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CHARACTERIZATION OF ETHYLENE GLYCOL BASED TiO_2 NANOFLUID PREPARED BY PULSED WIRE EVAPORATION (PWE) METHOD

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Abstract. In the present work, ethylene-glycol (EG) based nanofluids containing TiO_2 nanoparticles were prepared by one-step pulsed wire evaporation (PWE) method. The structural properties of TiO_2 nanoparticles were studied by X-ray diffraction (XRD) method and high resolution transmission electron microscopy (HRTEM). The thermal conductivity of EG-TiO_2 nanofluid increased with TiO_2 volume fraction, and the experimentally measured value of thermal conductivity coincided well with Hamilton-Crosser model.

1. INTRODUCTION

The thermal conductivity of heating or cooling fluid plays an important role in the development of energy-efficient heat transfer equipment. Among the various techniques for improving the heat transfer efficiency, an innovative way is to suspend nano-sized metallic or ceramic solid particles in traditional fluids such as water, ethylene glycol (EG) and oil since the thermal conductivities of most solid materials are significantly higher than those of base fluids [1-5]. The pulsed wire evaporation (PWE) method [6-10] is one of the gas condensation processes for the synthesis of nanoparticles with high efficiency and high production rate. The various metal and oxide nanoparticles can be prepared by charging a starting wire at argon and argon-oxygen mixed gas, respectively.

In the present work, the PWE method was applied to prepare TiO_2 nanofluid by one-step physical process. By using a rotary chamber in which the inner wall is covered by EG and a nozzle spray system, the nanoparticles synthesized by wire explosion directly contact EG without surface contamination. Then the thermal conductivity of the prepared nanofluid was experimentally measured as functions of TiO_2 volume fraction (0.5~5.5 vol.%) and temperature (20~90 °C). In addition, the experimental value of thermal conductivity was compared with the theoretical value of Hamilton-Crosser model.

2. EXPERIMENTAL

EG-based TiO_2 nanofluid was prepared by one-step PWE method. The apparatus consists of four main components: a high voltage dc power supply, a capacitor bank, a high voltage gap switch, and an evaporation/condensation chamber. Pure Ti (>99.9%) wire with a diameter of 0.5 mm was used as a starting material, and the feeding length of the wire into the reaction chamber was 100 mm. When a pulsed high voltage of 25 kV is driven through a thin wire, a non-equilibrium overheating induced in the wire makes the wire to evaporate into the plasma within few micro-second. Then the high-temperature plasma is cooled by an interaction with argon-oxygen mixed gas and condensed into small-size particles. The synthesized nanoparticles directly con-

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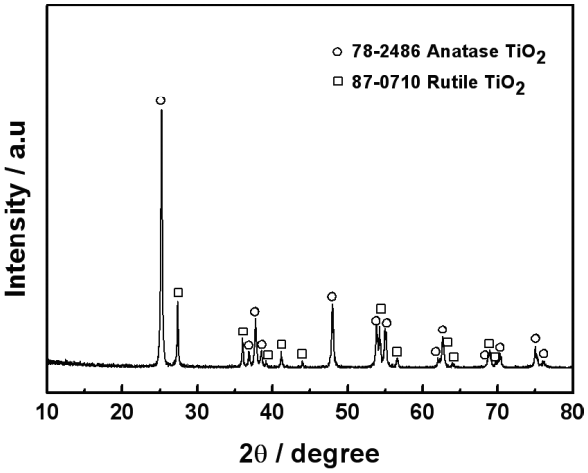

Fig. 1. X-ray diffraction (XRD) patterns of TiO_2 nanoparticles synthesized by pulsed wire evaporation (PWE) method.

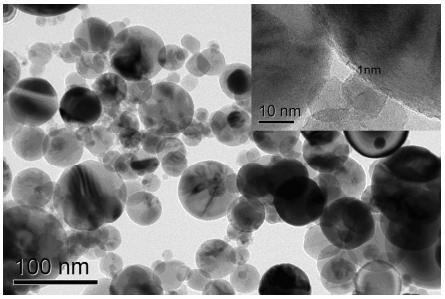

Fig. 2. Transmission electron microscopy (TEM) image of TiO_2 nanoparticles synthesized by pulsed wire evaporation (PWE) method.

tact EG inside the chamber wall, and the EG-based nanofluid containing TiO_2 nanopaticles was finally obtained without any surface contamination. The concentration of TiO_2 nanoparticles in EG was controlled by wire explosion number.

The structural properties of TiO_2 nanoparticles were studied by X-ray diffraction (XRD) using Cu K_α radiation (λ = 1.5406 Å) and transmission electron microscopy (TEM). The thermal conductivity was measured as functions of TiO_2 concentration (0.5~5.5 vol.%) and solution temperature (20~90 °C) by transient hot wire equipment (LAMBDA, F5 technology, Germany). A temperature-controlled bath was used to maintain a constant temperature. All the nanofluids were prepared with sufficient duration of sonification, so that the nanoparticles were well suspended with minimum coagulation. After measuring thermal conductivity of nanofluid, the sample cup and platinum wire were washed several times with acetone and distilled water.

