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Fabrication and thermo-physical characterization of silver nanofluids: An experimental investigation on the effect of base liquid

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ABSTRACT

Nanofluids (NFs) are solid-liquid composites prepared by stabilizing nanoparticles (NPs) in a base liquid, which is selected based on the technological area of application. For heat exchange applications the base liquid can be specified as water, ethylene glycol (EG), or their mixture. NFs have exhibited some potential to replace conventional heat transfer fluids due to enhancement of their thermal characteristics. The thermo-physical properties of NFs including thermal conductivity (TC) and viscosity may be affected by several factors including the base liquid, which is not well studied in the literature. Focus of the present work is to study the impact of base liquid by comparing the TC and viscosity of a commercial silver (Ag) NFs with lab-made water, EG and water/ethylene glycol (W/EG) mixture (50:50 by wt%) at different Ag NP loadings (1, 1.5 and 2 wt%). For this purpose, commercial water based Ag suspension (containing 1 wt% Ag NP) was acquired, which is used for the preparation of Ag NFs with different base liquids and NP loadings. Finally, the thermo-physical properties of NFs including TC and viscosity were measured and analyzed at 20 °C. The results revealed that W/EG based NFs containing 2 wt% Ag NP showed best performance with the highest TC enhancement of 12.4% and only 6.1% increase in viscosity, revealing that among different base liquids, W/EG based NFs are the most beneficial for heat transfer applications.

1. Introduction

Heat transfer fluids play important role in many industrial processes to remove excess heat. There are some challenges in conventional heat transfer fluids which must be solved to have effective cooling fluids. For instance, Water (W), ethylene glycol (EG) or their mixture (W/EG) as conventional heat transfer fluids have poor thermal conductivity (TC). One other challenge is about developing effective cooling methods for some high-tech applications for which traditional heat transfer fluids are not able to offer more effective solution. Transport, microelectronics, energy supply, microchannels and biomedical applications are some examples which have become priorities for the further development of effective heat transfer fluids [1–8]. Thus, there is a demand for efficient heat transfer fluids to solve these challenges. In the last decade nanofluids (NFs), which are nanotechnology based suspensions containing nano sized particles; nanoparticles (NPs) in conventional cooling liquids (i.e. base liquids), such as water EG and their mixture, have attracted attention due to their potential benefits in heat transfer applications [9]. Up to now several groups of materials and base liquids have been used to engineer NFs. Metal NPs such as Cu [10], Au [11] and Ag [12–14], ceramic compounds including oxide particles such as Al_2O_3 [15], TiO_2 [16], CeO_2 [17], mesoporous SiO_2 [18], or carbides such as SiC [19–21]. Two major techniques are commonly utilized to fabricate NFs; (i) one-step preparation method [22] which represents the direct formation of NPs inside the base liquids, and (ii) two-step method [23] wherein NPs are at first synthesized/acquired and then dispersed in the base liquids. NF system is a complex suspension which means that it's not simple dispersion of NP and base liquid and its characteristics such as thermo-physical properties including TC and viscosity maybe influenced by several factors, including composition and loading of NP and type of base liquid [24–25], morphology of NP (size and shape) [26], stability of suspension [27], NF fabrication method [28], and surface modifier [29]. Among all these factors, although the base liquids play a critical role by affecting TC and viscosity of NFs, its impact (base liquid effect) has not been studied in sufficient detail. A detailed literature survey showed that not only the number of studies reporting the impact of base liquid on thermo-physical properties of NFs (including TC and viscosity) is limited but also its effect on TC and viscosity of NFs is still under debate. Xie et al. [30–31] studied NFs with Al_2O_3 NPs in different base liquids and demonstrated that

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enhancement in TC of NFs take places if base liquid with lower TC is employed. Tsai et al. [32] reported the alteration of the base liquid viscosity (from 4.2 to 5500 cP, by mixing two base liquids with approximately the same TC) which resulted in a decrease in the TC of the Fe_2O_3 NFs as the viscosity of the base liquid increased. Timofeeva et al. [33–34] studied SiC NFs in water (W) and W/EG mixture with controlled concentration, particle sizes and pH. Their investigations revealed that the TC enhancement is higher in W/EG based NFs compared to the same NFs with water base liquid. We recently reported on water and W/EG based NFs containing α-SiC NPs to demonstrate the effect of base liquid on TC and viscosity of NFs [19–20]. Based on findings at 20 °C, NFs with W/EG base liquid exhibited more favorable performance than the similar water based NFs. In other research work, we studied the effect of base liquid on thermo-physical properties of ethylene and diethylene glycol (EG and DEG) based copper NFs containing various Cu NP loading (1, 2 and 3 wt%). Based on our results, EG based NFs exhibited more favorable characteristics than that of DEG based suspensions at the same Cu NP loading and temperature [35]. There is still a serious need to perform systematic investigation to study the effect of base liquid on thermo-physical properties of NFs. Ag nanoparticles (Ag NPs) have attracted great interest due to their expected high TC as well as excellent chemical and physical stability [14]. Although, there are reports on Ag NFs [12–14], there is no study on the (experimental and theoretical) impact of base liquid on thermo-physical properties of Ag NFs including TC and viscosity. For this purpose, we designed systematic experiments to study effect of base liquid on TC and viscosity of Ag NFs. In this work, our aim is to fabricate Ag NFs with different base liquids and various Ag NP loadings, and investigate the effect of base liquid and NPs loading on the thermo-physical properties of NFs including TC and viscosity. For this purpose, stable Ag NFs with different base liquids (water, W/EG and EG) and various NPs loading (1, 1.5 and 2 wt%) were fabricated. The thermo-physical properties of NFs including TC and viscosity were measured at 20 °C and our findings are presented in detail.

