

Experimental investigation of viscosity and thermal conductivity of ethylene glycol/water nanofluids containing low volume concentration of CuO nanoparticles, MWCNT and their mixture

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Abstract

Thermal conductivity and viscosity of CuO/ethylene glycol/water, multi-walled carbon nanotubes (MWCNT)/ethylene glycol/water and CuO/MWCNT/ethylene glycol/water nanofluid systems were determined experimentally at a temperature range of 5 to 50 °C and very low concentration (less than 0.008 vol.%). The obtained results show that the thermal conductivity of nanofluids significantly increases with increasing nanofluid temperature. It is also verified that the enhancement in thermal conductivity of nanofluid systems containing mixed CuO/MWCNT is more than systems containing CuO or MWCNT individually. Analyses of the viscosity data indicate that the viscosity diminishes with increasing temperature. The higher concentrations of all nanofluid systems possess higher viscosity. The results also show that the viscosity of nanofluid systems containing mixed CuO/MWCNT is between the viscosities of the systems containing CuO and MWCNT individually.

Keywords: Nanoparticle, Nanofluid, Thermal Conductivity, Viscosity; Mixed CuO/MWCNT

1. Introduction

Suspended nanoparticles in various base fluids can alter the fluid flow and heat transfer characteristics of the base fluids. These nanocolloidal systems are called nanofluids by Choi [1] of the Argonne National laboratory. They are expected to have superior properties compared to conventional heat transfer fluids, as well as fluids containing micro-sized metallic particles. The much larger relative surface area of nanoparticles, compared to those of conventional particles, should not only significantly improve heat transfer capabilities but also should increase the stability of the suspensions. Also, nanofluids can improve abrasion-related properties as compared to conventional solid/fluid mixtures. Successful employment of nanofluids will support the current trend toward component miniaturization by enabling the design of smaller and lighter heat exchanger systems. For a nanofluid, the base fluid can be any liquid such as oil, water, ethylene glycol, or conventional fluid mixtures. The nanoparticles are carbon, metals, metal oxides, and inorganic materials with properties of no dissolution or aggregation in the liquid environment. Available studies have shown that nanofluids made from different nanoparticles and water, ethylene glycol, or engine oil can improve heat transport by more than 40% compared to that of the base fluid [2-9]. Two different works have been reported to show the effect of particle size [10] and the effect of base fluids (water, ethylene glycol, and ethylene glycol/water mixture) [11] on the thermal conductivity of alumina nanofluids. Patel et al. [12] reported an experimental investigation on thermal conductivity enhancement in some oxide and metallic nanofluids. Their research was performed on different base fluids of water, ethylene glycol, and transformer oil with particle volume fractions of more than 0.5 vol.%. Recently, Ozerinc et al. [13] presented a very well review on the enhanced thermal conductivity of nanofluids. In this review, there is a useful table that collected a summary of experimental studies of thermal conductivity enhancement by nanofluid systems with different particle sizes, particle types, base fluid, and particle concentrations. Some other studies have focused on nanofluid viscosity. For example, Kulkarni et al. [14] investigated the rheological properties of copper oxide nanoparticle suspension. They observed that copper oxide nanoparticles at volume fractions of 5–15% in water behaved as non-Newtonian fluids in the

