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Thermal conductivity enhancement of Al_2O_3 nanofluids based on the mixtures of aqueous NaCl solution and CH_3OH

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ABSTRACT

Adding nanoparticles into the base fluids is expected to increase the gas absorption rate of it. In this study, the methanol (CH_3OH)-based Al_2O_3 nanofluids are prepared for application of the CO_2 removal system. The suspension stability and thermal characterizations are estimated by the Tyndall effect and by measuring the thermal conductivity of the nanofluids. Arabic gum (AG) is used as a steric stabilizer and NaCl is added to examine the salts effect on the stability and thermal conductivity of it. Increasing NaCl and CH_3OH concentrations increases the thermal conductivity enhancement of the nanofluids which was attributed to the high thermal conductivity ratio of the particle and the base fluids. It is found that the thermal conductivity enhancement of the nanofluids increases with increasing the concentrations of NaCl and CH_3OH, and the highest value is obtained ~6.34% for 10 wt% NaCl, 40 vol% CH_3OH and 0.1 vol% particle concentrations.

1. Introduction

It is so important to remove the sour gases from raw and/or flue streams in the energy conversion systems such as power plants, iron works and integrated gasification combined cycle (IGCC). For example, recently the IGCC is attracting extensive attentions as the next-generation energy plant using synthesis gases (SNG). In the IGCC, it is required to remove the acid gases such as carbon dioxide (CO_2) and hydrogen sulfide (H_2S) from the valuable feed gas streams. By doing so, the feed gas is made more suitable for combustion and further processing. Therefore, there are so many studies to improve the absorption rate of sour gases for energy systems [1–7]. Currently, the most used ways to remove CO_2 are absorption and adsorption methods [7]. However, the adsorption method needs too much energy for desorption process and is not proper for large-scale systems. The absorption methods are divided into physical and chemical types according to the types of absorbents. The chemical absorption type is suitable for atmospheric pressure. Therefore, this type of absorption is useful to remove the CO_2 from the exhaust gas stream. However, there are some problems such as degradation of the absorbent and the need of much energy for regeneration. On the other hand, the physical absorption method is used in the IGCC system due to its suitability for high pressure. Recently, the Rectisol system, that is physical absorption type, is used prevalently to remove the acid gases in the SNG production system. This system commonly uses methanol as an absorbent. The advantages of methanol absorbent are cheap and selective absorption of acid gases such as CO_2, H_2S and COS [8,9]. In the Rectisol system, the temperature of methanol absorbent should be maintained at least about −40 °C to increase the absorption rate according to the Henry's solubility law. Therefore, huge amount of energy is required to keep such a low temperature of methanol in the Rectisol system. Recently to overcome the drawback, the nanofluids (nanoparticle suspension in base fluid) have been studied to improve the CO_2 absorption rate [5,7]. Kim et al. [5] reported that the capacity coefficient of CO_2 absorption in water-based silica (SiO_2) nanofluid was 4 times higher than water without nanoparticles because the small bubble sizes in the nanofluid had large mass transfer areas and high solubility. Also in our previous report [7], it was found that the optimum concentration of Al_2O_3 and SiO_2 nanoparticles rages 0.01–0.05 vol% in the methanol-based nanofluids and the pH variation was closely related with the absorption enhancement by the dissociation of the particle surface, and then bonding of hydroxyl group to nanoparticles in the nanofluids.

In this study, the methanol (CH_3OH)-based Al_2O_3 nanofluids are prepared for application of the CO_2 removal system. The suspension stability and thermal characteristics of the nanofluids should be known to optimize the CO_2 absorption systems [3,7]. The suspension stability and thermal characterizations are estimated by the Tyndall effect and by measuring the thermal conductivity of the nanofluids. Arabic gum (AG) is used as a steric stabilizer and

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Nomenclature

b	parameter describing the dielectric curvature
c	electrolyte concentration [%]
k	thermal conductivity [W m^{-1} K^{-1}]
δ	dielectric decrement for the electrolyte solution
ε_{bf}	dielectric constant of the base fluid
ε_{bm}	dielectric constant of the CH_3OH/water mixture

Subscripts

bf	base fluid
bm	base mixture
np	nanoparticle

NaCl is added to examine the salts effect on the suspension stability and thermal conductivity of it. The transient hot-wire method is used to measure the thermal conductivities.

2. Experiment

2.1. Preparation for Al_2O_3 nanofluids

Al_2O_3 nanoparticles (Alfa Aesar, Johnson Matthey Korea, Korea) are used for the nanofluids with particle concentrations of 0.01 and 0.1 vol%. Fig. 1 shows the FE-SEM photograph of Al_2O_3 nano-powders of which the primary particle size has the Gaussian distribution ranging from 40 to 50 nm. The concentrations of 0, 10, 20, 30 and 40 vol% for methanol and 3.5, 10 wt% for NaCl are chosen for the preparation. Arabic Gum (AG) (Dae Jung Chemicals & Metals Co. Ltd., Korea) is used as a steric stabilizer and the absolute weight of AG is kept constant (i.e. 0.05 wt%) for all cases, which always has the equivalent weight with that of Al_2O_3 nanoparticle in the case of 0.01 vol% Al_2O_3 nanofluid.

