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Rheology and Thermal Conductivity of Three Metallic Oxides Nanofluids

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Abstract **–** Thermal properties and performance of nanofluids firstly depend on the types of nanoparticles followed by their concentration in base fluids which are traditional heat transfer fluids. Although it is well established that addition of nanoparticles increases the thermal conductivity of base fluids it also presents other challenges such as the increased viscosity and the potential rheology behaviour. This study investigates the thermal conductivity enhancement and the rheology behaviour of three aqueous-based metallic oxides nanoparticles (Al_2O_3, SiO_2 and TiO_2) nanofluids. Also, five low concentrations of each type of nanoparticles in the range of 0.01-0.2 vol.% are prepared and their thermal conductivity and viscosity are investigated. The results indicate an enhancement of thermal conductivity for the different types of nanoparticles increased with increasing the particles' concentrations up to 7.3 % for Al_2O_3 nanofluid at 0.2% particles concentration. Also, a Newtonian rheological behaviour for those three nanofluids is observed and an increase in viscosity with increasing nanoparticles' concentration up to 6.5% is found.

Keywords**:** Thermal conductivity, Rheology, viscosity, Nanofluids, Al_2O_3, SiO_2 and TiO_2

1. Introduction

Many industrial applications use thermal fluids for the heat transfer process in both cooling and heating of the heat transfer systems like heat exchangers. In previous decades, it was found that the performance of conventional thermal fluids such as water, ethylene glycol or oils can be enhanced by adding nanoparticles with higher thermal conductivity [1]. The latter is known as ''nanofluids'' which are found to improve the heat transfer process in numerous systems [2]. Many possible types of metallic and non-metallic nanoparticles such as Cu, Al, Au, CNTs, Al_2O_3, SiO_2 and TiO_2 can be dispersed into the conventional fluids to produce different types of nanofluids which open the door for a wide range of investigations on their varies thermophysical properties [2]. On another hand, not only the thermal conductivity increases by adding nanoparticles to the base fluid but also there is an increase in the viscosity which cause higher pumping power in the heat exchanger [3]. Most of the studies in the literature employed relatively large concentrations of nanoparticles for high enhancement of thermal conductivity [4–7]. However higher concentration significantly reduces the stability and sustainability of nanofluids. Besides thermal conductivity, stability and negative effects of other property increase need to be considered for their optimal performance in applications. Also, the possible change of the rheology behaviour might affect the heat transfer performance of these nanofluids which must be also well investigated [8]. Therefore, this study aims to investigate two key thermophysical properties namely thermal conductivity and viscosity taking into account their rheology behaviour of three popular metallic oxides (Al_2O_3, SiO_2 and TiO_2) nanofluids at low concentrations. The collected database of this study can establish the required confidence premises for implementing nanofluids for heat exchanger systems and can be used for further investigations (experimental and numerical) for tailoring nanofluids for different thermal applications.

2. Nanofluid samples and methods

The nanofluid samples are prepared using Al_2O_3 nanoparticles of d_p<50 nm, SiO_2 nanoparticles of d_p=20 nm (99.9% purity) and TiO_2 d_p=20 nm from IoLiTec (Germany) to be separately mixed with the base fluids for the five concentrations 0.01, 0.05, 0.1, 0.15 and 0.2 vol.% of each type of nanoparticles. Basefluids used in this study was distilled water (DW). Also, ultrasonication mixing process is applied for 20 minutes (using the Hielscher UP200Ht ultrasonicator for an amplitude of 60%) to improve the dispersion and stability of the nanoparticles into the fluids. Moreover, the stability of the produced nanofluids is evaluated using UV-1280 spectrophotometer device to check the change of the nanoparticles' concentration into the nanofluid samples with time. The results indicate good stability for Al_2O_3 and TiO_2 nanofluids for more than 3 weeks, while the SiO_2 nanofluid samples were stable for only less than 2 days. In addition, the properties of nanofluid samples are measured on the same day of preparation when samples achieve a very good level of stability.

In this study, the viscosity and rheology of the nanofluids and base fluids were measured using a viscometer DVNext from AMETEK Brookfield connected to a thermostatic bath with a pump and thermocouple sensor to obtain the wanted temperature of the sample. The measurements have been performed at several shear rates and temperatures for a volume of 0.5 mL (the amount needed for the viscometer device) for each sample.