temperature range of 5 to 50 °C. Prasher et al. [15] reported the effects of nanoparticle size, volume fraction, and temperature on the viscosity of aluminum-based nanofluids. Namburu et al. [16] studied the viscosity of copper oxide nanoparticles dispersed in ethylene glycol and water mixture. They reported that copper oxide nanofluids exhibit Newtonian behavior in ethylene glycol and water mixture for particle concentration varying up to 6.12%. Some research groups investigated either the viscosity or thermal conductivity of nanofluids. Wang et al. [17] studied CuO–water nanofluid with a particle size of 50 nm and the particle volume fractions from 2 to 4%. Kwak and Kim [18] studied the viscosity and thermal conductivity of copper oxide/ethylene glycol nanofluids. Murshed et al. [19] investigated the thermal conductivity and viscosity of TiO₂/water and Al₂O₃/water nanofluids. Their results on TiO₂–water nanofluids showed an increase of 60% over the viscosity of the base fluid for particle concentration up to 4.3%. For Al₂O₃–water fluid the increase was found to be about 82% at a particle concentration of 5%. The thermal properties of a distilled water-based MWCNT+Y₂O₃ combination with a 20:80 weight ratio were experimentally investigated. The results demonstrate that the thermal conductivity coefficient increases with both temperature and concentration, especially at high concentrations and high temperatures [20]. Lee et al. [21] studied the thermal conductivities and viscosities of aqueous nanofluids containing Al₂O₃ nanoparticles in the range of 0.01–0.3 vol.% and reported that the viscosity of the nanofluids decreased significantly with temperature and increased nonlinearly with the particle concentration. The motivations behind the current study are as follows. Firstly, as we know there is no experimental viscosity and thermal conductivity data on nanofluids containing a mixture of two different nanoparticles. Secondly, we couldn't find any experimental viscosity or thermal conductivity data at very low concentrations (infinite dilution) for nanofluids in the literature. In the present research work, thermal conductivity and viscosity of the following different nanofluid systems were measured: a) CuO/ethylene glycol/water, b) MWCNT/ethylene glycol/water and c) CuO/MWCNT/ethylene glycol/water. In all nanofluid systems ethylene glycol/water mixture (60:40 by weight) is the base fluid. In the later nanofluid system, the ratio of CuO and MWCNT was selected 50:50 by weight. All nanofluids were prepared at very low concentrations (less than 0.008 vol%) without any surfactant. Thermal conductivity and viscosity measurements were performed from 5 to 50 °C.

2. Experimental

2.1. Material

The copper oxide nanoparticles, with an average diameter of 60 nm and purity up to 99.95%, were purchased from Stanford Materials Co. The multi-walled carbon nanotubes (MWCNT) with an average diameter of 30 nm, average length of 1-10 μm and with purity higher than 95%, were prepared from PlasmaChem GmbH (Berlin). Ethylene glycol 99%, were purchased from Merck.

2.2. Sample preparation

The copper oxide nanoparticles, with an average diameter of 60 nm and a particle density of 6.35 g/ml, were purchased from Stanford Materials Co. The multi-walled carbon nanotubes (MWCNT) with an average diameter of 30 nm, an average length of 1-10 μm, and a particle density of 2.61 g/ml were prepared from PlasmaChem GmbH (Berlin). A two-step method is used to produce nanofluids with low concentrations of CuO, MWCNT, or CuO/MWCNT (50:50 by weight) nanoparticles from 0.0005 to 0.008 vol.% without any surfactant. The first step is to mix nanoparticles in ethylene glycol/water mixture (60:40 by weight), as base fluid. Since ultrasonic vibration breaks down agglomerates in the mixture, the next step is to homogenize the mixture using ultrasonic vibration. Sample preparation in the first step was carried out using a very sensitive mass balance with an accuracy of ±0.1 mg. The samples prepared by this technique were found to be stable for over 1 month with no visible sedimentation or settling.

2.3. Viscosity measurement

The viscosity was measured using a viscosity rotational type programmable viscometer (LV DVII+ Brookfield, Inc., USA) with a small sample adapter. The adapter consisted of a cylindrical sample holder, a water jacket and spindle. The viscometer drives the spindle immersed into the sample holder containing the test fluid sample. A wide range of spindle speeds are available in this viscometer (0–200 RPM). The spindle type and speed combinations will produce satisfactory results when the applied torque is between 10% and 100%; therefore, spindle types and speeds are selected in such a way that the torque values lie in this prescribed range. The temperature of the test sample is monitored by a temperature sensor embedded into the sample holder. The viscometer is connected to a computer which records the data automatically. The data collection is done by software (Wingather), which collects spindle RPM, torque, viscosity, shear stress, shear rate, temperature and time. The model has a specified accuracy of ±1%.

