Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22, 2009

An application of zeta potential method for the selection of nano-fluids to enhance IVR capability

Pham Quynh Trang*, Tae Il Kim, Soon Heung Chang
KAIST, 373-1, Guseong-dong, Yuseong-gu, Daejeon 305-701
*Corresponding author: pqtrang@kaist.ac.kr

1. Introduction

In-vessel Retention (IVR) is one of the key severe accident management strategies that have been applied currently for advanced light water reactors such as APR1000 or APR1400. The concept of IVR consists of external cooling of the reactor vessel by flooding the reactor cavity to remove the decay heat from the molten core through the lower head of the vessel. However, the heat removal process is limited by the occurrence of critical heat flux (CHF) at the reactor vessel outer surface that may lead to a sharp increase of local temperature, damaging the integrity of the reactor vessel. In order to obtain higher power of nuclear reactors and to assure the achievement of the IVR capability during accident conditions, an enhancement of CHF at the outer surface of the vessel is required. The potential use of nano-fluids to increase the CHF is among the main IVR enhancing approaches.

In this study, Al_2O_3 and CNT nano-fluids with different concentrations have been used as the potential coolant to enhance IVR capabilities. The dispersion stability of the nano-fluids was verified by zeta potential measurements. The results showed effects of time, concentration and pH on the stability of nano-fluids. Three types of nano-fluids were selected as the candidates to apply for the IVR.

A series of experiments have been performed in this study to understand the pool-boiling critical heat flux behavior on downward facing surfaces submerged in a pool of nano-fluids at very low concentration. The inclination angle was changed from horizontal to vertical to investigate the effect of orientation on CHF enhancement which is needed for the application in IVR.

2. Dispersion stability experiments with Al_2O_3 and CNT nano-fluids

2.1. Preparation of nano-fluids

Al_2O_3 and CNT nano-fluids were prepared by suspending Al_2O_3 and CNT nano-particles into DI water. The suspensions were transferred into an ultrasonic bath and sonicated for 1 hour at room temperature [1]. Boric acid was used as surfactant to change the pH of the fluids. For stability comparison, the suspensions of each nano-particle in DI water with and without boric acid and a combination of Al_2O_3 and CNT nano-particles in DI water were made in the same way.

2.2. Zeta potential measurements

The zeta potentials of prepared nano-fluids were measured by ELS-Z2 of Otsuka Electronics. The pHs of fluids were measured by MIL-56-pH of Sechang to verify the reliability of zeta potential results. Table 1 shows the concentrations and dispersing time.

Base fluid	Nano-particles	Boric acid	Variation time
DI water	Al_2O_3 0.05%		1~3 days
	Al_2O_3 0.05%	0.5%	
	Al_2O_3 0.05%	5%	
	Al_2O_3 0.05%	10%	
	CNT 0.05%		
	CNT 0.05% Al_2O_3 0.05%		
	CNT 0.05%	5%	
	CNT 0.05%	10%	

Table 1. Zeta potential and pH measurement test matrix

2.3. Results and discussion

The zeta potentials of the measured nano-fluids were shown in Figure 1. Al_2O_3 nano-fluid itself demonstrated good stability with the zeta potential in the range of 35~45 mV within 3 days after being sonicated. With the addition of boric acid, zeta potentials enhanced significantly. The Al_2O_3 nano-fluid with 10% volumetric concentration of boric acid showed very highly stable suspension.

It was shown that CNT nano-fluid did not have good stability. The zeta potential of CNT-nano-fluid was very low. However, the stability of CNT nano-fluid was increased by the support of boric acid. Especially, when the concentration of boric acid was about 10% of volume, the zeta potential reached the range of 35~45 mV. This might be explained due to the role of boric acid to lower the pH of the fluid. As reported in many previous works, the fluid stability is high when the pH is about 3~5 or 9~12 [1]. In this study, with 10% addition of boric acid, the pH decreased from 7 down to 4. Therefore, CNT nano-fluid with 10% of boric acid as surfactant can be a potential coolant for IVR.

