

Viscosity of hybrid nanofluids: Measurement and comparison

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ABSTRACT

The authors aimed to look into the consequence of shearing time on viscosity for various hybrid nanofluids at different temperatures. The preferred hybrid nanofluids are (80% CeO₂+20% Cu), (80% Al₂O₃+20% Cu), (80% TiO₂+20% Cu) and (80% SiO₂+20% Cu). The results exhibit that the viscosity of innumerable nanofluids, in addition to the base fluid, decreased as the temperature step up and increases with an add to volume fraction of nanoparticle. Additionally, nanofluids show signs of Newtonian individuality in all the investigated ranges of temperature and volume fractions. The rheological behavior of hybrid nanofluids, being an imperative quality in its application might be beneficial in perceptive viscosity profile of any nanofluid, whether changeable or invariable with shear rate. The augmentation of viscosity is pragmatic to be 52.8%, 36.9%, 43.2% and 38.6% over the viscosity of base fluid (water) at the 3.0% vol. for (80%CeO₂+20% Cu), (80% Al₂O₃+20% Cu), (80% TiO₂+20% Cu) and (80% SiO₂+20% Cu) hybrid nanofluids. Contemporary investigational measurements were judge against with existing literature carried out by various researchers and various models for viscosity of nanofluids. There is dissimilarity between investigational hybrid viscosities of nanofluids compared with the hypothetical values as reported by quite a lot of researchers.

Keywords: Hybrid nanofluids; Measurements; Rheology; Temperature; Viscosity.

INTRODUCTION

The traditional coolants have superior lubrication characteristics, but, their poor thermo physical properties restrict their application as industrial lubricants. The thermo physical properties of the conventional lubricants can be enhanced by mixing small sized particles (preferably nano sized) into it. However, their mixing shows serious issues such as erosion, micro sized channel clogging, pressure drops and importantly, the stability for longer times. To overcome these problems, the particles size is reduced to nano level, which helped in the evolution of specific class of lubricants named as 'Nanofluids' [1]. These nanofluids yield superior thermal conductivity, improved stability and lower pressure drop over conventional lubricant.

Nanofluids containing different nanoparticles suspended in typically conventional fluids have shown significant improvement in thermal conductivity and convective heat transfer performance of the base fluids.

Viscosity variation has been experimentally deliberated by several researchers [1-9]. Studies illustrate that viscosity increases with increase in volume concentration. Prasher *et al.* [10] reported 29, 36, 24(%) enhance in viscosity for 27, 40, 50 nm size for 3% volume concentration. Effect of particle size plays important role in increase of viscosity [5, 6, 10]. Studies performed by many authors suggest that apart from particle size and volume concentration, temperature also plays very important role in viscosity variation [11, 12]. The rheological behaviour of nanofluids plays an important role to understand its viscosity profile, whether changing or fixed with shear rate. To the best of author's knowledge, only a few researches are available on rheological behavior of nanofluids. Moreover, the available literature on rheological behavior is limited and has not been completely clarified [13]. Pak and Cho [14] observed non-Newtonian behavior of nanofluids. Rubio-Hernández *et al.* [15] attempted investigations on the viscosity of different types of metal oxide nanoparticles at different values of pH and could not observe non-Newtonian effects. Alphonse *et al.* [16] investigated on Titania nanoparticles enriched fluids. They reported Newtonian behavior of nanofluids. Chandrasekar *et al.* [17] reported Newtonian behavior in alumina/water nanofluid. Moreover, Longo *et al.* [18] reported Newtonian behavior of nanofluids at different temperature for all particle volumetric concentrations investigated. Fedele *et al.* [19] carried out an investigation on Titania based nanofluid and observed Newtonian behavior. Bobbo *et al.* [20] carried out an investigation on Titania/water nanofluid and observed a Newtonian behavior at different temperatures and at atmospheric pressure. On the contrary, few authors observed non-Newtonian behavior of nanofluids. Tseng and Lin [21] investigated on TiO₂ mixing in water at different volume concentration and noticed flow behavior of pseudo plasticity. The reviewed literature establishes that most of investigators reported a Newtonian behavior. However, more investigations need to be attempted to explore detailed explanation for such behavior of nanofluids.

