§11. Critical Heat Fluxes of Subcooled Water Flow Boiling in a Short Swirl Tube

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The knowledge of subcooled flow boiling critical heat fluxes (CHFs) in a short swirl tube is important to understand the mechanism of subcooled flow boiling critical heat flux at high liquid Reynolds number. 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 with an increase in liquid flow velocity from straight flow to swirl one even at a fixed mass velocity, not new mechanism of heat transfer crisis.

We have systematically measured the steady state critical heat fluxes, $q_{cr,sub,st}$, of the subcooled water flow boiling for the flow velocities (u=17.16 to 42.41 m/s) and the exponentially increasing heat input ($Q=Q_0\,exp(t/\tau)$, τ=10 s) by the experimental water loop comprised of a new multistage canned-type circulation pump with high pump head. The $q_{cr,sub,st}$ are proportional to $u^{0.4}$ for $u \le 13.3$ m/s and $u^{0.5}$ for $u>13.3$ m/s. The existing CHF correlation against outlet subcooling was modified to new one, Eq. (1), containing the u effect at high liquid Reynolds number based on these experimental data for the u higher than 13.3 m/s as follows:[1, 2)]

$$Bo = 0.0523\left\{\frac{d}{\sqrt{\sigma/g(\rho_l-\rho_g)}}\right\}^{-0.15} We^{-0.25}\left(\frac{L}{d}\right)^{-0.1} Sc^{0.7} \times\left[1+6.34\left\{\frac{\omega_p u}{\sqrt{\sigma/g(\rho_l-\rho_g)}}\right\}^{-0.6}\right] \qquad (1)$$

Most of the data (250 points) are within ±15 % diffrences of Eq. (1) for the wide ranges of outlet subcoolings ($\Delta T_{sub,out}$=59.46 to 127.67 K) and flow velocities (u=17.16 to 42.41 m/s).

The twisted-tape-induced swirl flow CHFs due to exponentially increasing heat input ($Q_0\,exp(t/\tau)$, τ=10 s) were systematically measured. 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) was used in this work. The twisted tapes with width (w=5.3 to 5.6 mm), thickness (δ_T=0.6 mm), total length (l=370 mm) and twist ratio [$y=H/d$=(pitch of 180° rotation)/d=3.39] as shown in Fig. 1 were used.

CHF

The induced swirl flow CHFs, $q_{cr,sub,sw}$, for the inner diameter of 6 mm with the twisted tape of y=3.39 were shown versus the outlet subcoolings, $\Delta T_{sub,out}$, with the swirl velocities, u_{sw}, of 5.39 to 18.03 m/s in Fig. 2. The $q_{cr,sub,sw}$ for each swirl velocity become higher with an increase in $\Delta T_{sub,out}$. The increasing rate becomes lower for higher $\Delta T_{sub,out}$. The $q_{cr,sub,sw}$ increase with an increase in swirl velocity at a fixed $\Delta T_{sub,out}$. The swirl velocities, u_{sw}, were defined by the flow velocities, u, for the empty tube in consideration of the increment of flow length by the twisted-tape as follows :[3)]

$$u_{sw} = u\frac{\pi d^2}{\pi d^2 - 4w\delta_T} \times \frac{(4y^2+2\pi^2)^{0.5}}{2y} \qquad (2)$$

CHF Correlation for Induced Swirl Flow

The CHF correlation for induced swirl flow in a circular tube with various twisted-tape inserts is derived as follows based on the effects of u_{sw} clarified in this work.

$$\frac{q_{cr,sub,sw}}{q_{cr,sub}} = \left(\frac{u_{sw}}{u}\right)^n \qquad (3)$$

where $q_{cr,sub}$ is the flow boiling CHFs for the empty tube, n=0.4 for $u \le 13.3$ m/s and n=0.5 for $u>13.3$ m/s.

The curves derived from Eqs. (1) and (3) are shown in Fig. 2 for comparison. The CHF data for $\Delta T_{sub,out} \ge 30$ K are in good agreement with the values given by these correlations. To confirm the applicability of Eqs. (1) and (3), the ratios of these CHF data for d=6 mm and L=59.5 mm with the twisted tape of y=3.39 (53 points) to the corresponding values calculated by Eqs. (1) and (3) are shown versus $\Delta T_{sub,out}$ in Fig. 3. Most of the data are within ±15 % diffrences of Eqs. (1) and (3) for the wide ranges of outlet subcoolings ($\Delta T_{sub,out}$=55.15 to 137 K) and swirl velocities (u_{sw}=5.39 to 18.03 m/s).

1) Hata K. and Masuzaki S., Paper No. NUTHOS7-134 (2008) pp. 1-16. 2) Hata, K., and Masuzaki S., Paper No. ICONE17-75818 (2009) pp. 1-15. 3) Hata, K. and Masuzaki S., Paper No. NURETH13-N13P1114 (2009) pp. 1-16.

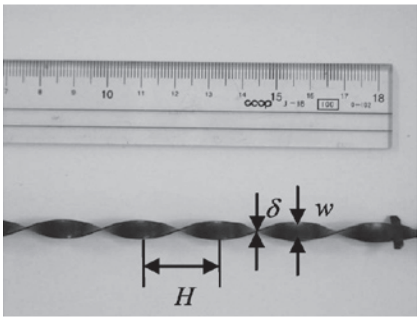

Fig. 1 Photograph of SUS304 twisted tape coated with epoxy resin.

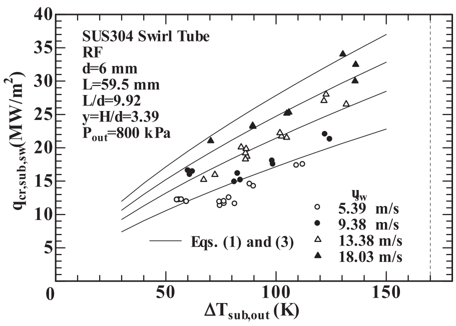

Fig. 2 $q_{cr,sub,sw}$ vs. $\Delta T_{sub,out}$ for circular tube of d=6 mm and L=59.5 mm with twisted tape of y=3.39 at P_{out}=800 kPa.

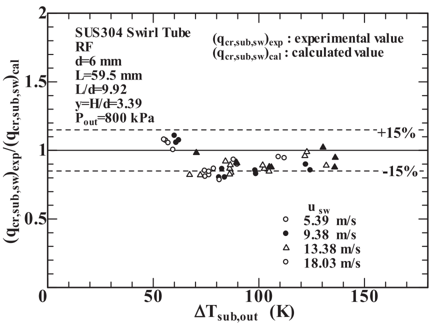

Fig. 3 Ratios of $q_{cr,sub,sw}$ to corresponding values calculated by Eqs. (1) and (3) versus $\Delta T_{sub,out}$.