2.4. Thermal conductivity measurement

The thermal conductivity was measured using a Decagon devices KD2 thermal analyzer (Inc., USA). The instrument had a probe of 60 mm length and a 1.3 mm diameter and included a heating element, a thermistor and a microprocessor to control and measure the conduction in the probe. The instrument had a specified accuracy of less than 5% over the whole temperature range. The samples were maintained at several temperatures using a temperature- controlled thermostat bath. A number of measurements were taken for each sample and a mean of only those measurements with 'R²' value (correlation coefficient) greater than 0.995 were considered.

3. Results and discussion

Five different low concentration nanofluids of 0.0005, 0.001, 0.002, 0.004, and 0.008 vol.% were prepared by dispersing of CuO nanoparticles, MWCNT or CuO/MWCNT in the base fluid of ethylene glycol and water mixture. The thermal conductivity and viscosity of these nanofluid systems were measured precisely from 5 to 50°C.

3.1. The thermal conductivity of nanofluids

Fig. 2 shows thermal conductivity of CuO/ethylene glycol/water nanofluids as a function of particle volume concentration and temperature. As there is no significant increase in thermal conductivity of nanofluids with increasing concentration from 0.000 vol.% to 0.0005 vol.% or from 0.001 vol.% to 0.002 vol.%, the results related to just three concentrations (0.001, 0.004 and 0.008 vol.%) have been shown in Fig.1.

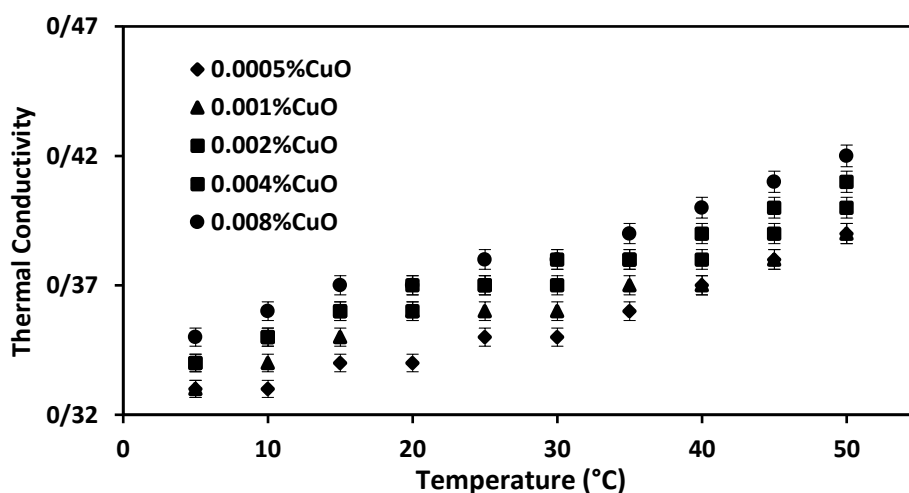


Fig. 1. Thermal conductivity of CuO/ethylene glycol/water nanofluids as a function of temperature and volume fraction.

The obtained results show that the thermal conductivity of nanofluids significantly increases with increasing nanofluid temperature. The same trend can be seen in Fig. 2 for MWCNT/ethylene glycol/water and in Fig. 3 for CuO/MWCNT/ ethylene glycol/water nanofluid systems. It can be clearly seen from Fig.1 to 3 that the enhancement in thermal conductivity ($(k_{nf} - k_{bf})/k_{bf}$) of ethylene glycol/water nanofluids containing CuO/MWCNT is more than MWCNT and it is more than CuO nanoparticles at all temperatures and concentrations. k_{nf} and k_{bf} refer to thermal conductivity of nanofluid and base fluid, respectively. In Table 1 the enhancement values in thermal conductivity at 50°C for the three nanofluid systems are collected. This is very interesting that in the same concentration, systems containing mixed CuO and MWCNT have more effect on the enhancement in thermal conductivity than CuO or MWCNT individually. This new foundation propose that CuO and MWCNT joining together and form a complex nanoparticle system with a different thermal properties in the nanofluid mixture.

