§7. Critical Heat Flux on a Flat Plate in Subcooled Liquid Helium

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Knowledge of the critical heat flux (CHF) in a pool of liquid helium is important as a database for the design of superconducting magnets cooled by liquid helium. There have been many CHF data on various diameter wires in saturated He I. The systematic data of CHF on flat plates under wide range of pressures are only those by Lyon [1] as far as we know. Shiotsu et al. [2] measured the CHFs on horizontal cylinders with the diameters ranging from 0.3 to 1.2 mm under saturated conditions between λ and critical temperatures. They presented a correlation that can describe not only the CHF data on horizontal cylinders for wide ranges of pressure and diameter but also those on horizontal surfaces facing upward in various kinds of liquids under pressures up to the critical ones.

On the other hand, there have been very few experimental data on the CHFs in subcooled liquid helium. Ibrahim et al. [3] and Sakurai et al. [4] measured the CHFs on a horizontal circular flat plate and on horizontal cylinders, respectively, for several subcoolings. However, little is known on the effect of subcooling and inclination of a flat plate upon CHF for liquid temperatures down to below λ temperature.

In this work, the CHFs were measured for the one-side insulated flat plates for bulk liquid temperatures from saturated ones down to 2.0 K, that is well below the λ temperature, at pressures of 101 and 130 kPa. The test plates were made of Manganin, 10 mm in width and 40 mm in length and 0.1 mm in thickness. They were heated by direct current. The temperature of the test plate was measured by resistance thermometry using the test heater as a thermometer. Effect of inclination of the test plate was systematically studied from the horizontal one facing upward ($\theta = 0$) to that facing downward ($\theta = \pi$).

Figure 1 shows the critical heat flux q_{cr} versus bulk liquid temperature T_b with the inclination angle θ as a parameter. Solid symbols show the results for the atmospheric pressure and open symbols show those for 130 kPa. As shown in the figure, the values of q_{cr} are significantly dependent on θ. They become lower with the increase in θ at a constant T_b. The decreasing rate become especially higher for the θ larger than $\pi/2$. The CHF increases with the decrease of bulk liquid temperature and becomes significantly higher for the T_b lower than lambda temperature. It should be noted that the effect of inclination disappears in the superfluid region.

A correlation of CHF in He I including the effects of subcooling and inclination was given based on the experimental data

$$q_{cr,sub}/L\rho_v = 0.17[\{\rho_l/(\rho_l+\rho_v)\}^{1.5}/\{1+0.01\exp\{(2-0.33S_c)\theta\}\}]$$
$$\times[g\sigma(\rho_l-\rho_v)/\rho_v^2]^{1/4}[1+0.065(\rho_l/\rho_v)^{0.8}S_c] \quad (1)$$

where $0 \le \theta \le \pi$, $S_c = c_{pl}\Delta T_{sub}/L$

The curves given by Eq. (1) for the pressures of 101 and 130 kPa are also shown in the figure. The experimental data for the pressures are described by the equation within 15 % difference .

References 1) D.N. Lyon, Advances in Cryogenic Engineering, Vol.10, pp.371-379 (1965). 2) M. Shiotsu et al., Cryogenics, Vol.29, pp.593-596 (1989). 3)Ibrahim, E.A.et al., Advances in Cryogenic Engineering, Vol.23, 333 (1978). 4)Sakurai, A., Shiotsu, M. and Hata, K., Advances in Cryogenic Engineering, Vol.35, 377-385 (1990).

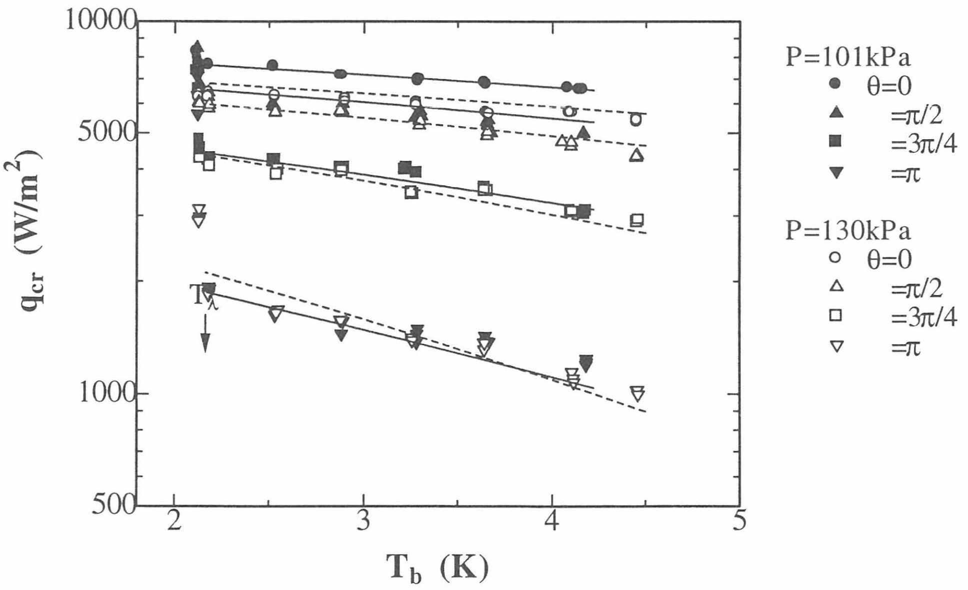

Fig.1 Relationship between critical heat flux and bulk liquiud temprature