The present study is focused on the investigating the effect of temperature on the nanofluids' viscosity at wide range of concentrations and temperatures. Moreover, the effect of shear rate and nanoparticle concentration on rheological behavior of the nanofluids is discussed.

METHODS AND MATERIALS

Nanofluids Preparation

The commercially available nanofluids containing Cerium Oxide (Dia 30 nm at 18 vol.% in water); Alumina (Dia 45 nm at 23 vol.% in water); Titania (20-35% in water) and Silica (Dia 10 nm at 30 vol.% in water) were procured from AlfaAesar[®]. The nanofluids were diluted by mixing base fluid to get the required concentration levels of 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 and 3 vol. %. The prepared nanofluid samples were placed under ultrasonic vibration for 6 h to achieve stability in fluid. A magnetic stirrer and an ultrasonic vibrator (make: Toshiba) capable of generating 100W ultrasonic pulses were used to break down agglomeration of the nanoparticle. In order to attain a longer stability, the processes of mechanical mixing and ultrasonication were adopted. Moreover, to prevent possible agglomeration, a fresh sample was prepared and tested immediately. Figure 1 shows the transmission electron microscopes (TEM) snap of hybrid nanoparticles.

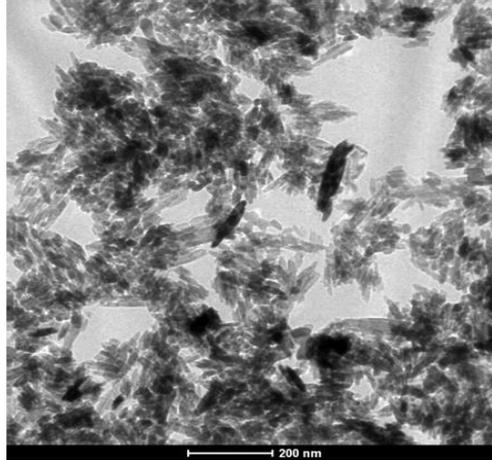


Figure 1. A TEM image of hybrid nanoparticles before properties measurements

Viscosity Measurement

The viscosity of prepared nanofluid samples were carried out by LVDV-II+Pro Brookfield Programmable digital viscometer with controlled temperature ranges from 50⁰C to 25 °C at 5 °C intervals. The minimum amount of 1 mL of nanofluid sample was used for the viscosity measurements. As the spindle rotates, the viscous drag of the liquid applied on the spindle is determined by the spring's deflection. The steady state was attained before the measurements. The nanofluid samples were remained in chamber for 10 min.

RESULTS AND DISCUSSION

The rheological experiments were carried out conducted by varying the shear rate applied on the nanofluid samples under constant temperature. Figures 2-5 illustrate the recorded shear stress versus shear rate exerted on the respective sample.