Table 1. Enhancement in thermal conductivity (eq.1) of ethylene glycol/water nanofluids Containing CuO nanoparticles, MWCNT and their mixture, at 50 °C.

Concentration (vol.%)	0.001%	0.004%	0.008%
CuO	10.8	16.5	19.3
MWCNT	13.6	19.3	22.2
CuO/MWNT(50:50)	22.2	27.8	30.7

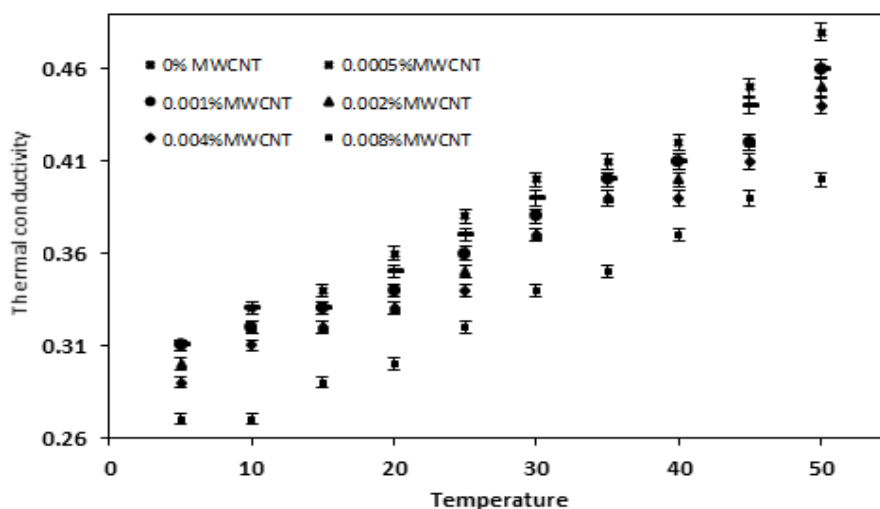


Fig. 2. Thermal conductivity of MWCNT/ethylene glycol/water nanofluids as a function of temperature and volume fraction.

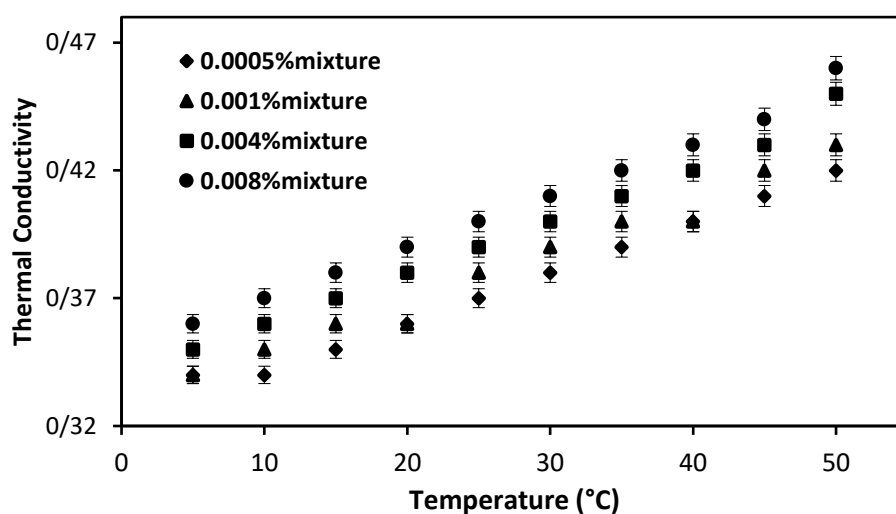


Fig. 3. Thermal conductivity of CuO/MWCNT/ethylene glycol/water nanofluids as a function of temperature and volume fraction.

