Thermophysical Properties of Carbide and Nitride Nanofluids

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Abstract—The total performance of a heat exchanger system is significantly influenced by the thermophysical (TP) characteristics of the used thermal fluids and especially for thermal nanofluids due to their complex design. In this study, three key TP characteristics for instance the density, specific heat capacity, and the dynamic viscosity of a carbide and nitride thermal nanofluids, namely Silicon Carbide (SiC) and Boron Nitride (BN) based thermal nanofluids are experimentally and theoretically investigated. These thermal nanofluids are produced for four very low particle concentrations from 0.01 to 0.04 vol.% dispersed into ethylene glycol/water (EG/DW) mixture. The results indicate that these thermal nanofluids have higher density and dynamic viscosity in comparison with their conventional base fluid (EG/DW) and they increase with increasing concentration of the nanoparticles. The maximum increase in dynamic viscosity of 4.1% at 0.04 vol.% was found. On the other hand, the specific heat capacity of these thermal nanofluids insignificantly decreased with the increasing of nanoparticles concentration in comparison with the conventional base fluid.

Keywords—nanofluids, SiC and BN nanoparticles, density, specific heat, viscosity.

I. INTRODUCTION

The enhancements in the TP characteristics of the thermal fluids perform a big role to improve the overall performance of many heat transfer systems and applications in a wide variety of industrial processes. The use of thermal nanofluids with enhanced transport properties has been suggested as a potential solution for developing heat transfer process in numerous applications [1], [2]. So far, several types of metallic and non-metallic nanoparticles were mixed with conventional thermal fluids and various thermal nanofluids were presented [3]. The latter led to the need for many studies on their TP characteristics toward the optimisation of their performance for specific engineering applications [4]. In this, some types of thermal nanofluids (the nanoparticles material and conventional base fluid) such as SiC and BN thermal nanofluids are still not often examined considering TP characteristics at different concentrations. So far, the conducted investigations on SiC and BN thermal nanofluids showed a promising solution to enhance the thermal performance [5], [6] that can be in several applications such as in heat sink for electronics cooling [7], for solar collector application [8], [9], for pool boiling [10], and other thermal management systems [11].

However, some properties such as density, dynamic viscosity and specific heat capacity of thermal nanofluids can negatively influence the thermal performance of thermal nanofluids which must be also well investigated [12]. Those properties are considered very important properties of nanofluid that can be influenced by diverse parameters such as nanoparticles type, stability, concentration, temperature etc. The density and dynamic viscosity of the thermal fluid are important, especially for the energy efficiency of the systems where their increases are unfavourable [13]. Therefore, this research intends to experimentally study three important properties; density, dynamic viscosity, and specific heat capacity of thermal nanofluids produced by adding SiC and BN nanoparticles to EG/DW mixture at very low concentrations.

II. NANOFLUID PREPARATION AND PROPERTIES MEASUREMENTS

The sample thermal nanofluids of both types were produced using SiC nanoparticles of around 50 nm and BN nanoparticles of 70 nm sizes. Both nanoparticles are spherical and have a purity of >99% as provided by the supplier (Iolitec Nanomaterials, Germany). Also, the mixture of 70% DW and 30% EG is used as the conventional base fluid. The samples are produced by dispersing four concentrations from 0.01 to 0.04 vol.% of each type of these nanoparticles into the conventional and an ultrasonication process is applied to enhance their dispersion and stability. Then, the dynamic viscosities of the thermal nanofluids are determined by using a viscometer from AMETEK Brookfield for several temperatures and shear rates. Furthermore, the densities of the thermal nanofluids are investigated at room temperature using a Density Meter provided by KEM KYOTO. On the other hand, in order to determine the specific heat capacity of thermal nanofluids, their thermal conductivity and the thermal diffusivity are measured using a single needle type KS-3 sensor (transient hot-wire (THW) technique) and a dual-needle type SH-3 sensor, respectively, by the Thermal Properties Analyzer (METER Group). It is to be noted that
numerous experimental tests were performed for each nanofluid. Moreover, the experimental apparatuses were validated, and a calibration procedure was followed by measuring these properties of standard/known fluids to guarantee the precision of the experimental tests. The uncertainties of the experimental tests for the dynamic viscosity, density, thermal conductivity, and thermal diffusivity were 2.5%, 1.5%, 1.0% and 0.5% at maximum from the referenced standards, respectively.

III. RESULTS AND DISCUSSION

A. Density

Fig. 1 shows the experimental relative density ($\rho_{nf}/\rho_{bf}$) results of SiC and NB thermal nanofluids for four concentrations at room temperature. According to the acquired data and as anticipated, density slightly increased with the addition of nanoparticles, reaching the highest increase of 0.23% at 0.04 vol.% for SiC thermal nanofluids and slightly lower for BN thermal nanofluids. The low increase in density can be explained by the very small concentrations of dispersed nanoparticles. Furthermore, the density of nanofluid samples can be defined using a common mixing law such as that used by Pak and Cho [14] which can predict density values with good accuracy. Therefore, the predicted relative densities for SiC and BN thermal nanofluids at the four particle concentrations are also presented in Fig. 1, using the mixing rule of Pak and Cho (Eq. (1)) [14].

$$\rho_{nf}/\rho_{bf} = \varphi(\rho_p/\rho_{bf}) + (1 - \varphi)$$  \hspace{1cm} (1)

where $\varphi$ is the nanoparticle concentrations, $nf$ corresponds to nanofluid, $bf$ is the base fluid (conventional) and $p$ is the nanoparticle. However, the value of density has an essential effect on the pressure drop thus the pumping power of the operation of heat exchanger systems and low relative density of thermal nanofluids (e.g., 0.23% obtained in this study) is preferable.

