Investigation on the rewetting temperature behavior in a vertical annulus geometry with uniform and cosine power distribution

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1. Introduction

All theoretical predictions for the rewetting process by the various models based on one-, two- and three-dimensional analytical and numerical studies require the knowledge of the rewetting temperature. (Kim and Lee, 1979) Incorrectly assumed values of rewetting temperature could lead to serious errors in the analysis of the problem. This parameter was assumed to be constant by many researchers such as Martini et al. (1973), Yamanouchi (1968), and Yu et al. (1977). However, the rewetting temperature is not constant and depends on the physical properties of the test section and coolant flow condition. In the present study, experimental data on the rewetting temperature acquired in the present reflood test series are compared with the previous rewetting temperature correlations proposed by Berenson (1961), Henry (1974), and Kim and Lee (1979).

2. Experimental Descriptions & Results

2.1 Test Facility

The present reflood tests were carried out in a vertical annulus flow channel. For the visual observation of the whole phenomena during the reflood process, the outer wall is made of pyrex glass tube whose inner diameter is 20 mm. At the center of the pyrex tube, a 9.5mm diameter heater rod was installed with four spacer grid. The length of the heated section is 1,830 mm. The detailed descriptions on the test facility can be found in Cho et al (2004).

Two types of spacer grids have been used, i.e. straight egg-crate grid (Flat type) and swirl vane grid, and power distributions of heater rods are uniform and cosine shape. The axial power shape of cosine rod can be seen in Fig. 1.

2.2 Test method and conditions

The present study has been performed at the atmospheric pressure condition. Overall heat losses were determined in steady-state conditions versus wall average temperature calculated from measured wall temperatures. Table 1 shows the test conditions and configuration of the test section.

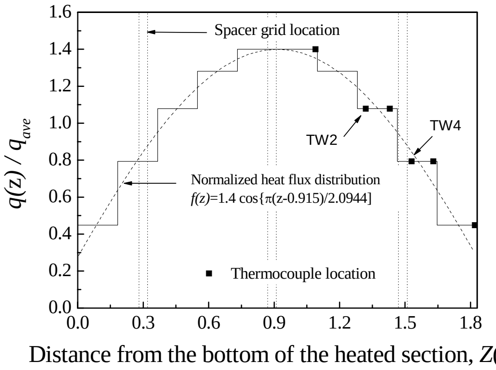

Fig. 1 Axial power shape of Cosine heater rod (Peaking factor: 1.4)

Table 1 Experimental ranges of investigated parameters and physical characteristics of test section

Parameter	Symbol	Unit	Value
Flooding velocity	U_F	cm/s	2, 5, 8
Inlet coolant temperature	T_{in}	^oC	20, 50, 75
Initial wall temperature	T_w	^oC	500, 600, 700
Type of Spacer grid-	-	-	flat, swirl-vane
Power Shape	-	-	Uniform, Cosine
Pressure	P	bar	1
Sheath material of heater rod	-	-	Inconel 600

2.3 Previous correlations on the rewetting temperature

Berenson (1961) assumed that the hydrodynamic wave instability theory of Taylor dominated the bubble spacing and growth rate near the minimum film boiling temperature. He proposed the analytical correlation on the rewetting temperature of an isothermal surface by incorporating the Taylor instability theory into the Bromley model, obtaining the following expression:

$$(\Delta T_{\min})_I = 0.127\frac{\rho_v h_{fg}}{k_v}\left[\frac{g(\rho_l-\rho_v)}{\rho_l+\rho_v}\right]^{2/3}\left[\frac{\sigma}{g(\rho_l-\rho_v)}\right]^{1/2}\left[\frac{\mu_v}{g(\rho_l-\rho_v)}\right]^{1/3}, \tag{1}$$

where $(\Delta T_{\min})_I = T_q - T_s$. To consider the effects of the wall to fluid interface temperature gradient, Henry (1974) proposed the micro-layer evaporation model based on Berenson's theory and indicated that the amount of surface cooling was dependent upon the amount of remaining liquid, the latent heat of vaporization, and the enthalpy of the wall. He proposed the following correlation.

