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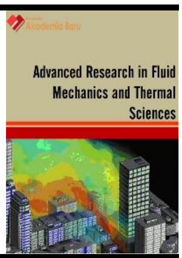

Thermal Conductivity and Viscosity Measurement of ZnO Nanoparticles Dispersing in Various Base Fluids

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ABSTRACT

In this paper, the Zinc oxide (ZnO) nanopowders suspended in three various base fluids water, Ethylene glycol (EG), and 50%EG+50%W are prepared experimentally. Both nanofluids and base fluids thermal conductivity and viscosity have measured and validated with available experimental and standard data. The hot wire mode and viscometer were utilized to measure the thermal conductivity and viscosity of ZnO nanofluid volume fraction with the range of 0.3 to 1.7% under initial condition temperature of preparation from 25^{o}C to 55^{o}C. Results offer the thermal conductivity enhancement and viscosity increasing by 23% and 52% respectively as increasing in volume fraction whereas, the thermal conductivity enhancement and viscosity decreasing with temperature increasing by 27% and 18% respectively. It observes that the measured data have good agreement with other researchers' data available in the literature with deviation less than 6%. The ZnO nanoparticle suspended in water has the elevated values of thermal conductivity and lowest worth of viscosity while, ZnO nanoparticle suspended in EG has the lowest values of thermal conductivity and highest values of viscosity.

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1. Introduction

The energy consumption demand is increasing continuously. The nanofluids thermal properties of the traditional fluid are the essential hindrance for ameliorative the efficiency of various devices. In arranging to overcome with this determination, preamble of nanoparticles in a traditional fluid can be deeming to lever up heat transfer capability of these fluids. The component that creates (nanofluids) will have improved heat transfer ability, even with a small particle percentage [1-5]. Experimental study of hybrid nanoparticles suspending in water to reduce the pumping power and growing heat transfer of heat exchanger carried out by Hussein *et al.,* [4] were utilize one-step physical mode, Lee *et al.,* [6] were studied the enhancement of thermal conductivity for ZnO nanofluids. It was shown; the thermal conductivity at higher concentration has high dependency of temperature. Experimental values were higher than Hamilton-crosser model and the nanofluids

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display Newtonian conduct. The theory outcomes specified that the nanofluid thermal conductivity was confirmed like base fluid. Metals possess higher thermal conductivities than those of fluids at room temperature as shown in Table (1) [7].

In order to measure the thermal conductivity of graphene nanofluids, the transient hot-wire mode has been adopted experimentally by Gupta *et al.,* [8]. Their study also scrutinized graphene oxide nanofluids and carbon nanotube (CNT). The results showed that the magnitude of enhancement was between carbon nanotube and metal oxide/metallic nanofluids. Li *et al.,* [9] investigated on two abnormal phenomena regarded to increase of thermal conductivity for Boron Nitride/EG nanofluids. The findings show that there is abnormal increment of thermal conductivity at very low concentration and at different particle size due to nanoparticles aggregation, because of the surface area difference as well as aspect proportion. For Al_2O_3 alone, many researches have done on various types of nanoparticles size, concentration and temperature.

Utilizing two types of nanoparticles CuO, SiO_2 with a various base fluid such as EG and water was studied by Peñas *et al.,* [10]. They were measured the thermal conductivity by using multi stream hot-wire method. The nanofluid concentrations were 5% in mass fraction. The said study particular that the results in a good agreement within 2%. Optimizing nanofluids thermal conductivity have been proposed by Xie *et al.,* [11] the study concluded various nanoparticles encompassing different sizes of Al_2O_3, SiC with various shapes, MgO, ZnO, Fe_3O_4, TiO_2, SiO_2, diamond and nanotubes. The base fluids have been used pure water, ethylene glycol, silicone oil, glycerol carbon and the EG and pure water bilateral mixture. The authors notified that the nanofluid thermal conductivity enhancements might be affected by number of parameters such as the nanoparticles size, the volume concentrations of nanoparticles, the examined temperature and thermal conductivity of the base fluid, the additives and the pre-treatment process of the fluids. Another realization behaved by Beck *et al.,* [12] which focused on the Al_2O_3 nanoparticles thermal conductivity sprinkled into ethylene glycol. It was appeared that the nanofluid thermal conductivity follows the base fluid behaviour ethylene glycol. In addendum, the nanofluid offered the summit value of thermal conductivity at an approximately self-same temperature in perspicuous base fluid. Meanwhile, Chadwick *et al.,* [13] thoughtful on the rheological conduct of titanium oxide in EG where the findings showed that increased in concentration would increase the viscosity.