3. RESULTS AND DISCUSSION

A crystalline phase of the TiO_2 nanopowder prepared by PWE method was confirmed by an XRD investigation as shown in Fig. 1. It is clearly seen that the XRD pattern reveals intense peaks which are indexed as anatase (JCPDS card No. 78-2486) and rutile (JCPDS card No. 87-0710) TiO_2. No other diffraction peaks corresponding to another oxide or an impurity were observed from the XRD pattern. Fig. 2 shows the typical TEM image of the synthesized TiO_2 nanoparticles. The TiO_2 nanoparticles exhibited spherical shape with the size smaller than 100 nm. The Brunauer, Emmett and Teller (BET) surface area S_s of the TiO_2 nanopowder was determined to be 35.7 m^2g^{-1} using the nitrogen gas adsorption method. Assuming all the particles to be mono-disperse spheres, the value of average particle size d_{BET} was determined by following Eq. (1) [11].

$$d_{BET} = \frac{6}{S_s \rho}, \tag{1}$$

where ρ is the density of powder ($\rho(TiO_2)$ ≒ 4.2 g/cm³). The average particle size d_{BET} of TiO_2 nanopowder was estimated to be about 40 nm from the BET measurement.

Fig. 3a illustrates the thermal conductivity enhancement of TiO_2 nanofluid as a function of temperature ranging from 20 to 90 °C. It can be seen from Fig. 3a that the enhanced ratio of thermal conductivity did not show a particular temperature dependency for all the TiO_2 concentrations. Fig. 3b depicts the thermal conductivity enhancement of EG-TiO_2 nanofluid as a function of the TiO_2 volume fraction. The thermal conductivity of EG-TiO_2 nanofluid increased with the volume fraction of nanoparticles, and the enhanced ratio of 5.5 vol.% EG-TiO_2 nanofluid was 16.2%. The Hamilton-Crosser (H-C) model [12] for thermal conductivity enhancement of solid-liquid mixture is given as

$$\frac{k_{eff}}{k_f} = \frac{k_p + (n-1)k_f + (n-1)\phi(k_p - k_f)}{k_p + (n-1)k_f - \phi(k_p - k_f)}, \tag{2}$$

where k_{eff} is the effective thermal conductivity of suspension; k_f, thermal conductivity of liquid; k_p, thermal conductivity of solid particles; ϕ, volume fraction of nanoparticles and n is the shape factor (3 for sphere and 6 for cylinder). For spherical shaped particle, H-C model is equal to the Maxwell's model [13].

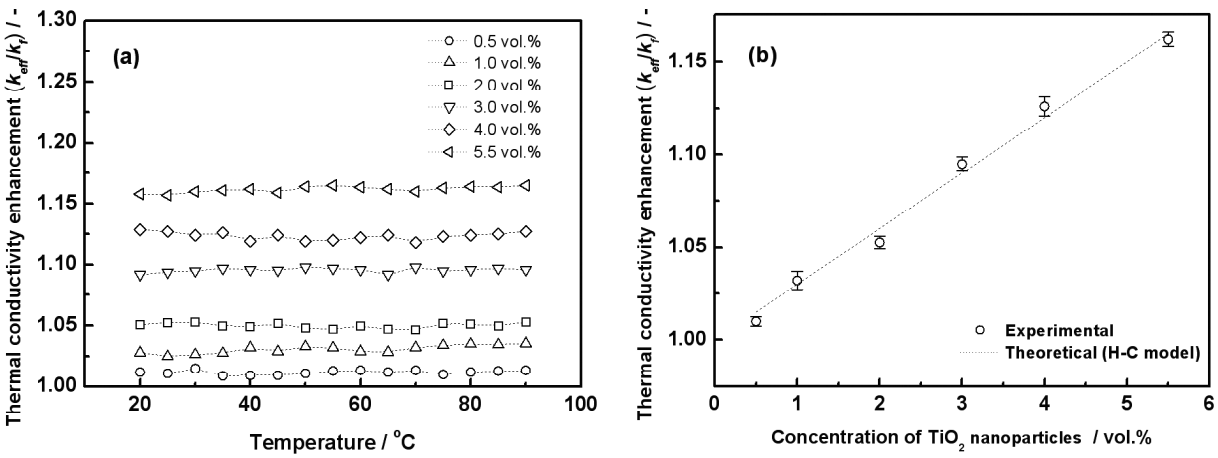

Fig. 3. Thermal conductivity enhancement of EG-TiO_2 nanofluid against (a) temperature and (b) TiO_2 volume fraction. The dotted line in Fig. 3b illustrates the theoretically calculated value with Hamilton-Crosser (H-C) model.

The thermal conductivity enhancement calculated by H-C correlation was plotted in Fig. 3b as a dotted line. It was noticeable that the enhanced ratio of thermal conductivity experimentally measured on EG-TiO_2 nanofluid was well fitted with that theoretically calculated by the classical H-C model. It has been generally reported [14-17] that the thermal conductivity of nanofluid is strongly dependent on the size of the suspended particles. The thermal conductivity increases with decreasing nanoparticle size. Therefore, the future work will be focused on downsizing the TiO_2 nanoparticles by controlling PWE process variables, leading to further enhancement of thermal conductivity.

4. CONCLUSIONS

The EG containing TiO_2 nanoparticles with the size smaller than 100 nm were successfully prepared by one-step PWE method. The thermal conductivity enhancement did not show a particular temperature dependency for all the TiO_2 concentrations. On the other hand, the enhanced ratio of thermal conductivity for EG-TiO_2 nanofluid increased with the volume fraction of TiO_2 nanoparticles, and the experimental value of thermal conductivity was in agreement with the theoretical one using the classical H-C model.

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