Experimental study on enhancement of flow boiling CHF in a completely wetted tube over atmospheric pressure

Kyung Won Hwang [a], Jun-Young Kang [b], Moo Hwan Kim [b*]
[a]*Department of Mechanical Engineering, POSTECH, Pohang, Republic of Korea*
[b]*Division of Advanced Nuclear Engineering, POSTECH, Pohang, Republic of Korea*
[*]*Corresponding author: mhkim@postech.ac.kr*

1. Introduction

Critical Heat Flux (CHF) enhancement has been receiving a great attention due to the importance of safety margin at NPPs(Nuclear Power Plants). Especially, the effect of liquid spreading effect or completely wetting (CA ~ 0°) on the CHF enhancement was well explained for pool boiling [1], internal flow boiling at atmospheric pressure condition [2]. But, there has been no report yet in real NPPs operation which is flow boiling situation beyond the atmospheric pressure. So, in this study internal flow boiling experiment is conducted beyond the atmospheric pressure to explain the CHF enhancement with liquid spreading effect and completely wetting.

2. Experiments & results

Flow boiling CHF was experimentally investigated inside a tube which has excellent wettability and liquid spreading beyond the atmospheric pressure. Detailed descriptions of the experimental facilities, test section, and results are provided in the following sections.

2.1 Experimental setup

The experimental facility of two-phase steam-water flow is schematically illustrated in Fig. 1. The major parameters controlled and measured were mass flow rate of the working fluid (water), temperature of the working fluid at the inlet and outlet of the test section, system pressure, and wall heat flux applied to the working fluid. The loop consists of a water tank, a diaphragm pump to flow working fluids, a coriolis mass flow meter, two pre-heaters, a test section, a condenser, a sub cooler, and a back pressure regulator to maintain and control the system pressure. Flow boiling CHF were investigated in bare zirconium alloy tubes and micro-structured tubes at a mass flux of 500 kg/m^{2}s and 700 kg/m^{2}s and outlet pressure of 6 bar, 8 bar, and 12 bar.

Working fluid flows vertically upward inside a test tube. Heated length of the test section is 350 mm and inner diameter and outer diameter is 8.48 mm and 9.69 mm, respectively. Material of the test tube is zirconium alloy 702. The test tube is electrically direct-heated. Temperatures of the test tube are measured by K-type thermocouples at points of 305 mm and 335 mm to detect CHF occurrence from a significantly rapid increase in the wall temperature.

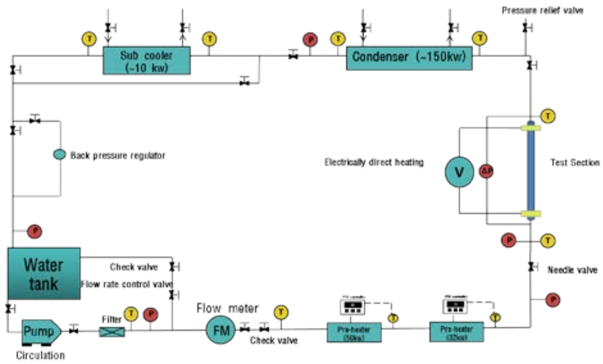

Fig. 1. Schematic image of experimental loop

The microstructures were created inside a zirconium alloy 702 tube via anodic oxidation process to increase wettability of the tube for enhancing CHF [2]. The fact that static contact angles of bare tube and micro-structured tube were 88° and 0°, respectively and the microstructures inside the tube resulted in the completely wetting were reported [2]. Fig. 2 shows the contact angle of bare and micro-structured zirconium alloy 702 tube and Fig. 3 shows those inside the test tubes after CHF in this study. One can notice that the microstructures still remain after CHF.

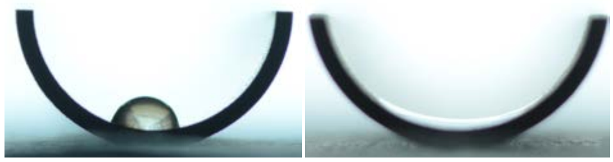

Fig. 2 The static contact angles inside tube (Left: bare zirconium alloy 702 tube with 98°, Right: the micro-structured tube with about 0°)