In this study, ZnO nanoparticles suspended in three types of base fluids (water, EG and 50%EG+50%W) prepared in laboratory as well as the measurement of thermos-physical properties have been performed experimentally. Results are validated with standard and other researcher's data available by comparison.

2. Methodology

The two-step method has been employed for nanofluids preparation. This method involves preparing the nanoparticles in a form of powder by the manufacturer which is Nova Scientific Resources (M) Sdn. Bhd, then suspending it in distilled water. By double distillation, water was willing in laboratory before using it for the test. The nanoparticles have selected with size diameters 40nm. In order to achieve a homogenously dispersed solution, mechanical stirrer was utilized. After that the mixture (ZnO and water) subjected to ultrasonic around 3h to violate up any superfluity agglomerations [13]. To calculate the required quantity of ZnO (mp), the following equation was used with accuracy (0.001 g) [14]

$$\phi = \left(\frac{m_p}{(m_p + m_f)}\right) * 100$$

$$\varphi = \frac{\left(\frac{m_p}{\rho_p}\right)}{\left(\frac{m_p}{\rho_p}+\frac{m_w}{\rho_w}\right)} \times 100 \quad (1)$$

Depending on nanoparticles density (ρ_p) and base fluid density (ρ_f) at 25°C, Eq. (1) becomes

Table 1
Thermophysical properties of basefluid

	Water	EG
Thermal conductivity	0.6 W/m.°C	0.24 W/m.°C
Viscosity	1 mPa.s	13.646 mPa.s

$$\varphi = \frac{\frac{m_p}{\rho_p}}{\frac{m_p}{\rho_p}+\frac{m_f}{\rho_f}} \quad (2)$$

There are many of researchers used retreating equations of specific heat capacity (C_{nf}) and density (ρ_{nf}) as [15]

$$\rho_{\mathrm{nf}} = \left(\frac{\varphi}{100}\right)\rho_p + \left(1-\frac{\varphi}{100}\right)\rho_f \quad (3)$$

$$C_{nf} = \frac{\frac{\varphi}{100}(\rho C)_p+\left(1-\frac{\varphi}{100}\right)(\rho C)_f}{\rho_{nf}} \quad (4)$$

The transitory hot-wires mode is shown in Figure 1(a) is applied to measure the nanofluids thermal conductivity experimentally. The wire was immersed in the container containing the fluid whose need measure of thermal conductivity. In Order to quantity higher than that of else metals, the wire materiality (platinum) has high electrical resistivity as well as high temperature coefficient of impedance. The electrical resistivity, temperature coefficient of impedance, and wire diameter is 1.06 × 10−7Ω m, 0.0003925 ◦C−1 and 100 µm, respectively [13].

Calibration method was employed with standard fluid (glycerin) which was previously imparted with equipment. Standard deviation between the reading data and standard is 1.5%. After that, the verification has been conducted by utilizing the pure water and the standard fluid to get 2.5% standard deviation.

The spherical nanoparticle thermal conductivity ratio dispersed in liquids has been theoretically evaluated by Maxwell in 1904 [1]. Moreover, for non-spherical nanoparticles suspended in liquids the Hamilton and Crosser model have been applied by Hamilton and Crosser in 1962 [1]. In addendum, there are much classic models in this way like research by Davis in 1986 and Bruggeman in 1935 [1].