![Fig. 1. The relative density of the nanofluids.](image)

B. Viscosity

The viscosity of thermal nanofluids is significant for heat transfer applications due to the impact on the flow profile (including boundary layer and flow regime) and the convective heat transfer. Therefore, the dynamic viscosity of the SiC and NB thermal nanofluids at various nanoparticle concentrations and room temperature were measured and are presented in Fig. 2. Furthermore, in this study, the dynamic viscosity of SiC and BN thermal nanofluids ($\mu_{nf}$) are predicted by the popular model of Krieger and Dougherty (K-D) [15] as shown in Eq. (2) for the same particle concentrations of the experimental measurements. K-D model has been used to predict the dynamic viscosity of thermal nanofluids in many studies (e.g., [16]), thus it is worth checking its capability for the current study conditions (very low particle concentrations and new types of nanoparticles).

$$\mu_{nf} = \mu_{bf}(1 - \varphi)/\varphi_m)^{-\mu/\varphi_m}$$  \hspace{1cm} (2)

where $\mu_{bf}$ is the conventional base fluid’s viscosity, $\varphi_m$ is the largest packing concentrations and the value of 0.64 is chosen for the used nanoparticles, and the value of 2.5 is the intrinsic viscosity [$\mu$].

Experimental results from the measurement of viscosity are shown in Fig. 2 which confirms an increase in the dynamic viscosity of SiC and BN thermal nanofluids by increasing the particles concentration. Also, there is a close increase in dynamic viscosity for both SiC and BN with the addition of nanoparticles beginning by 1.04% for 0.01 vol.% up to 4.3% for 0.04 vol.%, with inconsiderable slightly lower values for BN nanoparticles that can be explained by their smaller density in comparison with SiC nanoparticles. The latter finding agrees with the correlated findings in the literature [15], [17]. Furthermore, the determination of the K-D dynamic model against the experimental data showed its inaccuracy for low particle concentration as well as for the nanoparticle types, where the predicted dynamic data severely underpredict the experimental results. Such underprediction of viscosity results of thermal nanofluids by existing classical models is quite common in the literature [15] and due to the fact that those models were developed for suspensions of larger particles, not for nanoparticles.

![Fig. 2. The viscosity of BN and SiC thermal nanofluids for several concentrations of nanoparticles.](image)

C. Specific Heat

In this study, the specific heat capacity ($c_p$) of the thermal nanofluids was also evaluated at room temperature (20°C) based on the obtained experimental results of density ($\rho$), thermal diffusivity ($\alpha$) and thermal conductivity ($k$) as shown in Eq. (3). Numerous measurements for each nanofluid were conducted with 20 minutes of resting time.

$$c_p = \frac{k}{\rho\alpha}$$  \hspace{1cm} (3)
The impact of the loadings of nanoparticles into the conventional base fluid on the specific heat capacity of thermal nanofluids was investigated. Furthermore, the specific heat capacity of SiC and BN thermal nanofluids ($c_{p, nf}$) are predicted by the mixture rule of Xuan and Roetzel [18] shown in Eq. (4) which was commonly applied for thermal nanofluids [4], [13], [16]. The theoretical specific heat capacity predictions were determined for the same particle’s concentrations and compared with experimental data as presented in Fig. 3.

$$c_{p, nf} = \frac{\varphi (\rho c_p)_p + (1-\varphi)(\rho c_p)_{bf}}{\rho_{nf}}$$  \hspace{1cm} (4)

Fig. 3. Specific heat of SiC and BN thermal nanofluids.

The findings demonstrate that the specific heat of these two types of thermal nanofluids generally has a trend to reduce by adding nanoparticles. The decreasing trend of the specific heat capacity of thermal nanofluids is well-understood through the smaller specific heat capacity of nanoparticles in comparison with any liquid (conventional base fluids). Moreover, the SiC thermal nanofluids show lower values than BN thermal nanofluids which can be explained by the lower specific heat capacity of the SiC materials. The lowest value of specific heat capacity was obtained for SiC nanofluid at 0.04 vol.% with a decrease of 0.3%, in comparison with the conventional base fluid. This trend of reducing the specific heat capacity of thermal nanofluids (in comparison with their conventional base fluids) agrees with the literature [4], [12], [16] and this should be considered in the investigations of thermal nanofluids TP properties due to its importance in many engineering applications.

IV. CONCLUSIONS

In this work, silicon carbide and boron nitride thermal nanofluids of different concentrations between 0.01-0.04 vol.% are produced and their three important TP characteristics namely regarding specific heat, dynamic viscosity and density are investigated. The dynamic viscosity and density of the thermal nanofluids were tested and analysed, showing an increase of density (insignificant) and viscosity (low) with increasing particle concentration for both thermal nanofluids. Also, the specific heat capacity was slightly reduced for these two types of thermal nanofluids by increasing the concentration of these nanoparticles. These properties are crucial for exploring their numerous applications such as in advanced cooling, energy conversion and storage and so on.

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