$$\frac{T_q-(T'_{\min})_I}{(T'_{\min})_I-T_l}=0.42\left[\sqrt{\frac{k_l\rho_l C_{pl}}{k_w\rho_w C_{pw}}}\frac{h_{fg}}{C_{pw}(\Delta T_{\min})_I}\right]^{0.6}, \qquad (2)$$

where $(T'_{\min})_I=(\Delta T_{\min})_I+T_s$, and $(\Delta T_{\min})_I$ is the isothermal minimum film boiling temperature predicted by Eq.(1). Kim and Lee (1979) also suggested the following Eq. (3) of the rewetting temperature correlation on the basis of dimensional analysis for the vertical circular channels.

$$T_q=19.51T_{WS}\left[\frac{T_{Sl}}{T_{WS}}\right]^{0.107}\left[\frac{C_{pw}G\delta}{k}\right]^{-0.162}\left[\frac{k\rho^2T_{WS}}{\delta G^3}\right]^{-0.0989}\left[\frac{Z}{\delta}\right]^{-0.163}+T_S, \qquad (3)$$

where $T_{Sl}=T_S-T_l, T_{WS}=T_W-T_S$, and δ means the wall thickness of heated tube.

Berenson’s correlation only contains the properties of coolant. Henry (1974) extends the Berenson’s correlation to include the properties of heated wall. Finally, Kim and Lee’s (1979) correlation includes the thickness of heated tube and the location of quenching front.

2.4 Comparison with the present experimental data

The present data is compared with the correlations in Fig. 2 and 3. Berenson’s correlation presents a rather underestimated value from the present data. The predicted values by Henry’s correlation show a wide scattering with the variation of the test conditions.

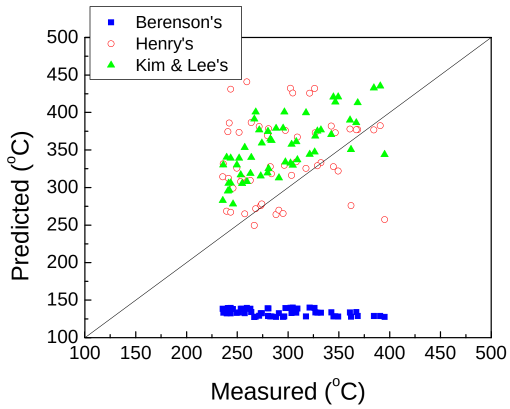

Fig. 2 Comparison between the present rewetting temperature data and the previous correlations (*Cosine heater rod, measured by TW02 in Fig.1*)

In spite of the fact that large deviations from the measured value exist, the Kim and Lee’s correlation shows a different behavior with the axial location of the rod. As can be observed in Fig. 2 and 3, the deviations of the Kim and Lee’s correlation from the present data become small with the increase of the vertical height from the bottom of the heated section. This indicates that there should be more elaborated consideration on the vertical height and the power shape of the heated section in the rewetting temperature correlation to increase the prediction accuracy.

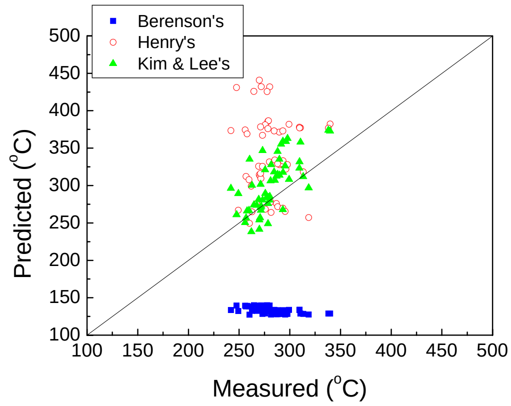

Fig. 3 Comparison between the present rewetting temperature data and the previous correlations (*Cosine heater rod, measured by TW04 in Fig.4*)

3. Conclusions

In the present work, experimental observation on the rewetting phenomena was performed, and the data have been compared with the previous correlations. Among these, Kim and Lee’s correlation shows a relatively good performance. However, there is a strong need to enhance or modified the correlation with respect to the vertical height and the power shape of the heater rod.

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