Fig. 4 shows other interesting phenomena that in the lower range of temperature (from 5 to 25°C), the effect of CuO nanoparticles on increasing thermal conductivity is more than MWCNT and in the upper range of temperature (from 25 to 50°C) this effect is reverse. This observable fact can be seen for all three studied concentrations 0.001, 0.004 and 0.008 vol.% in Figures. 4a, 4b and 4c, respectively.

It means that the ability in thermal conductivity of nanofluids containing CuO or MWCNT at a fixed concentration at lower and upper range of temperatures is completely different.

Considering that in this research work, contrary to the general work done in the field of thermal conductivity, for the first time, the combination of MWCNT and CuO was used in very low concentrations, but the ratio of increase in thermal conductivity in this case was significant and compared to the works done in high concentrations are equal and sometimes more. In Table 2, a comparison has been made between this work and some previous works that have been done in high concentrations.

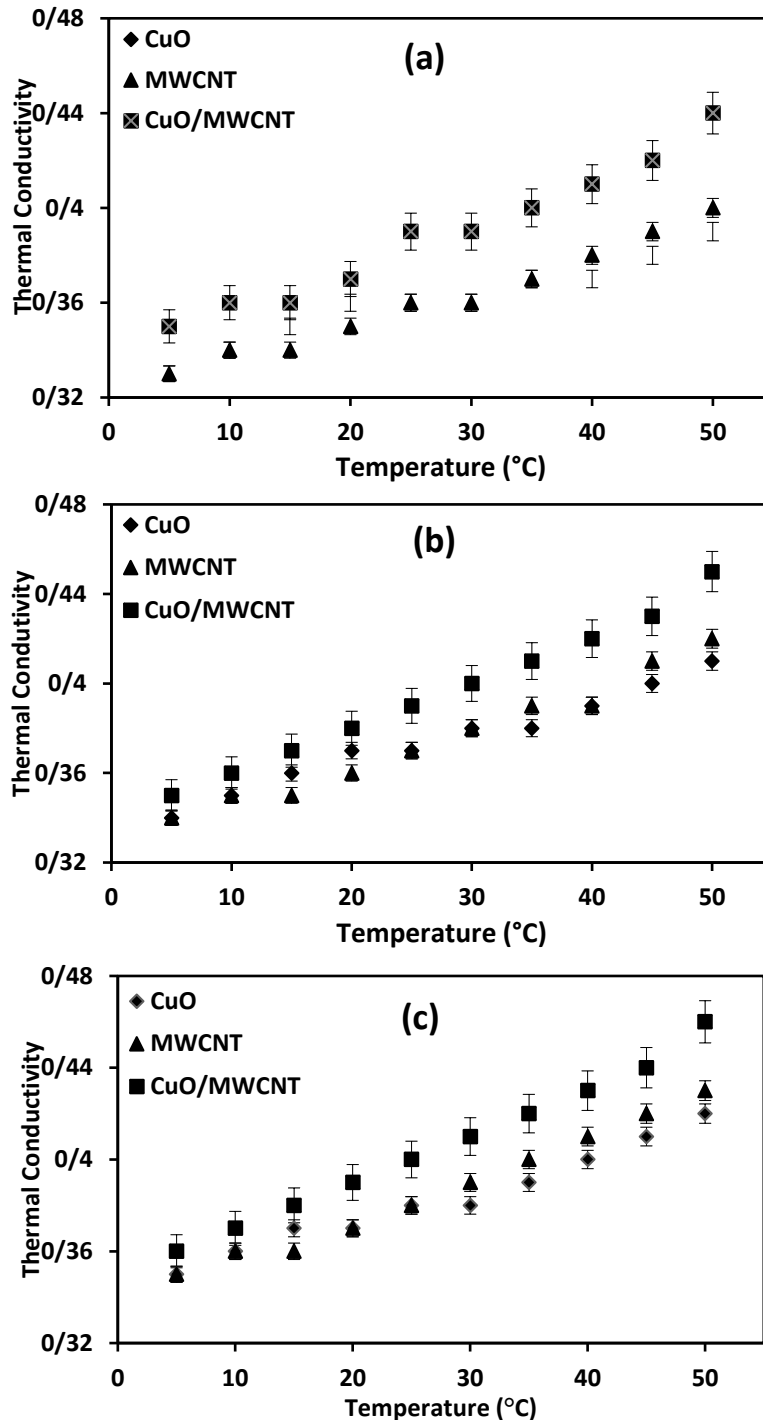


Fig. 4. Effect of nanoparticle type on thermal conductivity of nanofluids at fixed concentration: (a) 0.001 vol.%, (b) 0.004 vol.%, (c) 0.008 vol.%.

Table 2. Comparison of thermal conductivity in this work with previous works.

Nanoparticle	Base fluid (%)	Temperature Enhancement	Concentration	Enhancement (%)	Ref.
MWCNT	Water	15-75	0.01-3	48	[22]
MWCNT	Water	25-55	0.05-1	45	[23]
CuO	Ethylene glycol	Ambient	0.181.14	14	[24]
MWCNT/CuO (50:50)	Ethylene glycol /water(50:50)	5-50	0.0005-0.008	> 47	This work

3.2. The viscosity of nanofluids

