initial calibration was done using standard potassium chloride solution with known conductivity. For reliability, Electrical conductivity of aqueous Propylene glycol (PG/W-30/70) is determined for three times and the same is compared with the standard values. A k-type thermocouple is used to inspect the change in temperature of nanofluids during EC measurements. Fig. 2 shows the comparative results of present experimental data for water and data of Sundar (2014). It can be observed that present data is in good agreement with the reference data (Sundar, 2014) having ±12% deviation, thus confirming the validity of measurements.

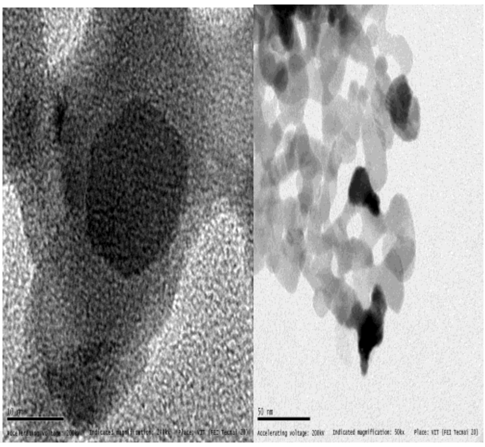

Fig. 1. TEM images of Zinc Oxide nanoparticle.

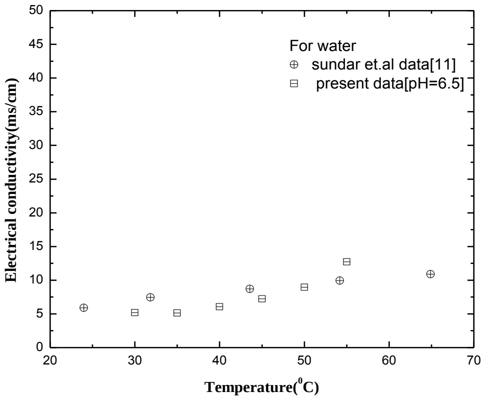

Fig. 2. Validation of the electrical conductivity instruments.

From literature ZnO nanoparticle electrical conductivity is found to be 1.62 µs/m (Shen, 2012). Electrical conductivity values of glycol mixture vary due to the purity of glycol and water which is tested and also with an accuracy of the instruments. Electrical conductivity enhancement of aqueous Propylene glycol and Ethylene glycol at different temperature and volume fraction of ZnO nanoparticles are studied. The electrical conductivity of the ZnO nanofluids changes with concentration of nanoparticle addition and size of the nanoparticles (White and Shih, 2010).

Results from the experimental data are analysed through graphs, Figs. 3 to 6 represent the electrical conductivity of nanofluids having ϕ =0.01-0.05% and temperature in the range of 30-55^{0}C. Figure 3 presents the change in electrical conductivity values of WEG-ZnO nanofluid having ϕ=0.0-0.05% with (30EG/70W) as a base fluid in the temperature range (30-55^{0}C). It can be observed that value of EC for WEG-ZnO nanofluid varies between 1400-2300 µs/cm in the temperature range of 30-55^{0}C. The EC value of the WEG-ZnO nanofluid at ϕ =0.01% show the highest and at ϕ =0.04% it is least. It is observed that addition of ZnO nanoparticles increases the value of EC only up to ϕ

=0.01% and then decrease with the further addition of particles compared to base fluid. ZnO nanofluids with ϕ=0.01% show maximum increase of 12% in EC values when compared with the base fluid at 55^0C. The reason for this behaviour might be due to the availability of conducting pathway which increases by the addition of nanoparticles to the base fluid leading to the enhancement of electrical conductivity. At ϕ=0.01%, the formation of surface charges is more due to the polarisation of nanoparticles when dispersed in a base fluid. This polarization leads to the increase in the thickness of the electric double layer, also oppositely charged ions are developed around the Nanoparticle surrounded by the base fluid.

Regression equations of the polynomial form are developed using measured values of EC at each volume concentration and temperature of WEG-ZnO nanofluids for the particle size of 50nm. However, the effect of temperature is observed to be more on EC values than particle addition. The EC values show almost a linear variation on increase in temperature for ϕ =0.01-0.05% as shown in Table 1.

Table 1 Electrical conductivity of WEG- ZnO nanofluids

Volume Concentration, ϕ %	Electrical Conductivity, σ μS/cm	R^2
0.01	$-0.1007T^2 + 41.331T + 352.14$	0.991
0.02	$-0.0343T^2 + 35.623T + 392.46$	0.9862
0.03	$-0.225T^2 + 50.051T + 134.66$	0.9764
0.04	$-0.185T^2 + 43.628T + 296.63$	0.9779
0.05	$-0.3364T^2 + 58.231T - 43.6$	0.9905

Figure 4 presents the enhancement in EC values WEG-ZnO nanofluid on volume concentration and temperature. It can be noticed that highest enhancement of 20-58% is measured for ϕ =0.01% compared to other volume concentration. Similarly, lowest enhancement of 5-52% is observed for ϕ=0.03%. The reason for this behaviour is due to less number of free electrons or ions to conduct at that temperature in the nanofluid suspension.

Figure 5 shows the change in electrical conductivity values of WPG-ZnO nanofluid having ϕ=0.0-0.05% with (30PG/70W) as a base fluid in the temperature range (30-55^0C). It can be observed that value of EC for WPG-ZnO nanofluid varies between 600-1400 μs/cm in the temperature range of 30-55^0C.The electrical conductivity of the nanofluids increases with increase in volume fraction of the nanoparticle and then start to decreases after particular volume fraction due to ion condensation effect. From the Fig. 5, nanofluids show an increase in electrical conductivity by increasing the volume fraction up to 0.04%. Furthermore, at ϕ=0.05%, an increase of EC begins to level off due to ion condensation effect in high charge surface regime. For ϕ=0.04%, WPG-ZnO nanofluids show up to 20% highest enhancement with base fluid (PG/W-30:70) due to high net electric charge density on particles surfaces which in turn electrophoretic mobility.

