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Critical Heat Flux in Various Inclined Rectangular Narrow Channels

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1. Introduction

In the Three-Mile Island Unit 2 (TMI-2) accident, the lower part of the reactor pressure vessel had been overheated and then rather rapidly cooled down [1,2], as was later identified in a vessel investigation project. This accounted for the possibility of cooling in the narrow gap on the order of millimeters and centimeters that may have been formed between the solidified core debris and the reactor vessel lower head. Post-test analyses, completed as part of the TMI-2 Vessel Investigation Project [3] suggested the presence of the core material-to-vessel gaps. For this reason, additional data are needed to quantify critical heat flux (CHF) in narrow gaps and gain insight into the potential in-vessel retention (IVR). Thus, the CHF test sections need to address key features of the engineering device to simulate the IVR environment. In particular, these one-dimensional experiments with two kinds of copper blocks were performed with the geometric parameters affecting the CHF to account for aspect ratio of heated length to gap size and surface inclination angle as well as gap size effects in the rectangular channel.

2. Experimental Work

In a one-dimensional CHF experimental apparatus, the heat was supplied by a quasi-direct heating method to generate sufficient heat flux. The one-dimensional CHF experiments were carried out for a rectangular channel with two kinds of heater assemblies. One, named copper block type A, has the heated surface of 35×15 (length×width) mm^2, the other is copper block type B having a heated area of 105×5 mm^2. All K-type thermocouples were inserted into the holes 0.6 mm below the wetted surface of the heater assembly. The copper block type A is shown in Fig. 1.

After sticking the copper block heater into the housing, a flexible stainless steel tube was attached to the flange located at the bottom of the housing and a vacuum pump loaded about 10^{-4} torr, which can considerably reduce the heat loss from the bottom of the copper block heater. Pyrex glass was imbedded into the edge of the housing and designed to precisely maintain the gap sizes and visualize the bubbles in various test sections having narrow rectangular channels.

The experiments were performed using the test heater assembly with varying gap size and rectangular channel for inclination angles from vertical (90°) to downward facing position (180°) in a pool of saturated water under atmospheric pressure, as shown in Fig. 2.

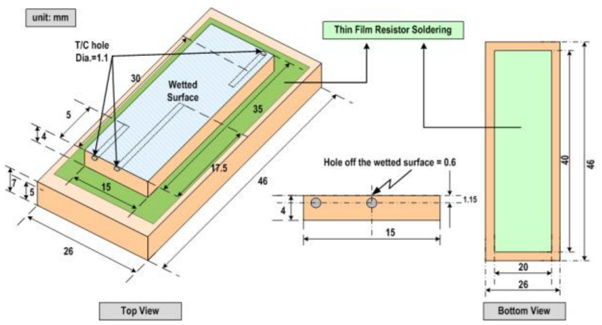

Fig. 1. Schematic diagram of copper block type A.

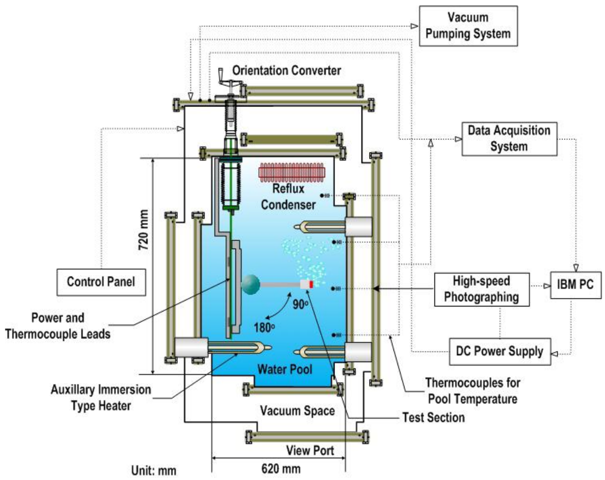

Fig. 2. Schematic diagram of CHF test apparatus.

3. Results

CHF experiments were performed for gap sizes of 1, 2, 5 and 10 mm with surface inclination angle from vertical (90^o) to downward-facing position (180^o) in the saturated bulk temperature under atmospheric pressure. The quantitative CHF data and temperature profiles were obtained and Fig. 3 shows the temperature history for copper block type B.

Katto and Kosho [4] underestimates and overestimates the CHF data with copper block type A for 10 mm gap and pool boiling (no gap), respectively, whereas Kim and Suh [6] overestimates the overall CHF data. Monde et al. [5] predicts the best approximation to the CHF data in the inclination angles below 155^o for 10 mm gap and pool boiling, as presented in Fig. 4.

