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Experimental investigation of thermal conductivity and dynamic viscosity on nanoparticle mixture ratios of TiO_2-SiO_2 nanofluids

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ABSTRACT

In recent years, research is focused on enhancing the thermo-physical properties of single component nanofluids. Hence, the hybrid or composite nanofluids are developed to enhance the heat transfer performance. The thermo-physical properties of TiO_2-SiO_2 nanoparticles suspended in a base fluid of water (W) and ethylene glycol (EG) mixture with 60:40 vol ratio are investigated. The experiments were conducted for 1.0% volume concentration of TiO_2-SiO_2 nanofluids with different mixture ratios of 20:80, 40:60, 50:50, 60:40 and 80:20. The measurements of thermal conductivity and dynamic viscosity were performed in the temperature range of 30–80 °C by using KD2 Pro Thermal Properties Analyzer and Brookfield LVDV III Ultra Rheometer respectively. The highest thermal conductivity for TiO_2-SiO_2 nanofluid was obtained with a ratio of 20:80 and the maximum enhancement exceeded up to 16% higher than the base fluids. The nanofluids with a ratio of 50:50 provided the lowest effective thermal conductivity. Meanwhile, the dynamic viscosity variation for all mixture ratios is always lower than the ones with a ratio of 50:50. The properties enhancement ratio suggests that TiO_2-SiO_2 nanofluid with 1.0% volume concentration will aid the heat transfer for all mixture ratios except for the ratio of 50:50. As a conclusion, the optimum mixture ratios for TiO_2-SiO_2 nanofluids are attained with 40:60 and 80:20 ratios where the combination of enhancement in thermal conductivity and dynamic viscosity had more advantages to heat transfer as compared to other ratios.

1. Introduction

In order to improve the heat transfer performance, studies with various types of nanoparticles and approaches were investigated by many researchers [1–6]. Several studies in the engineering fields such as heat exchanger, cooling system, lubrication, solar collector and microelectronics proved that nanofluids have the ability to improve the heat transfer characteristics of industrial equipments [7–10]. Nanofluids are stable particle suspensions with sizes of less than 100 nm that are uniformly distributed in a heat transfer fluid [11,12]. The advancement in nanofluid research is then ventured into composite and hybrid nanofluids. Most of the recent investigations were focused on the determination of the characteristics and thermo-physical properties of hybrid nanofluids [13–16]. Hybrid or composite nanofluids can be defined as a combination of two or more different nanoparticles suspended in a base fluid to obtain a stable homogeneous mixture [17]. The interest in studies on hybrid nanofluids required an extensive understanding of its behaviour. Until recently, a few papers on hybrid nanofluids were reviewed by Sidik et al. [18] and Hamzah et al. [19]. The both papers presented on the method of preparation, performance and applications of the hybrid nanofluids. Therefore, the investigations on thermal conductivity and viscosity are essential in understanding the behaviour of the hybrid nanofluids for further implementation in heat transfer applications.

Thermal conductivity is an important parameter which influences the enhancement of convective heat transfer [20]. There are several factors that affect the enhancement in thermal conductivity such as (i) concentration (ii) temperature, (iii) particle size, (iv) surface to volume ratio of nanoparticles, and (v) stability of nanofluids [21–24]. A study by Jana et al. [25] observed that the AuNP nanofluids with 1.4% volume concentration showed 37% enhancement in thermal conductivity as compared to water. In another paper, Ho et al. [26] studied the effect of dispersing Al_2O_3 nanoparticles in MEPCM suspension. They found that the

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Nomenclature

ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineer
EG	ethylene glycol
k	thermal conductivity
k_r	ratio of nanofluid to base fluid thermal conductivity (k_{nf}/k_{bf})
MEPCM	microencapsulated phase change material
R	ratio of TiO_2 to SiO_2
SAE	Society of Automotive Engineers
TEM	transmission electron microscopy
W	water
V	volume
ΔV	additional volume

Greek symbols

ϕ	volume concentration, %
μ	dynamic viscosity, kg/m s
μ_r	ratio of nanofluid to base fluid viscosity, (μ_{nf}/μ_{bf})
ρ	density, kg/m^3
ω	weight concentration, %

Subscript

bf	base fluid
nf	nanofluid
hnf	composite nanofluid
p	nanoparticle
r	ratio
1	initial
2	final

thermal conductivity of the composite suspension increased by more than 4% with nanoparticle mass fraction. Turgut et al. [27] found that the thermal conductivity increased by 7.4% with particle volume fraction over the base fluids. An investigation of Al_2O_3-Cu composite nanofluids with water as the base liquid was undertaken by Suresh et al. [28]. They reported an enhancement up to 12% with increasing volume concentrations.

