Film boiling heat transfer from a round wire to liquid hydrogen flowing upward in concentric annulus

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Film boiling heat transfer coefficients were measured for the heater surface superheats up to 400 K under pressures from 400 to 1100 kPa, liquid subcoold temperatures from 0 to 11 K and flow velocities up to 7 m/s. The test wire used was 1.2 mm in diameter and 120 mm in length made of WC6 (0.5 at. % C) alloy, which was located at the center of 8 mm diameter conduit made of PFRP (Fiber Reinforced Plastics). The heat transfer coefficients were higher for higher pressure, higher subcooling, and higher flow velocity. The heat transfer coefficients were about 1.6 times higher than those predicted by Shiotsu-Hama equation for forced flow film boiling in a wide channel. Discussions were made on the mechanism of difference between them.

EXPERIMENTAL APPARATUS

Introduction

Knowledge of film boiling heat transfer from a heated wire to forced flow of liquid hydrogen in a narrow gap is important for conductor design and quench analysis of superconducting magnets cooled by liquid hydrogen. However, there have been few experimental data as far as we know. Recently, we have performed a series of experimental study for liquid hydrogen cooling. Experimental system without using a pump was developed. Steady-state and transient boiling heat transfer (in a pool) and forced flow boiling heat transfer and its OEM heat flux for wide range of pressures below the critical one were reported. The purpose of this study is twofold. First is to obtain the experimental data of forced convective heat transfer from a round wire to liquid hydrogen flowing upward in concentric annulus with a narrow gap. Second is to clarify whether the experimental data can be described by conventional correlation.

RESULTS AND DISCUSSION

Typical Heat Transfer Processes

Fig. 9 Film boiling heat transfer coefficients for saturated condition at P=400 kPa.

Fig. 10 Film boiling heat transfer coefficients at wall superheat of 200 K versus flow velocity.

Comparison with Conventional Correlation

Shiotsu and Hama studied the saturated and subcooled film boiling heat transfer from a vertical cylinder in subcooled condition. Recently, we have performed a series of experimental study for the pressure of 1100 kPa and liquid subcooling of 11 K for instance, the film boiling heat transfer coefficients for velocities are about 70% higher than those for the pressure of 400 kPa.

CONCLUSIONS

Film boiling heat transfer coefficients are higher for higher pressure, flow velocity and subcooling. Film boiling heat transfer coefficients are about 1.7 times higher than those predicted by Shiotsu and Hama for subcooled condition and 1100 kPa in the present study. Vidap film layer around the wire heater may be made thinner by a very narrow gap of 3.4 m in this study. Modification of the equation to include the effect of gap length is a future problem and now in progress.

ACKNOWLEDGMENTS

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Abstract

Film boiling heat transfer coefficients were measured for the heater surface superheats up to 400 K under pressures from 400 to 1100 kPa, liquid subcooling from 0 to 11 K and flow velocities up to 7 m/s. The test wire used was 1.2 mm in diameter and 120 mm in length made of WC6 (0.5 at. % C) alloy, which was located at the center of 8 mm diameter conduit made of PFRP (Fiber Reinforced Plastics). The heat transfer coefficients were higher for higher pressure, higher subcooling, and higher flow velocity. The heat transfer coefficients were about 1.6 times higher than those predicted by Shiotsu-Hama equation for forced flow film boiling in a wide channel. Discussions were made on the mechanism of difference between them.

EXPERIMENTAL APPARATUS

Test heater: PdCu wire
- Diameter: 1.2 mm
- Length: 120 mm
- Pressure: 400 kPa, saturated condition, subcooling 5 K
- 700 kPa, saturated condition, subcooling 0 K
- 1100 kPa, saturated condition, subcooling 11 K

- The heat flux distribution was measured by using a direct current source (max. 400 A at a power level of 4.8 kW).
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- Surface temperature of the wire was calculated by solving the conduction equation in a radial direction of the heater using the measured average temperature and the heat flux.

Non-boiling heat transfer coefficient

\[ \frac{1}{h_{\text{non}}} = \frac{1}{h_{\text{sat}}} + \frac{1}{h_{\text{sub}}} \]

Film boiling heat transfer coefficients

\[ h_{\text{film}} = h_{\text{sat}} + k \frac{q}{T_{\text{sat}}} \]

Shiotsu and Hama equation

\[ h_{\text{Shiotsu-Hama}} = \frac{1}{\frac{1}{h_{\text{sat}}} + \frac{1}{h_{\text{sub}}}} \]

Dittus-Boelter correlation

\[ h = \frac{\nu \cdot \mu}{\delta} \left( \frac{k}{\nu} \right)^{0.5} \cdot \left( \frac{k}{\nu} \right)^{0.1} \]

With the increase of pressure and subcooling, film boiling heat transfer coefficients increase significantly. At the pressure of 1100 kPa and liquid subcooling of 11 K, the film boiling heat transfer coefficients for velocities are about 70% higher than those for the pressure of 400 kPa.

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