First of all, it is necessary to verify if the nanofluids behave in a Newtonian or non-Newtonian manner. The equation governing Newtonian behavior of a fluid is given by (eq. 1):

$$\tau = \eta \dot{\gamma} \quad (1)$$

where τ is the shear stress, η is the coefficient of viscosity and $\dot{\gamma}$ is the shear strain rate. The obtained experimental results for all three nanofluid systems show that shear stress versus shear strain rate (eq.1) is linear with R^2 value greater than 0.995, over the whole temperature range of 5 to 50°C and for all concentration. A typical linear behavior for nanofluid system of CuO/MWCNT at 25°C and 0.008 vol.% is shown in Fig. 5. We believe that since ethylene glycol/ water mixture exhibits Newtonian behavior (Namburu et al. 2007), it dominates the rheological property and the three types of nanofluids behave like a Newtonian fluid with low concentrations of the nanoparticles.

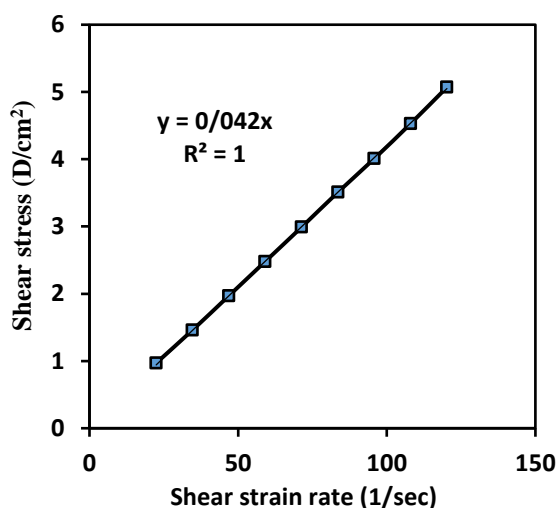


Fig. 5. Shear stress in dyne/cm² versus shear strain rate for 0.008 vol.% of CuO/MWCNT at 25 °C.

In contrast to thermal conductivity, viscosity of the nanofluids significantly increase with small increasing in concentration, so therefore all viscosity values related to the five concentrations of nanofluid systems from 0.0005 to 0.008 vol.% have been shown in Figures. 6 to 8. In these figures the viscosity of CuO, MWCNT or CuO/MWCNT/ethylene glycol/water nanofluid systems are plotted as a function of temperature and volume fraction. Preliminary analyses of the experimental data indicate that the viscosity diminishes with increasing temperature. Higher concentrations of nanofluids possess higher viscosity. The variation trends of viscosity with temperature for all concentrations of nanofluids are similar.

