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Experimental investigation on thermal properties of silver nanofluids

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ABSTRACT

This paper reports on an experimental investigation of the thermal properties behavior of 0.5 wt% silver nanoparticle-based nanofluids (NF) containing oleic acid (OA) and potassium oleate surfactant (OAK^+) with concentrations of 0.5, 1, and 1.5 wt% respectively. The experiments were conducted from 20 °C to 80 °C. It was shown that the NF with 1 wt% OAK^+ yielded the highest thermal behavior enhancement of about 28% at 80 °C compared to deionized water. The thermal performance had higher than the base fluid/nanofluids at approximately 80%. Moreover, the NF containing OAK^+ showed higher thermal conductivity and dynamics of specific heat capacity than deionized water in all of the experimental conditions in this study. The rheological experiment showed that viscosity of NF was significantly dependant on temperature. As shear rate increased, the shear stress of the NF increased; however, the viscosity of the nanofluids decreased first and then stabilized. It was further found that NF containing OAK^+ at a range of operating temperatures produced Newtonian behavior.

1. Introduction

Cooling is one of the most important challenges facing numerous industrial sectors. Despite the considerable amount of research and development focusing on industrial heat transfer requirements, major improvements in cooling capability are still insufficient because conventional heat transfer fluids possess poor heat transfer properties. Nanofluids, which are engineered by suspending ultrafine metallic or non-metallic particles of nanometer dimensions in traditional cooling fluids, have shown great enhancement in thermal conductivity and convective heat transfer coefficiency (Choi and Eastman, 1995; Khandekar et al., 2008; Parametthanuwat, 2012; Sreeremya et al., 2014).

This section also contains the literature review for thermal properties. Many researchers have discussed the thermal properties points on which this study is based, together with the background of the research and explanations of the problems faced. This study highlights the theories and experiment for investigating the characteristics of thermal properties. Points of importance will be emphasized, with significance given to the properties of nanofluids and surfactants and their use in this experiment. Also included is the explanation of the characteristics of nanofluid behavior in silver nanofluids containing surfactant. Thus, the researchers used different methods depending on the base fluids, nanofluid/nanoparticle type, etc. Recently, Thermal conductivity of 0.1–0.4% volume concentration silver (Ag) nanoparticles in water were investigated. The nanofluids were formulated using the ultrasonic vibration method for 3 h and thermal conductivity enhancement showed 10% at 0.4% of concentration (Kang et al., 2006). Using a different method, the synthesis of silver nanofluids was performed using high-pressure homogenization with a volume fraction 0.1–0.3% in water. The highest thermal conductivity of the nanofluids showed an 18% increase at the concentration of 0.3% (Oliveira et al., 2014). Moreover, regarding the difference in base fluid, Ag nanofluids in toluene have shown 9% thermal conductivity enhancement with a very low loading of 1.10–3 vol% (Daungthongsuk and Wongwises, 2007; Patel et al., 2003; Trisaksri and Wongwises, 2007; Wang and Mujumdar, 2007). Consequently, nanofluids show better cooling capacity with respect to water in conventional heat pipes since nanoparticles can flatten the temperature gradient of the fluids and reduce the boiling limit (Daungthongsuk and Wongwises, 2007; Khandekar et al., 2008; Trisaksri and Wongwises, 2007). In addition, the concentration of nanofluids may affect the enhancement of thermal conductivity. The studied silver nanofluids in ethylene glycol (EG) with 10,000 ppm concentrations showed 18% thermal conductivity enhancement (Sharma et al., 2011). Then, the investigated carbon black (CB) in deionized water with sodium dodecylsulfate (SDS) as well as Ag nanoparticles in silicon oil with

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Nomenclature

NF	silver nanofluids
NP	silver nanoparticles
OAK^+	potassium oleate surfactant
OA	oleic acid
K and n	consistency index and low power index
k_{eff}	the effective thermal conductivity
k_p	thermal conductivity of particle, $W(m\,K)^{-1}$
k_l	Thermal conductivity of liquid, $W(m\,K)^{-1}$
V_p	volume of nanoparticles in fluid, m^3
V_l	volume of base fluid, m^3
$C_{p,nf}$	specific heat capacity of nanofluids, $J(kg\,°C)^{-1}$
$C_{p,n}$	specific heat capacity of nanoparticles, $J(kg\,°C)^{-1}$
$C_{p,bf}$	specific heat capacity of base fluid, $J(kg\,°C)^{-1}$
$C_{p,eff}$	the effective specific heat capacity, $J(kg\,°C)^{-1}$
x_i	the independent variable to be estimated
μ_i	the manufacturer reported precision of the measurement
Q	heat transfer rate, W
T_{out}	outlet temperature at condenser section, °C
T_{in}	inlet temperature at condenser section, °C
$\dot{m}$	mass flow rate, $kg\,s^{-1}$
Greek symbols	
ρ_n	density of nanoparticles, $kg\,m^{-3}$
ρ_{bf}	density of base fluid, $kg\,m^{-3}$
η	apparent viscosity
$\dot{\gamma}$	shear rate
ϕ	volume fraction of suspension

oleic acid (OA), and with the maximum enhancement of thermal conductivity compared to the base liquid, was 9% for the wt% of the carbon black (CB) nanofluids and the wt% of the Ag nanofluids respectively (Hwang et al., 2008). The .1 wt% copper (Cu) aqueous nanofluids with 0.14 wt% of sodium dodecylbenzene sulfonate (SDBS) as surfactant can generate maximum thermal conductivity enhancement up to 10.7% (Li et al., 2008).

