§22. Effect of Test Heater Diameter on Critical Heat Flux in He II

Shiotsu, M., Hata, K., Takeuchi, Y., Hama, K.
(Inst. of Atomic Energy, Kyoto Univ.)

Superfluid liquid helium (He II), especially that under a subcooled condition at atmospheric pressure, is expected as a coolant for large scale superconducting magnets because of its excellent cooling properties. Knowledge of critical heat flux on a solid surface in He II for saturated and subcooled conditions is necessary as a database for design of a He II cooled large scale superconducting magnet.

Critical heat fluxes on single horizontal test wires with diameters of 0.08, 0.2, 0.3, 0.5, 0.7 and 1.2 mm in a pool of He II were measured for liquid temperatures ranging from 1.80 to 2.15 K at pressures from each saturated to atmospheric. Critical heat flux, q_{st}, for a test wire under a saturated condition becomes higher for higher liquid head above the wire. The q_{st} value for a fixed liquid head increases with decreasing bulk liquid temperature, T_b, from λ temperature (He II-He I transition temperature) and has a maximum value at around $T_b = 2$ K and gradually decreases with further decreasing T_b. The q_{st} value under a subcooled condition at a pressure higher than the λ pressure becomes higher with decreasing T_b. The q_{st} value for a fixed T_b is lower for larger wire diameter.

Following CHF correlation on a horizontal wire in saturated and subcooled He II was already presented by the authors[1] slightly modifying the solution of the Gorter-Mellink equations. This correlation was based upon the assumption that the critical heat flux was determined by the condition that liquid in the vicinity of the wire, which was initially under a subcooled condition due to the pressure $P_L (= P_g + \rho g H)$ at the wire surface, had reached the saturation temperature, $T_{sat}(P_L)$, or the λ temperature, T_λ.

$$q_{st} = K[\frac{2}{r}\int_{T_b}^{T_{sat}(P_L)} \frac{1}{f(T)} dT]^{\frac{1}{3}} \quad \text{for } T_{sat}(P_L) \le T_\lambda \qquad (1)$$

$$q_{st} = K[\frac{2}{r}\int_{T_b}^{T_\lambda} \frac{1}{f(T)} dT]^{\frac{1}{3}} \quad \text{for } T_{sat}(P_L) > T_\lambda \qquad (2)$$

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

The modification coefficient K, in Eqs.(1) and (2) was fitted to be 0.58. The exponent of 6.8 in the equation of $f(T)^{-1}$ was changed from the original value of 5.7 to agree better with the experimental data of q_{st}; the bulk liquid temperature at which the maximum of $f(T)^{-1}$ occurs was moved from 1.923 K to 1.96 K with this modification.

All of the q_{st} data on a 0.08 mm diameter wire for T_b ranging from 1.80 to 2.1 K and for system pressures ranging from the saturation value for each T_b to atmospheric, namely for various subcoolings at the level of the horizontal test wire axis due to liquid head and system pressure, are well described by the theoretical equations, (1) and (2).

Figure 1 shows the q_{st} data at atmospheric pressure versus test wire diameter with T_b as a parameter. The theoretical q_{st} versus wire diameter curve for each bulk liquid temperature predicted by Eq.(2), which is a straight line with the gradient of -1/3, is also shown in the figure for comparison. The data for $T_b = 2.1$ K on each diameter wire, and the data for $T_b = 1.85$, 1.90 and 2.0 K on 0.08, 0.2 and 0.5 mm diameter wires are all in good agreement with the corresponding theoretical curves, though the data for $T_b = 2.15$ K are somewhat higher than the predicted values.

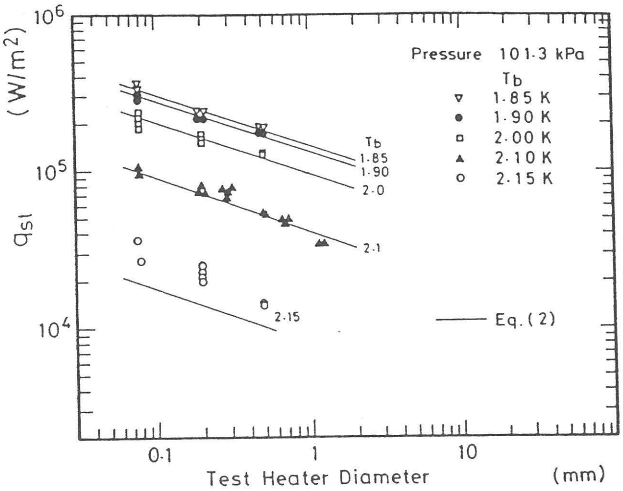

Fig. 1. q_{st} at atmospheric pressure for various test wire diameters compared with the authors' equation.

References
1)Sakurai, A., Shiotsu, M., and Hata, K., Transient Heat Transfer for Large Stepwise Heat Inputs to a Horizontal Wire in Saturated He II, Advances in Cryogenic Engineering, Vol.37A, pp.25-35, (Plenum 1991).