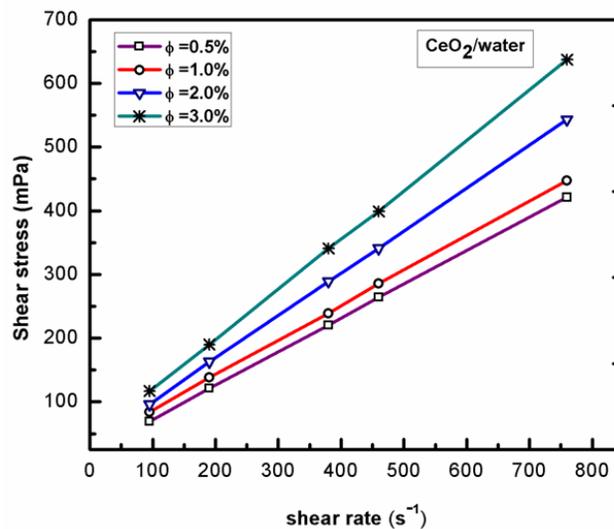


Figure2. Shear stress Vs shear rate for (80%CeO₂+20%Cu)/water hybrid nanofluid

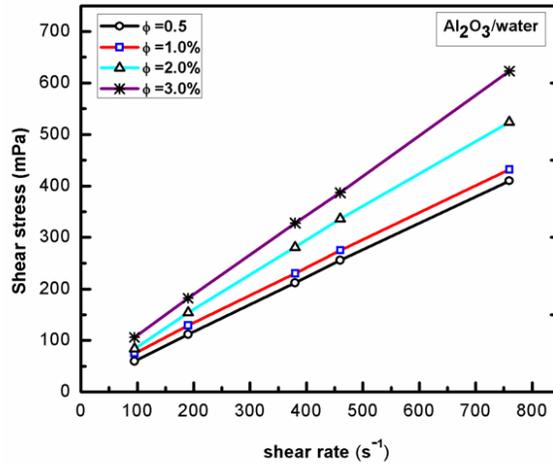


Figure3. Shear stress Vs shear rate for(80% Al₂O₃+20% Cu)/water hybrid nanofluid

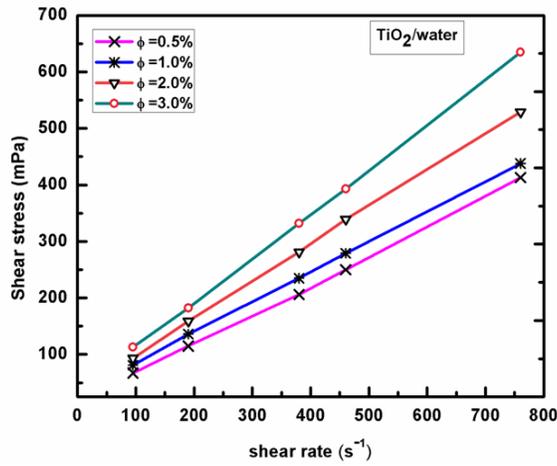


Figure4. Shear stress Vs shear rate for (80% TiO₂+20% Cu)/water hybrid nanofluid

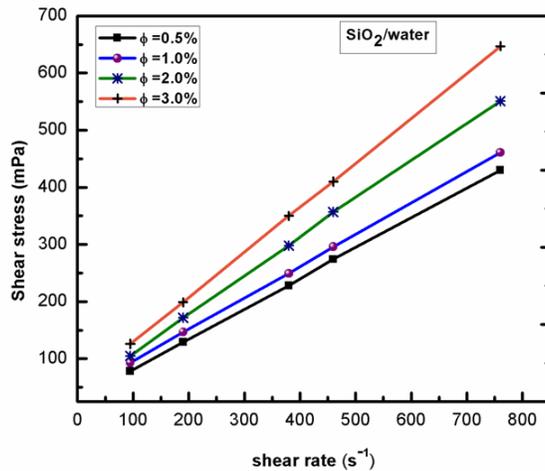


Figure5. Shear stress Vs shear rate for (80% SiO₂+20% Cu)/water hybrid nanofluids

It is observed that the shear stress is dependent linearly on shear rate for all volumetric fractions which indicates the Newtonian behavior of different nanofluid samples at volumetric concentrations used in the present research. The slope of line increases with the rise of volumetric concentration, justifies that the nanofluids' viscosity increases with the rise of particle volumetric fraction.

