Critical Heat Flux of Vertical Upward Water Flow in Uniformly Heated Round Tube

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1. Introduction

It has long been known that the heat transfer and CHF can be enhanced using devices such as rifled tubes, twisters, springs and various grooved, ribbed, and corrugated tubes. An internally rifled surface is usually used to enhance flow boiling heat transfer in once-through boilers. However, the state of the art of enhanced heat transfer inside rifled tubes is much less advanced than that of conventional boiling heat transfer. In addition, the heat transfer and CHF enhancement in the rifled tubes largely depends on the detailed rifled tube geometry such as number of ribs, rib pitch, rib height, rib width and helical angle. Evaporator tubes used in once-through boilers have a long heated length and large inside diameters, while conventional CHF tests are concentrated to relatively small heated length and small inside diameters.

Currently, KAERI is performing CHF tests in order to develop a CHF design correlation for the rifled tube. A series of CHF test is planned for smooth tubes with uniform and non-uniform circumferential heat fluxes, and rifled tube with non-uniform circumferential heat flux. From these three tests, a rifled tube CHF correlation will be developed using a conventional CHF prediction method for smooth tubes, the modification factor for circumferential heat flux distribution, and the CHF enhancement factor by rifled tube.

As a first step, the present study provides water CHF test results in vertical tube with smooth inner surface having large diameter and investigates the prediction reliability of the conventional CHF prediction methods. This CHF data using round tube with smooth inner surface will be used as a reference for future CHF experiments and the development of the rifled tube CHF correlation.

2. Test Facility and Test Method

The CHF experiments have been carried out in the reactor coolant system thermal hydraulic loop facility (RCS loop facility) of the Korea Atomic Energy Research Institute (KAERI). A detailed description on the facility can be found in Moon et al. [1]. Figure 1 shows the test section and instrumentations. A round tube test section with smooth inner surface is made of stainless steel 316, and has the heated length of 3000 mm, inner diameter of 17.2 mm and outer diameter of 25.0 mm. The test section is heated directly by a DC power supply with maximum power capacity of 75 V and 6000 A. Ten K-type thermocouples with a sheath diameter of 0.5 mm are embedded on the test section outer surface to measure the wall temperature and detect a CHF occurrence. The inside wall temperature was calculated from heat generation and heat conduction through the wall. By preliminary test, the CHF condition is defined as an inner wall superheat larger than 50 ^{o}C.

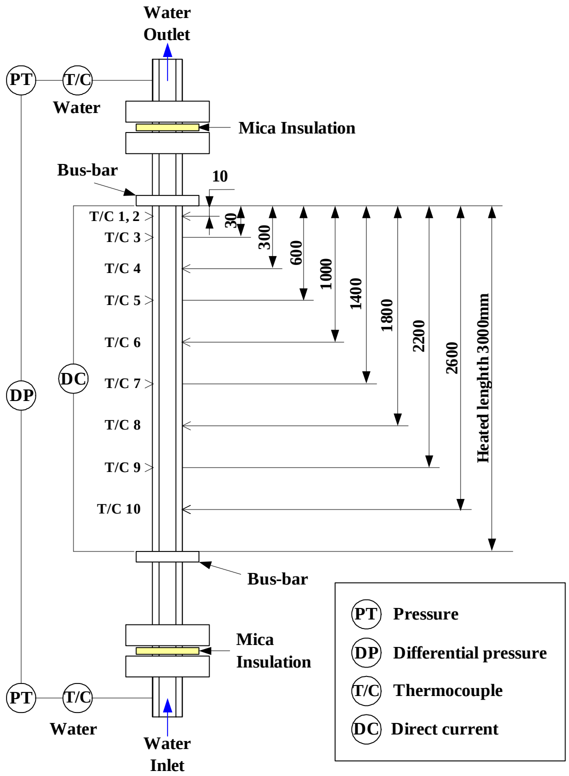
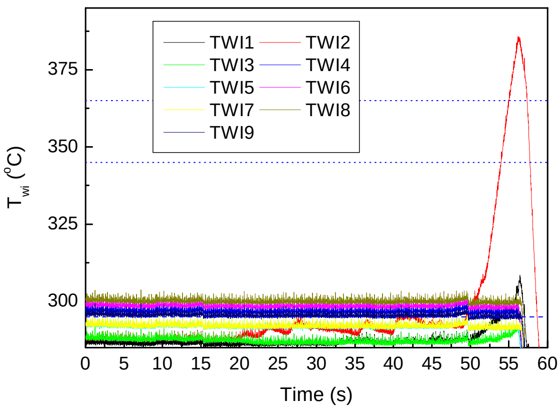


