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Effect of nanofluids on reflood heat transfer in a long vertical tube

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ABSTRACT

Experiments were conducted to investigate the effect of nanofluids on reflood heat transfer in a hot vertical tube. The nanofluids, which are produced by dispersing nano-sized particles in traditional base fluids such as water, ethylene glycol, and engine oil, are expected to have a reasonable potential to enhance a heat transfer. 0.1 volume fraction (%) Al_2O_3/water nanofluid was prepared by two-step method and 0.1 volume fraction (%) carbon nano colloid (CNC) was prepared by the process self-dispersing by carboxyl formed particle surface. Transmission electron microscopy (TEM) images are acquired to characterize the shape and size of Al_2O_3 and graphite nanoparticles. The dispersion behavior of nanofluids was investigated with zeta potential values. And then, the reflood tests have been performed using water and nanofluids. We have observed a more enhanced cooling performance in the case of the nanofluid reflood. Consequently, the cooling performance is enhanced more than 13 s and 20 s for Al_2O_3/water nanofluid and CNC.

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1. Introduction

"Nanofluids" could be regarded as an alternative for the effective coolant in the various fields of industry. Those are a new class of nanotechnology-based heat transfer fluids engineered by dispersing nanoparticles into conventional heat transfer fluids such as water, ethylene glycol, and engine oil [1]. Several researchers have carried out experiments to confirm the capabilities of nanofluids for a boiling heat transfer [2–6]. The general consensus in their researches is that nanofluids enhance the critical heat flux (CHF) significantly, however, they have no significant effect on a heat transfer in a nucleate boiling region. Recent studies have shown that a CHF enhancement is attributed to a high wettability of a thin layer formed on a heating surface by a deposition of nanoparticles [7]. The film boiling heat transfer rate in nanofluids was lower than that in the water for a sphere specimen [8]. Nanoparticles deposition on the sphere surface resulted in quick quenching of the hot sphere [9,10]. More recently, the rodlet specimen with nanoparticles deposition led to the premature disruption of film boiling and quenching acceleration [11].

Most of the studies on a heat transfer of nanofluids have been concentrated on the nucleate boiling region and the CHF phenomenon. A quenching (rewetting) phenomenon is important for analysis of the reflood phase associated with the emergency cooling in water-cooled nuclear reactor core under a loss of coolant accident and the reflood is happened when water refills the reactor vessel and quenches the fuel rod at the time of the severe accident in nuclear power plant. In this work, we have observed a quenching phenomenon of a hot vertical tube during a reflood using water-based nanofluids as a coolant, instead of water.

2. Experiment

2.1. Preparation of the nanofluids

Al_2O_3/water nanofluid is prepared by dispersing Al_2O_3 nanoparticles into water as a base fluid. Al_2O_3 nanoparticles in this work were manufactured by Alfa Aesar, A Johnson Matthey Company (true density = 3,970 kg/m^3, thermal conductivity = 40 W/(mK)). It is well-known that the properties of the nanofluids depend on the shape and size of nanoparticles. To identify the morphology of nanofluids, transmission electron microscopy (TEM) image is acquired. As shown in the image of Fig. 1, we identified that Al_2O_3 nanoparticles have a cylinderical shape. Their size is less than 50 nm.

The process of preparation of Al_2O_3/water nanofluids is as follows: (1) weigh the mass of Al_2O_3 nanoparticles by a digital electronic balance; (2) put Al_2O_3 nanoparticles into the weighed water and prepare the Al_2O_3/water mixture; (3) sonicate the mixture continuously for 12 h with sonicator to obtain uniform dispersion of nanoparticles in water. Through this preparation, the temperature of nanofluids increases from 24 °C to 55 °C.

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Nomenclature

Greek symbols
φ mass concentration of nanoparticles (%)
ρ density (kg/m^3)

Subscripts
f base fluids
m mass
p nanoparticles

CNC is made through the process self-dispersing by carboxyl formed particle surface (N-Baro Tech Company, Republic of Korea). As shown in the image of Fig. 2, we identified that graphite nanoparticles have a spherical shape. Their size is less than 50 nm.

Al_2O_3/water nanofluid and CNC were fabricated in 0.1 volume fraction (%). These values are calculated by the following conversion formula and this conversion formula is used conventionally, as it is very difficult to measure the precise volume of nanoparticles [5].

$$\varphi = \frac{1}{\left(\frac{1-\varphi_m}{\varphi_m}\right)\frac{\rho_p}{\rho_f} + 1} \quad (1)$$

where, φ_m is the mass concentration of nanoparticles, ρ_p is the density of nanoparticle and ρ_f is the density of base fluid.

