International Communications in Heat and Mass Transfer 90 (2018) 23–28

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Thermal conductivity of an ethylene glycol/water-based nanofluid with copper-titanium dioxide nanoparticles: An experimental approach

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A R T I C L E I N F O

Keywords:
Hybrid nanofluid
Non-hybrid nanofluid
Thermal conductivity
Surfactant
pH
Sonication time

A B S T R A C T

Heat transfer fluid with low thermal conductivity limits the efficiency of thermal systems, such as heat exchangers, which require heat transfer fluid with high thermal conductivity. There is a demand to synthesize heat transfer fluids with high thermal conductivity. The emergence of nanoparticles has led to the development of nanofluids. Nanofluids can be classified as non-hybrid and hybrid nanofluids. This study investigated the thermal conductivity characteristics of a copper-titanium dioxide (Cu-TiO_2) hybrid nanofluid and compared with those of a non-hybrid (Cu and TiO_2) nanofluid. In addition, the effects of various factors (weight percentages of the nanoparticles, types of surfactants, pH values of the base fluid solution and sonication times) on the thermal conductivity of theCu-TiO_2 hybrid nanofluid were studied. The thermal conductivity of theCu-TiO_2 hybrid nanofluid increased in accordance with an increment in the weight percentage of the nanoparticles. The hybrid nanofluid containing 0.8 wt% of Cu-TiO_2 and polyvinylpyrrolidone (PVP) as surfactant showed the highest thermal conductivity, exhibiting an improvement of 9.8% compared to that of the base fluid.

1. Introduction

A nanofluid is an engineered colloid, which consists of two main components: a base fluid and nanoparticles. This newly developed heat transfer fluid was developed by a group of scientists in Argonne National Laboratory in the 1990s [1]. Since then, an extensive amount of research has been conducted to evaluate nanofluids thermal conductivity. Most of the studies found that the nanofluids thermal conductivity was augmented as compared to that of a base fluid alone [2–5]. Nanofluids have potential uses in various applications, such as solar thermal collectors [6–7], shell and tube heat exchangers [8–9], heat pipes [10–11] and automotive radiators [12–14].

Recently, attention has switched to the thermo-physical properties and thermal performance of hybrid nanofluids. Sarkar et al. [15] defined a hybrid nanofluid as (a) a fluid to which two or more different types of nanoparticles had been added to the base fluid or (b) a fluid to which nanocomposites had been added to the base fluid. The authors further added that the objectives of producing hybrid nanofluids is to obtain favourable properties of the constituent materials. Minea [16] came to a similar conclusion in her review article. Akilu et al. [17] used the term 'composite nanofluids' instead of hybrid nanofluids in their review article and concluded that the properties of these composite nanofluids depended upon their constituent materials.

In recognition of the benefits of hybrid nanofluids, thermal scientists and researchers have begun to study their synthesis and thermal conductivity characteristics. Abbasi et al. [18] investigated the influence of a functionalization approach on the stability and thermal conductivity of carbon nanotubes (CNTs)/gamma alumina (γ-Al_2O_3) based nanofluids. In their study, they used a solvothermal process to synthesize hybrid nanoparticles and found that the thermal conductivity of the nanofluids seemed to depend on its stability. They concluded that thermal conductivity enhancement up to 14.75% can be achieved at a particle volume fraction of 0.01 for nanofluids with added gum arabic (GA) surfactant.

In another comprehensive study of hybrid nanofluids, Hemmat Esfe et al. [19] added silver (Ag) and magnesium oxide (MgO) (50% each by volume) nanoparticles to water and then evaluate the thermal conductivity of the Ag-MgO/water hybrid nanofluid. They used cetyl trimethyl ammonium bromide as surfactant. The authors proposed a new thermal conductivity correlation for the Ag-MgO/water hybrid

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https://doi.org/10.1016/j.icheatmasstransfer.2017.10.005

Available online 20 November 2017

nanofluid at particle volume fraction ranges between 0 and 2%. They reported good agreement between data predicted by the thermal conductivity correlation and experimental values.

Hemmat Esfe et al. [20] also studied the thermal conductivity of copper/titanium dioxide (Cu/TiO_2)-water/ethylene glycol hybrid nanofluids. They added Cu and TiO_2 nanoparticles to a base fluid and dispersed the nanoparticles via a magnetic stirrer and ultrasonic processor. They then examined the thermal conductivity of the hybrid nanofluid at various particle concentrations (0–2%) and temperatures (30–60 °C). Based on their findings, they developed two new thermal conductivity models using artificial neural network and correlation modeling. The study indicated that both the artificial neural network model and correlation model were able to predict the thermal conductivity of the nanofluid. However, they concluded that the accuracy of the artificial neural network model was higher than that of the correlation model.

Kumar et al. [21] fabricated in-situ hybrid copper-zinc (Cu−Zn) (50:50) nanoparticles, which were added in vegetable oil, paraffin oil and Castrol oil. Sodium dodecyl sulphate surfactant was added to stabilize the suspension. They reported that the effective thermal conductivity of the nanofluids increased in accordance with an increment in the concentration of the particles. The vegetable oil-based nanofluid exhibited higher effective thermal conductivity than the other oil-based nanofluids. The authors attributed this finding to the paraffin and Castrol oils having higher viscosity and lower thermal conductivity than vegetable oil.

