CHF and Bubble Departure Dynamics of the Thin Flat Plate Heater

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1. Introduction

As noted by Lienhard and Dhir, the finite size of heater affect bubble departure characteristics during boiling and enhance CHF comparing to the heater with sufficiently large heat transfer area. There are competitive theories to explain it: Lienhard and Dhir's model based on the instability following Zuber and the macro film model of Haramura and Katto. Lee et al. recently produced CHF data for the heaters with thinner width than the data used to evaluate those models which were scattered and covered the estimation of both models. However, the CHF data of Lee et al. clearly showed that the CHF model of Lienhard and Dhir is better than the model of Haramura and Katto in the more thinner width than the conventional data set.

Furthermore, Lee et al found that the CHF model of Lienhard and Dhir even underpredicted CHF data obtained from their experiments. It was found that the empirical correlation from the data fitting has the value of exponent from -3/8 to -1/2 which is bigger than -1/4 of Lienhard et al.

In the present paper, we provided a partial explanation of this abrupt change of CHF enhancement departed from the phenomena based on the flow instability of Lienhard and Dhir.

2. Experiments

The pool boiling facility is made in the form of the double-walled water chamber as shown in Fig. 1. It is composed of (a) the external chamber of $32\times42.5\times29.5$cm and (b) the internal chamber of $19.5\times29.5\times27$cm with tempered glass. The 2×0.8 kW heaters are installed in the internal chamber filled with demineralized water. In the external chamber, saturated water is filled and the sub heater (d) of 2×0.3 kW is installed to supply the heat that loses through the wall of chamber. Thick brass rod of 20mm diameter that minimizes internal resistance and fixes the heater is mounted at the teflon cover (f) which is installed on top of the internal chamber and the PCB test heater is mounted between electrodes.

Power supply (h) which has the control range of 0~330A current and 0~20V voltage is connected with the brass rods, and the output power is automatically controlled. For the data acquisition, 34970A HP Agilent, 0.004% accuracy in 6 1/2 digit (22bit) resolution and DC voltage, is used. System current is measured by using shunt resistor which is made by manganin.

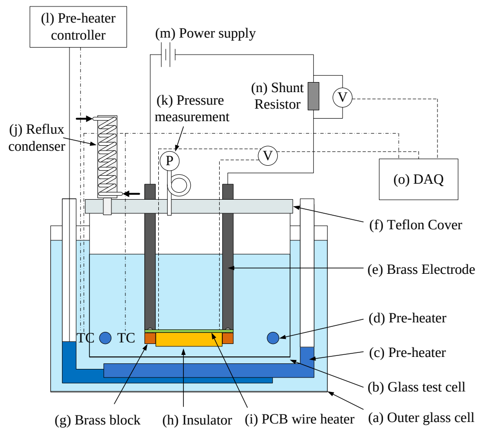

Fig. 1 Experimental apparatus for measuring the pool boiling characteristic of the thin flat plate heater.

3. The Bubble Curvature and Heater Width

If we assume that there is a vapor film on the surface of the heater with the cross sectional area as depicted in Fig. 2 with the length of L, we can deduce the relationship between the width of the heater, w, and the radius of curvature of the bubble, r, as

$$\sin\theta = \frac{w}{2r},\quad \cos\theta = \sqrt{1-\left(w/2r\right)^2} \tag{1}$$

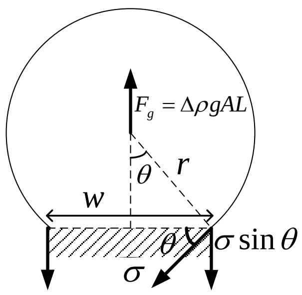

Fig. 2 The diagram of the heater width and the curvature of the bubble

We can derive the force balance in the vertical direction only considering the buoyancy force and the surface tension force as

$$2\sigma\sin\theta L = g\Delta\rho A L \tag{2}$$

where A is the cross section area of the vapor film defined as

$$A = \pi r^2 - \left[\frac{1}{2}r^2(2\theta) - \frac{1}{2}wr\cos\theta\right] \tag{3}$$