The dynamic viscosity of composite Al_2O_3-MEPCM nanofluids was determined by Ho et al. [26]. They observed an enhancement with increasing mass fraction of the nanoparticles. In another study, Esfe et al. [29] used Ag-MgO/water composite nanofluids. They found that the dynamic viscosity of composite nanofluids increased with increasing volume fraction and developed a correlation for viscosity. In comparison, their correlation predicts higher values compared to existing correlations in the literature. Soltani et al. [30] undertook viscosity experiments with MgO-MWCNT composite nanofluids in the concentration range of 0.1–1.0% and temperature range of 30–60 °C. Their findings indicated that the nanofluids behaved as Newtonian fluid. The effect of temperature is observed to be significant for nanofluids at high concentrations.

The need to study the thermo-physical properties of various types of composite nanofluids is essential. This is important to understand the behaviour and factors that affect the properties which lead to the improvement in heat transfer performance. To the author's knowledge, the study on the effect of mixture ratio for two types of nanoparticles in the composite form of nanofluids was limited in the literature. Furthermore, the use of composite nanofluid with two different nanoparticles will result in the increment of relative viscosity compared to a single component of nanofluids [31]. Due to these issues, the present study is carried out by emphasizing the effect of the mixture ratio on the thermo-physical properties and determining the optimum mixture ratio by considering the properties enhancement ratio. Additionally, new correlations are proposed for the estimation of thermal conductivity and dynamic viscosity of TiO_2-SiO_2 nanofluids useful for heat transfer applications.

2. Methodology

2.1. Preparation of TiO_2-SiO_2 nanofluids

TiO_2 and SiO_2 nanoparticles were used in the present experimental study. The original single nanofluids were suspended in water based fluids. The TiO_2 and SiO_2 nanofluids were procured from US Research Nanomaterials, Inc. with the initial weight concentration of 40% and 25% respectively (see Table 1). Later, the TiO_2-SiO_2 nanofluids were prepared for a constant volume concentration of 1.0% by directly mixing the TiO_2 and SiO_2 nanofluids. The experiments were conducted at five nanoparticle mixture ratios (TiO_2:SiO_2) of 20:80, 40:60, 50:50, 60:40, and 80:20. Furthermore, the present study prepared the suspended TiO_2-SiO_2 nanoparticles in water-EG mixture base fluid with 60:40 by volume ratio as stated in the previous studies [32,33]. Eq. (1) is used to convert the original weight concentration (%) of suspended TiO_2 and SiO_2 to volume concentration (%). Later, the dilution process is undertaken with the aid of Eq. (2), where V_1 is known to prepare the nanofluid samples at different mixture ratios and 1.0% volume concentration.

$$\phi = \frac{\omega\rho_{bf}}{\left(1-\frac{\omega}{100}\right)\rho_p + \frac{\omega}{100}\rho_{bf}} \tag{1}$$

$$\Delta V = (V_2 - V_1) = V_1\left(\frac{\phi_1}{\phi_2} - 1\right) \tag{2}$$

Transmission electron microscopy (TEM) is used to observe the dispersion of nanoparticles in the base fluid [13,34]. The TEM images for TiO_2 and SiO_2 nanofluids at 2.0% volume concentration are shown in Fig. 1(a) and (b), respectively. From the TEM images, the average diameter of TiO_2 and SiO_2 single nanoparticles are observed to be 50 and 22 nm respectively and estimated by using *Image J* software [7]. Since the size of SiO_2 nanoparticles is smaller compared to the TiO_2 nanoparticles, the space between the particles of TiO_2 is filled with SiO_2 nanoparticles. The particle distribution of TiO_2-SiO_2 nanoparticles is shown in Fig. 1(c). In general, the coordination of the two nanoparticles strongly depends on the mixture ratios which represent the percent of each nanoparticle in the final solution. This condition will contribute to the reduction in space between the bigger particles hence giving advantage to the thermal properties such as thermal conductivity and specific heat. In addition, the physical properties such as viscosity and density are also expected to change by this condition. In order to evaluate the special characteristic of the two nanoparticle distribution, the present work investigates the effect of nanoparticle mixture ratio on effective thermal conductivity and relative viscosity of TiO_2-SiO_2 nanofluids.

2.2. Stability of TiO_2-SiO_2 nanofluids

The TiO_2-SiO_2 nanofluid solution was subjected to a sonication process to enhance its stability and reduce the agglomeration size of the particles [35,36]. The sample of 200 mL was prepared and