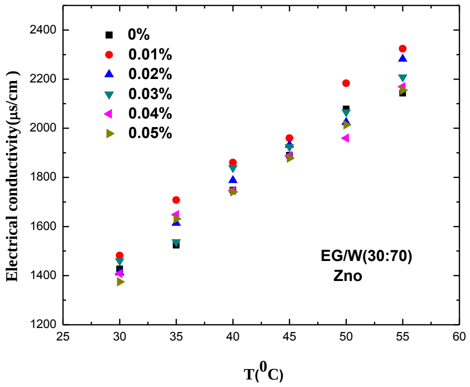

Fig. 3. Electrical conductivity of aqueous Ethylene glycol based ZnO nanofluid at different volume fractions and temperature.

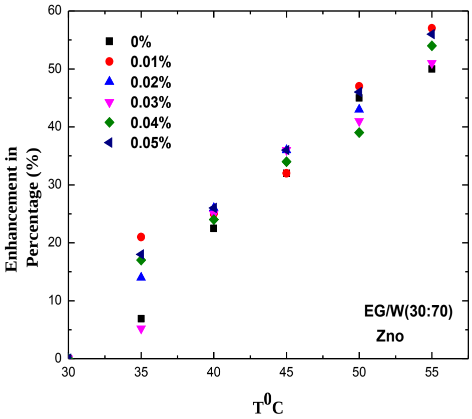

Fig. 4. Electrical conductivity enhancement of aqueous Ethylene glycol based ZnO nanofluid of different volume fractions against temperature.

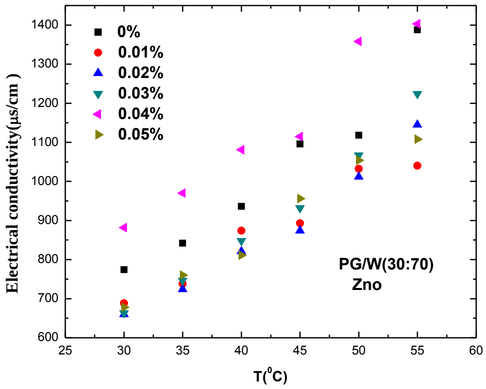

Fig. 5. Electrical conductivity of aqueous propylene glycol based ZnO nanofluid at different volume fractions and temperature.

Figure 6 presents the enhancement in EC values WPG-ZnO nanofluid on volume concentration and temperature. It can be noticed that highest enhancement of 12-86% is measured for ϕ=0.03% compared to other volume concentration. Similarly, lowest enhancement of 6-50% is observed for ϕ=0.01%. Enhancement in EC value for each volume concentration is almost linear with temperature. The maximum enhancement of EC value is achieved at a higher temperature (55^0C) for all volume concentration.

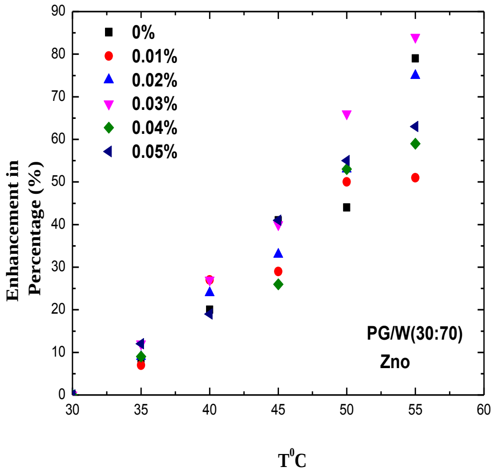

Fig. 6. Electrical conductivity enhancement of aqueous propylene glycol based ZnO nanofluid of different volume fractions against temperature.

Regression equations of the polynomial form are developed using measured values of EC at each volume concentration and temperature of WPG-ZnO nanofluids for the particle size of 50nm as shown in Table 2.

Table 2 Electrical conductivity of WPG- ZnO nanofluids

Volume Concentration, ϕ %	Electrical Conductivity, σ µS/cm	R^2
0.01	$-0.1414T^2 + 27.227T - 13.886$	0.9596
0.02	$+0.3636T^2 + 11.806T + 691.23$	0.9943
0.03	$+0.3586T^2 - 8.4671T + 599.37$	0.998
0.04	$+0.2236T^2 + 2.7279T + 598.77$	0.9615
0.05	$+0.0343T^2 + 15.24T + 182.37$	0.9828

4. CONCLUSION

This study is concerned about the measurement of electrical conductivity for two different aqueous glycol based nanofluids dispersed with ZnO nanoparticles. The ZnO nanoparticles of 50 nm average diameter are added to (30:70) Glycol: Water mixture at ϕ=0.01%-0.05% and measurements are made in the temperature range of 30-55^0C. The following observations are made in the study.

Transport properties of the ZnO nanofluids vary on base fluids, temperature and volume fraction of nanoparticles. For aqueous propylene and ethylene glycol nanofluids, higher electrical conductivity enhancement up to 20 % and 12% is obtained at a volume concentration of 0.04% and 0.01% between temperature range (30 -55^0C) respectively.

From the present results, aqueous propylene glycol nanofluids are recommended as coolants for electronic applications because of its low electrical conductivity than aqueous ethylene glycol nanofluids in the range of volume fraction and temperature considered. Further, detailed life cycle analysis for same nanofluids must be conducted in future to ensure the consistency of specific properties for a longer duration.

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