On the other hand, the thermal conductivity of the samples was measured at room temperature (20°C) by a Thermal Properties Analyzer (METER Group) which works based on transient hot-wire (THW) technique which is well-established and suitable (thus widely used) for the measurement of thermal conductivity of nanofluids [9]. Several readings for the same sample (fluid) were taken and the resting time between the measurements was about 20 minutes. Moreover, a calibration process was done for the experimental apparatus with the base fluid and the maximum found variation was 1.6% from the standard referenced values. The sensor needle (length of 6 cm and a thickness of 1.3mm) has been inserted in the vial containing the nanofluid sample (around 40 mL volume).

3. Results and Discussion

3.1. Thermal conductivity

The results presented in Fig. 1 confirm that the thermal conductivity of nanofluid increases with increasing of particle volume fraction for the three types of nanoparticles (Al_2O_3, SiO_2 and TiO_2), reaching the maximum enhancement for the highest particles concentration 0.2 vol.% about 7.3 %, 4.2% and 2.2% for Al_2O_3, TiO_2 and SiO_2 nanofluids, respectively. The thermal conductivity of Al_2O_3 nanofluids show the highest values compared to other nanofluid types (TiO_2 and SiO_2 nanofluids) for all particles concentrations (0.01, 0.05, 0.1, 0.15 and 0.2 Vol.%). However, it can be noticing an inconstancy for some results of SiO_2 and TiO_2 Nanofluids due to the low change in the values by adding nanoparticles that can set in the error bars of the device accuracy (2%). In another hand, the lower stability performance of SiO_2 may affect the thermal conductivity measurements.

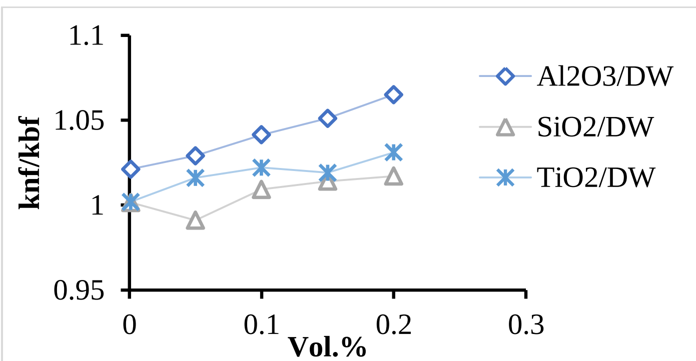

Fig. 1 Thermal conductivity enhancement of nanofluids.

3.2. Rheology Behaviour

Rheological behaviour of any fluids particularly nanofluids is very important for any applications involving their flow and convective heat transfer in any heat exchange system. Therefore, the flow characteristics of all prepared nanofluids were determined and are presented in Fig. 2 for several shear rate values.

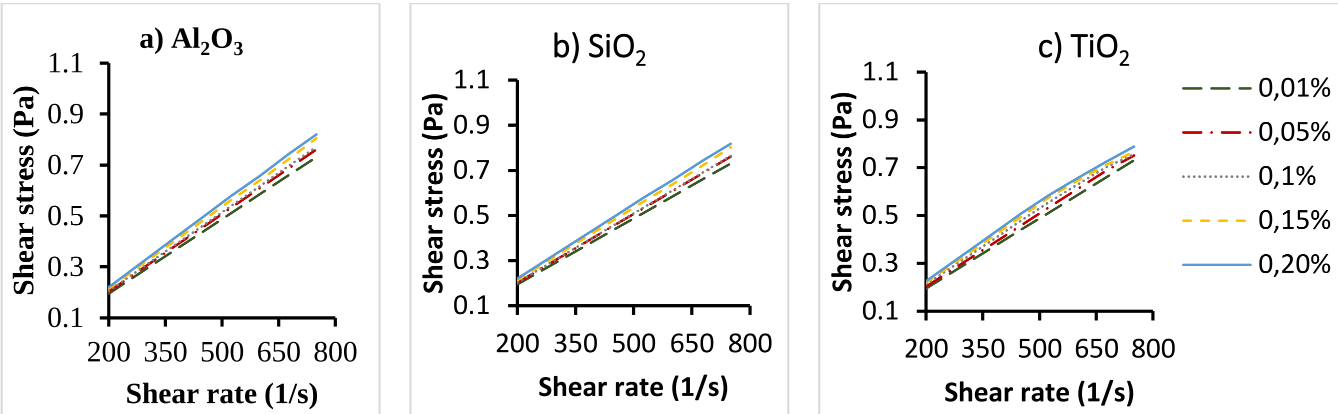

Fig. 2 Rheology behaviour of nanofluids by adding nanoparticles to the base fluid: a) Al_2O_3, b) SiO_2, c) TiO_2.

