§31. Transient Critical Heat Fluxes of Subcooled Water Flow Boiling in a SUS304-Tube Caused by a Rapid Decrease in Mass Velocity from Nucleate Boiling Regime

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Transient critical heat fluxes of subcooled water flow boiling in a SUS304-tube caused by a rapid decrease in mass velocity from nucleate boiling regime is necessary to investigate the reliability of a divertor in a nuclear fusion facility at a loss of flow accident for Fusion Reactor Safety (FRS). The nuclear fusion facility has two operation modes. One is the steady-state operation mode, and the other is the transient one. The plasma facing material in transient operation mode is exposed to a heat load three times larger or more than during steady-state operation for several seconds. The knowledge of high heat flux heat removal during various decelerations caused by the rapid decreases in velocity (flow transients) becomes especially very important to take the heat out of the plasma facing material for short pulse high heat flux test mode.

Figure 1 shows typical example of the time variations in the inlet and outlet pressures, P_{in} and P_{out}, the inlet and outlet liquid temperatures, T_{in} and T_{out}, heater inner surface temperature, T_s, heat flux, q, and inlet flow velocity, u, for the initial flow velocity, u_0=7.09 m/s, the initial heat flux, q_0=15.73 MW/m^2, which is equivalent to the CHF measured by exponentially increasing heat input ($Q_0\,exp(t/\tau)$, τ=around 8 s) at the flow velocity of 4 m/s and deceleration caused by a rapid decrease in velocity, α=-1.771 m/s^2, at initial outlet pressure, P_{out0}=801.37 kPa, initial inlet subcooling, $\Delta T_{sub,in0}$=145.83 K. The values of P_{in}, P_{out}, T_{in}, T_{out}, T_s, q and u keep almost constant until the beginning of a decrease in flow velocity. The pump input frequency was linearly reduced to 0 Hz at a deceleration time setting, t_d, of 20 seconds by the inverter function. As soon as the inlet flow velocity decreases, the P_{in} and P_{out} oscillate violently and the T_{out} has started to increase. At the elapsed time of 6.35 seconds, that is, the flow transient CHF, $q_{cr,sub}$, the heater inner surface temperature, T_s, rapidly increases, although the heat flux keeps constant to near the flow transient CHF point. The current for the heat input to the test tube was automatically cut off when the measured average temperature increased up to the preset temperature, which was several tens of Kelvin higher than corresponding flow transient CHF surface temperature. This procedure avoided actual burnout of the test tube. The heat flux, the outlet pressure, P_{out}, the flow velocity, u_{cr}, and the deceleration caused by a rapid decrease in velocity, α, at the flow transient CHF were measured 17.726 MW/m^2, 703.29 kPa, 4.56 m/s and -1.771 m/s^2 in this run [1].

The flow transient CHFs, $q_{cr,sub}$, at the initial heat flux, $q_0=(q_{cr,sub,st})_{u=4m/s}$, which is equivalent to the CHF measured by exponentially increasing heat input ($Q_0\ exp(t/\tau)$, τ=around 8 s) at the flow velocity of 4 m/s, for the decelerations caused by a rapid decrease in velocity, α, ranging from -5.444 to -0.326 m/s^2 are shown as green and orange open circle symbols with the initial flow velocities, u_0, of 6.9 and 9.9 m/s, respectively, in Fig. 2. Most of the flow transient CHF data are within -18.8 to 15.0 % differences of the values calculated from the steady-state CHF correlation against inlet subcooling for the circular test tube, Eq. (1) [1].

$$Bo_{cr} = C_1 D^{*-0.1}\, We^{-0.3} \left(\frac{L}{d}\right)^{-0.1} e^{-\frac{(L/d)}{C_2\, \mathrm{Re}_d^{0.4}}}\, Sc^{*C_3} \quad (\Delta T_{sub,in} \geq 40\ \mathrm{K}) \quad (1)$$

The ratios of flow velocity at flow transient CHF point to flow velocity calculated from Eq. (1) with initial heat flux, q_0, by a try-and-error method, $u_{cr}/u_{cr,st}$, and those of flow transient CHF, $q_{cr,sub}=q_0$, to steady-state critical heat flux calculated from Eq. (1) with the flow velocity at flow transient CHF point, $(q_{cr,sub}/q_{cr,sub,st})$, for the SUS304 circular test tube of d=6 mm and L=59.5 to 59.7 mm with inlet liquid temperatures, T_{in}, of 290.12 to 308.51 K at the initial flow velocities, u_0, of 6.9 and 9.9 m/s are shown versus the deceleration caused by a rapid decrease in velocity, α, at initial heat flux, q_0, which is equivalent to the CHF at the flow velocity of 4 m/s, $(q_{cr,sub,st})_{u=4m/s}$, in Fig. 3. The experimental data of $u_{cr}/u_{cr,st}$ and $q_{cr,sub}/q_{cr,sub,st}$ for the SUS304 test tube of d=6 mm with the rough finished inner surface can be expressed for the α ranging from -5.444 to -0.326 m/s^2 by the following correlations [1]:

$$\frac{u_{cr}}{u_{cr,st}} = -0.275\alpha + 0.794 \qquad (2)$$

$$\frac{q_{cr,sub}}{q_{cr,sub,st}} = 0.05\alpha + 1.038 \quad (\alpha < -0.75\ \mathrm{m/s^2}) \qquad (3)$$

1) Hata, K., et al., Proceedings of ICONE22 (2014) 1-12.

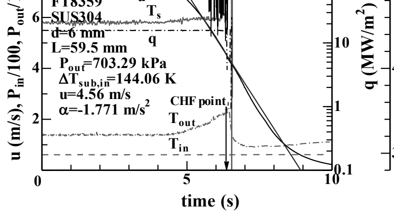

Fig. 1 Time variations in P_{in}, P_{out}, T_{in}, T_{out}, T_s, q and u for u_0=7.09 m/s, q_0=15.73 MW/m^2 and α=-1.771 m/s^2 at P_{out0}=801.37 kPa and $\Delta T_{sub,in0}$=145.83 K

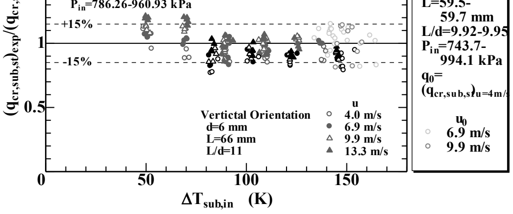

Fig. 2 Ratios of CHF data for the inner diameter of 6 mm to the values derived from the inlet CHF correlation, Eq. (1), versus $\Delta T_{sub,in}$ at inlet pressures of 743.7 to 994.1 kPa

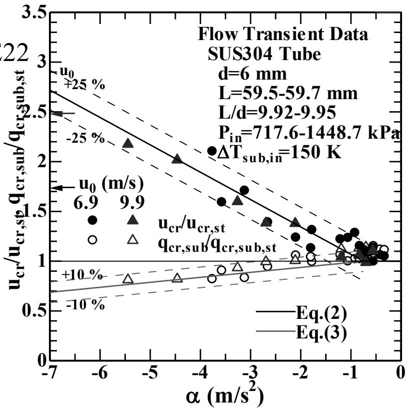

Fig. 3 Relationship between $u_{cr}/u_{cr,sub,st}$ and α and that between $q_{cr}/q_{cr,sub,st}$ and α with u_0=6.9 and 9.9 m/s at $q_0=(q_{cr,sub,st})_{u=4m/s}$ W/m^2 for P_{out}=800 kPa and T_{in}=290.12 to 308.51 K