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Research Paper

Thermal conductivity of water and ethylene glycol nanofluids containing new modified surface SiO_2-Cu nanoparticles: Experimental and modeling

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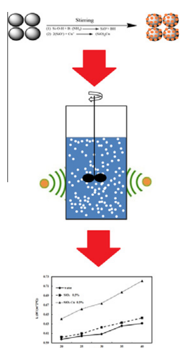
HIGHLIGHTS

- The SiO_2 nanoparticles and SiO_2-Cu nanocomposites are synthesized and characterized.
- The nanoparticles were used to prepare water and ethylene glycol nanofluids.
- Both nanofluids show about 11% thermal conductivity increment at 1% particle volume fraction.
- A core shell based model is used to modify the Maxwell model prediction.

GRAPHICAL ABSTRACT



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ABSTRACT

In the present study SiO_2-Cu nanocomposites are synthesized and characterized. At the next stage the thermal conductivity of the SiO_2-Cu/water and SiO_2-Cu/EG nanofluids are measured and reported. The results show that chemical deposition of a small amount of Cu on the SiO_2 surface results in considerable rise in thermal conductivity of the base fluid. A water nanofluid contains less than 1% of modified nanocomposites can increase the thermal conductivity of water up to 11%. The increment on thermal conductivity of the EG with the same amount of nanoparticles was about 11.5% (temperature 25 °C). One of the most important features of this work is that this type of nanofluids contains particles which have a density close to SiO_2 but a thermal effect similar to copper. Finally, a core-shell model has been presented for the thermal conductivity prediction.

1. Introduction

Heat transfer can be enhanced via active or passive techniques to reduce the weight and size of the heat transfer equipments. In spite of the active techniques, passive techniques don't required external power. One of the most famous passive techniques for heat transfer enhancement is the use of nanofluids as the cooling or heating media in heat transfer devices. Passive method for heat transfer enhancement has been investigated by several authors which can be find in literatures (for example see the Refs. [1–6]). Nanofluids (NF) are new kinds of engineering fluids which are stabilized dispersion of nanoparticles in a base fluid. These types of fluids were invented originally to enhance the thermal properties of heating and cooling fluid mediums [4–6], but now, the researchers tend to explore new properties of NFs such as enhanced mass transfer [7].

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Nomenclature

k_p	thermal conductivity of the core particle	β	ratio between the nanolayer thickness and the original
k_b	thermal conductivity of the base fluid	r	distance in radial direction from the center of the particle
k_{eq}	thermal conductivity of the equivalent nanoparticle	h	the thickness of nanolayer around a particle
k_{layer}	thermal conductivity of the nanolayer		
k_{eff}	effective thermal conductivity		
ρ	density		
ϕ	particle volume fraction		

Thermal conductivity of typical cooling fluids such as water and ethylene glycol (EG) is less than solid particles such as metals, metal oxides, and carbon nanotubes by an order of magnitude. Therefore, adding a few percents of metal nanoparticles into the base fluid shows anomalous enhancement in the fluid's thermal conductivity [8,9].

There are two main approaches for synthesis of NFs [10]. In the first approach, called single–stage synthesis, the production of nanoparticles and the stabilization of them in the fluid medium are combined in a single process [11], but in the second approach, called two-stage synthesis approach, the nanoparticles are synthesized first and then stabilized in the fluid medium with mechanical and/or chemical treatments [12,13].

SiO_2 nanoparticles are popular in nanoparticle synthesis due to high chemical and thermal stability. Several studies have been devoted to SiO_2 nanofluids characterization [14–16] and the nanoparticle surface modification [17].

In the present work, SiO_2 nanoparticles with the copper modified surface have been synthesized and dispersed in water and ethylene glycol (EG) fluid mediums and the enhanced thermal conductivity of the fluids containing this type of nanoparticle has been studied.

One of the most important features of the present work is that the new synthesized particle has a density close to SiO_2 but its thermal properties are close to copper. NFs containing pure metals such as Cu/water NF have a big potential to be oxidized when expose to air. In the present work, a new nanofluid has been synthesized that doesn't have the disadvantage of the metallic nanoparticles.

2. Methods and materials

All chemicals were purchased from Merck chemical company. Scanning electron micrograph (SEM) (AIS2100 (Seron Technology)) microscope and field emission scanning electron microscope (FE-SEM,Carl Zeiss, Germany) were used for imaging from samples. FT-IR analysis was carried out using a Shimadzu FTIR-8400S spectrophotometer with KBr pellet. The elemental ratio of prepared nanocomposites was characterized by SEM-EDX (Tescan). The surface areas of SiO_2-Cu and SiO_2 nanoparticles were measured by using Brunauer–Emmett–Teller (BET) technique at 300 °C and 196 °C, respectively.

3. Experimental

3.1. Synthesis of SiO_2 nanoparticles

SiO_2 nanoparicles were synthesized according to Stöber method by hydrolysis and condensation of tetraethyl orthosilicate (TEOS) (3 ml) in a mixture of ethanol (55 mL) and water (3 ml), using ammonia (6 ml) as a catalyst to initiate the reaction. The reaction took place under stirring condition for about 2 h. The products were filtered and rinsed by ethanol, and then dried at temperature below 100 °C for 2 h [18].

3.2. Synthesis of SiO_2-Cu nanocomposites

For preparation of copper modified surface SiO_2 particles, 25 mmol of SiO_2 nanoparticles synthesized in the previous section was added to 100 ml of deionized water in a highly stirred beaker and then about 11.74 mmol ammonia and 11.16 mmol $CuCl_2$ were added to the mixture at ambient temperature for 6 h. The products were filtered and purified by washing with ethanol, and then for 2 h at the room temperature were dried. Finally, Cu-SiO_2 nanocomposite was obtained. The schematic of the reaction is depicted in Fig. 1.

3.3. Preparation of nanofluids containing SiO_2 and SiO_2-Cu nanoparticlse

The nanofluids were prepared by dispersing certain amounts of SiO_2 and SiO_2-Cu nanoparticles in known quantities of water and EG using a magnetic stirrer for around 3 h and then the suspension was treated by ultra-sonicating for 2 h using a 250 W sonicator. The NFs remain stable at least for two weeks.

To measure the thermal conductivity of fluids, a transient hot wire (THW) technique is used [19]. Each experiment is repeated at least for 3 times. The experimental results show that the uncertainties for water and ethylene glycol systems are respectively ±1.2% and ±0.9% [19].

4. Results and discussion

4.1. Characterization of SiO_2 and SiO_2-Cu nanoparticles

The SiO_2 nanoparticles surface area and their morphology were evaluated by BET and SEM methods respectively. The latter is illustrated in Fig. 2a. The image shows sub-100 nm spherical silica particles with an average size of about 75 nm. The BET surface area of silica nanoparticles was measured 67.8404 m^2/g.

The SiO_2-Cu particles were characterized by FESEM, EDX spectroscopy and BET. The Surface morphology of the SiO_2-Cu nanocomposite is shown Fig. 2b.

The EDX analysis of SiO_2-Cu nanocomposite shows that there are Si, O, and Cu elements in nanoparticles. According to EDX results (Fig. 3) the weight percent of Cu is about 8%. BET surface area for SiO_2-Cu nanocomposite is measured 31.44 m^2/g. The surface area decrease is due to deposition of Cu particles on the surface of silica spheres [17].

4.2. Thermal conductivity of SiO_2/water and SiO_2/EG nanofluids

The thermal conductivity of water as a base fluid versus temperature is shown in Fig. 4a. The two nanofluids contain 0.5% w/w and 1% w/w SiO_2 nanoparticles, respectively. As can be seen from