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Study on the CHF for Cerium Oxide Nanofluid Under Various Volume Concentration Condition

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1. Introduction

Boiling heat transfer with high latent heat is the most efficient heat transfer mechanism for heat removal of thermal fluidic systems with extremely high heat flux such as nuclear power plant, supercomputer, compact heat exchanger etc. The performances of the thermal fluidic system are limited by Critical Heat Flux (CHF). When the heat flux of system reaches CHF, bubble patches coalesce, and vapor film is formed near the heater surface. Due to poor heat transfer characteristics of vapor film, the temperature of the heater surface increase abruptly which can threaten the material integrity of the heater.

Various technologies including nanofluid were proposed and studied to enhance the CHF limit [1, 2]. Nanofluid which is a colloidal suspension of nanoparticles in base fluid shows superior thermal conductivity than that of conventional fluids [3] and exhibit enhanced CHF value for the various type of nanoparticles respectively. [1, 4-5].

For thorium fuel cycle-based breeder reactor, the external part of the reactor is covered by thorium blanket for breeding. In accident condition, decay heat from the reactor core should be properly removed. To evaluate a feasibility of thorium oxide-dispersed aqueous blanket concept, thorium oxide nanofluid was chosen to investigate boiling heat transfer and CHF. In the present study, cerium oxide (CeO2) is chosen as a simulant of thorium oxide (ThO2), which also shows comparable thermo-physical properties with uranium oxide (UO2) [6] including actinide nuclides. Cerium oxide nanofluids dispersed in De-Ionized (DI) water are used to study the CHF behavior for the various experimental condition.

2. Experimental Setup and Results

2.1 Experimental Setup

Cerium oxide (CeO_2) nanoparticle with size less than 25nm (Sigma-Aldrich) was used to from 0.01, 0.03, 0.05, 0.07 and 0.1 volume percent of cerium oxide nanofluid with DI water as a base fluid. The volume percent of each solution was calculated by equation (1). Where ϕ means particle concentration, W means weight, ρ means density and subscripts *vol* means volume, *np* means nanoparticle and *bf* means base fluid respectively.

After adding cerium oxide nanoparticles into base fluids, 200 min sonification with POWERSONIC 420 from Hwashin Tech Co. were used to disperse the nanoparticles properly. In this paper samples of 0.05, 0.07 and 0.1 vol % cerium oxide nanofluids which have good dispersion behavior are studied. The results of sonification of 0.05, 0.07 and 0.1 vol % are shown in figure 1. Note that 0.01 and 0.03 vol % cases are excluded due to the poor dispersion characteristics.

$$\phi_{vol} = \left(\frac{W_{np} / \rho_{np}}{W_{np} / \rho_{np} + W_{bf} / \rho_{bf}} \right) \times 100 \quad [\%] \qquad (1)$$

The heat flux controlled saturated pool boiling experiments at 1 atm are conducted with 5kW DC power supply. Nichrome wire with length (L) of 5.5 cm and diameter (D) of 0.5mm is used as specimen for the experiment. Rectangular Pyrex glass basin is placed on the hot plate to maintain fluid as saturation temperature. Copper blocks are used to connect the electric wire and test specimen. The volume concentration of nanofluids is maintained constant by utilizing the condenser. The electric current in the experimental circuit is determined by the standard resistance of 0.001Ω. The experimental data of voltage difference between specimen (V_S)and standard resistance (V_R) are measured by Data Acquisition System (DAS, Agilent 34980A).

Schematic diagram of pool boiling experiment facility is shown in figure 2. The current (I) of the experimental circuit is obtained from equation (2) and heat flux (q'') applied to nichrome wire is calculated from equation (3).

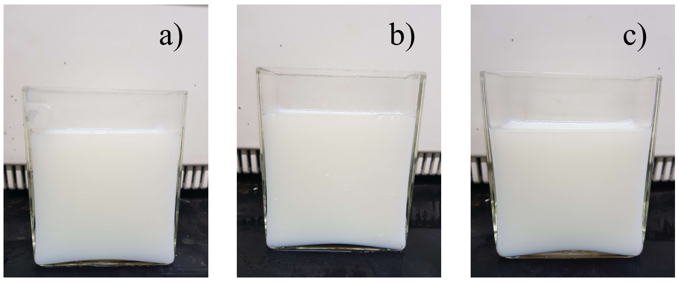

Fig. 1. Different volume concentration cerium oxide nanofluid a) 0.05 vol%, b) 0.07 vol%, c) 0.1 vol%.

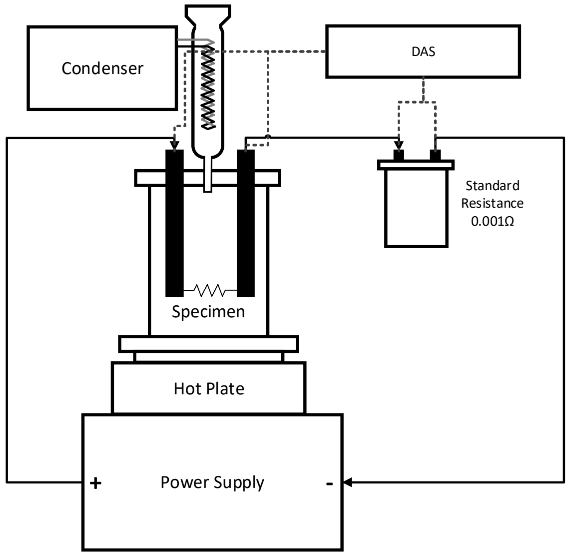

Fig. 2. Schematic diagram of pool boiling experiment facility.

$$I = \frac{V_R}{0.001\Omega} \quad (2)$$

$$q'' = \frac{V_s \times I}{\pi DL} \quad (3)$$

2.2 Experimental Procedure

In CHF experiment with nanofluid, effects of nanoparticles deposition on heater surface are significant. Therefore, the time interval between each step and heat flux are tightly controlled for consistency of each case. Power input is applied in a stepwise way with an increment of 100kW/m^2 for all cases. The time interval between each step to achieve steady states are set as 2 minutes.