The rheological behavior of nanofluids is essential in establishing adequate application and design of processing. The 8 wt% titania nanoparticles in the EG showed Newtonian behavior at a low shear rate, and the shear viscosity was strongly dependent on the temperature and concentration of the nanoparticles (Chen et al., 2007a). Then, the studied 1 vol% silver NP in ethanol with polyvinylpyrrolidone (PVP) was stabilized (Singh and Raykar, 2008). The rheological results suggest that the PVP helped to decrease the nanoparticle's size, resulting in low fluid viscosity and Newtonian fluid behavior but remarkably high thermal conductivity. Meanwhile, the 4.38 vol% silver nanofluids in the diethylene glycol (DEG) showed Newtonian behavior at high viscosity (Tamjid and Guenther, 2010). However, different literature data have shown that nanofluids have non-Newtonian behavior, particularly at a low shear rates. The most important influence could be the effective particle concentration, the range of shear rate, and the viscosity of the base liquid (Singh and Raykar, 2008). Then, it was found that the TiO_2 nanoparticle in the EG exhibited shear thinning behavior when the particle concentration was higher than ~2% (Chen et al., 2007a). The investigated shear thinning behavior was 3% γ-Al_2O_3 and 10% TiO_2 in water (Pak and Cho, 1998). Another main reason for the non-Newtonian behavior could be the aggregation of nanoparticles in the nanofluids. Lu reported that physical properties may change when the surfactant affects surface tension and viscosity. For instance, Al_2O_3 in water, at a 1:10 weight ratio with ammonium poly (PMAA-NH4), has demonstrated shear thinning behavior (a decrease in viscosity with an increased shear stress rate), which yields a good dispersion rate when using PMAA suspension up to 47.5 vol% (Lu and Kessler, 2006). Then it was found that the 4 vol% of γ-Al_2O_3, TiO_2, and CuO nanofluids with 0.5 wt% of carboxymethyl cellulose (CMC) in deionized water containing up to 4 vol% of particle concentration showed non-Newtonian behavior with shear thinning (Hojjat et al., 2011).

In this paper, 0.5 wt% silver nanoparticle-based aqueous nanofluids with oleic acid (OA) and potassium oleate surfactant (OAK^+) as surfactant were prepared by sonicating in water bath with a cooling technique for a period time of 12 h. The effect of the additive concentration on the thermal properties was studied experimentally (thermal conductivity, specific heat, density, viscosity, contact angle, and application of thermal enhancement), and the rheological behavior (the correlation between shear stress and shear rate) was investigated experimentally and theoretically. Moreover, the heat enhancement cooling of the fluid (HEC) was investigated experimentally and it was confirmed that nanofluids/-nanofluids containing surfactant could be used in the application of heat transfer. The methods of the experiment are briefly explained in Section 2. Section 3 shows the experimental results and offers a discussion. The conclusions to the study are in Section 4.

2. Materials and methods

2.1. Nanofluids and thermal property study

Fig. 1 shows a schematic diagram of the preparation the nanofluids. Water-based silver nanofluids were formulated with dry silver nanoparticles (Sigma–Aldrich, USA), OA, and OAK^+ (Sigma–Aldrich, USA) by using a two-step method (Hwang et al., 2008; Moghaddam et al., 2013). The 0.5, 1, and 1.5 wt% of OA and OAK^+ were added to the 0.5 wt% silver nanofluids, which showed controlled and variable parameters as seen in Table.1. After sonicating for 12 h with a cooling technique, the particle size was measured using a nano-size particle analyzer (ZEN 3600 MALVERN, USA) in the range between 0.6 nm and 6.0 μm. The thermal properties of the nanofluids were measured using the hot-wire method (PSL Systemtechnik GmbH) from 20 °C to 80 °C. The rheological characteristics of the NF were analyzed using a Rheo-microscope Physica MCR301 (Anton Paar GmbH). The measurements were based on the controlled shear stress model with the stress ranging from 0.05 to 5 Pa. The maximum uncertainty was found to be 1.7% (Chen et al., 2007b; Moghaddam et al., 2013; Parametthanuwat, 2012).

The rheological behavior of the NF containing OAK^+ can be expressed with the power model in Eq. (1) with the viscosity as following the power law model indices less than $n \leqslant 1$.

$$\eta = K\gamma^{n-1} \tag{1}$$

In Eq. (1), η is the apparent viscosity, $\dot{\gamma}$ is the shear rate, K is the consistency index, and n is the power law index. The power law index of the nanofluids decreases with increasing nanoparticle concentration, and increases with increasing temperature (Hojjat et al., 2011). Apparently, the viscosity of the NF decreases as the shear rate increases.