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Effect of the collision medium size on thermal performance of silver nanoparticles based aqueous nanofluids

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ABSTRACT

The present paper describes an influence of different ball sizes (1 mm, 3 mm and 5 mm) of the planetary ball milling machine on the thermal conductivity characteristics of silver-based aqueous nanofluids. Nano-metric silver dispersed water based nanofluids with various loadings (1 wt%, 2 wt% and 3 wt%) have been prepared by a single-step approach. It has been observed that the ground silver nanoparticles suspended in conventional fluids have superior thermal conductivity performance mainly due to flattened particles and/or increased aspect ratio. The silver particles present in colloidal phase have been characterized by scanning electron microscopy (SEM), transmission electron microscopy (TEM), UV–visible spectroscopy, particle sizing system (PSS) and zeta potential measurements. The stability as well as thermal conductivity of these nanofluids have been measured at wavelength ranging from 300 to 800 nm and at temperature ranging 20–40 °C, respectively. As a result, the silver nanoparticles ground by 1 mm ball size that dispersed in aqueous solution (1 wt%) is showed highest thermal conductivity (621 W/mk) which was greater than that of the nanofluids prepared by other conditions, at a temperature of 40 °C. A significant trends in the thermal conductivity of nanofluids are attributed to several specific reasons which have been discussed in this article.

1. Introduction

The innovative concept of ‘nanofluids’ heat transfer fluids consisting of nanoparticle suspensions has been proposed as a solution to these challenges [1]. The term “nanofluid” was coined in 1995 by Choi of Argonne National Laboratory, USA [2] to describe the material conceived to surpass the performance of common heat transfer liquids. Nanofluids are a type of new engineering material composed of solid nanoparticles measuring 1–100 nm suspended in base fluids. Thermal properties of nanofluids, as summarized by Eastman et al. [3], are characterized by many fold increase in thermal conductivity compared to that of the base fluids as a function of loadings of nanoparticles and temperature. This property make nanofluids a potential candidate for application in the fields of key engineering sectors like microelectronics, automobiles, power generation, transportation, aerospace and nuclear power plants [4,5].

Metal nanostructures have been attracted considerable interest in various fields of chemistry due to their novel physicochemical properties. They are different significantly from macroscopic metal phases. Among the various metal nanostructures, noble metal nanoparticles are currently one of the most attractive materials in nanotechnology [6]. Silver ‘Ag’ is most widely recognized noble metal for its unique optical properties, as manifested by its central role in photography [7]. ‘Ag’ nanoparticles have been used in a broad range of applications including as a substrate for surface-enhanced Raman scattering [8], an antibacterial agent [9], a catalyst [10], a biosensor [11], in diagnostic biomedical imaging [12], and in lithography [13] due to their special electrical and mechanical properties as well as high thermal conductivity [14].

The key step in improving the thermal conductivity of fluids using nanoparticles is synthesis. There are two main techniques used to produce nanofluids: (i) the one-step direct evaporation method, through which nanoparticles are directly formed within base fluids, and (ii) the two-step method, through which nanoparticles are formed and subsequently dispersed in base fluids. Compared to the two-step method, the one-step process has many advantages, such as smaller particle size, less contamination of the particle surface, and high dispersibility. However, the one-step process only produces nanofluids in small quantities, and the produced nanofluids are expensive. Furthermore, the concentration of nanoparticles is much more limited in the one-step process com-

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pared with that in the two-step technique. To resolve this issue, the pulsed-wire evaporation (PWE) method [15–17] is used to synthesize nanofluids in this work.

Several researchers have reported different methods for the preparation of 'Ag' nanoparticles with tailored sizes and shapes such as wires [18], rods [19], cube [20], rice [21], and sphere [22]. In addition, 'Ag' nanoparticles are most commonly prepared by reduction of silver salts in solution by a reducing agent (e.g. sodium borohydride) in the presence of a stabilizer such as polyvinyl pyrrolidone (PVP). However, in nanofluids applications, although additives can improve the dispersion stability, it may cause several problems such as contamination of the heat transfer media and the production of foams. Furthermore, additives molecules adsorbed on the surface of particle may enlarge the thermal resistance between the particles and the base fluid, which limits the enhancement in the effective thermal conductivity [23]. Thus, no surfactants are used in the present work. Moreover, it was found that the flattened (plate) nanoparticles generally show higher thermal conductivity than that of the particles with spherical shape. It has been established that this higher thermal conductivity of plate nanoparticle is mainly associated to the aspect ratio of the particle [24,25]. Because of this phenomena, several researchers have attained to control the shape of nanoparticles by using a chemical and physical methods. Until now, the planetary ball milling (mechanical method) machine with systematic investigation of parameters such as various ball size, however, has not yet been utilized to enhance the thermal conductivity of 'Ag' nanoparticles by adjusting the particle shape.