The viscosity of the nanoparticle enriched fluids is generally found more than that of the base fluid. Moreover, it depends on both, the type of particles and its concentration. It is noticed that, the viscosity of nanofluids increases with the rise of nanoparticle volumetric concentration. This can be attributed to the agglomeration of nanoparticles in suspension at higher concentration. Moreover, it leads to the enhancement in internal shear stress of nanofluid due to the higher force required for dissipating the solid component of the dispersion and hence increases the viscosity. The relative viscosity of various nanofluids as a function of nanoparticle volumetric concentration is illustrated in Figures 5-8. The viscosity measured in the present investigation has been compared with values published in literature for the validation of the results. Figure 6 depicts that the increase of viscosity of Cerium oxide based nanofluid are ~9.9%, ~12.1%, ~15.2%, ~18.9%, ~21.8%, ~26.9% and ~51.6%, at nanoparticle volumetric concentrations of 0.5%, 0.75%, 1%, 1.25%, 1.5%, 2% and 3% respectively as compare to water. For alumina based nanofluid, the increase of the viscosity at 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 and 3 vol. % are ~8.0%, ~11.2%, ~12.9%, ~14.5%, ~17.7%, ~22.6% and ~35.9% respectively (Figure. 7). Figure 8 shows that the enhancements of the viscosity for TiO₂ nanoparticle enriched nanofluid at 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 and 3 vol. % are ~8.0%, ~11.3%, ~14.5%, ~17.7%, ~20.9%, ~27.4% and ~41.9%, respectively. The values obtained for TiO₂nanoparticles enriched fluid in present investigation is significantly greater than that observed by Pak and Cho[14]. Figure 8 shows that the increase in viscosity for SiO₂ nanoparticles enriched fluid at 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 and 3 vol. % are ~10.4%, ~13.0%, ~15.6%, ~18.2%, ~20.9%, ~26.4% and ~37.8% respectively. Interestingly, it is observed that the anomalous enhancement of viscosity reported in many of the articles is greater than the base fluid which could not be explained by the classical equation. Therefore, it is the need of time to attempt few more investigations on the basic mechanism responsible for the increase in viscosity of nanofluids.

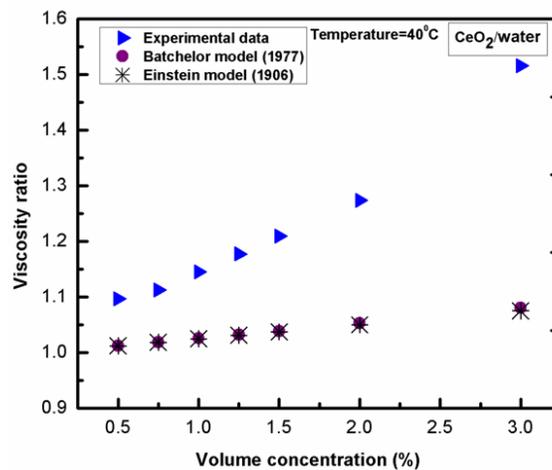


Figure6. Viscosity ratio (80%CeO₂+20%Cu)/water hybrid nanofluid.

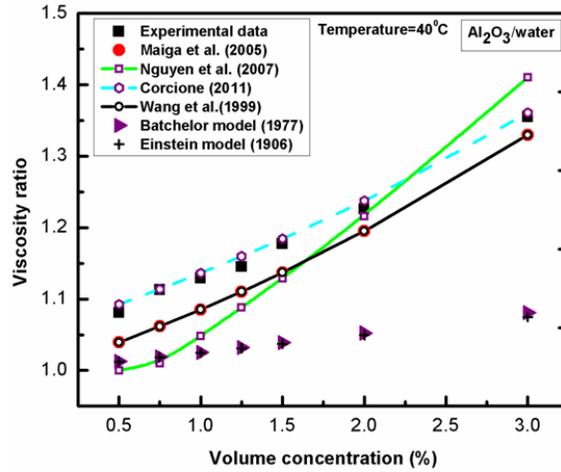


Figure 7. Viscosity ratio (80% Al₂O₃+20% Cu)/water hybrid nanofluid.

