Effects of Al_2O_3 and Carbon Nanofluids on Reflood Heat Transfer in a Long Vertical Tube

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1. Introduction

Quenching phenomena based on rapid cooling of a liquid on a hot surface are governed by boiling phenomena. The reflood phase for emergency cooling following a large brake LOCA is mainly characterized by performance of the quenching coolant rewetting the hot fuel rod.

Nanofluids recently have been introduced as an alternative coolant for improving heat transfer 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]. The literatures showed that boiling and CHF were affected by nanoparticles deposition layers formed during boiling in nanofluids [2]. Therefore, some efforts have also been made on the effects of nanofluids on quenching characterized by boiling phenomena. The results were not so good. The film boiling heat transfer rate in nanofluids was lower than that in the water for a sphere specimen [3]. Only, nanoparticles deposition/coating made in advance on the sphere surface showed quick quenching of the hot sphere [4, 5]. Similarly, the rodlet specimen with nanoparticles coating layer led to the premature disruption of film boiling and quenching acceleration [6]. Such positive effects could be made only by precoating of nanoparticles to the surfaces. However, the studies have been restricted to general, simple geometries such as sphere and short rodlet compared to a long vertical fuel rod in nuclear reactors.

Therefore, a long vertical tube in the present work is adopted to more thoroughly investigate effects of nanofluids on the reflood heat transfer.

2. Experiment

2.1 Preparation of the Nanofluids

Alumina nanofluids are prepared by using the two-step method [1]. Carbon nanofluids (Carbon Nano Colloid, CNC) were prepared through the process self-dispersing by carboxyl formed particle surface (N-Baro Tech Company, Republic of Korea).

2.2 Reflood Test

Fig. 1 shows the reflood heat transfer facility at KAERI. The test section made of SS 304 tube (the inner diameter: 8 mm and the heating length: 1000 mm), are electrically heated by direct current. 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 tube was heated up to 600 ℃ ~ 750 ℃ (The standard TC is the fourth TC from below and this was heated up to almost 700 ℃), and then the nanofluid at 20 ℃ in the reservoir tank 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. Nanofluids at a concentration of 0.1 v% are used.

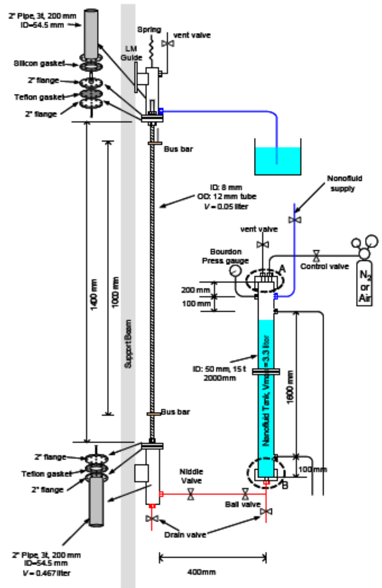

Fig. 1. Schematic diagram of the reflood test apparatus.

3. Results and Discussion

The injection flow rate may vary during a reflood, since phase change of the coolant and back pressure in the test section occur. Fig. 2 shows the variation of the coolant level in the reservoir as a function of time during the reflood. The coolant level with time shows the perfect linearity. Therefore, the injection flow rate did not vary in this experiment.

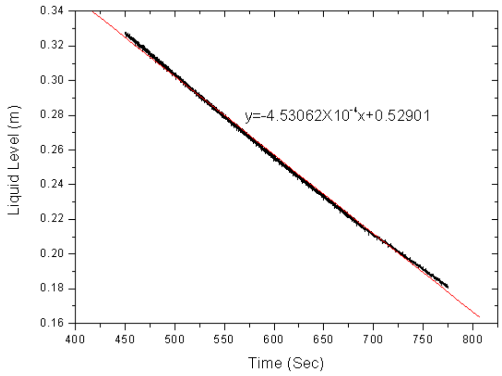

Fig. 2. Time variation of the coolant level in the reservoir.

The wall temperature behavior for the nanofluid refloods was compared with those for the water refloods. The quenching time was faster in 54 seconds and 36 seconds for alumina nanofluid and CNC compared with water, respectively as shown in Fig. 3. The enhancement of cooling performances is attributed to a high wettability of a thin layer formed on a heating surface by deposition of nanoparticles during evaporation. During the reflood phase, the liquid droplets including nanoparticles, which are dispersed into vapor flow only for a long tube, can be deposited on heating surface before fluids are moved. So, the thin layer of nanoparticles can be formed in advance resulting in making a pre-coating effect characterized by higher wettability.

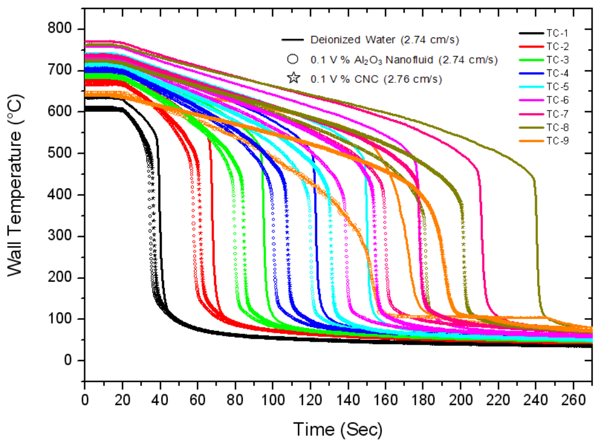

Fig. 3. Wall temperature variations during DIW, Al_2O_3/DIW nanofluid, and CNC reflood.

The increase of quenching velocity for nanofluids is attributed to rupture of vapor blanket/film due to turbulence enhancement. The improved radiation heat transfer could reduce thickness of vapor film and turbulence-enhancement by nanoparticles for the interfacial area between vapor film and bulk liquid could make early and irregular rupture of vapor film surrounding the hot rod. It would cause locally nonuniform cooling in nanofluids quenching.

4. Conclusions

As a potential application of nanofluids comes to Emergency Core Cooling System (ECCS), the situation of interest is quenching phenomena of fuel rods during the reflood phase.

The present work was carried out to investigate effects of nanofluids on reflood heat transfer in a long vertical tube. The results show that nanofluids can enhance the reflood heat transfer performance in terms of quenching speed for a long tube or rod causing liquid-droplets-induced depositions of nanoparticles .

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