Sundar et al. [22] synthesized magnetic nanodiamond iron oxide (Fe_3O_4) nanoparticles via an in-situ growth and wet-chemical reaction method. The results of a zeta potential analysis showed that these hybrid nanoparticles were well dispersed in distilled water. The authors revealed that the thermal conductivity of the water-based nanofluids was higher than that of ethylene glycol- and water-based nanofluids. They concluded that the improvement in thermal conductivity depended on the type of base fluid and heat transfer between the particle–fluid interface. Higher heat transfer occurred when the interfacial area increased. They attributed this finding to the Brownian motion of nanoparticles creating micro-convection due to the contact between the nanoparticles and water molecules.

Sarbolookzadeh Harandi et al. [23] mixed dry functionalized multiwalled (MWCNTs) and Fe_3O_4 nanoparticles in an equal volume. They used ethylene glycol as the base fluid. Thermal conductivity increased in accordance with an increase in the particle concentration and temperature. The authors found that the effect of temperature on thermal conductivity was more noticeable at a higher particle concentration. The recorded maximum thermal conductivity enhancement was 30%, which was observed at 50 °C and 2.3 vol% of nanoparticles.

Farbod and Ahangarpour [24] examined the thermal conductivity characteristics of water-based nanofluids containing Ag-decorated MWCNTs. They produced a range of samples with pristine and functionalized MWCNTs and different reflux times, mass ratios of Ag/MWCNT, concentrations of Ag/MWCNTs and Ag-decorated and undecorated MWCNTs. They observed a substantial thermal conductivity improvement in the MWCNT nanofluids containing Ag-decorated MWCNTs compared to that of the undecorated samples.

Toghraie et al. [25] dispersed an equal amount of zinc oxide (ZnO) and TiO_2 nanoparticles in an ethylene glycol base fluid to produce a hybrid nanofluid. They discovered that the thermal conductivity of the nanofluid increased in accordance with a rise in the temperature and concentration of nanoparticles, with higher temperatures and concentrations of particles associated with better thermal conductivity than lower temperatures and lower concentrations. These results were in accordance with those of the aforementioned experimental studies.

Wei et al. [26] examined the thermal conductivity of a silicon carbide (SiC)/TiO_2 hybrid nanofluid, in which oleic acid was used as surfactant to ensure suspension stability. The authors reported that the thermal conductivity of this hybrid nanofluid was higher than that of SiC or TiO_2 diathermic oil-based nanofluids. This finding contradicted that of Akilu et al. [17], who concluded that the properties of hybrid nanofluids are between their constituent materials.

Hemmat Esfe et al. [27] added single-walled CNTs (SWCNT) (20%) and MgO (80%) to ethylene glycol to produce a hybrid nanofluid. The relative thermal conductivity of the hybrid nanofluid was between the single type of nanofluids, with the SWCNT nanofluid yielding the highest value at 0.75 vol% of nanoparticles, regardless of the temperature. In another study, Hemmat Esfe et al. [28] determined the thermal conductivity and optimization of silicon dioxide/MWCNTs (85:15%)–ethylene glycol hybrid nanofluids. They measured the thermal conductivity at various particle volume fractions (0.05–1.95%) and temperatures (range: 30–50 °C). Their results suggested that the thermal conductivity ratio of the hybrid nanofluid increased nonlinearly with a rise in the temperature and concentration of nanoparticles added to the nanofluid. In their study, the highest thermal conductivity augmentation was 22.2%.

TiO_2 has a number of favourable properties compared to those of other types of nanoparticles. These include stability, reduced toxicity, durability and low cost [29–30]. A problem with TiO_2 is its poor thermal conductivity, which is only 8.4 W/m·K at 300 K [31]. In contrast, the thermal conductivity of Cu can be as high as 401 W/m·K at the same temperature [31]. Suresh et al. [32] stated that poor stability and reactivity hindered the use of metallic nanoparticles, such as Cu. Addition of a small amount of Cu to low thermal conductivity nanoparticles such as TiO_2 expected to enhance the thermal conductivity of a nanofluid without compromising its stability. Thus, in the present study, we used Cu and TiO_2 nanoparticles as the two constituent materials.

In this study, the thermal conductivity characteristics of a hybrid (Cu-TiO_2 ethylene glycol/water-based) nanofluid were investigated and compared with those of a non-hybrid (Cu, TiO_2) nanofluid. In addition, the effects of various factors (weight percentage of nanoparticles, types of surfactants, sonication times and pH values of the base fluid solution) on the thermal conductivity of the hybrid nanofluid were studied.

2. Methodology

2.1. Nanoparticles

Commercial Cu and TiO_2 nanoparticles were used. The properties of these nanoparticles provided by the manufacturer are illustrated in Table 1. To synthesize Cu-TiO_2, ascorbic acid was first added to distilled water. Then, hydrogen peroxide was added to this solution, and the solution was mixed using a magnetic stirrer for 5 min. Hydrogen peroxide acts as a reducing agent. The mixture of the hydrogen peroxide and ascorbic acid solution was heated to 90 °C. Solid Cu alloy was then immersed to the solution. Copper ascorbate was produced as a result of the chemical reaction between the Cu alloy and ascorbic acid. The precipitation of the copper ascorbate at the bottom of the beaker was filtered through a filtration flask and dried in an oven at a temperature of 90 °C for about 6 h. The dried copper ascorbate particles were then crushed to smaller sized particles using a mortar and pestle. The prepared copper ascorbate (3 g) was added to a solution containing TiO_2 (5 g) and distilled water (200 ml) and stirred using a magnetic stirrer for another 2 h. The solution was then filtered and dried in an oven for 6 h. The final output of this process was Cu-TiO_2 particles, which were crushed to a smaller size using a mortar and pestle. The surface

Table 1
Properties of Cu and TiO_2.

	Cu [33]	TiO_2 [34]
Purity	≥ 99.5% trace metals basis	99.7% trace metals basis
Size (nm)	40–60	< 25