The standard deviation of the measured results for each nanofluid and temperature were less than 0.15% in all tested cases. Viscosity is significant indicator of the evaluation of the nanofluids thermophysical properties. A Brookfield prime viscometer (shown in Figure 1(b)) was used for viscosity measurement at different rpm and temperatures. This device has more options for measuring a different domain of viscosity for both Newtonian and non-Newtonian liquids. In addition, it has more accuracy especially for low viscosity as well as it allows getting the self-same shear rate anywhere. By tuning a domain of rotation velocity (rpm), various shear rate values can be tested, in order to discover the liquid rheological behaviour and locate its viscosity rate. Besides these parameters, torque value is well planned. Following that, the cylinder was fixed on the viscometer carefully and after 8 minutes of water bath; the sample is tested to find the lower and upper boundaries (rpm) and taking into account their torque worth. When these values were found, the program should be group rely on the former calculated boundary values. Deionized water was employed to measure viscosity for standardization, following whose nanofluids are utilized to measure viscosity. In spite of the manufacturer's standardization of the viscosity device, it must be checked for accuracy.

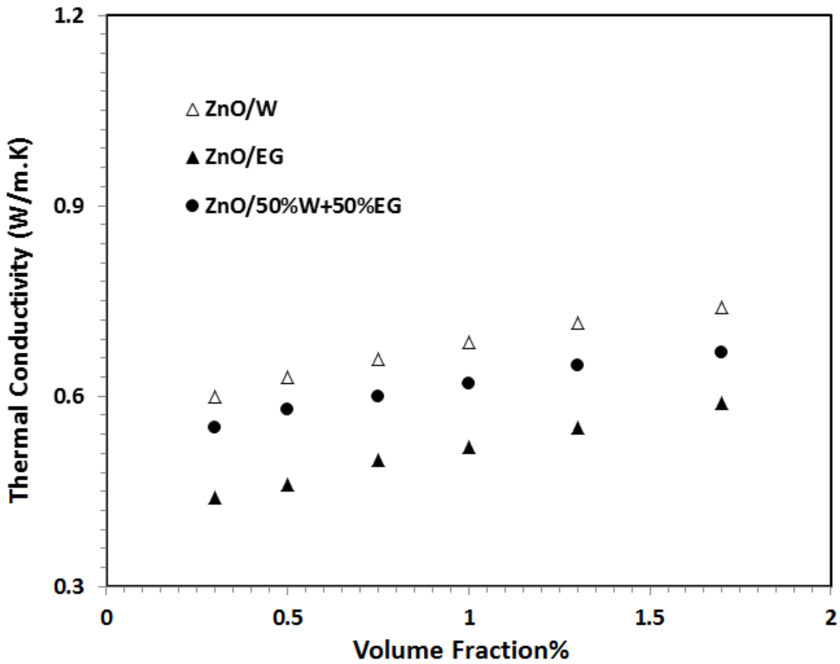
(a) (b)

Fig. 1. Measurements equipment; (a) Thermal conductivity equipment (b) Viscosity equipment

