Critical heat flux and boiling behaviors on a horizontal surface in saturated pool boiling at high pressure

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Introduction

Accurate prediction of critical heat flux (CHF) is a key issue for safety assessments of nuclear reactors and other thermal devices with high heat flux components. Kutateladze derived the well-known CHF correlation (1) for the CHF on upward facing large surfaces based on a dimensional analysis.

\[ q_{CHF} = K \cdot \rho_i^2 H_f g [\sigma (\rho_i - \rho_v)]^{1/4} \]  

(1)

The value of K is a constant, and 0.13 to 0.19 was recommended depending on the kind of liquid for pool boiling on a large horizontal flat surface.

In the past several decades, there were many studies for this issue, however, the research at high-pressure condition is rare. There were several experiments carried on high-pressure condition, but scattered data cannot be used to check Eq. (1) correct or not. The present study measured the CHF of saturated boiling on an upward circular surface for ethanol, R141b, and water at high pressures, and observed the boiling behaviors from low heat flux to near the CHF.

Experimental results

Boiling curves and boiling behaviors

![Fig. 3 boiling curve of ethanol](image)

![Fig. 4 boiling behaviors at different heat fluxes for R141b at 0.95MPa (CHF=0.87 MW/m²)](image)

Fig. 3 shows the boiling curve of ethanol, symbols represent experiment results, the solid lines are the predicted results with Stephan correlation. Fig. 4 shows...
the boiling behaviors with increasing heat fluxes for R141b at 0.95 MPa. At low heat fluxes, small coalesced bubbles detach from the heating surface. With increasing heat flux, the detached bubbles increased in size, and grow to large deformed vapor masses with size close to that of the heating surface, then the CHF occurs.

The boiling behaviors for ethanol and water were similar to those of R141b. These observation results suggest that: the occurrence of the CHF in the pressure range of the present experiments is closely related to the formation of the large vapor masses and consumption of the liquid layer beneath the vapor masses.

Critical heat fluxes

Fig. 5 shows the experiment results of CHF versus pressure for ethanol and R141b. The present data for ethanol and R141b agree well with Eq. (1) in the whole range of pressures. Fig. 6 shows the measured CHF for water. Different from the CHF for ethanol and R141b, Eq. (1) does not explain the variation in the CHF with pressure for water. It may be explained by the reason that the wettability of ethanol and R141b are quite well and little affected by pressure, while wettability of water at around atmospheric pressure is poor and improves with increasing pressure (temperature). The present study examined the CHF for water from the viewpoint of change in surface wettability with temperature.

Effect of wettability on CHF for water

The present study measured the contact angle of water droplets on the surface using the apparatus in Fig. 2 and compares the present data with other researcher’s results as shown in Fig. 7. Present data have a similar tendency with the previous data. It is found that above 100-120°C the contact angle steeply decreases with the increase in temperature. Eq. (1) is independent of surface conditions. Correlations for CHF incorporating the effect of the surface wettability have been proposed by Kirichenko and Chernyakov (1971), and Kandlikar (2001). Kandlicar developed a theoretical model to predict CHF as shown in Eq. (2). The correlation by Kirichenko and Chernyakov is given as Eq. (3).

where \( \theta \) is the contact angle.

The present study applied these two correlations to CHF of water, the contact angles were estimated by the fitted curve to the present data (the solid line in Fig. 7). The author plots the predicted results of Kandlicar and Kirichenko in Fig. 6. The predictions with the two correlations plot fairly close to the present data.

Conclusions

- At high heat fluxes near the CHF, large vapor masses covering the heating surface are formed for the boiling of ethanol, R141b, and water in the whole range of pressures in the present experiment.
- For boiling of ethanol and R141b, Eq. (1) explains well the variation of the CHF with pressure. For boiling...
of water, Eq. (1) underestimates the pressure dependence of the CHF.
• When considering the effect of the contact angle, the correlations by Kandlikar, and Kirichenko and Chernyakov, which include the effect of surface wettability on CHF, can fit with the present data for water reasonably