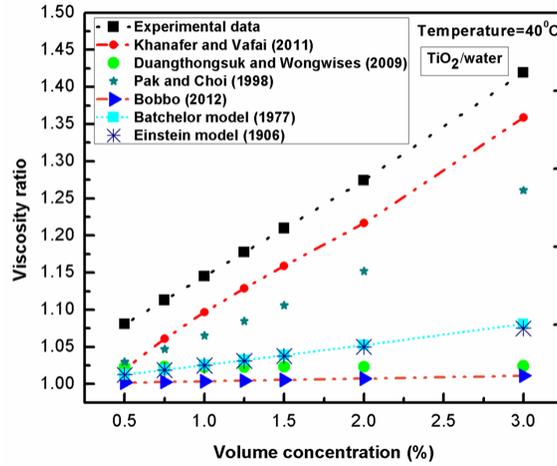


Figure 8. Viscosity ratio (80% TiO₂+20% Cu)/water hybrid nanofluid.

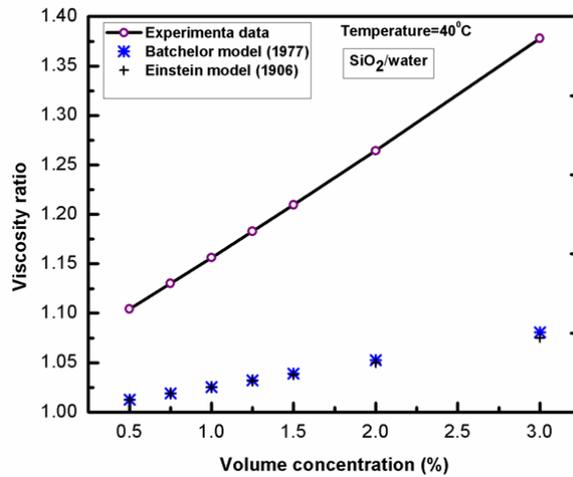


Figure 9. Viscosity ratio (80% SiO₂+20% Cu)/water hybrid nanofluids

Figures 10-13 illustrate the temperature dependency behavior of viscosity of the different hybrid nanofluid samples at various volume fractions. A sharp decrease in viscosity is noticed with the increase of temperature for all volumetric concentrations. The temperature effect of viscosities is related to the weakening of the interparticle and intermolecular adhesion forces. With increase of nanofluids' temperature, the kinetic energy of the molecules increases and the period of time they remain in contact with its closest particle, decreases. Therefore, as temperature is increased, the average intermolecular forces are decreased, and reduce the viscosity.