Figure 1. Test section and instrumentation

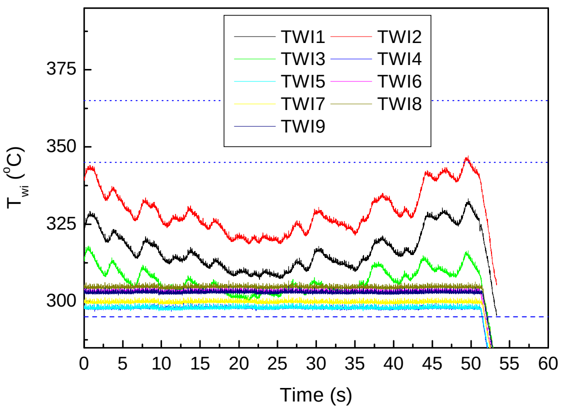
3. Test Results and Discussion

Figure 2 shows the inner wall temperature excursion at CHF occurrences. As shown in Fig. 2 (a), at high mass flux and high inlet subcooling conditions, the wall temperature abruptly increases and the temperature excursion is very high. On the while, at low mass flux and low inlet subcooling conditions, the wall temperature slowly increases and reaches the CHF conditions. In these two cases, the power increase rate was very small, less than 1.5% compared with that before the CHF occurrence.

Figure 3 shows the effects of mass flux and inlet subcooling at pressure of 8.0 MPa. As shown in the figure, the CHF increases with increasing mass flux for fixed inlet subcooling. The increase rate of the CHF becomes smaller as the mass flux increases. For fixed mass flux and pressure conditions, the CHF increases linearly with increasing inlet subcooling. These effects of various parameters on the CHF are consistent with previous understandings.



(a) G = 700 kg/m^{2}s, Δh_{in} = 290 kJ/kg



(b) G = 250 kg/m^{2}s, Δh_{in} = 90 kJ/kg

Figure 2. Inner wall temperature trends (P = 8.0 MPa)

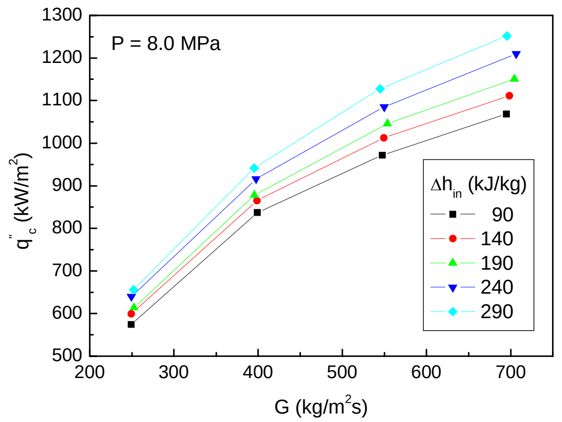


Figure 3. Effect of mass flux and inlet subcooling

The CHF data obtained in this study are compared with existing CHF correlations which are used in general for nuclear industry and boiler evaporators of fossil-fired systems and are known to show reliable predictions for round tubes. Figure 4 shows the prediction results by these correlations. Both heat balance (HBM) and direct substitution methods (DSM) are used for CHF correlations having the local conditions type. Using heat balance method, the 1995 CHF look-up table and Biasi correlations show reliable CHF prediction having RMS errors of 6.5% and 8%, respectively. Katto correlation predicts well the CHF for pressure larger than 3 MPa. However, the Katto correlation significantly overpredicts the CHF at 1.0 MPa. Drescher and Kohler verified that Doroshchuk correlation fitted best for DNB type CHF and Konkov et al.'s correlation fitted best for dryout type CHF [2]. The combination of these two CHF correlations shows a reliable CHF prediction which has a similar RMS error with Bowirng and Katto correaltions.

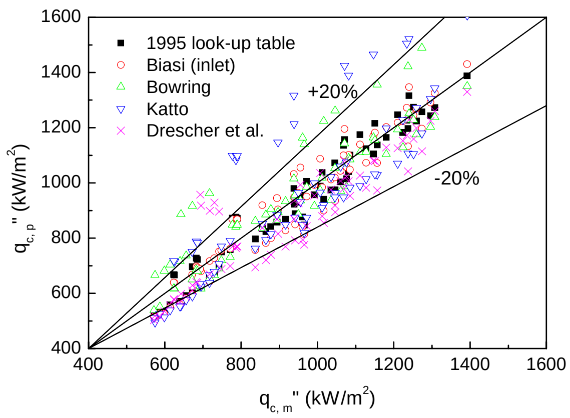


Figure 4. Comparison with conventional CHF correlations (HBM method)

4. Conclusion

The inner wall temperature excursion at the CHF occurrence shows a significant difference according to the possible CHF mechanism (DNB or dryout). The effects of the various parameters are consistent with general understandings. The 1995 CHF look-up table and Biasi correlation show reliable CHF prediction having RMS errors of 6.5% and 8%, respectively. The present CHF data for a smooth tube with uniform circumferential heat flux will be used as a reference value for future CHF experiment and CHF correlation development for a rifled tube.

Acknowledgements

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References

[1] S.K. Moon, S.Y. Chun et al., An Experimental Study on the Low Flow CHF in Vertical Rod Bundle with Non-Uniform Axial Heat Flux Distribution, Proc. of the 10th Int. Topical Meeting on Nuclear Thermal Hydraulics (NURETH-10), Oct. 5-11, Seoul, Korea, 2003.

[2] S. Kakac, Boilers, Evaporators, and Condensers, John Wiley & Sons, New York, 1991.