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Experimental investigation of thermal conductivity of nanofluids containing of hybrid nanoparticles suspended in binary base fluids and propose a new correlation

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ABSTRACT

In this experimental study, preparation, stability and thermal conductivity of the MWCNTs-SiC/Water-EG hybrid nanofluid were investigated. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) methods were used to characterize the nanoparticles. Nanofluid stability was monitored by DLS test. According to the DLS results, the nanofluid contained nanoparticles. The thermal conductivity of the hybrid nanofluid was measured using the KD2-Pro thermal analyzer and the KS-1 sensor at a temperature range of 25–50 °C and a solid volume fraction range of 0–0.75%. According to the results, the thermal conductivity of the nanofluid increased further at higher concentrations of the nanoparticles. Therefore, the effect of temperature on the thermal conductivity was higher at higher temperatures. The maximum thermal conductivity of the nanofluid increased up to 33% relative to the base fluid at a temperature of 50 °C and a concentration of 0.75%. A correlation with high accuracy was obtained by fitting the experimental data. The correlation was used to calculate the thermal conductivity of the nanofluid. Given the desirable thermal properties of this nanofluid, it can be used as an alternative fluid in practical systems with high heat transfer potential in the field of heat transfer.

1. Introduction

Today, heat transfer science is one of the most important and most applied engineering sciences. Given the need for energy management, saving energy and achieving a higher efficiency are of great importance [1–3]. The fluid heat transfer is extensively used in various industries including cooling of power plant equipment, automobile industry, electronic equipment and heat exchangers. Increased heat transfer rate by fluids increases thermal efficiency while improving the design and performance of thermal systems. Conventional fluids in the industry have insignificant heat transfer capability. From an industrial perspective, there is a need for developing fluids with a higher thermal conductivity and higher heat transfer coefficients [4,5].

Nanofluids, as a new achievement, have a higher heat transfer potential than conventional heat transfer fluids. Nanofluids are prepared from the suspension of metallic and non-metallic nanoparticles of dimensions less than 100 nm in a base fluid such as water, oil, ethylene glycol, etc. [6]. Due to the very small size of the particles, corrosion, impurities and pressure drop are reduced significantly. Furthermore, the stability of nanofluids is considerably improved against sedimentation [7,8]. By adding nanoparticles to the base fluid in a nanofluid, thermophysical properties will change relative to the base fluid. Since thermophysical properties are dependent on temperature and the concentration of nanoparticles in the base fluid, maximum desirable thermophysical properties can be achieved by changing these two factors. Generally, nanofluids have a high thermal conductivity leading to a high heat transfer rate [9–11].

Thermal conductivity of nanofluids plays a very important role in heat transfer applications. The thermal conductivity of nanoparticles is much higher than that of liquids. Consequently, the addition of nanoparticles to liquids will increase their thermal conductivity. Table 1 shows a summary of previous studies on methods for improving the thermal conductivity of nanofluids.

It can be seen from the results in Table 1 that the thermal conductivity increases significantly compared to the base fluid by adding a limited mass of nanoparticles. This nanofluid feature can greatly help its application in various industries.

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Nomenclature

DLS	dynamic light scattering
EG	ethylene glycol
k (W/m · K)	thermal conductivity
MWCNT	multi-wall carbon nanotubes
SEM	scanning electron microscope
SiC	silicon carbide
T (°C)	temperature
XRD	X-ray crystallography
Greek symbol	
φ(%)	nanoparticle volume concentration
ρ (kg/m^3)	density
Subscripts	
bf	base fluid
Exp	experimental
nf	nanofluid
np	nanoparticle
pred	predicted

Below, literature in this field is reviewed. Maxwell was one of the first researchers who analytically studied the thermal conductivity using a suspension of particles. He considered a very dilute suspension of spherical particles by ignoring interactions between the particles and the base fluid. The results of this study were presented in the form of following analytical relationship [19].

$$\frac{k_{nf}}{k_{bf}} = \frac{k_{np} + 2k_{bf} + 2(k_{np} - k_{bf})\varphi}{k_{np} + 2k_{bf} - (k_{np} - k_{bf})\varphi} \tag{1}$$

Other researchers such as Hamilton-Crosser [20] and Yu and Choi [21] studied the impact of various parameters such as particle shape, interfacial effects and thermal resistance on the effective thermal conductivity of mixtures.