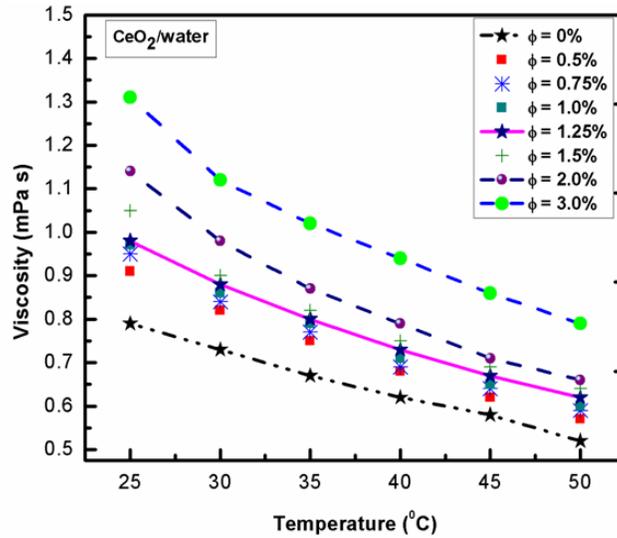


Figure 10. Viscosity (80%CeO₂+20%Cu)/water hybrid nanofluid Vs temperature

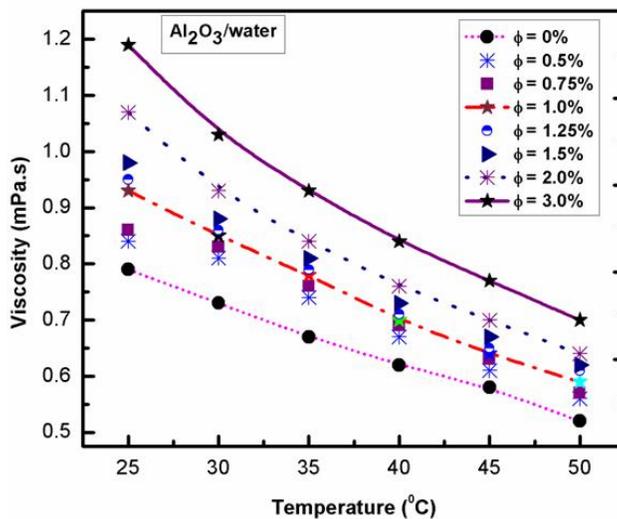


Figure11. Viscosity (80%Al₂O₃+20%Cu)/water hybrid nanofluid Vs temperature

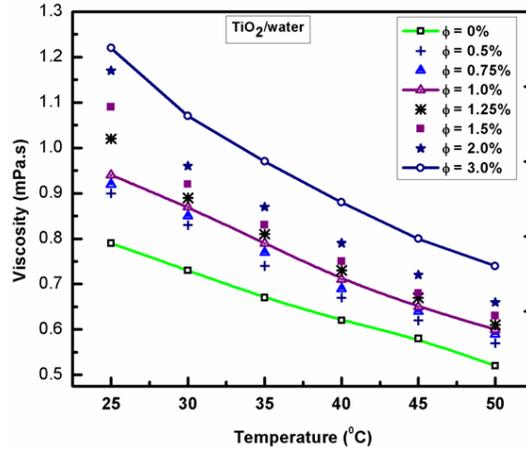


Figure12. Viscosity (80% TiO₂+20%Cu)/water hybrid nanofluid Vs temperature

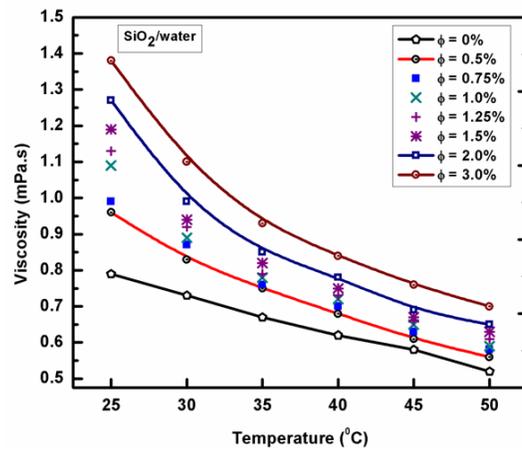


Figure13. Viscosity (80% SiO₂+20%Cu)/water hybrid nanofluid Vs temperature

CONCLUSIONS

In present study, the viscometric properties of various hybrid nanofluids of different concentrations (0.5~ 3 vol. %) are examined at a range of temperatures(25 °C ~ 50 °C) and shear rates. All the way through this study it is establish that temperature and volume concentration have substantial upshot over viscosity of hybrid nanofluids. shear- thinning activities is observed in all the test samples at different temperatures. It is implicit from the experimental results that at lesser volume concentration to upto 3% the shear thinning of hybrid nanofluid is due to Newtonian character. It is also observed that the viscosity ratio of hybrid nanofluids decline with rise in temperature. This turn out due to the deteriorating of intermolecular communications and adhesion forces among the molecules. The experimental outcomes have been compared with predictions by the existing theoretical models. It has been found that the experimental results are notably greater than those predicted by different models given by different investigators. Drop off in viscosity with raise in temperature is shows potential for using nanofluids as superior coolants in thermal managing applications.

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