2. Experimental

2.1. Materials and methods

Commercial water based suspension containing 1 wt% Ag NP was purchased and NFs with 1.5 and 2 wt% were prepared using original suspension. Ethylene glycol (EG) was acquired from Sigma Aldrich (Germany). All the suspensions/liquids were used as received, without further purification.

2.2. Fabrication of Ag NFs

In order to fabricate NFs with different base liquids and various Ag NPs loading, water based suspension containing 1 wt% Ag NP (as original sample) was used. For fabrication of water based NFs at higher Ag NP loading (1.5 and 2 wt%), the centrifuge and sonication were used. To keep sample history as well as the particle size the same, NFs with higher concentrations were obtained by ultracentrifuging and concentrating these samples. It should be noted that the ultracentrifuge technique is a well-known method which can be used for separating and precipitating suspended NPs in suspensions. For example, to prepare 25 mL of Ag NF with 2 wt% Ag NP loading, 50 mL of NF at NP loading of 1 wt% was centrifuged at 10000 rpm for 10 min at 20 °C. It was observed that the sample was separated in two phase including the precipitated Ag NPs and liquid free from NPs. Then 25 mL of the solvent decanted to concentrate Ag NFs. New NF with higher concentration of Ag NPs was sonicated, for dispersing the NPs, and evaluated for TC and viscosity properties. The same procedure was followed to fabricate NFs with other NP loading. The EG based NFs containing 1, 1.5 and 2 wt% Ag NP loading also were fabricated using original suspension using the same method. Removal of water from the Ag NPs is necessary as water has higher TC than EG and the presence of water may result in incorrect TC data. Therefore, the NPs obtained were finally dispersed in ethylene glycol under an argon environment in a glovebox. Finally, W/EG based Ag NFs with different Ag NP loading of 1, 1.5 and 2 wt% were prepared by mixing 50% (by wt%) of each water and EG based Ag NF systems. All fabricated NFs (Table 1) were stable for six months without any visual precipitation.

Table 1
Ag NFs with different base liquids evaluated for TC and viscosity properties.

Sample	NP	Base liquid	NP loading (wt%)	pH
Ag NF-EG-1 wt%	Ag	EG	1	–
Ag NF-EG-1.5 wt%	Ag	EG	01.5	–
Ag NF-EG-2 wt%	Ag	EG	2	–
Ag NF-W-EG-1 wt%	Ag	W/EG[a]	1	6
Ag NF-W-EG-1.5 wt%	Ag	W/EG[a]	1.5	6
Ag NF-W-EG-2 wt%	Ag	W/EG[a]	2	6
Ag NF-W-1 wt%	Ag	W	1	6
Ag NF-W-1.5 wt%	Ag	W	1.5	6
Ag NF-W-2 wt%	Ag	W	2	6

[a] Water/ethylene glycol mixture (50:50) by wt%.

2.3. Characterization techniques

Microstructure and morphology of Ag NPs were evaluated by using Scanning Electron Microscopy (SEM; FEG-HR Zeiss-Ultra 55). Transmission Electron Microscopy (TEM) analysis of the particles was carried out using JEOL 2100 at 200 kV acceleration voltage. Zeta potential analysis of Ag NPs was performed for evaluating NFs stability region; average hydrodynamic/solvodynamic particle size distribution of Ag NPs was evaluated by Beckmann-Coulter Delsa Nano C system. The TC measurements of NFs at various NP loading was measured using KD2 Pro thermal property analyzer, based on the principle of transient hot wire (THW) method [36]. The KS-1 sensor was oriented vertically in the sample and the measurements were recorded at low power mode with read time of 1 min. All TC measurements of NFs were carried out at 20 °C and repeated for three times for each NF systems. The validity of the THW instrument was checked by comparing with a standard source for thermodynamic properties of water (IAPWS reference) [37]. Compared to the reference the accuracy of measurement for water was within 2.5%. Finally, the viscosity of NFs was assessed using DV-II + Pro-Brookfield viscometer and the validity of this equipment was also verified using distilled water.

3. Results and discussion

3.1. Morphology analysis

The structure and morphology of NPs was investigated by SEM analysis. Agglomerated spherical NPs with average diameter of 40 ± 5 nm were observed. Microstructure and electron diffraction pattern of Ag NPs were analyzed by TEM which revealed Ag NPs have near spherical morphology with an estimated average particle size of 25 ± 4 nm from the TEM micrographs. Selected area electron diffraction (SAED) pattern displayed in inset images in Fig. 1(b), was indexed for Ag (ICDD no: 05-0664), reveals crystalline nature of the Ag NPs.

3.2. Zeta potential/dynamic light scattering (DLS) analyses

Characterizing NPs dispersions and understanding the role of various parameters, which may affect colloidal properties, are important for any NF system. The pH of a suspension has important role not only on the rheological property of suspension but also in terms of fabrication of stable suspension, which is related to the electrostatic charge on