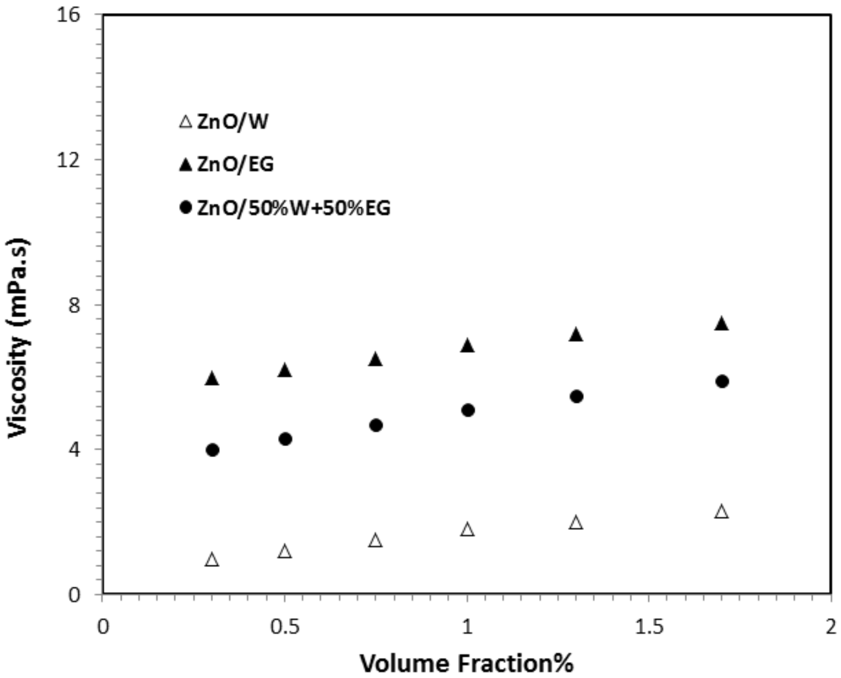
3. Results and Discussion

Thermal conductivity and viscosity were always increased when nanopowders addition on base fluid to prepare nanofluid. Furthermore, thermal conductivity increases and viscosity decreases the increasing of temperature.

Figure 2 shows the thermos-physical properties with volume fraction of ZnO dispersed in water, EG and 50%EG+50%W at 25°C. Figure 2(a) indicated thermal conductivity against the concentrations volume of nanoparticle. It can be observed that the enhancement of thermal conductivity is approximately 12%, 7%, 13% and 15% from 1% to 4% volume fraction for ZnO suspended in EG, water and 50%EG+50%W respectively. It can be mention that the thermal conductivity values are too high for nanoparticles dispersed in water but too low for nanoparticles suspended in EG. Likewise, the enhancement of thermal conductivity is increasing rapidly with 50%EG+50%W, as compared to EG base fluid due to water thermal conductivity impact. Figure 2(b) showed the effect of nanofluid volume concentrations on the nanofluid viscosity. It was observed that the viscosity of nanofluid increases due to the nanoparticles volume concentrations increase. It can be noted that the nanofluid viscosity enhancement is approximately 30% and 80% for 1% and 4% respectively as compared to base fluids. The nanofluids viscosity becomes almost constant value with few changes as compared to base fluids viscosity, which was taken right after preparation [16-18].