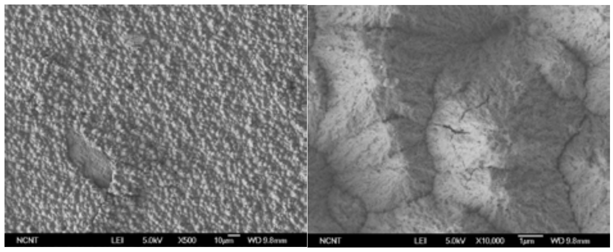

Fig. 3 Scanning Electron Microscope(SEM) images for the test specimen after CHF

2.2 Results

The mechanism of CHF strongly depends on the flow regime at a point where CHF occurs. Thus, the flow regimes at the outlet of test section were confirmed by the flow regime map of Hewitt & Roberts [3]. The fact that CHF were occurred at an annular regime in this study was also confirmed.

The measured values of CHF in a bare zirconium alloy tube were compared with values from the CHF look-up table [4] for the reliability test on the experimental facility. The results are shown in figure 4.

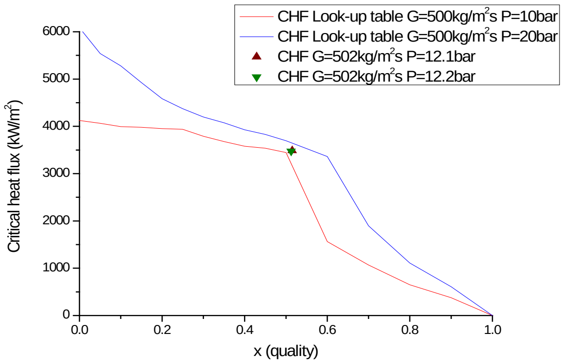

Fig. 4 Comparison of measured CHF to CHF predicted by look-up table [4]

Figure 5 shows the enhanced CHF ratio in micro-structured tubes compared to bare tubes with the outlet pressure for a given mass flux. CHF were enhanced at most cases except for the case with an outlet pressure of 12 bar and mass flux of 700 kg/m^{2}s. The enhancement ratio of CHF decreased with the outlet pressure for a given mass flux.

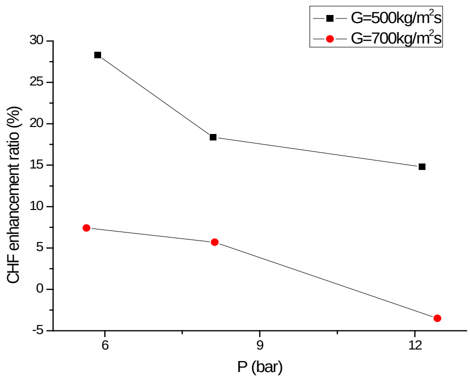

Fig. 5 Enhanced CHF ratio with pressure for a given mass flux

CHF were occurred at high flux with the increase of mass flux. And the enhancement ratio for CHF was reduced with the mass flux for a given pressure as shown in figure 6.

In previous research, the enhancement ratio for CHF increased with the mass flux at atmospheric condition [2]. However, the enhancement ratio decreased with the mass flux at higher pressure than the atmospheric pressure in this study. In the case of high mass flux, CHF values were largely reduced along with pressure which resulted lower CHF enhancement ratio at high mass flux than that of at low mass flux.

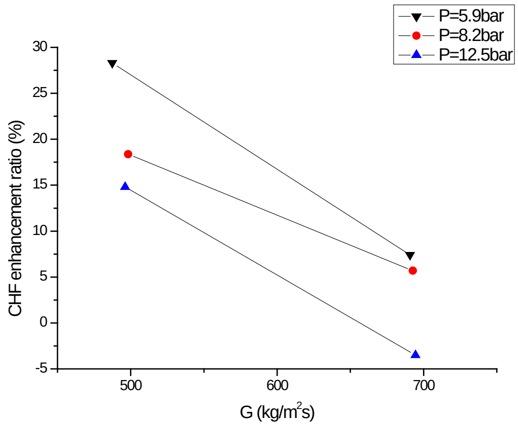

Fig. 6 Enhanced CHF ratio with mass flux for a given pressure

3. Conclusions

Flow boiling CHF were investigated in bare zirconium alloy 702 tube and micro-structured tubes at a pressure higher than the atmospheric pressure. The enhanced CHF was confirmed at conditions with the highest pressure as well as atmospheric condition from Ahn et al. [2]. However, the enhancement ratio decreased with pressure and the mechanism of CHF enhancement in completely wetting tube at annular regime is not clear thus, requires further investigations.

Acknowledgments

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