§38. Transient Critical Heat Fluxes of Subcooled Water Flow Boiling in a SUS304-CIRCULAR Tube with Twisted-Tape Insert

Hata, K. (Inst. of Advanced Energy, Kyoto Univ.),
Masuzaki, S.

The influence of heating rate on subcooled flow boiling critical heat fluxes (CHFs) in a test tube with twisted-tape insert is necessary to investigate the reliability of a divertor in a nuclear fusion facility for short pulse high heat flux test mode.

The SUS304 tube of the inner diameter (d=6 mm), heated length (L=59.4 mm), L/d=9.9 and wall thickness (δ=0.5 mm) with the rough finished inner surface (Surface roughness, Ra=3.89 μm) were used. The SUS304 twisted-tape of width (w=5.6 mm), thickness (δ_T=0.6 mm), total length (l=372 mm) and twist ratio [$y=H/d$=(pitch of 180° rotation)/d=3.37] was mainly employed. The transient CHFs, $q_{cr,sub}$, at the inlet subcooling of around 150 K are shown versus the exponential period, τ, with the τ ranging from 26.85 ms to 8.42 s at the swirl velocities, u_{sw}, of 5.37, 9.35, 13.34 and 17.97 m/s in Fig. 1. The figure also illustrates the trends in the variation of transient CHF with decreasing exponential period. The transient CHFs, $q_{cr,sub}$, are almost constant for the exponential period, τ, higher than around 800 ms and they become higher with the decrease in the τ at a fixed u_{sw}. The transient CHFs in the whole experimental range become higher with an increase in swirl velocity at a fixed τ. The curves given by the steady-state CHF correlation against inlet subcooling for a SUS304-circular tube with various twisted-tape inserts, Eq. (1), at each swirl velocity are shown in Fig. 1 for comparison. The transient CHF data for the τ higher than 800 ms are -22 % lower than the values given by Eq. (1) [1, 2].

$$Bo_{cr,sw} = C_1 D^{*-0.1} We_{sw}^{-0.3} \left(\frac{L}{d}\right)^{-0.1} e^{-\frac{(L/d)}{C_2 Re_d^{0.4}}} Sc^{*C_3}$$

if inlet subcooling is known ($\Delta T_{sub,in}$≥40 K) (1)

For power transient experiments, the rate of increasing heat input is very high. It takes time to form the fully developed temperature profile in the test tube because the test tube has some heat capacity. Then the temperature profile in the conductive sub-layer on the test tube surface grows, and vaporization occurs. It also takes some time to occur instantaneously the heterogeneous spontaneous nucleation on the test tube surface at the transient CHF. Namely, it is explained to be as a result of the time lag of the formation of the transient CHF for the increasing rate of the heat input. Figure 2 shows the influence of the non-dimensional exponential period, $p^*=\tau u/\{\sigma/g/(\rho_l-\rho_g)\}^{0.5}$, for the exponentially increasing heat input, τ, on the ratios of the difference between the transient CHFs, $q_{cr,sub}$, and the steady-state ones, $q_{cr,sub,st}$, to the $q_{cr,sub,st}$, $(q_{cr,sub}-q_{cr,sub,st})/q_{cr,sub,st}$, at the fixed inlet subcooling of around 150 K. The ratios for the non-dimensional exponential period ranging from 48.21 to 5.196 ×10^3 were shown versus the p^* with the swirl velocity as a parameter. As shown in Fig. 2, the values of $(q_{cr,sub}-q_{cr,sub,st})/q_{cr,sub,st}$ become linearly higher with the decrease in the non-dimensional exponential period, p^*. The values of $(q_{cr,sub}-q_{cr,sub,st})/q_{cr,sub,st}$ obtained from Eq. (2) are shown as solid curve in Fig. 2 for comparison.

$$\frac{q_{cr,sub} - q_{cr,sub,st}}{q_{cr,sub,st}} = 11.4\, p^{*-0.6} \qquad (2)$$

Equation (2) can also describe these ratios for the p^* ranging from 48.21 to 5.196×10^3 (49 points) within ±50 % difference [3].