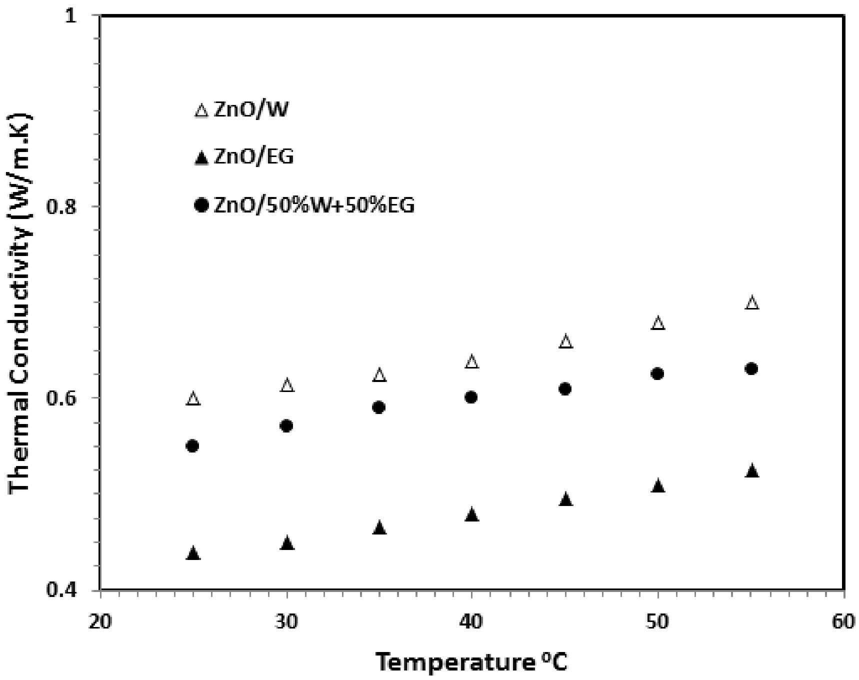
(a) Thermal conductivity



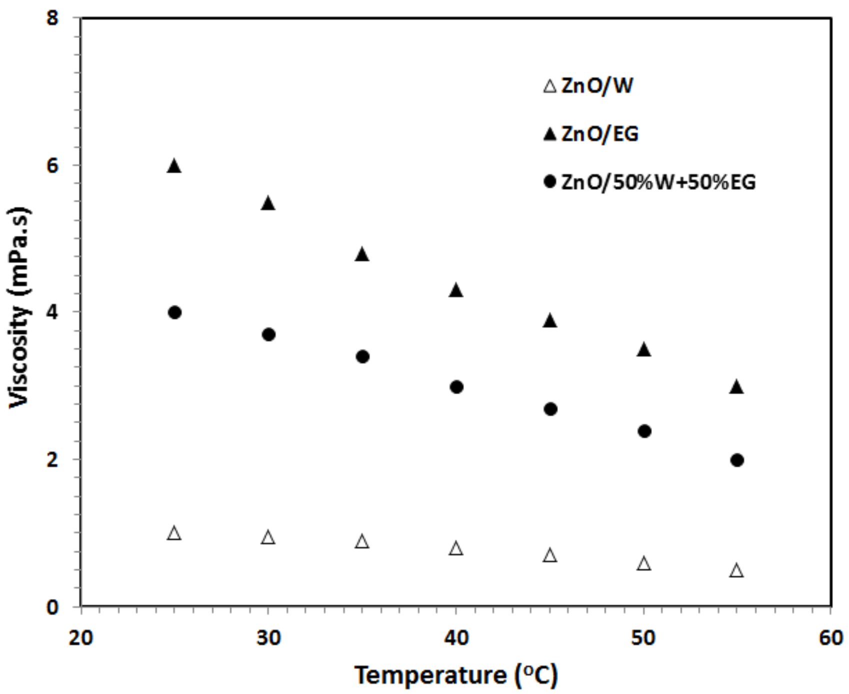
(b) Viscosity

Fig. 2. The effect of the nanofluid volume fractions on the thermo-physical properties

Thermal properties of ZnO nanoparticles suspended in EG, water and 50%EG+50%W respectively have been indicated in Figure 3. The measured thermal conductivity values have been tended to increase with increasing of temperature in Figure 3(a). The nanofluid thermal conductivity increases slightly as compared to water. The measurements on top of 50°C are not considered as the accuracy of thermal conductivity measured. The reason to focus to the reading less than 50oC is the reducing of nanofluid viscosity and the readings will not stable and scattered then it will not represent a true value for the nanofluid thermal conductivity [9]. The nanofluid viscosity was measured at various temperatures and illustrated in Figure 3(b). Firstly, the distilled water viscosity has been measured for apparatus calibration, and ensuring the reading is on the right side. It was observed that the viscosity of nanofluid decreases with temperature increase. This behaviour represents a decrease in viscosity by 60% and 27% from 25°C to 50°C for water and EG respectively as a base fluid. The reason for the decrease in the viscosity as temperature increases is the thermal energy that gives the molecules the ability to move faster, which decreases the resistance to flow [13].



