§2. Transient Heat Transfer Produced by a Stepwise Heat Input to a Flat Plate on One End of a Rectangular Duct Containing Pressurized He II

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The purpose of this study is twofold. First is to obtain the experimental data of transient heat transfer produced by large stepwise heat inputs to a flat plate pasted on one end of a rectangular duct containing subcooled He II. Second is to clarify the effect of the ratio of the cross sectional duct area to the heater area, A_d/A_h, on the lifetime of quasi-steady state governed by Kapitza conductance and present a correlation of lifetime.

Four test heater plates made of Manganin with the same dimensions of 10 mm in width, 40 mm in length and 0.1 mm in thickness were used. Three of them were located at one end of rectangular ducts made of 4 mm thick fiber reinforced plastic (FRP) with the cross sections of 10 ×40 mm^2, 16.3×40 mm^2, and 20×40 mm^2, and all 100 mm in length. One side of each test plate was thermally insulated by pasting it on an inner side of a FRP end-plate and the other end of the duct was opened to a pool of pressurized He II.

Transient heat transfer coefficients for stepwise heat inputs with the heights larger than the values corresponding to the steady-state critical heat flux, q_{st}, were measured for the bulk liquid temperatures of 1.8, 1.9, 2.0 and 2.1 K at atmospheric pressure. Initially, the heat input rapidly increases in time and then it takes a constant value, Q_s, after $t = t_A$. The surface temperature difference and the heat flux remain constant at ΔT_s and q_s, respectively, for a certain duration ($t_B - t_A$), then they begin to increase and decrease, respectively, at $t = t_B$. The duration $t_L = t_B - t_A$ is defined as the lifetime of the quasi-steady-state heat flux q_s.

For the transient heat transfer in a He II channel with $A_d/A_h = 1$ due to a sudden addition of the heat flux q at t=0 at one end, the following theoretical solution was given based on the two fluid model.

$$\Delta t^* = a^{-4}\overline{\rho c}\, f(T)^{-1}(T_\lambda - T_B)^2 q^{-4} \quad (1)$$

Where Δt^* is the time to film boiling, a is the numerical coefficient of order unity, and the properties, ρ, $\bar{c}$, and $f(T)^{-1}$ are those averaged over from T_B to T_λ.

Figure 1 shows the $\log(t_L)$ versus $\log(q_s)$ plot of the experimental data for the ducts with $A_d/A_h = 1.0$, at bulk liquid temperatures of 1.8 K. Data of Van Sciver[3] for 2-m-long tube are also shown. As shown in these figures, our data for t_L longer than around 1.2 ms and their data seem to be on a single line with the gradient of −4 on this graph. However, the value of t_L becomes longer than that given by the line for further increase of q_s (t_L <1.2 ms). The values of t_L on a flat plate in a pool of He II are also shown in the figure. They agree well with those for the duct with $A_d/A_h = 1.0$ throughout the experimental range including the high q_s range (t_L <1.2 ms), although the q_{st} is higher than that for the test plate with a duct. It is from this fact that the two or three dimensional heat flow from a flat plate in a pool of He II occurs only near the q_{st}, and the transient heat transfer can be regarded as one-dimensional except this range near the q_{st}.

These data of t_L for the duct with $A_d/A_h = 1.0$ and for a test plate in a pool of He II are well described by the following equations already derived by the authors[10] based on Eq. (3) and the experimental data for the test plates with various widths in a pool of pressurized He II.

$$t_L = a^{-4}\overline{\rho c}\, f(T)^{-1}(T_\lambda - T_B)^2 q_s^{-4} \quad \text{for } t_L \geq 1.2\text{ ms} \quad (2)$$

$$t_L = \overline{\rho c}\, B(T)^{-1}(T_\lambda - T_B)^2 q_s^{-2} \quad \text{for } t_L < 1.2\text{ ms} \quad (3)$$

where $a = 1.16$, $B(T)^{-1} = s^2 T / A^*$, and $A^* = 8000$ m^3/(kg s).

Figure 2 shows the $\log(t_L)$ versus $\log(q_s)$ plot of the data on the flat plates in the ducts with the ratio of A_d/A_h higher than unity for the bulk liquid temperatures of 1.8 K. The curves given by Eqs. (2) and (3) are also shown in the figure for comparison. As shown in the figure, the data of t_L agree well with the curves for the q_s higher than a certain value. With the decrease of q_s from the value, they become longer than those given by Eq. (2) more significantly for the ducts with higher values of A_d/A_h. The data of t_L for the test plate without a duct are also shown in the figure. It should be noted that the threshold value of q_s (lower limit of q_s) for the one-dimensional heat flow regime is almost the same for the flat plates with and without ducts. For the q_s lower than the value, two- or three-dimensional heat flow expansion would occur most significantly for the bare test plate in a pool of He II, less significantly for the ducts with smaller values of A_d/A_h.

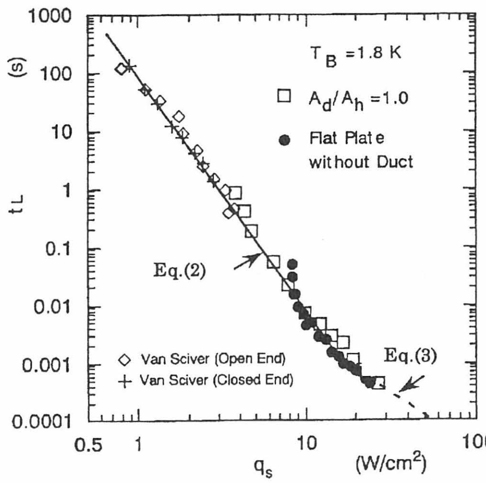

Fig.1 The $\log(t_L)$ versus $\log(q_s)$ plot of the experimental data for the ducts with $A_d/A_h = 1.0$ and for a test plate without duct for bulk liquid temperature of 1.8 K.

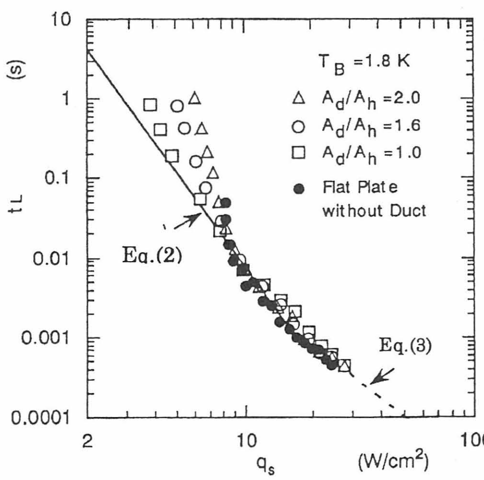

Fig.2 The $\log(t_L)$ versus $\log(q_s)$ plot of the data on the flat plates in the ducts with the ratio of A_d/A_h higher than unity for the bulk liquid temperatures of 1.8