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Thermo-physical property evaluation of diathermic oil based hybrid nanofluids for heat transfer applications

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ABSTRACT

Diathermic oil has high boiling point, low vapor pressure and low pour point, so it has been widely used as a heat carrier in heat transfer systems. Due to the excellent thermo-physical property of nanofluids, a kind of hybrid nanoparticles (SiC/TiO_2) was dispersed in diathermic oil to fabricate nanofluids with concentration up to 1 vol% in this paper. And there was no visually observable sedimentation or stratification even after ten days. As two characteristics of thermo-physical property, the thermal conductivity and viscosity were measured under the same conditions respectively, and the experimental results showed that the thermal conductivity of nanofluids increased with increasing volume fractions of nanoparticles and increasing of temperature. With the loading further increasing, the thermal conductivity of SiC/TiO_2 nanofluids is higher than SiC or TiO_2 nanofluids', and the maximum of thermal conductivity enhancement ratio is 8.39% at 1 vol%. Thermal conductivity enhancement ratio was a linear relationship with the volume fraction. Suspending SiC/TiO_2 nanoparticles can enhance thermal capacity of the system. In rheological experiment, the shear viscosity almost maintained constant with shear rate increasing at the given temperature, which means that the samples are Newtonian fluid. And the higher the nanofluids concentration was, the larger value of their shear viscosity. There were some anomalous phenomena occurred in rheological behavior, which may be caused by the breaking up of hybrid of two types of nanoparticles.

1. Introduction

As innovative heat transfer fluids, nanofluids were proposed by Choi (1995) et al. [1] to improve their thermo-physical property. Nanofluids are solid-fluid composite materials consisting of solid nanoparticles or nanofibers with sizes typically of 1–100 nm. Compared with conventional heat transfer fluids, nanofluids have higher thermal conductive capability, which makes they widely apply in the field of heat exchanger system [2,3], solar energy system [4,5], engineering [6] and others [7,8]. Until then, there are extensive literatures on the thermo-physical properties and heat exchange performance of nanofluids of different base fluids [9–11]. In industrial production, it is common to use heat carrier as heat transfer medium, which makes heat transfer more evenly. Among a great amount of heat carriers, water is the most frequently used in the solar collector field [12], heat recovery system [13]. Although water has many advantages, such as high heat transfer efficiency, low viscosity and large latent heat of evaporation, its pour point is 0 °C, the critical temperature is 374.1 °C and the critical pressure is 220 atm. When the temperature is past 100 °C, as the sharply increasing of temperature and pressure, its steam thermal efficiency is low and it is not suitable for heating over 200 °C. Compared with water, diathermic oil has high boiling point, low vapor pressure and low pour point. It can be heated to higher than 300 °C and no vaporization occur under atmospheric conditions, and it can be cooled to -60 °C and no condensation occurs. Therefore diathermic oil is more appropriate to high temperature heating system and cryogenic cooling system. But the biggest drawback is its thermal inertia and heating slower so that it cannot meet the requirement of modern industry. If we can improve its thermal conductivity, the speed of heating will increase, and cooling time will reduce, at the same time reducing the amount using of diathermic oil and volume of heat exchanger. So far, research on diathermic oil has little. Colangelo et al. [14] used the diathermic oil with CuO, Al_2O_3, ZnO and Cu particles, and found that the thermal conductivity enhancement of nanofluids with diathermic oil is higher than with demineralized water. They also measured viscosity of Al_2O_3-diathermic oil nanofluids [15], and found that viscosity increases by increasing the volume fraction and a marked non-Newtonian behavior at high volume

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Nomenclature

Symbols
- k Thermal conductivity [W/m °C]
- φ_v Volume fraction of nanofluids [%]
- ρ density [g/cm^2]
- m mass [g]
- k_r Relative thermal conductivity
- ζ Zeta potential [mV]
- μ Viscosity [mPa·s]
- T Temperature [°C]

Subscripts
- nf nanofluids
- f base fluid
- n nanoparticles
- *SiC* SiC nanoparticles
- TiO_2 TiO_2 nanoparticles

fraction. Hekmatipour et al. [16] researched the effect of adding copper nanoparticles to heat transfer oil in the mixed convection heat transfer rate, and found an increase in the heat transfer rate to reach 16% and improvement of combined free and forced convection. Aberoumand et al. [17] prepared Ag/heat transfer oil by a novel one-step method. They observed the enhancements of convective heat transfer coefficient and the Nusselt number, and the maximum thermal conductivity enhancement was measured to be 30% and viscosity enhanced about 28%. Derakhshan et al. [18] investigated on the heat transfer characteristics of MWCNT-heat transfer oil based nanofluids. Li et al. [19] fabricated diathermic oil based SiC nanofluids, and found that the maximum enhancement of thermal conductivity was 7.36% on the 0.8 vol%. Despite the efforts mentioned above, no more studies of diathermic oil based nanofluids have been found.