Advances in the manufacture of nanoparticles in the last decade have led to new compounds of nanofluid called hybrid nanoparticles. Here, some studies in this area are reviewed.

Hemmat et al. [22] studied the effect of temperature rise (in the range of 30–50 °C) as well as solid volume fraction (up to 1 vol%) of zinc oxide and multi-wall carbon nanotube hybrid nanoparticles in the water-ethylene glycol as base fluid. According to their results, the thermal conductivity increased by 28.1% at 1% concentration and 50 °C of this hybrid nanofluid.

In an experimental study, the thermal conductivity of ZnO-Ag (50–50) hybrid nanofluid in the water base fluid was investigated at a temperature range of 25–50 °C and a solid volume fraction of 0.125–2%. According to the results, the maximum thermal conductivity of the nanofluid was measured at a concentration of 2% at 50 °C [23]. Hemmat et al. experimentally studied the effects of temperature and solid volume fraction of hybrid nanofluids composed of SWCNT-MgO nanoparticles in the ethylene glycol base fluid at a temperature range of 30–50 °C and solid volume fraction of 0.05–2%. The results showed that the maximum thermal conductivity increased by 32% relative to the base fluid at 50 °C and a solid volume fraction of 2% [24].

Hemmat et al. experimentally investigated the effects of temperature and solid volume fraction of hybrid nanofluids composed of SWCNT-ZnO nanoparticles dispersed in the water-ethylene glycol base fluid at a temperature range of 26–50 °C and solid volume fraction of 0.05–1.25%. According to their results, the maximum thermal conductivity increased by 45% at 50 °C and solid volume fraction of 1.25%. They also provided a correlation to calculate the thermal conductivity [25]. Harandi et al. [26] introduced F-MWCNTs-Fe_3O_4 nanoparticles as a suitable compound for improving the thermal properties of ethylene glycol base fluid. According to their results, the thermal conductivity of the nanofluid increased by 30% relative to the base fluid at a volume fraction of 2.3%. Munkhbayar et al. [27] used silver nanoparticles to improve the surface properties of carbon nanotubes. They studied effective parameters such as concentration and temperature in the range of 0–3 vol% and 15–40 °C, respectively. According to their results, the thermal conductivity increased by 14.5% relative to the base fluid. In an experimental study, Siam et al. investigated the effects of temperature rise and solid volume fraction in a hybrid nanofluid composed of iron oxide nanoparticles and multi-wall carbon nanotubes in water base fluid. They performed experiments at temperatures between 20 and 60 °C and solid volume fraction up to 3%. According to their results, the thermal conductivity increased by 31% at 60 °C at a volume fraction of 3% [28]. They also studied the effect of hybrid nanofluid on convective heat transfer and friction coefficient. In another experimental study, Hemmat et al. investigated the effects of temperature rise and concentration of copper and titanium oxide nanoparticles in a hybrid base fluid and a mixture of water and ethylene glycol at temperatures between 30 and 60 °C and a solid volume fraction of 2%. The results showed that the thermal conductivity increases by 44% at a temperature of 60 °C and a volume fraction of 2% [29]. Due to desirable properties of nanofluids, in addition to overcoming the problems with energy conversion and transmission, nanofluids can be an alternative fluid for development of thermal systems to reduce the size of heat exchangers, increase productivity, reduce fuel consumption, and save costs [30–33,35–41].

In this study, hybrid carbon nanotubes and silicon carbide nanoparticles are used to improve the heat transfer properties of the base fluid. Silicon carbide nanoparticles are easily dispersed in the water-ethylene glycol base fluid and have long-time stability. On the other hand, functionalized carbon nanotubes have unique thermal properties. The mixture of water-ethylene glycol (50–50) was used as the base fluid in this study. This study aims at improving the thermal properties of the water-ethylene glycol base fluid because of its widespread use in the industry. Experiments were carried out at a temperature range of 25–50 °C and a solid volume fraction of 0.05–0.75%. Finally, the results of experiments were analyzed and compared in the form of graphs. A correlation was presented for the ratio of the thermal conductivity variation of the hybrid nanofluid to calculate the thermal conductivity of the nanofluid.

2. Experiments

2.1. Preparation methods of nanofluids

One of the challenges in the use of nanofluids is their successful preparation and stability because uniform and improved properties in nanofluids are dependent on nanofluid stability. A two-stage method was used in this study to prepare a stable nanofluid. The base fluid was water-ethylene glycol with a volume ratio of