(a) Thermal conductivity



(b) Viscosity

Fig. 3. The thermos-physical properties of nanofluid with temperature

The data measured of thermal properties should compare with other researchers' data to be validated. Previous data comparison is not easy due to many parameters affecting against behaviour of nanofluid as employed the pH values or preparation method.

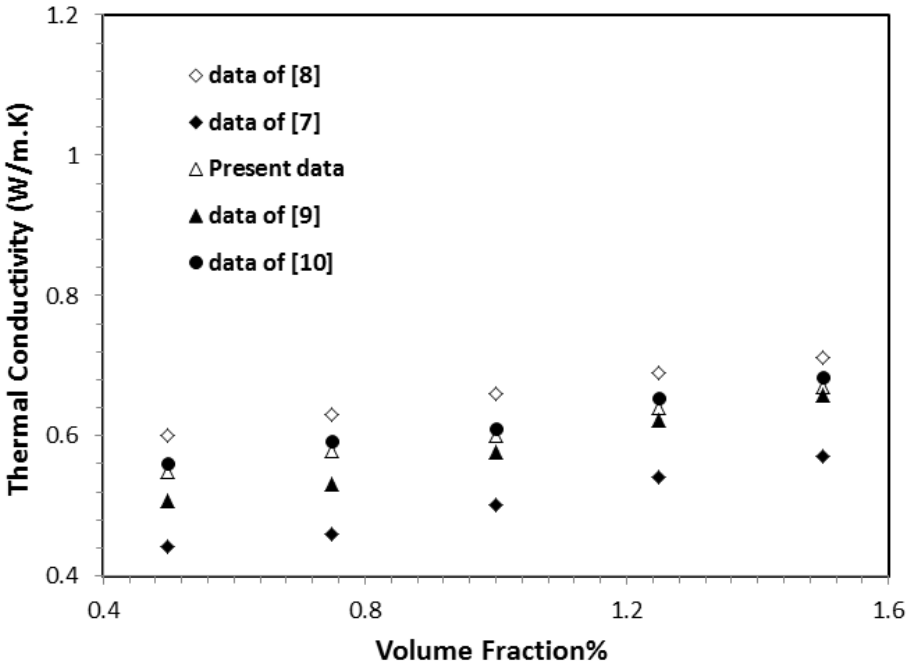
Figure 4(a) indicates the thermal conductivity validation for SiO_2-Water with experimental data of researchers as [4-9]. The thermal conductivity has the same behaviour as increasing with the concentrations volume of nanofluid increasing by 25% approximately deviation. It should be suggested that there might be a complex mechanism involved between the base fluid and the nanoparticle depending upon the nanoparticle size, volume fraction and interaction between the base fluid and the nanoparticle. The thermal conductivity of nanofluids enhancement is increased as temperature increase for all volume concentrations. Finally, there are good agreement between data measured and other experimental data. The values calculated from Maxwell in 1904 and Bruggeman in 1935, models indicated as a dash dot and solid black lines respectively. It can be seen that the correlations clearly under predicts the thermal conductivity enhancement.

The nanofluid viscosity weighted values are compared to the other researchers' experimental data and models to be validated. The plot between the relative viscosity of ZnO/W nanofluid at different volume fraction of nanoparticle shows in Figure 4(b).