In this article, a one-step technique is applied to synthesize the 'Ag' based aqueous nanofluids with different loadings (1 wt%, 2 wt% and 3 wt%). The objective of this study is established as following threefold: (i) to produce 'Ag' nanofluids using a simple one-step process via the PWE technique, (ii) to find the optimum collision medium size (among the ball sizes of 1 mm, 3 mm and 5 mm) of planetary ball milling machine in order to adjust the particle shape and aspect ratio and (iii) to enhance the thermal conductivity of 'Ag' nanofluid by controlling the particle shape as well as aspect ratio.

2. Experiment

2.1. Materials

'Ag' wire is used as received without further purification. Pure 'Ag' (>99.9%) wire with a diameter of 0.2 mm (purchased from Nano Technology Inc., Korea) is used as the starting material. Distilled water (DI water) is used as the base fluid of the nanofluids.

2.2. Preparation of 'Ag' nanofluids

'Ag' nanoparticles based aqueous nanofluids are prepared by a one-step physical technique using the PWE method (Portable, Nano Colloid Maker, Nano Technology Inc., Korea). A photograph of one-step technique used in this study is shown in Fig. 1. The apparatus used consists of four main components: a high-voltage DC power supply, a capacitor bank, a high-voltage gap switch, and an evaporation/condensation chamber. The feeding length of the wire into the reaction chamber was 90 mm. When a high-voltage pulse of 300 V is driven through a thin wire, the non-equilibrium overheating induced in the wire causes the wire to evaporate into plasma within several micro-seconds. The high-temperature plasma is cooled by interaction with an argon–oxygen mixed gas and condensed into small particles.

A planetary ball mill (HPM-700) (provided by Haji Engineering, Korea) is used to grind samples in this study. Based on our previous

Fig. 1. A photograph of portable nano-colloid synthesizer (NTi-MiniP).

work [26], the 'Ag' nanoparticles are ground under wet condition at a rotation speed of 500 rpm for 1 h. The direction of the pot rotation is set counter to that of the disk revolution. A detailed expression of grinding process is completely reported in following published literature [27]. Monosized spherical zirconia (ZrO_2) balls are used as the collision medium. To find the optimum ball size for the purpose of increasing the thermal conductivity of silver based aqueous nanofluids, three different balls with sizes of 1 mm, 3 mm and 5 mm are used to change the particle shape.

For better dispersion, previously synthesized the 'Ag' nanoparticles in aqueous solution was ground under relatively different conditions that were completely dispersed in the base fluid using an ultrasonication in Branson ultrasonic cleaner model 1510E-DTH (Branson Ultrasonic Corporation 41, Danbury, CT 06813, USA) for 1 h. Calorimetry was performed to measure the output power and frequency of the applied ultrasonic vibration: 63 W and 42 kHz, respectively. Ice water was repeatedly added to the ultrasonic bath during ultrasonication to prevent an increase in the temperature of the suspension. The stabilities of the nanofluids are examined approximately 48 h after ultrasonication. As a result, 1 mm ball size of PBM has been found as a optimum condition among three different ball sizes in order to improve the dispersibility and thermal conductivity of 'Ag' nanofluids. Based on above finding, the 'Ag' nanoparticles based aqueous nanofluids with 1 wt%, 2 wt% and 3 wt% are prepared by 1 mm ball size of PBM to compare the dispersion and thermal characteristics of the nanofluids. The concentration of 'Ag' nanoparticles in aqueous solution was controlled by adjusting the wire explosion number.

2.3. Characterization techniques

Firstly, scanning electron microscopy (SEM) (JSM-5610, JEOL, and Tokyo, Japan) is used to characterize the structure, size, shape and purity of 'Ag' nanoparticles synthesized by single-step technique. Moreover, the extent to which the nanoparticles shape are changed was analyzed by SEM. The structure and morphology of 'Ag' nanoparticles based aqueous solution are confirmed by transmission electron microscopy (TEM) (JEM-2100 F, JEOL; Tokyo, Japan). In order to justify the particle size measured by SEM and TEM, the particle sizing system (PSS, NICOMP 380, and Santa Barbara, California, USA) is used to measure 'Ag' nanoparticles produced by one-step method in the present study. UV