§3. Critical Heat Fluxes on a Flat Plate Attached to One End of a Rectangular Duct Containing Pressurized He II

Tatsumoto, H., Shirai, Y., Shiotsu, M. (Dept. of Energy Science & Technology, Kyoto University), Hata, K., Hama, K. (Institute of Advanced Energy, Kyoto University)

The purpose of this study is twofold. The first is to obtain the experimental data of steady-state heat transfer and critical heat flux (CHF) on rectangular ducts with a sudden change in cross-sectional area in pressurized He II for wide ranges of experimental conditions. The second is to present a CHF correlation which can describe the experimental data.

Six FRP ducts of the same lengths L, 100 mm with different cross-sectional area were used. One side of the flat plate heater made of Manganin was attached to the end plate of each FRP duct and the other end of the duct was opened to a pool of pressurized He II. All flat plate heaters were 10 mm in width, 40 mm in length and 0.1 mm in thickness. The widths of the cross-sectional duct area, w', were 10, 16.1, 19.6, 22.1, 26.3 and 35.0 mm, respectively. Therefore, the ratio of the cross-sectional area A_d to the heater area A_h, A_d/A_h, of six duct heaters was varied from 1.0 to 3.5. The CHFs of steady-state heat transfer were measured on six ducts with the various size of A_d/A_h in subcooled He II at atmospheric pressure for the bulk liquid temperatures ranging from 1.8 to 2.1 K.

Figure 1 shows the relationship between critical heat flux, q_{cr}, and bulk liquid temperature, T_B, at atmospheric pressure with A_d/A_h as a parameter. The CHF increases with the decrease in bulk liquid temperature, T_B. As A_d/A_h increases, the values of CHF for a fixed T_B tend to increase and approach a constant value: CHF on the infinitely long flat plate immersed in a pool of pressurized He II for the corresponding conditions.

The CHF correlation for a duct with a sudden change in cross-sectional duct area was derived from a CHF model on a flat plate and on a Gorter-Mellink duct. First, if the heat flow rapidly expands from the flat plate attached to the end of the FRP duct to the duct containing He II and is uniform in the duct, the CHF q_{cr} can be expressed by using Gorter-Mellink equation.

$$q_{cr}=\left(\frac{A_d^{\,3}}{A_h^{\,3}}\frac{1}{L}\int_{T_B}^{T_\lambda}f(T)^{-1}dT\right)^{1/3}=\left(M\int_{T_B}^{T_\lambda}f(T)^{-1}dT\right)^{1/3} \qquad (1)$$

where $M=A_d^{\,3}/(A_h^{\,3}L)$.

On the other hand, it is assumed from the experimental results that the values of the CHF for the duct with large A_d/A_h approaches the value for the flat plate with width, w, and infinitely long length under the corresponding conditions. Therefore the CHF for the infinitely long flat plate can be described by using a CHF correlation on a flat plate [1].

$$q_{cr}=\left(\frac{4\times0.58^3}{w}\int_{T_B}^{T_\lambda}f(T)^{-1}dT\right)^{1/3}=\left(N\int_{T_B}^{T_\lambda}f(T)^{-1}dT\right)^{1/3} \qquad (2)$$

where $N=0.78/w$. It can be seen from Eq. (1) and Eq. (2) that the value of the coefficients, M and N, are dependent only on the heater geometry. Therefore it is expected that the CHF for the duct with a sudden change in cross sectional area can be expressed in terms of geometry-dependent coefficient k.

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

The coefficient k may be expressed as the approximate form by using the geometry coefficients, M and N.

$$\frac{1}{k}=\left\{\left(\frac{1}{M}\right)^n+\left(\frac{1}{N}\right)^n\right\}^{1/n} \qquad (4)$$

where the exponent n will be determined by the experimental data.

Figure 2 shows the relationship between the values of the coefficient k in Eq. (3) obtained from the experimental data and the value of A_d/A_h with bulk liquid temperature as a parameter. The data of the coefficient for each bulk liquid temperature were obtained by substituting the measured values of CHF and integrated values of $f(T)^{-1}$ under each condition into Eq. (3). The values predicted by N in Eq.(2) and M in Eq.(1) are expressed in this figure. The experimental data become lower than the values predicted by Eq. (1) with increasing A_d/A_h and approach the constant value given by Eq. (2). It is assumed that the heat flow for the duct with a sudden change in cross-sectional area would not rapidly expand from the flat plate heater to the duct unlike Photenhauer's treatment [2]. The exponent n in Eq. (4) was determined to be 1.5 based on the experimental data. The values of the coefficient predicted by Eq. (4) with n=1.5 were drawn as a broken line in the figure. It was confirmed that the CHF correlation can describe the data of the coefficient within 20 % difference.

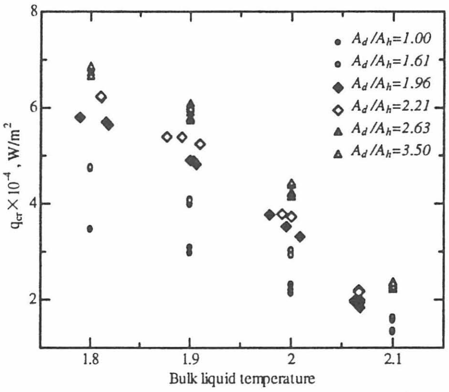

Fig.1 Relationship between critical heat flux and bulk liquid temperature

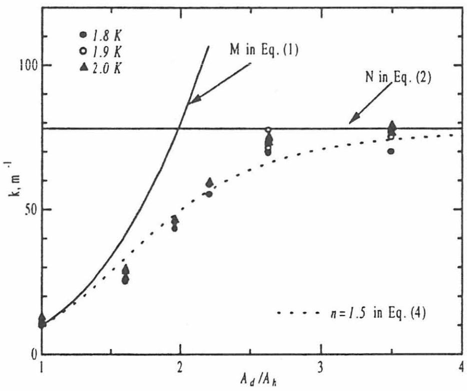

Fig.2 Relationship between coefficient and ratio of cross sectional duct area to heated surface area

References

1. H. Tatsumoto, K. Hata, K. Hama Y. Shirai and M. Shiotsu, "Proc. of 17th International Cryogenic Engineering Conference", IPC Science and Technology Press, Guildford (1998), 683
2. J.M. Pfotenhauer, *Cryogenics*. **32**(1992)466