The zeta potential measurement of Al_2O_3-CNT combined nano-particles in water with low concentration for each (0.05% volume) was also conducted. This combination showed really good stability with the zeta potential enhance up to 55~60mV.

Considering the stability requirement that is needed for the use of IVR coolant, three different types of nano-fluids were selected for the use of coolant in IVR, which are Al_2O_3 0.05%, CNT 0.05% - Boric acid 10%, Al_2O_3 0.05% - CNT 0.05%.

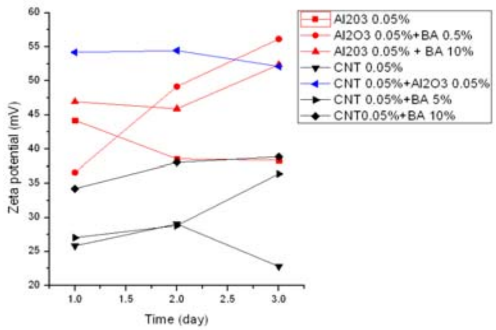

Figure 1. Zeta potential measurement results

The time dependence of fluid-stabilities was not shown clearly in this study. However, previous work showed that zeta potential slightly increased as time went by due to the delay in formation of electrical double layer [2].

3. Pool boiling experiment with an inclined downward facing surface

3.1. Experiment apparatus

The experiment loop is constructed to operate under atmospheric pressure. The schematic diagram of it is shown in Figure 2.

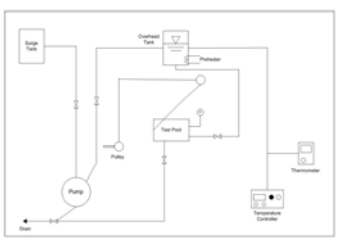

Figure 2. Schematic diagram of experiment loop

The test pool and test section are made of Type 316-stainless steel. The upper head of the pool is open for easy observation of phenomenon. The test section is a plate (270x33x2 mm) which is installed at the center of the test pool. A pulley is installed at the side of the experiment loop which is used to control the orientation of the test section [4]. The orientation of the test section is measured by an angler meter.

The upper surface of the test section is isolated by high temperature resistant epoxy for sealing the heated surface and to diminish heat loss from the test section. Two copper electrodes are welded to the ends of the plate to transfer the electric power from a 50V, 4000A DC power supply system. The test section plate and copper electrodes are electrically insulated from the other parts of the loop by teflon rods.

Five type K thermocouples are used to measure the temperature of the test section. Voltages signal from the test section are measured and processed by the system.

3.2. Experiment procedure

The test pool is filled with DI water or one of the three selected nano-fluids. The test section is fixed at a desired orientation. The working fluid is circulated by a centrifugal pump and boiled by a pre-heater. The input power is increased slightly until CHF condition is detected. When CHF occurs, the power is immediately stopped [3,4].

Before and after the experiment, samples of working fluids are extracted to measure zeta potential and pH to confirm the stability of fluids.

The inclination angle is changed step by step from horizontal to vertical. CHF data will be compared when the coolant is DI water and when nano-fluids are applied [3].

3.3. Results and discussion

The CHF data will be obtained and reported by the presentation time.

4. Conclusions

Zeta potential is important parameter for selecting highly stable nano-fluids for the use of IVR coolant. Various nano-fluids have been prepared and their zeta potentials have been measured for the stability verification. Moreover, addition of boric acid in this study helped improve the suspension stability. In this study, three nano-fluids with best stabilities were selected which are Al_2O_3 0.05%, CNT 0.05% - Boric acid 10%, Al_2O_3 0.05% - CNT 0.05%.

Pool boiling experiment will be performed to investigate the CHF enhancement at the surface of an inclined stainless steel plate. Results will be compared with the data of CHF with pure water. Inclination angle will be changed from horizontal to vertical to find the effects of orientation to the CHF enhancement.

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