As it can be depicted by Fig. 2 the shear stress results show a linear relation with shear rate values for all the types of particles and their concentrations which indicates a Newtonian behaviour for those nanofluids. This conclusion agreed with the findings of other studies that have been done in this field for similar nanofluids [10,11]. It is to be noted that the rheological behaviour of nanofluids can change due to different factors such as the concentration of nanoparticles [10,11].

3.3. Viscosity

Similar to the most results in literature [3,10] viscosity of the nanofluid samples are measured as a function of temperature and concentration of nanoparticles and found to be higher than the base fluid and decrease with increasing temperature.

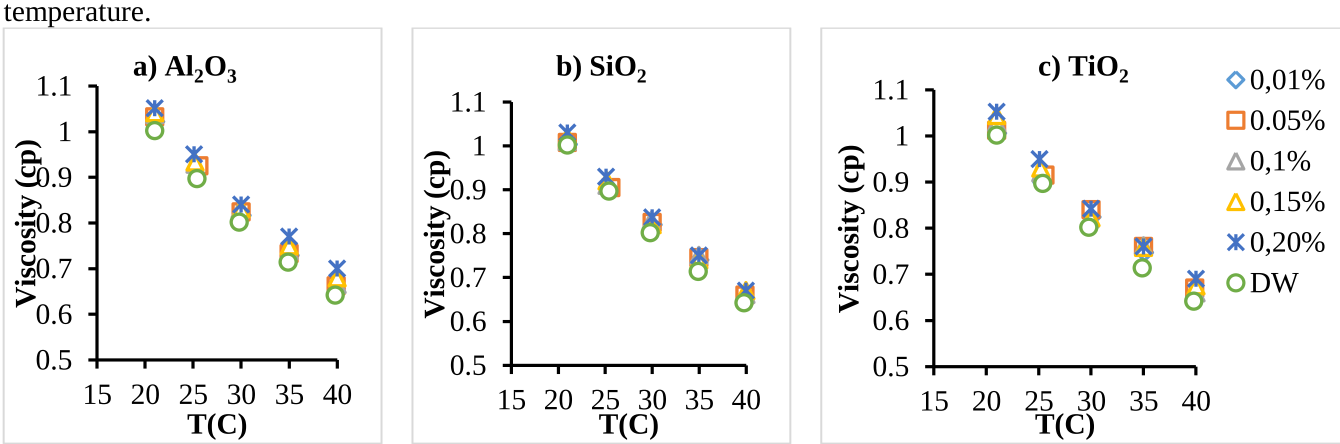

Fig. 3 Viscosity of nanofluids for several temperatures and three types of nanoparticles: a) Al_2O_3, b) SiO_2, c) TiO_2.

As shown in Fig. 3, the viscosity of Al_2O_3, SiO_2 and TiO_2 nanofluids increases with the rise of the nanoparticles' concentration and reduces significantly by the increase of temperature. The results reported a similar increase of viscosity for TiO_2 and Al_2O_3 with increasing the nanoparticles concentrations starts by 2.1 % for 0.01 vol.% to around 6.5% for 0.2 vol.%. While the SiO_2 nanoparticles caused relatively lower viscosity increases for the nanofluid (from 1.55 for 0.01 Vol.% up to 4.5% for 0.2 Vol.%) due to their lower density in comparison with TiO_2 and Al_2O_3 nanoparticles. Also, the viscosity of nanofluid samples is decreased with reducing the temperature, for example viscosity of Al_2O_3 nanofluid at 0.2 vol.% reduces about 34% due to rising temperature from 21°C to 40 °C. These results are inconsistent with the results of the literature [3,10].

4. Conclusion

In this work, Al_2O_3, SiO_2 and TiO_2 nanofluids (0.01-0.2 vol.%) are prepared and their properties of thermal conductivity, viscosity and rheological behaviour are examined. The enhancement of thermal conductivity for the different types of nanoparticles and concentrations are presented, reporting a maximum enhancement of about 7.3 % for Al_2O_3 nanofluid at 0.2% particles concentration. Also, the effect of nanoparticles concentration and type on the viscosity as well as on the rheology behaviour of those three nanofluids was clarified. The shear stress results for Al_2O_3, SiO_2 and TiO_2 nanofluids showed linear relation with the applied shear rate range, reporting Newtonian behaviour. Moreover, viscosity was found to increase with increasing nanoparticles' concentration for all nanofluids and decreased with rising the temperature.

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