§19. Critical Heat Flux on a Flat Plate in Subcooled He II at Atmospheric Pressure

Shiotsu, M., Hata, K., Takeuchi, Y., Hama, K.
(Kyoto University)

Critical heat flux q_{st} on a flat plate in subcooled He II was measured for bulk liquid temperatures ranging from 1.9 to 2.1 K at atmospheric pressure. The flat plate was made of Manganin, one side insulated, 10.3 mm in width, 40 mm in length and 0.1 mm in thickness.

Figure 1 shows the data of q_{st} versus bulk liquid temperature, T_B. As shown in the figure, the value of q_{st} significantly increases with the decrease in T_B from near λ temperature. Experimental data of q_{st} by Kobayashi and Yasukochi [1] on a 5 mm × 25 mm flat plate are also shown in the figure for comparison. Their data are similar in the trend of dependence on T_B: they are about 12 % higher than our data at each T_B. Kobayashi and Yasukochi [1] measured the q_{st} on flat plates with the widths ranging from 0.6 to 9 mm. They reported that q_{st} were inversely dependent on the width. However, no theoretical correlation of q_{st} on a flat plate has been reported until now as far as the authors know.

On the other hand, the authors[2] have already presented the following correlation for the q_{st} on a horizontal test wire in subcooled He II (for $T_{sat}(P_L) > T_\lambda$) by slightly modifying the solution obtained from the Gorter-Mellink equations.

$$q_{st} = K[\frac{2}{r_0}\int_{T_B}^{T_\lambda}\frac{1}{f(T)}dT]^{\frac{1}{3}} \qquad (1)$$

where
$f(T)^{-1} = g(T_\lambda)[T_R^{6.8}(1-T_R^{6.8})]^3$,
$g(T_\lambda) = \rho^2 s_\lambda^4 T_\lambda^3/A_\lambda$, $\quad T_R = T/T_\lambda$,
$s_\lambda = 1559$ J/(kg K) , $\quad A_\lambda \simeq 1150$ m s/kg .

The modification coefficient K, in Eq.(1) was determined to be 0.58 by using the experimental data of q_{st} for various diameter wires. It was confirmed that the correlation can describe well the data of q_{st} for wire diameters ranging from 0.08 to 0.7 mm[3].

This correlation was modified as follows to describe the q_{st} for a flat plate of width w and length L. Suppose a box of the dimension $\Delta x \times w \times L$ covering on the plate, and that the heat flux is uniform on the surface of the box with the total surface area of $Lw + 2(L+w)\Delta x$. The heat flux on the box surface is $[X/(X+\Delta x)]q_0$ where $X = Lw/\{2(L+w)\}$ and q_0 is the heat flux on the surface of the flat plate. On the other hand, the heat flux for a cylinder at Δr from the cylinder surface is $[r_0/(r_0+\Delta r)]q_0$. It can be understood by comparing these expressions for a flat plate and a cylinder, the term of $X = Lw/\{2(L+w)\}$ in the former expression corresponds to the term of radius in the latter. By inserting X instead of r_0 in Eq. (1), the equation of q_{st} for a plate is given by,

$$q_{st} = K[\frac{2}{Lw/\{2(L+w)\}}\int_{T_B}^{T_\lambda}\frac{1}{f(T)}dT]^{\frac{1}{3}} \qquad (2)$$

The values derived from Eq. (2) are compared with the corresponding experimental data in Fig. 1. As shown in the figure, these data are within 10 % of the predicted values: the data of this work are slightly higher than, and those by Kobayashi et al. are slightly lower than the predicted values. Figure 2 shows comparison of the q_{st} predicted by Eq.(2) with the data of Kobayashi and Yasukochi [1] for 2 cm-long flat plates with widths ranging from 0.7 to 9 mm. The experimental data are within ± 10 % of the predicted values.

References
[1] Kobayashi, H. and Yasukochi, K., Proc. of 8th Internat. Cryogenic Eng. Conf., (IPC Science and Technology Press 1980) 171.
[2] Shiotsu, M. et al., Advances in Cryogenic Engineering, 37A, (Plenum 1992), 25-46.
[3] Shiotsu, M. et al., Advances in Cryogenic Engineering, 41, (Plenum 1996) 241.

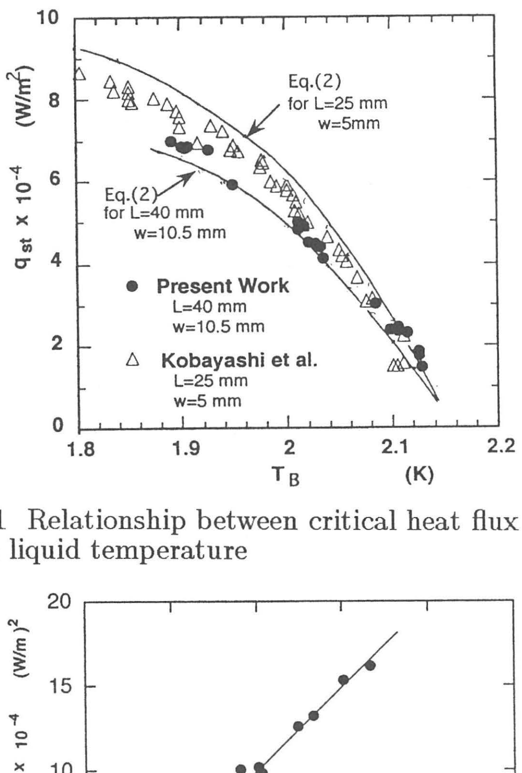

Fig.1 Relationship between critical heat flux and bulk liquid temperature

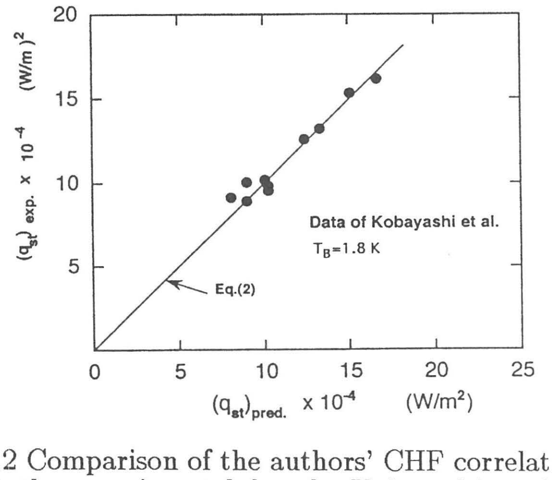

Fig.2 Comparison of the authors' CHF correlation with the experimental data by Kobayashi et al.