The transient CHF correlation against inlet subcooling for the test tubes with various twisted-tape inserts is derived due to the effect of boiling number based on swirl velocity, $Bo_{cr,sw}$, and Weber number based on swirl velocity, We_{sw}, on the basis of Eq. (2), the steady-state CHF correlation against inlet subcooling for the test tubes with various twisted-tape inserts [1,2], Eq. (1), and the transient CHF correlation against inlet subcooling for the empty test tubes as follows:

$$Bo_{cr,sw} = C_1 D^{*-0.1} We_{sw}^{-0.3} \left(\frac{L}{d}\right)^{-0.1} e^{-\frac{(L/d)}{C_2 Re_d^{0.4}}} Sc^{*C_3} \times \left(1 + 11.4\, p^{*-0.6}\right)$$

if inlet subcooling is known ($\Delta T_{sub,in}$≥40 K) (3)

The ratios of transient CHF data to the values calculated from the transient CHF correlation against inlet subcooling for the test tubes with various twisted-tape inserts, Eq. (3), are shown versus the p^* at the inlet pressures of 853.44 to 989.96 kPa in Fig. 3. This correlation can describe the transient CHF data for the SUS304-tube with the twisted-tape of the twist ratio, y, of 3.37 (49 points) obtained in this work for the wide range of the non-dimensional exponential periods (p^*=48.21 to 5.052×10^4) and the swirl velocities (u_{sw}=5.37 to 18.11 m/s) at $\Delta T_{sub,in}$=around 150 K within -27 to 0 % difference as shown in Fig. 3 [3].

1) Hata, K., and Masuzaki, S., *Journal of Engineering for Gas Turbines and Power*, **133** (2011) 052906-1-11.
2) Hata, K. and Masuzaki, S., *Journal of Thermal Science and Engineering Applications*, **3** (2011) 012001-1-12.
3) Hata, K., et al., Proceedings of ICONE20POWER2012 (2012) 1-13.

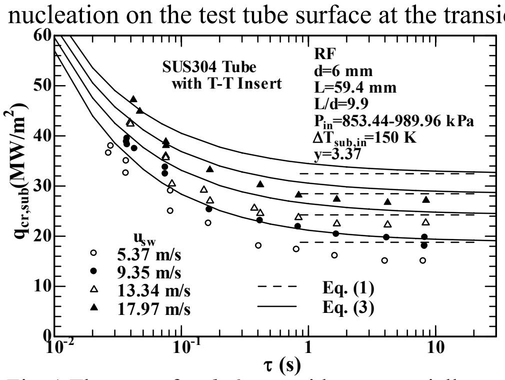

Fig. 1 The $q_{cr,sub}$ for d=6 mm with exponentially increasing heat input at $\Delta T_{sub,in}$=150 K for τ=26.85 ms to 8.42 s

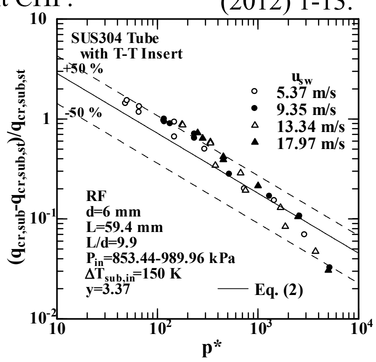

Fig. 2 $(q_{cr,sub}-q_{cr,sub,st})/q_{cr,sub,st}$ versus p^* for d=6 mm with exponentially increasing heat input

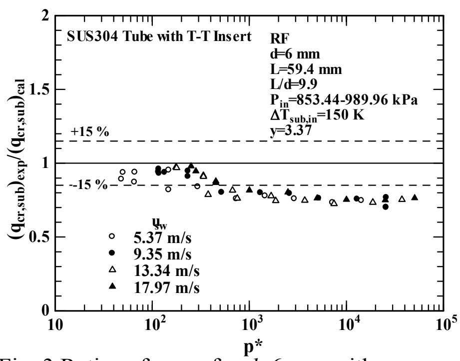

Fig. 3 Ratios of $q_{cr,sub}$ for d=6 mm with exponentially increasing heat input (49 points) to values calculated by Eq. (3) versus p^*