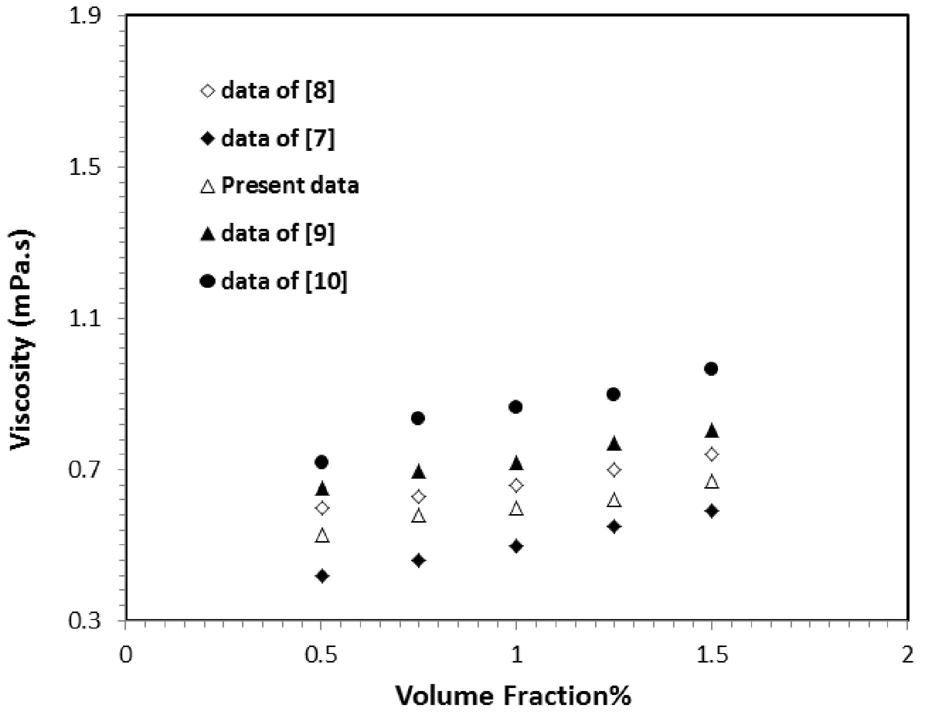
It was memorable that the viscosity increases as increase of nanofluid volume fraction [10-14]. This refers to capable to make the use of these nanofluids questionable for practical applications. However, if a good balance between the increased viscosity and the rate of heat transfer achieved, this nanofluid might find its way for practical purpose. The reason may be related to number of parameters as pH meter, preparation method of nanofluid and size diameter. The present data of viscosity ratio are among these data with deviation not more than 20%.

The of thermal conductivity enhancement (*k%*) represented percentage deviation of nanofluids thermal conductivity against base fluid that can be estimated as [6]

