§18. The Effect of Diameter on CHFs in Vertical Heated Tubes with Upward Flow of Subcooled Water

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Flow boiling critical heat fluxes (CHFs) on solid surfaces in highly subcooled flowing water at various pressures were studied recently by many researchers, because boiling with phase change in subcooled water is an attractive cooling method for high heat flux components such as plasma facing ones in fusion experimental facilities. However, there were few data of CHFs in highly subcooled and pressurized water systematically measured for wide ranges of independent variables such as flow rate, subcooling and pressure until quite recently.

The CHFs for inlet subcoolings ($\Delta T_{sub,in}$) on inner surface of a short tube in water flowing upward at various pressures had been measured for various flow velocities using a 9 mm inner-diam. (ID) test tube[1]. It was clarified that the CHFs were clearly divided into three groups for low, intermediate and high $\Delta T_{sub,in}$. Namely, first, the CHFs for low $\Delta T_{sub,in}$ decrease down to the minimum one, secondly those for intermediate $\Delta T_{sub,in}$ increase up to a certain CHFs, and thirdly those for high $\Delta T_{sub,in}$ also increase with the different increasing rate of CHFs lower than that for the intermediate $\Delta T_{sub,in}$ with an increase in $\Delta T_{sub,in}$. Though the CHFs for lower and intermediate $\Delta T_{sub,in}$ were clearly dependent on the pressures, those for high $\Delta T_{sub,in}$ were almost independent of the pressure. The different CHFs mechanisms for the $\Delta T_{sub,in}$ were suggested. The experimentally measured CHFs for 9 mm ID test tube for low, intermediate and high $\Delta T_{sub,in}$ are well expressed by the following correlations[1].

(CHFs correlation for low $\Delta T_{sub,in}$)

$$q_{cr,sub} = 1.32\times 10^{6} P^{0.261} u^{0.287} + \left(7.61\times 10^{3} - 1.73\times 10^{2} P\right)\Delta T_{sub,in} \quad (1)$$

(CHFs correlation for intermediate $\Delta T_{sub,in}$)

$$q_{cr,sub} = q_{cr,sat}\left[1 + K_2(u)\left(\rho_l/\rho_g\right)^{0.69}\left(c_{pl}\Delta T_{sub}/h_{lg}\right)^{1.5}\right] \quad (2)$$

$$q_{cr,sat} = K_1(u) h_{lg}\rho_g\left[\sigma g\left(\rho_l - \rho_g\right)/\rho_g^{\,2}\right]^{1/4} \quad (3)$$

$$K_1(u) = 0.135 + 0.0283\, u^{1.03}$$

$$K_2(u) = 0.608 + 0.245u - 0.302\, u^{0.95}$$

(CHFs correlation for high $\Delta T_{sub,in}$)

$$q_{cr,sub} = K_3(u)\,\Delta T_{sub,in}^{\;0.73} \quad (4)$$

$$K_3(u) = 2.65\times 10^{5} + 4.58\times 10^{4} u^{0.92}$$

The CHFs for 6 and 12 mm ID test tubes were measured at the same experimental conditions of 9 mm ID test tube. The measured CHFs for low, intermediate and high $\Delta T_{sub,in}$ were compared with those for the 9 mm ID test tube in Fig. 1. The trends of CHFs against low, intermediate and high $\Delta T_{sub,in}$ measured for both test tubes were almost identical with that already obtained from 9 mm ID test tube.

The ratios of experimentally measured CHFs for the pressure of 800 kPa at the velocity of 9.9 m/s to corresponding ones calculated from the correlations for low, intermediate and high $\Delta T_{sub,in}$, $q_{cr,exp}/q_{cr,cal}$, are shown in Fig. 2 with the tube diameter as a parameter. The ratios for the intermediate and high $\Delta T_{sub,in}$ up to about 140 K were almost within around ±10% differences of unity as shown in Fig. 2.

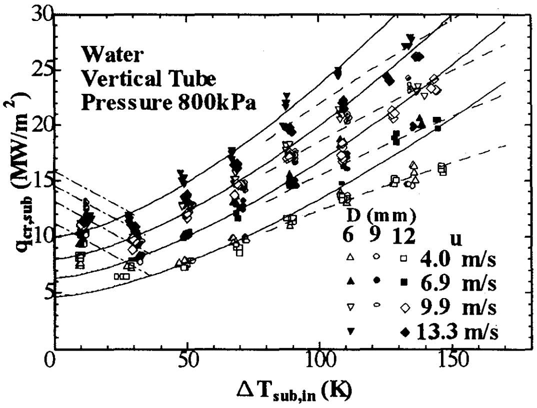

Fig. 1 CHFs versus $\Delta T_{sub,in}$ for several flow velocities at a pressure of 800 kPa with curves derived from correlations.

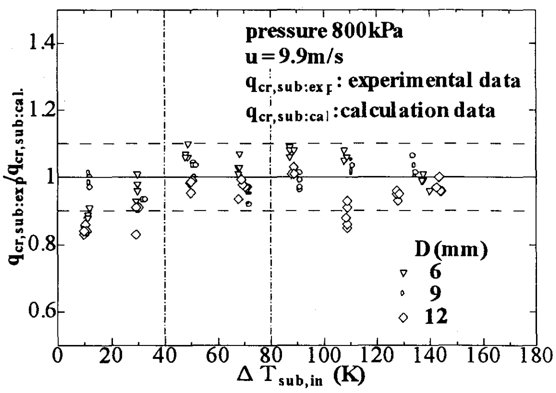

Fig. 2 Ratio between measured CHFs and calculated CHFs derived from correlations versus inlet subcooling.

Reference

1) Hata K., Fukuda K., Shiotsu M., Sakurai A., Noda N., Motojima O. and Iiyoshi A., 1998, Critical Heat Fluxes in Subcooled Boiling of Water Flowing Upward in a Vertical Tube for Wide Ranges of Liquid Velocity, Subcooling and Pressure, *Proc. of 6th International Conference on Nuclear Engineering*, Paper No. ICONE-6362, pp.1-16.