2.3 Results and Discussion

The Zuber's CHF model [7] in equation (4) based on hydrodynamic instability theory can be applied to pure fluids with planar heat transfer surface, where ρ is a density, h_{fg} is a latent heat, σ is a surface tension, g is a gravitational acceleration constant respectively where with subscript g means a gas, f dose a fluid.

$$q''_{Zuber} = \frac{\pi}{24}\rho_g^{1/2} h_{fg} \sqrt[4]{\sigma g(\rho_f - \rho_g)} \quad (4)$$

The CHF value from Zuber model for pure DI water (h_{fg} = 2257 kJ/kg, ρ_g = 0.6 kg/m3 ρ_f = 958.10.6 kg/m^3, σ = 0.059 N/m) is 1,100kW/m^2 and experimental CHF value for bare nichrome wire is 1,044kW/m^2. showing 5.05% deviation. For the cerium oxide nanofluids cases, Zuber model which consider only hydrodynamic aspects of fluid is hard to be applied to predict the CHF values for modified heat transfer surface.

The experimental CHF values for cerium oxide nanofluid with 0.05, 0.07, 0.1 vol % are 1,541 kW/m^2, 1,491 kW/m^2 and 1,503 kW/m^2 respectively and corresponding CHF enhancement are 47.59%, 42.78%, 43.90% for 0.05, 0.07, 0.1 vol % respectively.

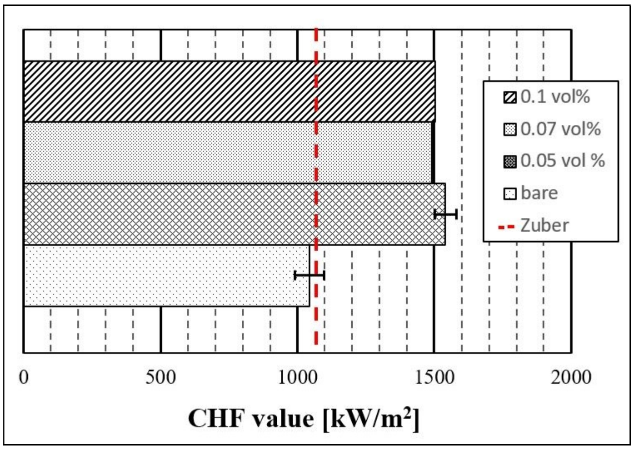

Fig. 3. Experimental CHF value for bare and 0.05, 0.07, 0.1 vol % of cerium oxide nanofluid.

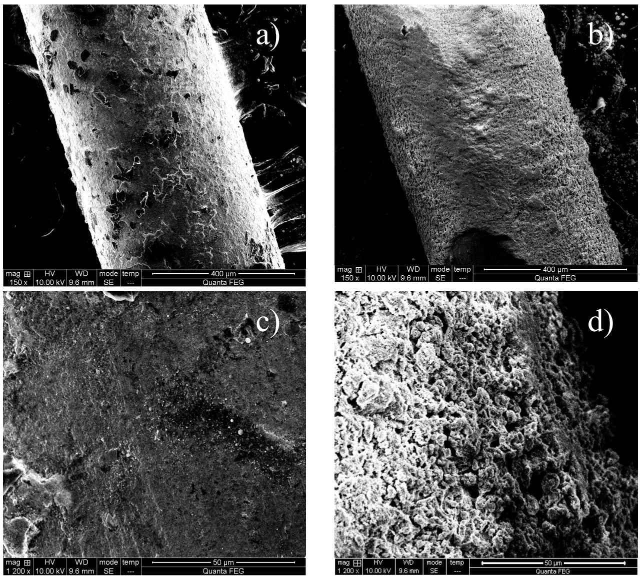

Fig. 4. SEM image of a) 150 times magnified bare nichrome wire, b) 150 times magnified cerium oxide nanoparticle coated wire of 0.05 vol% nanofluid, c) 1,200 times magnified bare nichrome wire, d) 1,200 times magnified cerium oxide nanoparticle coated wire of 0.05 vol% nanofluid.

In the case of cerium nanofluid, nanoparticles deposition layers are formed after the pool boiling experiment as shown in (b) and (d) of figure 4. The enhancement of CHF values is attributed to surface characteristics modification by nanoparticles deposition. As shown in (d) of figure 4, deposited cerium oxide nanoparticles layer forms the porous structure on the surface. Capillary wicking force due to the porous structure improves the rewetting performance on the heater surface showing enhancement of CHF.

The effects of nanoparticle deposition time on CHF will be studied by separating the effect of nanoparticles deposition during the boiling and CHF on the coated surface. The constant heat flux corresponding to 30%, 60%, 90% of CHF measured in the current study will be applied during different deposition time for nanoparticle deposition to investigate the deposition time effect on cerium oxide nanofluid CHF.

3. Summary and Future work

Saturated pool boiling experiment with cerium oxide nanofluid with size less than 25nm at 1atm is conducted for 0.05, 0.07, 0.1 vol %. Utilizing the cerium oxide nanofluids shows improved CHF values 47.59%, 42.78%, 43.90% for 0.05, 0.07, 0.1 vol% respectively. The effects of deposition time of cerium nanofluid on the CHF will be studied in detail near future.

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