§6. Critical Heat Flux on a Flat Plate at the Middle of a Duct Containing Pressurized He II

Tatsumoto, H. (High Energy Accelerator Research Organization),
Hata, K., Hama, K., Shirai, Y., Shiotsu, M.
(Kyoto University)

Superfluid liquid helium (He II) is expected as a coolant for large scale superconducting magnets for nuclear fusion facilities and accelerators because of its outstanding heat transport characteristics. The cooling of superconducting magnets is carried out through the network of narrow channels formed between conductors equipped with spacers and electric insulating materials. Therefore, it is important for the cooling design of the magnets to understand the steady-state and transient heat transport mechanism of He II in the channels.

In the present study, the experimental data of CHF are obtained in parallel ducts having various gap lengths filled with pressurized He II. Effects of the gap length on the CHF are clarified. A correlation of CHF that can describe the experimental data is derived.

Fig.1 shows schematic view of a parallel duct used in this experiment. The duct was made of FRP (Fiber Reinforced Plastic) plate with the thickness of 4.0 mm. A flat plate heater, which is made of Manganin and is 10 mm long, 40 mm wide and 0.1 mm thick, is located at the middle wall of the duct with the length of 100 mm. The inner width of the duct is 40 mm, which is equal to the width of the flat plate heater. Six ducts with the gaps, d, of 2.0, 3.0, 5.0, 10.0, 15.0, and 20.0 mm were used. Steady-state critical heat fluxes on the same sized flat plates located at middle of the parallel ducts were measured at bath temperatures of 1.8, 1.9, 2.0 and 2.1 K in subcooled He II at atmospheric pressure.

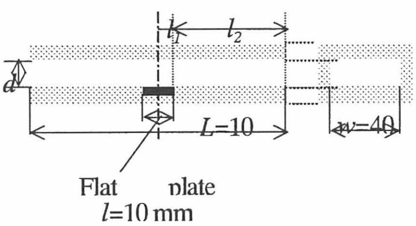

Fig. 1 Test heater in the parallel duct

Fig.2 shows the data of CHF versus bath temperature with gap length as a parameter. With increase in the gap to around 5 mm, the data of CHF increases in proportion to the gap length. For d >5 mm, the increasing rate rapidly decreases and then the values of CHF seem to approach a certain value.

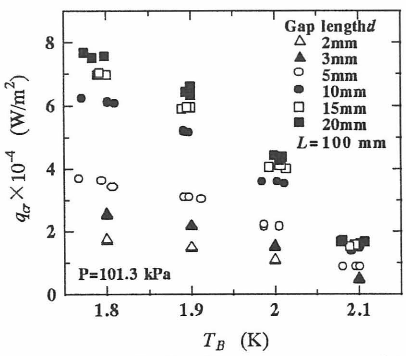

Fig. 2 CHF versus bulk liquid temperature with duct gap as a parameter.

The following correlation of CHF was given based on a simple model. Details are shown in [1]. If it is supposed that the heat from the heater immediately expands to full cross-section of the duct and uniformly transported to both ends, the CHF will be given as,

$$q_{cr} = \left(\alpha \int_{T_B}^{T_\lambda} f(T)^{-1} dT\right)^{1/3} \tag{1}$$

$$\alpha = \left\{ \frac{l_1^4}{4d^3} + \frac{A_{l/2}^{\ 3}}{A_{ch}^{\ 3}} l_2 + \frac{A_{l/2}^{\ 3}}{A_{ch}^{\ 3}} \frac{dw}{0.78(d+w)} \right\}^{-1} \tag{2}$$

On the other hand, the CHFs for fully large duct gap would correspond to those for an infinitely wide flat plate with the length of $l(=2l_1)$ under the corresponding conditions, because the heat flow along the width direction of the test heater is prevented by the adiabatic wall. The CHF in this case can be described as,

$$q_{cr} = \left(\beta \int_{T_B}^{T_\lambda} f(T)^{-1} dT\right)^{1/3} \tag{3}$$

$$\beta = 4 \times 0.58^3 / l \tag{4}$$

The values of α and β are dependent only on the geometry of the heater and the duct. It seems that the correlation of CHF for the parallel duct would be also expressed in terms of geometry-dependent factor γ, which may be expressed as the following approximate form by using α and β.

$$q_{cr} = \left(\gamma \int_{T_B}^{T_\lambda} f(T)^{-1} dT\right)^{1/3} \tag{5}$$

$$\frac{1}{\gamma} = \left\{ \left(\frac{1}{\alpha}\right)^{\varepsilon} + \left(\frac{1}{\beta}\right)^{\varepsilon} \right\}^{1/\varepsilon} \tag{6}$$

Fig.3 shows relationship between the geometric factor, γ, and gap length, d. The values of γ are obtained from the experimental data of CHF and Eq. (5). The values of α and β are also shown in the figure for comparison. It is found from the figure that the values of γ are independent of bath temperature. For d < 5 mm, the values of γ agree with those by Eq. (2). With further increase in d ($A_{ch}/A_{l/2}$>1), the data of γ gradually approaches a constant value (β=78.0). Then for d=20 mm the data almost agree with those for infinity wide flat plate. The exponent in Eq.(6), ε, was determined to be 1.0 based on the experimental data. The values of γ with ε =1.0 are also shown in the figure. The correlation can describe the experimental data of CHF in the parallel duct within 13 % errors.

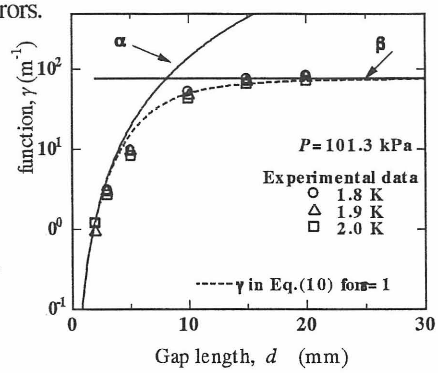

Fig. 3 Geometry Function γ vs. Gap Length

References

1) H. TatsumotoK. Hata, K. Hama Y. Shirai and M. Shiotsu, to be presented at ICEC19, Grenoble France, 22-26 July, 2002.