Among various materials candidates for nanofluids, SiC received more attention because of its particularly high thermal performances [20,21]. And from the production perspective, the nanoparticles are easy to obtain due to their mature production technology. In previous work, there were quite a great amount of literatures about SiC nanofluids [22–25]. Although SiC nanofluids have good thermo-physical properties [26], their stability impedes the applicability. Considering this aspect, some materials, such as TiO_2 and Al_2O_3 [27], exhibit several excellent properties such as stability and chemical inertness, while their thermal conductivity is relatively low. The utilization of TiO_2 nanoparticles is well accepted for their durability, heat resistance and especially the safeness and harmlessness for humans [28–31]. The incorporation of TiO_2 nanoparticles into SiC nanoparticles can significantly improve the stability and thermal properties. There are a lot of literature prepared nanofluids suspended hybrid nanoparticles to get higher performance. Sunden et al. [32] prepared a hybrid nanofluid containing alumina nanoparticles and multi-walled carbon nanotubes (MWCNTs) by mixing the Al_2O_3/water nanofluids and MWCNT/water nanofluid at a certain proportion. And results showed that the heat transfer was enhanced, which might be caused by the increase in thermal conductivity, random motion of nanoparticles and others. Labib et al. [33] illustrated new concept of combine nanofluids, and the combination of CNTs and Al_2O_3 tends to enhance the convective heat transfer performance significantly. Rashidi et al. [34] synthesized a hybrid of silica nanosphere/multiwall carbon nanotube (MWCNT) by wet chemical method at room temperature. And the results showed that the effective thermal conductivity of hybrid nanomaterials was a value between MWCNT and silica nanoparticles. The hybrid with more amount of MWCNTs showed better influence on thermo-properties. Batunkh et al. [35] used a modified silver particle added into TiO_2 based aqueous nanofluids. Because the "Ag" itself is a very good conductor and the interface of Ag/TiO_2 composite, the combination of TiO_2 and "Ag" particles exhibit a higher thermal conductivity than TiO_2-only nanofluids. Suresh et al. [27] fabricated nanocrystalline alumina-copper hybrid powder by a thermochemical synthesis method, then prepared nanofluids using two step method. The results showed that the thermal conductivity decreases over time until it reaches a special constant, and the thermal conductivity significantly increase almost linearly with increasing particle volume fraction. This may be caused by the formation of large-free regions in the liquid. Afrand et al. [36] reported Fe_3O_4-Ag hybrid nanofluid, which is dispersed equal volumes of Fe_3O_4 and Ag nanoparticles in EG. The samples with lower solid volume fractions showed Newtonian behavior, while exhibited non-Newtonian in higher concentration. The results also revealed the viscosity of hybrid nanofluids decreased with enhancing temperature. In these experiments, because of random motion of nanoparticles and other factors such as interaction and collision of nanoparticles and velocity difference between nanoparticles and based fluid, nanofluids showed better thermo-physical properties than original solution. Thus these nanofluids have good prospects for development, but the current researches have not been studied deeply so far. To summarize what has been mentioned above, the hybrid nanofluids containing SiC/TiO_2 nanoparticles are prepared in this paper.

In order to fill this gap in literature, the current experimental investigation preparing SiC/TiO_2-oil nanofluids with different volume fractions, and measuring their thermal conductivity. In addition, one of the most crucial physical parameters in the heat transfer and flow applications is the viscosity, which controls the interface friction between the fluids' level. The viscosity of nanofluids for drop, fluids' processability and fluid volume of pump has also critical implication, particularly in industrial applications [37,38]. So the rheological behavior of SiC/TiO_2-diathermic oil nanofluids was measured. The effect of volume fraction and temperature were also taken into consideration. We believe our work will be helpful to future studies.

2. Experimental

2.1. Methods and materials

In this work, silicon carbide (SiC) nanoparticles were purchased from C.W. Nanotechnology Company (Shanghai, China), and titanium dioxide (TiO_2) nanoparticles with anatase structure, were purchased from Beijing DK nanotechnology Co. Ltd (Beijing, China). Their basic information is listed in Table 1. L-QC 320 diathermic oil, as the base fluid, was supplied by Diego Asian Petroleum Chemical Co., Ltd. The density of selected HTO is 0.86 g·cm^{-3} and the temperature operation range is −10 to 320 °C. To identify the morphology of isolated nanoparticles, the transmission electron microscope (TEM) was used. As shown in Fig. 1, SiC nanoparticles have a spherical shape and TiO_2 has a bulk shape. They are in the form of large agglomerates.