§37. Critical Heat Fluxes of Subcooled Water Flow Boiling in a Short Horizontal Tube

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The knowledge of the turbulent heat transfer (THT), the nucleate boiling heat transfer (NBHT) and the critical heat fluxes (CHFs) in subcooled water flow for HORIZONTAL circular test tube is important for the design of a helical type divertor plate in a nuclear fusion facility. The influence of test tube installation on THT, NBHT and CHF in subcooled water flow will be immediately supposed to be applied to thermal analysis of the divertor of a helical type fusion experimental device which is Large Helical Device (LHD).

For many years we have already measured the transient CHFs by exponentially increasing heat input ($Q_0\,exp(t/\tau)$, τ=16.8 ms to 23 s), ramp-wise one ($Q=\alpha t$, $\alpha=6.21\times10^{8}$ to 1.63×10^{12} W/m^{3}s) and stepwise one ($Q=Q_s$, $Q_s=2.95\times10^{10}$ to 7.67×10^{10} W/m^3) for the VERTICAL SUS304 test tube with the wide range of experimental conditions such as inner diameters (d=2 to 12 mm), heated lengths (L=22 to 149.7 mm), L/d (=4.08 to 74.85), outlet pressures (P_{out}=159 kPa to 1.1 MPa) and flow velocities (u=4.0 to 42.4 m/s) to establish the database for designing the divertor of the LHD. And furthermore, we have given the transient CHF correlations against outlet and inlet subcoolings based on the effects of test tube inner diameter (d), flow velocity (u), outlet and inlet subcoolings ($\Delta T_{sub,out}$ and $\Delta T_{sub,in}$), ratio of heated length to inner diameter (L/d) and non-dimensional reduced time, ($t^*=\omega_p u/\{\sigma/g/(\rho_l-\rho_g)\}^{0.5}$) on CHF.

Outlet subcooling:

$$Bo = 0.082 D^{*-0.1}\,We^{-0.3}\left(\frac{L}{d}\right)^{-0.1} Sc^{0.7}\times\left(1+6.34\,t^{*-0.6}\right)$$

for $\Delta T_{sub,out}\geq30$ K and $u\leq13.3$ m/s (1)

Inlet subcooling:

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

for $\Delta T_{sub,in}\geq40$ K and $u\leq13.3$ m/s (2)

where C_1=0.082, C_2=0.53 and C_3=0.7 for $L/d\leq$around 40 and C_1=0.092, C_2=0.85 and C_3=0.9 for $L/d>$around 40. Most of the data for the exponentially increasing heat input (3194 points), the ramp-wise one (208 points) and the stepwise one (105 points) are within ±15 % difference of Eqs. (1) and (2) for $\Delta T_{sub,out}\geq30$ K and $\Delta T_{sub,in}\geq40$ K.

The cross-sectional view of 6 mm inner diameter HORIZONTAL test section[1)] is shown in Fig. 1. The SUS304 test tube with rough finished inner surface (RF) was used in this work. Wall thickness of the test tube, δ, was 0.5 mm. The heated length, L, of the SU304 test tube was 59.4 mm. The silver-coated 5-mm thickness copper-electrode-plates to supply heating current were soldered to the surfaces of the both ends of the test tube.

Figure 2 shows the steady-state CHFs, $q_{cr,sub,st}$, versus the outlet subcoolings, $\Delta T_{sub,out}$, for the HORIZONTAL SUS304 test tube of the inner diameter (d=6 mm), the heated length (L=59.4 mm), L/d (=9.9) and the wall thickness (δ=0.5 mm) obtained for the flow velocities, u, ranging from 4 to 13.3 m/s at the outlet pressure, P_{out}, of around 800 kPa[1)]. The CHF data for the VERTICAL SUS304 test tube of d=6 mm, L=66 mm, L/d =11 and δ=0.5 mm with the flow velocities ranging from 4.0 to 13.3 m/s are also shown in the figure for comparison. As shown in the figure, the $q_{cr,sub,st}$ for each flow velocity become higher with an increase in $\Delta T_{sub,out}$ and the increasing rate becomes lower for higher $\Delta T_{sub,out}$. The CHFs in the whole experimental range become higher with an increase in the flow velocity at a fixed $\Delta T_{sub,out}$.

The curves given by Eq. (1) for the VERTICAL SUS304 test tube are shown in Fig. 2 at each flow velocity for comparison. The CHF data for $\Delta T_{sub,out}\geq30$ K are in good agreement with the values given by the correlation. Equation (1) was derived based on the experimental data for the VERTICAL SUS304 test tube with the flow velocity ranging from 4 to 13.3 m/s. To confirm the applicability of Eq. (1) to the data for the flow velocity of 4 to 13.3 m/s, the ratios of these CHF data to the corresponding values calculated by Eq. (1) are shown versus $\Delta T_{sub,out}$ in Fig. 3. Most of the data for the HORIZONTAL test tube[1)] (69 points) and the VERTICAL one (110 points) are within ±15 % difference for 4 m/s≤u≤13.3 m/s and 29.7 K≤$\Delta T_{sub,out}$≤125.38 K.

1) Hata, K., Kai, N., Shirai, Y. and Masuzaki, S., NURETH14-098 (2011) 1-23.

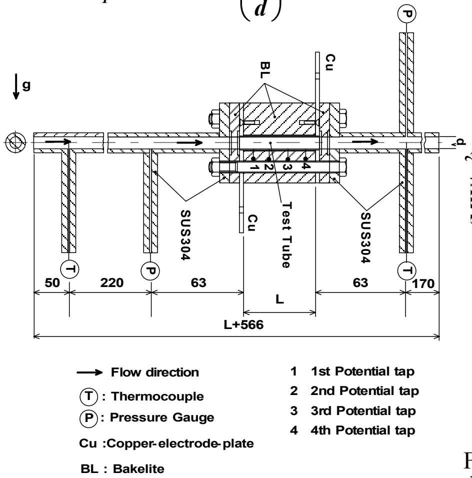

Fig. 1 Horizontal cross-sectional view of 6-mm inner diameter HORIZONTAL test section

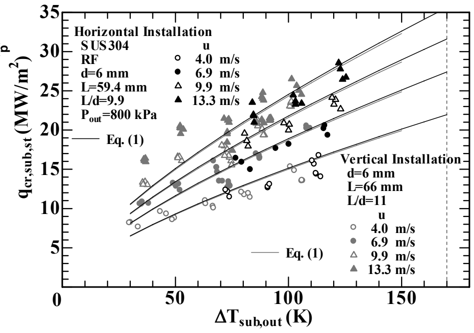

Fig. 2 $q_{cr,sub,st}$ vs. $\Delta T_{sub,out}$ for an inner diameter of 6mm with the heated length of 59.4 mm at an outlet pressure of around 800 kPa

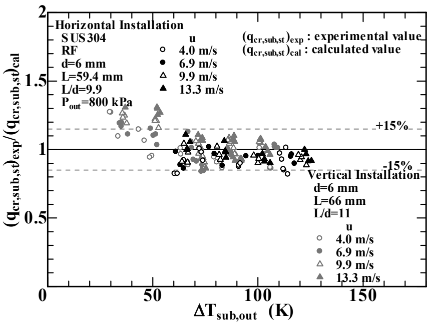

Fig. 3 Ratio of CHF data for the inner diameter of 6 mm to the values derived from the outlet CHF correlation versus $\Delta T_{sub,out}$ at outlet pressure of around 800kPa