Eq.(2) and (3) gives

$$2\sigma\sin\theta = \Delta\rho g\left[\pi r^2 - \frac{1}{2}r^2(2\theta) + \frac{1}{2}wr\cos\theta\right] \quad (4)$$

Eq.(4) is transformed into the dimensionless form as

$$4\sin\theta = 2\pi r'^2 - 2r'^2\theta + w'r'\cos\theta \quad (5)$$

where $r' = \frac{r}{\sqrt{\sigma / g\Delta\rho}}$ and $w' = \frac{w}{\sqrt{\sigma / g\Delta\rho}}$. Since the trigonometric simplification as follows,

$$\theta = \sin^{-1}\frac{w}{2r} \approx \frac{w}{2r} \quad (6)$$

$$\cos\theta = \sqrt{1-\left(\frac{w}{2r}\right)^2} \approx 1 \ for \left(\frac{w}{2r}\right)^2 << 1 \quad (7)$$

can be applied to Eq.(5) and we have

$$2\frac{w'}{r'} = 2\pi r'^2 - r'w' + w'r' \quad (8)$$

Therefore, the dimensionless radius of curvature of the attached film bubble is proportional to the 1/3 power of the dimensionless width (or characteristic width) :

$$r' = \left(\frac{w'}{\pi}\right)^{1/3} = 0.683 w'^{1/3} \quad (9)$$

As shown in Fig.3, the present theoretical model depicted in the experimental data plot made by the air-water and steam-water instability test (Lee et al.).

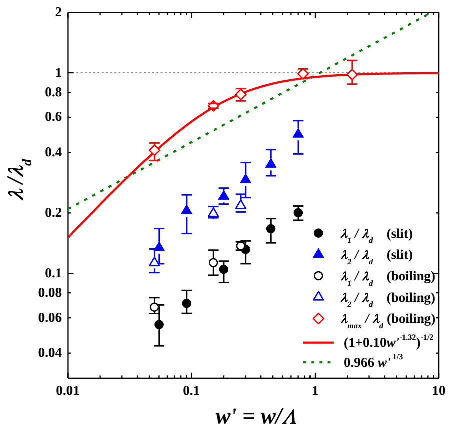

Fig. 3 The wavelengths observed in the thin slit test and boiling

The slope of the experimental data of first mode and second mode instabilities made a good agreement. However, the largest wavelengths observed in boiling test (the red white diamonds) showed some discrepancy to the other data.

4. Helmholtz Wavelength for CHF and the Radius of Curvature

As noted by Lee et al. the most dangerous wavelength in the thin flat plate heater is determined by multiplying the weighting factor which is proportional to characteristic radius of curvature

$$\lambda_{df} = \left(\sqrt{2r'}\right)\lambda_d = (0.966 w'^{1/3})\lambda_d \quad (10)$$

If we apply the most dangerous wavelength for the finite flat plate heater defined as Eq.(11) into the CHF model proposed by Lienhard and Dhir is given

$$\frac{q''_{CHF}}{q''_{CHF\infty}} = \frac{24}{\pi}\eta\sqrt{\frac{2\pi\Lambda}{2\sqrt{0.155\pi w\lambda_{df}}}} \times 0.155 = 1.01 w'^{-1/3} \quad (11)$$

5. Prediction of CHF

The present results have larger power of -1/3 than -1/4 of Lienhard and Dhir. As shown in Fig. 4, the present prediction is little bit higher but still made a good agreement of the experimental data of Lee et al..

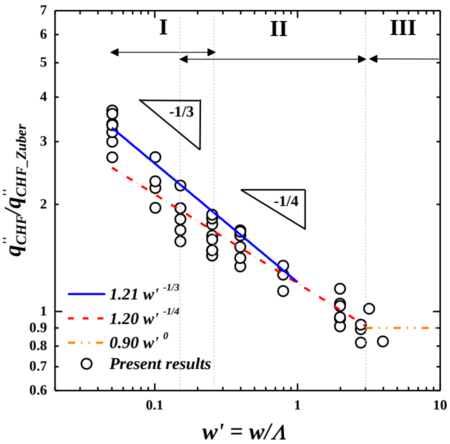

Fig. 4 CHF data of Lee et al. and prediction of the present model and Lienhard and Dhir.

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