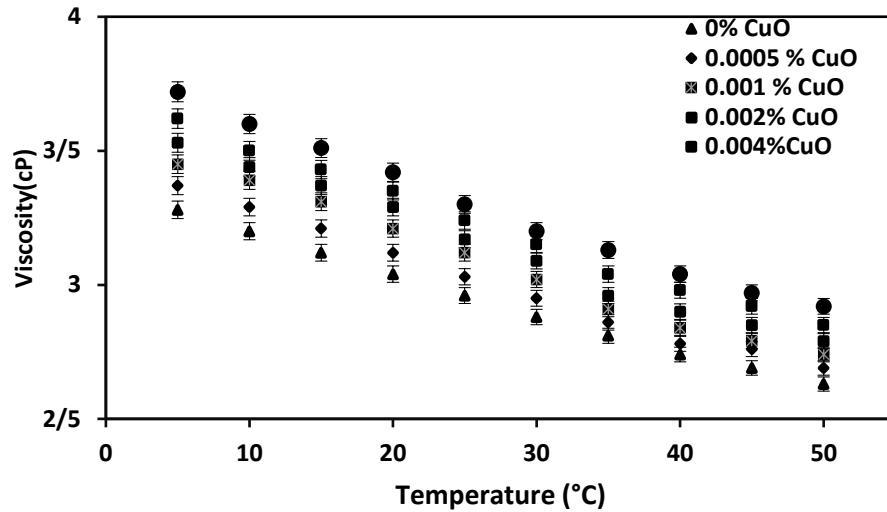


Fig. 6. Viscosity of CuO/ethylene glycol/water nanofluids as a function of temperature and volume fraction.

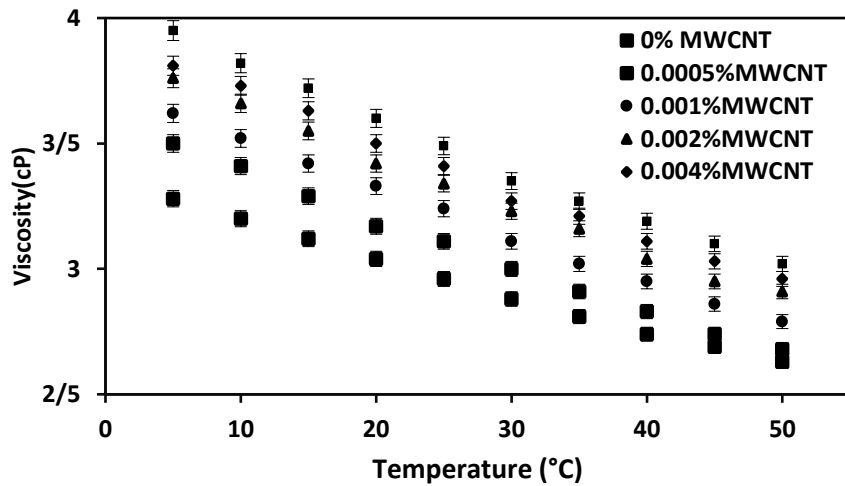


Fig. 7. Viscosity of MWCNT/ethylene glycol/water nanofluids as a function of temperature and volume fraction.