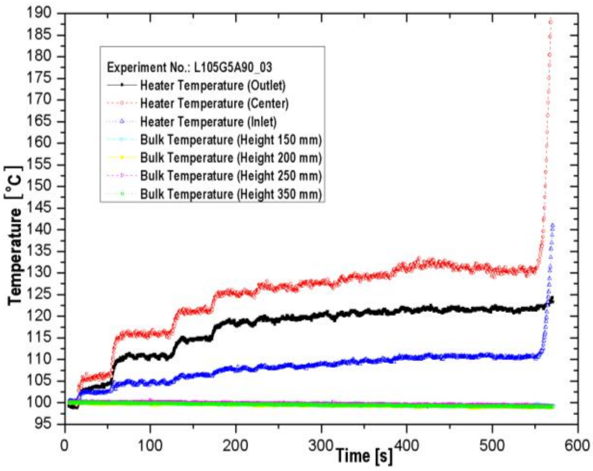

Fig. 3. Temperature and heat flux histories for copper block type B with 5 mm gap at vertical position (90°)

The semi-empirical CHF correlations of Katto and Kosho [4] and Kim and Suh [6] are as follows, respectively.

$$\frac{q_{CHF}/\rho_g h_{fg}}{\sqrt[4]{\sigma g\left(\rho_f-\rho_g\right)/\rho_g^2}}=\frac{0.18}{1+0.00918\cdot\left(\dfrac{\rho_f}{\rho_g}\right)^{0.14}\cdot\sqrt{\left(g\left(\rho_f-\rho_g\right)d^2/\sigma\right)}\cdot\left(\dfrac{d}{s}\right)}$$

$$\frac{q_{CHF}/\rho_g h_{fg}}{\sqrt[4]{\sigma g\sin(\theta)\left(\rho_f-\rho_g\right)/\rho_g^2}}=\frac{0.17}{1+6.8\times10^{-4}\cdot\left(\rho_f/\rho_g\right)^{0.62}\left(D_h/s\right)}$$

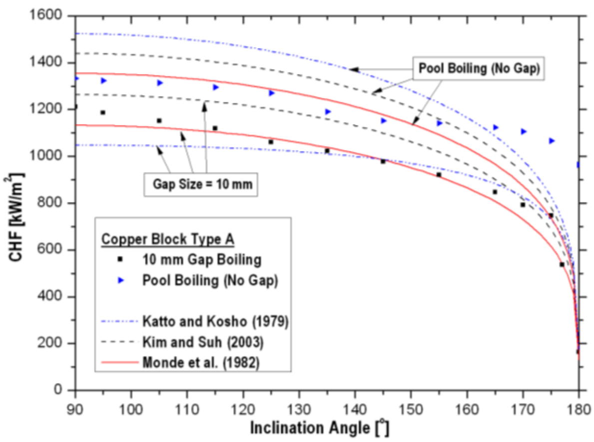

Fig. 4. Comparison between CHF data and some correlations.

Utilizing the copper block type B, CHF experiments were carried out to verify the relation between the heated length to gap ratio (*l*/*s*) and the equivalent diameter to gap ratio (D_h/s), and modify the CHF correlations [4,6]. Excluding fully downward facing position (180°), a semi-empirical CHF correlation was obtained in the near vertical region based on the CHF data with copper block type A and B in the work as follows.

$$\frac{q_{CHF}/\rho_g h_{fg}}{\sqrt[4]{\dfrac{\sigma g\sin(\theta)\left(\rho_f-\rho_g\right)}{\rho_g^2}}}=\frac{0.163}{1+6.431\times10^{-4}\left(\dfrac{\rho_f}{\rho_g}\right)^{0.564}\left(\dfrac{g\sin(\theta)(\rho_f-\rho_g)s^2}{\sigma}\right)^{0.011}\left(\dfrac{l}{s}\right)}$$

The reason why the correlation of Monde et al. [5] could predict the best approximation to the CHF data in the rectangular channel is that they had not used the ratio of equivalent heated surface diameter to the gap size (D_h/s) or the ratio of heated disk diameter to gap size (*D*/*s*) but the heated length to gap size ratios (*l*/*s*).

The developed correlation in this work agrees with the experimental CHF data with copper block type A and B within about ±12%, as shown in Fig. 5.

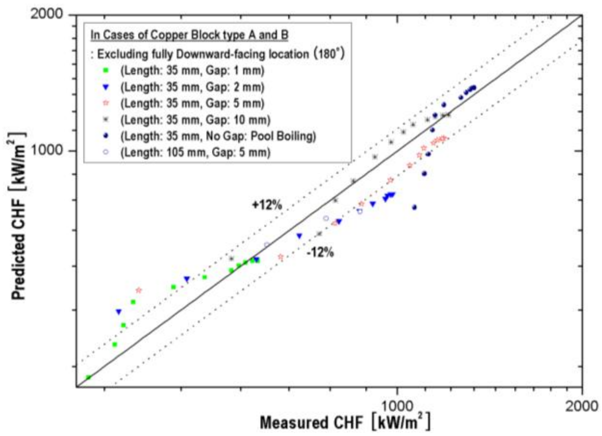

Fig. 5. Comparison between measured and predicted CHF values.

Acknowledgments

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