The two-step method is used to produce the Al_2O_3 nanofluids based on the mixtures of aqueous NaCl solution and pure methanol. The detailed procedures on nanofluids preparation is as follows: (1) Mixing the deionized (DI) water and pure methanol with a specific vol%, which is followed by adding the Al_2O_3 nanoparticles, AG and solid NaCl to produce a primary suspension; (2) The suspension is mixed using the ultrasonic vibration for 1 hr, and then finally the nanofluids are prepared. The details of experimental conditions for preparation are summarized in Table 1.

2.2. Thermal conductivity measurement

The transient hot-wire method is used for measuring the thermal conductivity of the nanofluids in this study. It measures the time rate of change in the electric resistance of metal-wire (i.e. Pt-wire in this study) by its temperature dependence. The time rate of temperature change in metal-wire during the electric heating process varies depending on the thermal conductivity of the surrounding fluid [10]. Fig. 2 shows the schematic diagram of the transient hot-wire method (including (a) the Wheatstone bridge and (b) test section), and the specifications of the dimensions of test section and test conditions are shown in Table 2. In this study, the Pt-wire (isonel-insulated platinum wire, A–M Systems, Inc., WA, US) of 185 mm in length and 25 μm in diameter is utilized as the metal-wire. The bridge input and output voltages are measured using a computerized data acquisition system (LabView 8.5) and the input voltage is configured at 5 V.

To verify the transient hot-wire setup, DI water and pure methanol are used as the test samples prior to the main experiments. The measurements are carried out 6 times for each case in the initial temperature of 293.15 K. By comparing the measured thermal conductivities of DI water and pure methanol with those from literature, the present apparatus is validated. The mean values of thermal conductivities of DI water and pure methanol are estimated at 0.5953 and 0.2049 W m^{-1} K^{-1}, which are ~0.03% and ~0.09% deviations, respectively, from the literature values. The results for the present apparatus are shown in Table 3. It yields an accurate value within 0.48% of experimental error. In the main experiments, the calibrations are carried out using DI water prior to each measurement and all the measurements are obtained at the initial temperature of fluids at 293.15 K.

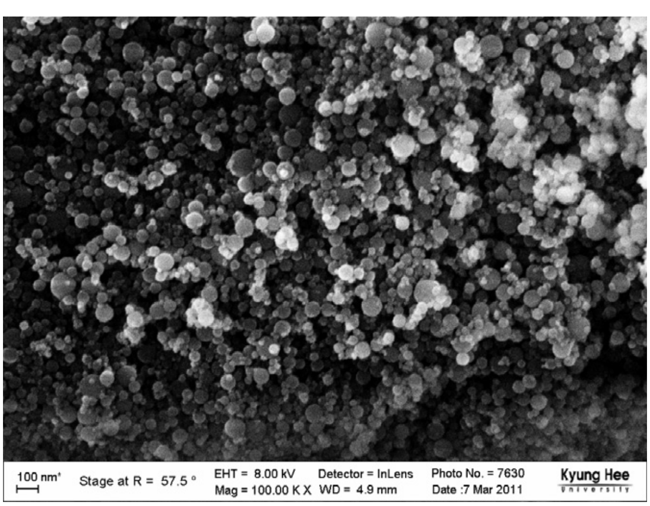

Fig. 1. FE-SEM photograph of Al_2O_3 nano-powders (40–50 nm).

Table 1
Experimental conditions.

Base fluid	Methanol/aqueous NaCl solution	
Concentration of methanol	0/10/20/30/40 vol%	
Concentration of NaCl	0/3.5/10 wt%	
Nanoparticle	Al_2O_3 (0.01/0.1 vol%)	
Particle diameter	40–50 nm	
Stabilizer	Arabic Gum	
Stirring condition	700 rpm	
Total volume of sample	600 mL	
Ultra sonication	Time	1 h
	Frequency	20 kHz
	Power	750 W

2.3. Zeta potential measurement

Absolute value of zeta potential is one of the evaluation parameter for colloidal stability [11]. However the zeta potential measurement of the nanofluids prepared in this study is difficult because the base fluid is the CH_3OH/water mixture containing NaCl. So prior to the measurement of the zeta potential, the dielectric constants for the nanofluids should be obtained. We used the prevalent method to estimate the dielectric constant for the electrolyte solution. The dielectric constant (ε_{bf}) of the base fluid depending on the electrolyte concentration (c) is given by [12],