§1. Influence of Inner Surface Roughness on Subcooled Flow Boiling Critical Heat Flux in a Short Vertical Tube

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The subcooled flow boiling CHF and the heat transfer characteristics for the flow velocities (u=4.0 to 13.3 m/s), the inlet subcoolings ($\Delta T_{sub,in}$=137.49 to 153.87 K), the inlet pressure (P_{in}=740.67 to 975.78 kPa) and the dissolved oxygen concentration (O=8.63 to 0.0288 ppm) are systematically measured by the experimental water loop installed the pressurizer. The SUS304 tubes of d=3 mm and L=66.5 mm (L/d=22.17) with the inner surfaces of rough, smooth and mirror finished (RF, SF and MF) are used [1]. The inner surface roughness (Ra) measured for each test tube was 3.18, 0.26 and 0.14 μm respectively.

Heat Transfer

The heat transfer curves on RF, SF and MF surfaces for flow velocities of 4 and 13.3 m/s are shown in Fig. 1 to see the effect of surface roughness clearly. At a fixed flow velocity, the heat flux gradually becomes higher with an increase in $\Delta T_{sat}=T_s-T_{sat}$ on the non-boiling forced convection curve derived from Nusselt correlation up to the point where the slope begins to increase with heat flux following the onset of nucleate boiling, and increases up to a value called CHF where the heater surface temperature rapidly jumps from the nucleate boiling heat transfer regime to the film boiling one. The CHF and its superheat become higher with an increase in flow velocity. The nucleate boiling curves in higher heat flux range for the flow velocity agree with each other forming a single straight line on the log-log graph. The equation of incipient boiling superheat given by Sato and Matsumura [2] is shown in the figure for comparison. The incipient boiling superheat for each flow velocity is slightly higher but almost in agreement with that predicted by the equation. The nucleate boiling curves in the higher heat flux range are almost parallel to the curve by Sato and Matsumura. Little effect of surface roughness can be seen for low and high heat flux ranges, although the measured average roughness, Ra, varied from 0.14 to 3.18 μm.

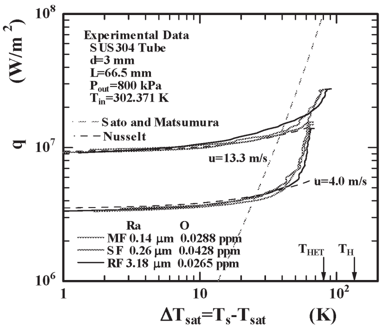

Fig. 1 Heat transfer characteristics for d=3 mm with Ra=0.14 to 3.18 μm.

Critical Heat Flux

The CHFs for the test tube with smooth finished inner surface were measured at dissolved oxygen concentrations, O, of 8.63, 0.983, 0.1004, 0.428 and 0.0413 ppm. Typical CHF data for inlet subcooling of about 145 K at the outlet pressure of around 800 kPa with the inlet flow velocities of 4 to 13.3 m/s are shown in Fig. 2. The corresponding curves obtained from the CHF correlation against inlet subcooling [3] are also shown in the figure. The CHFs for smooth inner surface for higher flow velocities seem to be lower than those for the rough. Reproducibility of the data was very good as shown in the figure.

The CHFs for the test tube with mirror finished inner surface at dissolved oxygen concentrations, O, of 5.94, 0.974, 0.0997 and 0.0288 ppm are shown in Fig. 3. The curves given by the CHF correlation against inlet subcooling are shown in figure for comparison. The CHFs for mirror finished inner surface for higher flow velocities seem to be lower than those for the smooth surface shown in Fig. 3 (further lower than those for the rough finished surface). However, the $q_{cr,sub}$ data for higher flow velocities at the lowest dissolved oxygen content are higher than those for others and seem to be slightly lower than the predicted values.

The CHFs on rough, smooth, and mirror finished inner surfaces for the lowest dissolved oxygen concentration are shown versus the surface roughness, Ra, with the flow velocity as a parameter in Fig. 4. The $q_{cr,sub}$ for each flow velocity are almost constant independently of the surface roughness. The corresponding curves for each flow velocity obtained from the CHF correlation against inlet subcooling are also shown in the figure. The $q_{cr,sub}$ are well expressed by the equation. It seems that the influence of surface roughness disappeared at the lowest dissolved oxygen concentration. The mechanism is not clear at present. Reproducibility of the data at the lowest dissolved oxygen concentration need to be further studied.

Reference

1) Hata, K., et al., Paper No. IMECE 2004-61453, (2004) 1
2) Sato, T., Matsumura, H., Bulletin of JSME **7**, (1963) 392
3) Hata, K., et al., Ann. Rep. NIFS (2003-2004) 216

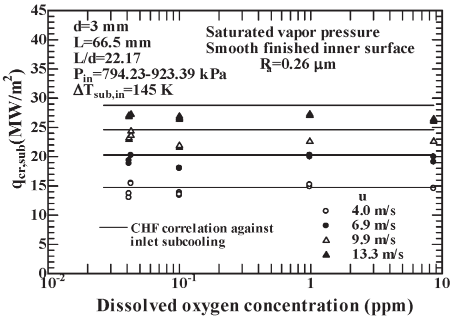

Fig. 2 The $q_{cr,sub}$ for d=3 mm with Ra=0.26 μm for O=0.0413 to 8.63 ppm.

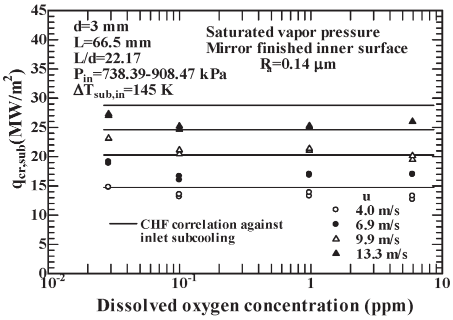

Fig. 3 The $q_{cr,sub}$ for d=3 mm with Ra=0.14 μm for O=0.0288 to 5.94 ppm.

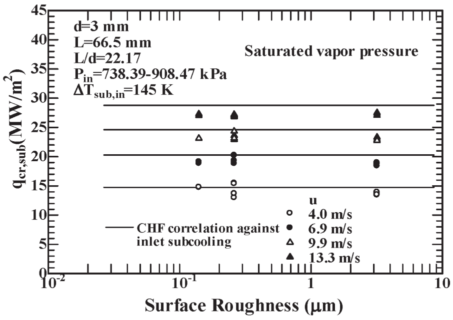

Fig. 4 The $q_{cr,sub}$ for d=3 mm with Ra=0.14 to 3.18 μm.