§3. Critical Heat Fluxes of Subcooled Water Flow Boiling in a Short Vertical Tube at High Liquid Reynolds Number

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The knowledge of subcooled flow boiling critical heat fluxes (CHFs) in a short vertical tube at high liquid Reynolds number is important to discuss the mechanism of CHFs. We have supposed that the enhancement of CHFs for the swirl tube will be due to reduction of laminar boundary layer thickness on heated surface of test tube due to an increase in liquid flow velocity from straight flow to swirl one, not new mechanism of heat transfer crisis.

We have measured the transient CHFs of the subcooled water flow boiling for ramp-wise heat input and stepwise one with the wide ranges of flow velocities, inlet subcoolings and inlet pressures. The transient CHF correlation against inlet subcooling based on the CHF data with exponentially increasing heat input was modified for various heat input waveform as follows: [1-3)]

$$Bo = C_1\left\{\frac{d}{\sqrt{\sigma/g(\rho_l-\rho_g)}}\right\}^{-0.1} We^{-0.3}\left(\frac{L}{d}\right)^{-0.1} e^{-\frac{(L/d)}{C_2 Re^{0.4}}} Sc^{*C_3} \times\left[1+11.4\left\{\frac{\omega_p u}{\sqrt{\sigma/g(\rho_l-\rho_g)}}\right\}^{-0.6}\right] \quad (1)$$

where C_1=0.082, C_2=0.53 and C_3=0.7 for L/d≤around 40 and C_1=0.092, C_2=0.85 and C_3=0.9 for L/d>around 40. The reduced times, ω_p, for exponentially increasing heat input, ramp-wise one and stepwise one are τ, $t_{cr}/2$ and t_{cr}, respectively.

The critical heat fluxes (CHFs) of the subcooled water flow boiling for the flow velocities (u=17.16 to 42.41 m/s), the inlet subcoolings ($\Delta T_{sub,in}$=80.86 to 147.57 K), the inlet pressures (P_{in}=812.07 to 1181.48 kPa) and the increasing heat inputs ($Q_0\ exp(t/\tau)$, τ=10, 20 and 33.3 s) are systematically measured by the experimental water loop comprised of a new multistage canned-type circulation pump with high pump head. The SUS304 test tube of d=6 mm, L=59.5 mm, L/d=9.92 and wall thickness (δ=0.5 mm) with surface roughness (Ra=3.18 μm) is used in this work.

CHF

The CHFs, $q_{cr,sub}$, for the inner diameter of 6 mm were shown versus the inlet subcoolings, $\Delta T_{sub,in}$, with the flow velocities of 4.0 to 40 m/s in Fig. 1. The $q_{cr,sub}$ for each flow velocity become higher with an increase in $\Delta T_{sub,in}$. The increasing rate becomes lower for higher $\Delta T_{sub,in}$. The $q_{cr,sub}$ increase with an increase in flow velocity at a fixed $\Delta T_{sub,in}$. The $q_{cr,sub}$ for the wide range of flow velocities are proportional to $\Delta T_{sub,in}^{0.7}$ for $\Delta T_{sub,in}$≥40 K. The effect of flow velocity on CHFs for $\Delta T_{sub,in}$=140 K was represented versus u in Fig. 2. The values of $q_{cr,sub}$ become linearly higher with an increase in u and the increasing rate becomes higher for u>13.3 m/s. The $q_{cr,sub}$ are proportional to $u^{0.4}$ for u≤13.3 m/s and $u^{0.5}$ for u>13.3 m/s.

CHF correlation at high liquid Reynolds number

The CHF correlation against inlet subcooling at high liquid Reynolds number (u>13.3 m/s) is derived as follows based on the effects of u clarified in this work.

$$Bo = C_1\left\{\frac{d}{\sqrt{\sigma/g(\rho_l-\rho_g)}}\right\}^{-0.15} We^{-0.25}\left(\frac{L}{d}\right)^{-0.1} e^{-\frac{(L/d)}{C_2 Re^{0.5}}} Sc^{*C_3} \times\left[1+11.4\left\{\frac{\omega_p u}{\sqrt{\sigma/g(\rho_l-\rho_g)}}\right\}^{-0.6}\right] \quad (2)$$

where C_1=0.0523, C_2=0.144 and C_3=0.7 for L/d≤around 40 and C_1=0.092, C_2=0.85 and C_3=0.9 for L/d>around 40.

The curves derived from Eqs. (1) and (2) are shown in Figs. 1 and 2 for comparison. The CHF data for $\Delta T_{sub,in}$≥40 K are in good agreement with the values given by these correlations. To confirm the applicability of Eqs. (1) and (2), the ratios of these CHF data for d=6 mm (312 points) to the corresponding values calculated by Eqs. (1) and (2) are shown versus $\Delta T_{sub,in}$ in Fig. 3. Most of the data for $\Delta T_{sub,in}$≥40 K are within ±15 % diffrence of Eqs. (1) and (2) for the wide ranges of inlet subcoolings and flow velocities.

1) Hata, K. and Noda, N., Paper No. NURETH12-050, (2007) 1
2) Hata, K. and Noda, N., *Journal of Heat Transfer*, Trans. ASME, Series C, **130**, (2008) 054503-1
3) Hata, K. and Noda, N., Paper No. ICONE16-48164, (2008) 1

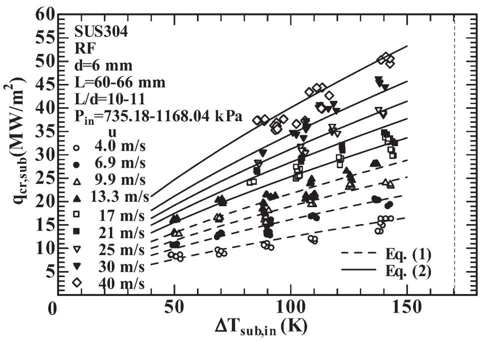

Fig. 1 $q_{cr,sub}$ vs. $\Delta T_{sub,in}$ for d=6 mm and L=60 to 66 mm with u=4 to 40 m/s.

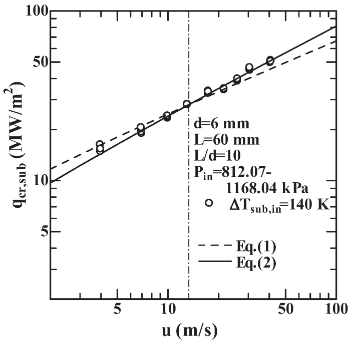

Fig. 2 $q_{cr,sub}$ vs. u for d=6 mm and L=60 mm at $\Delta T_{sub,in}$=140 K.

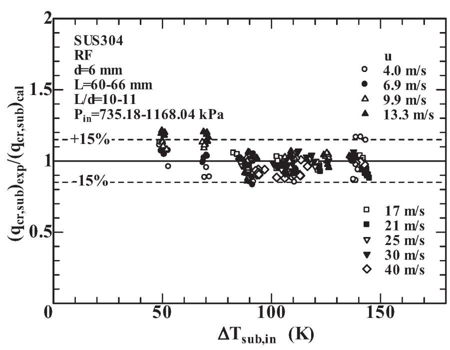

Fig. 3 Ratios of $q_{cr,sub}$ to corresponding values calculated by Eqs. (1) and (2) versus $\Delta T_{sub,in}$.