In terms of the colloidal stability or stable nanoparticles-dispersion, zeta potential is a key parameter. Zeta potential of Al_2O_3/water nanofluid and CNC was 36 mV (Fig. 3) and 40 mV (http://www.n-barotech.co.kr/product/product8.html). It may say that these values are moderate stability.

2.2. Reflood Test

Fig. 4 shows the reflood test apparatus. The test section are made of SS 304 tube of 8 mm in the inner diameter and 1000 mm in the heating length, and are directly heated by a direct-current passing through the tube wall. In order to measure the tube wall temperature, the nine K-type ungrounded thermocouples (TCs) with a sheath outer diameter of 0.5 mm are attached to the outer wall surface at intervals of 100 mm.

The experimental procedure is as follows. The heated section was heated up to 600 °C ~ 750 °C (The standard TC is fourth TC from below and this was heated up to almost 700 °C), and then the cold nanofluid of the temperature of 20 °C in the coolant reservoir was injected into the test section by nitrogen gas pressure. Just before the nanofluids reached the inlet of the heated section, the dc power supplied to the tube was switched off. The injection flow rate was controlled by the nitrogen gas pressure and the needle valve in the upstream of the test section, and was determined from the time variation of the coolant level in the reservoir. In this experiment, water-based Al_2O_3 nanofluids and CNC were prepared for the volume concentrations of 0.1%.

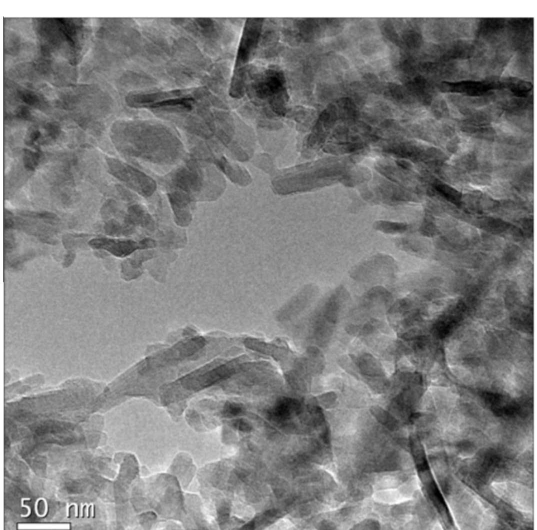

Fig. 1. TEM image of Al_2O_3 nanopaticles.

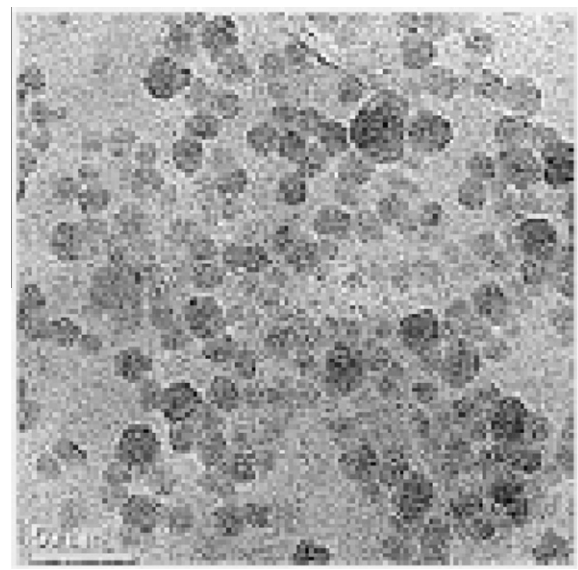

Fig. 2. TEM image of graphite nanoparticles.

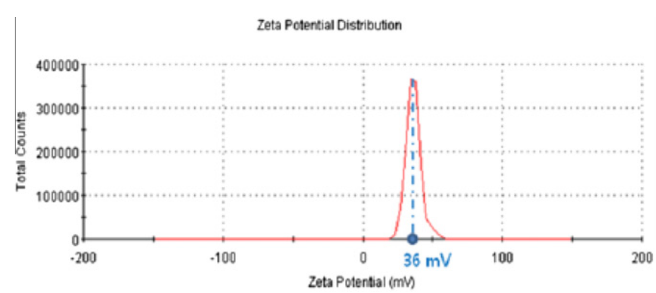

Fig. 3. Zeta potential of Al_2O_3/water nanofluid.

3. Results and discussion

The injection flow rate may vary during a reflood, since a phase change of the coolant and a back pressure in the test section occur. Fig. 5 shows the variation of the coolant level in the reservoir as a function of time during the reflood. The coolant level with time

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