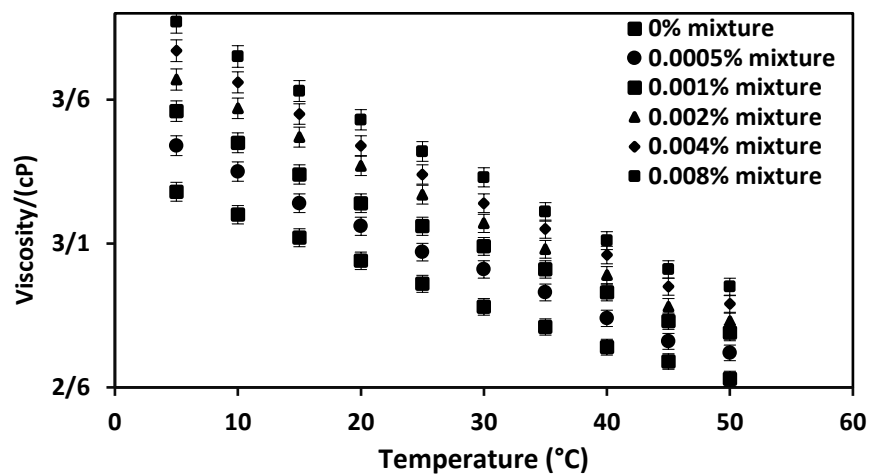


Fig. 8. Viscosity of CuO/MWCNT/ethylene glycol/water nanofluids as a function of temperature and volume fraction.

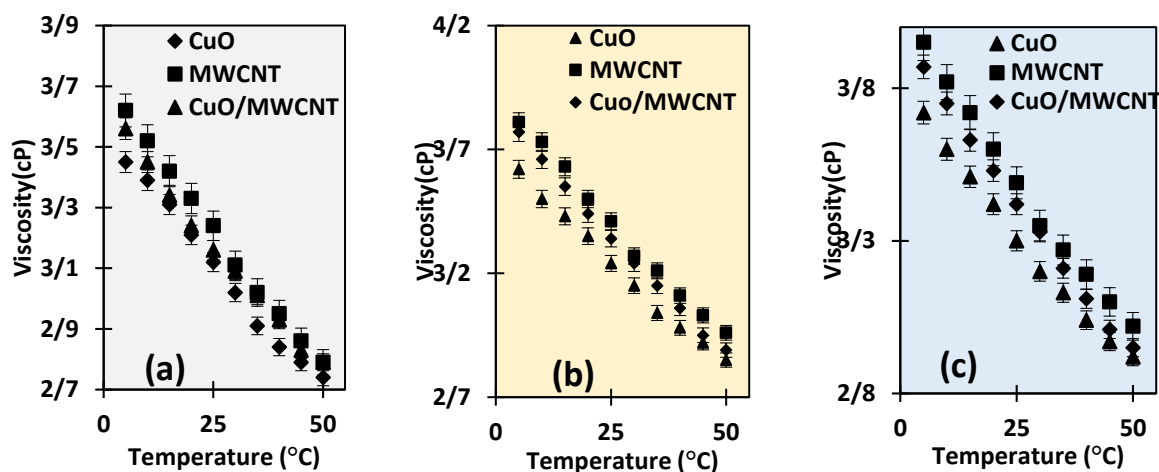


Fig. 9. Effect of nanoparticle type on viscosity of nanofluids at fixed concentration: (a) 0.001 vol.%, (b) 0.004 vol.%, (c) 0.008 vol.%.

In Fig. 9 the effect of nanoparticle type on viscosity of nanofluids at a fixed concentration has been shown. As can be seen for all three concentrations in Figures. 9a, 9b and 9c the viscosity of the mixed nanofluid system of CuO/MWCNT is between CuO and MWCNT systems. On the other hand, at a fixed concentration within the whole range of temperature the viscosity of MWCNT/ethylene glycol/water system is more than viscosity of CuO/ethylene glycol/water system.

4. Conclusion

In the present study, for the first time the thermal conductivity and viscosity of CuO/ethylene glycol/water, MWCNT/ethylene glycol/water and CuO/MWCNT/ethylene glycol/water nanofluid systems with very low particle volume concentrations of 0.0005, 0.001, 0.002, 0.004 and 0.008 vol.% at temperature range of 5 to 50°C were investigated experimentally. It is concluded that, the nanofluid system containing mixed CuO/MWCNT particles has more thermal conductivity than systems containing CuO or MWCNT individually. On the other word, the high light of this research work is increasing of thermal conductivity and decreasing of viscosity of MWCNT/ethylene glycol/water nanofluid system by adding CuO nanoparticles and constructing a more effective mixed nanofluid. This conclusion is very important for designing the heating and cooling systems.

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