$$k\% = \left(\frac{k_{nf}-k_f}{k_{nf}}\right) * 100 \quad (5)$$



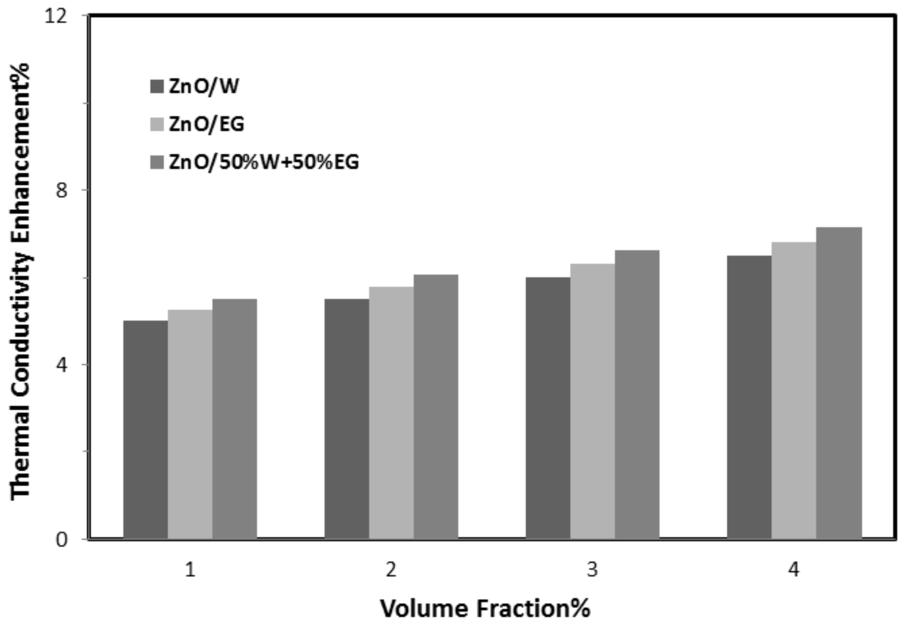
(a) Thermal conductivity validation



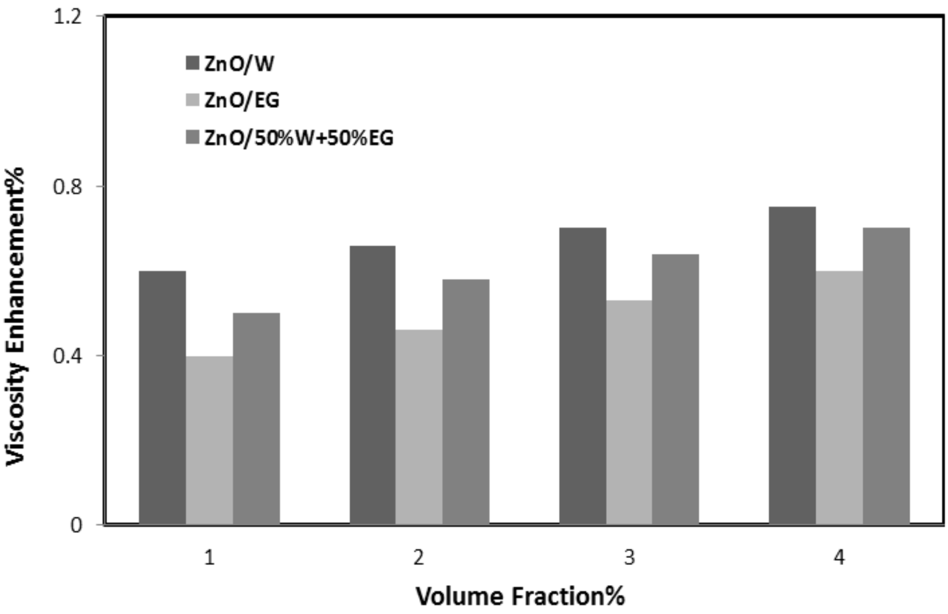
(b) Viscosity validation

Fig. 4. Validation of experimental data

The thermal conductivity enhancement illustrated in Figure 5. The increases of thermal conductivity enhancement as temperature increases by 9%, 11%, 12% and 13% with base fluid EG, water and 50%EG+50%W respectively. It seems that significant using of these types of base fluids with ZnO as nanofluids compered to standard properties [19].



(a) Thermal Conductivity Enhancement



(b) Viscosity Enhancement

Fig. 5. Comparison among materials

4. Conclusion

In this study, Thermal properties of ZnO nanoparticles suspended in three types of base fluids (EG, water and 50%EG+50%W) have been measured experimentally. Nanofluids have prepared with 1, 2, 3 and 4% volume concentrations. Thermal conductivity has measured experimentally between 25°C and 50°C, by increment 5°C for each step. The thermal conductivity outcome indicated that the volume concentrations and temperatures increase due to increase of thermal conductivity of nanofluids by 20% as compared to base fluids. In addition, the increase of nanofluid volume fractions was led to increase of viscosity by 60%. Likewise, the increase in temperature has led to increase in thermal conductivity by 30% while the increase in temperature has led to decrease in viscosity by 20%. Thermal conductivity of ZnO solid nanoparticles suspended in water have the highest values followed by 50%EG+50%W and finally, the nanoparticles suspended in EG which have the poor thermal conductivity values. Likewise, viscosity of ZnO nanoparticles suspended in water have the lowest values followed by 50%EG+50%W and finally, the nanoparticles suspended in EG which have the highest viscosity values. The results of the thermal properties show that the experimental data are different from those acquired by other researchers can be caused by different parameters like different sources of particle, particle preparation, particle size, or even the measurement methods However, the measured data are in the safe side among the data available in the literature with deviation not exceeding 10%.

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