§3. Numerical Analysis of Transient Heat Transfer from a Flat Plate at One End of a Rectangular Duct in Pressurized He II

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The authors have developed a computer code of two-dimensional heat transfer in He II named SUPER-2D based on the two fluid model. They reported that the solutions of steady-state CHFs on a flat plate in the ducts with the two-dimensional expansion agreed well with the experimental data measured by Tatsumoto et. al. [1]. The purpose of this work is to perform the numerical analysis of the two- dimensional transient heat transfer on the flat plate in the ducts with the two-dimensional expansion by using the SUPER-2D code.

The heated plate with the width of w, 10 mm and length l, 40 mm is attached to one end of a duct with the length, L, of 100 mm. The other end of the duct is opened to a pool of He II. The inner cross sections of the ducts have the lengths l' equal to l and widths, w', of 10.0 mm, 16.0 mm, and 20.0 mm. Therefore, the ratio of the cross-sectional duct area to the heated surface area, A_d/A_h, is varied from 1.0 to 2.0.

Two dimensional numerical analysis was performed for the transient heat transport due to step heat inputs in the above mentioned three ducts in pressurized He II at 101.3 kPa by using the computer code, SUPER-2D. The finite difference method with the staggered grids system was used. The dimensions of a grid were 0.25 mm by 0.25 mm. Time integration was performed explicitly with a time step of 4.0×10^{-7} sec. The heat flux applied to the heater was kept constant until the temperature adjacent to the heater reaches the λ temperature.

The calculated liquid temperature adjacent to the center of the heated surface in the duct is typically as follows. For the step heat flux lower than steady-state CHF, the temperature increases rapidly from the application of step heat flux at $t = 0$ sec, and then approaches a constant value. For the step heat flux higher than the value, the temperature first increases rapidly, then increases with lower speed, and again increases rapidly up to the λ temperature . Time delay from the application of the step heat flux to the occurrence of the λ transition exists when the step heat input is higher than the steady-state CHF. The time delay corresponds to the lifetime, t_L, of the quasi-steady-state.in He II reported by Shiotsu et al. [2].

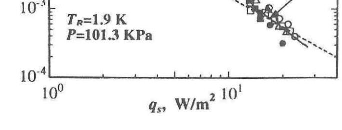
Figures 1 shows relations between lifetime and step heat flux with A_d/A_h as a parameter on log-log graph. The solutions of lifetime were expressed in terms of solid symbols. The data of lifetime measured by Shiotsu et. al. [3] for the same sized ducts at corresponding conditions were expressed by open symbols for comparison. Shiotsu et. al. [4] have presented the following correlation of lifetime for one-dimensional heat flow systems.

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

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

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

The values given by Eqs. (1) and (2) were also shown in these figures as two straight lines for comparison. With increase in the step heat flux from each CHF, the lifetime rapidly decreases and approaches the line with the gradient of –4 predicted by Eq. (1). The decreasing rate of the lifetime becomes smaller with decrease in A_d/A_h. The lifetime for the ducts with any values of A_d/A_h agrees with the line given by Eq.(1) for the step heat flux higher than a certain value. Effect of two-dimensional heat expansion can only be observed for the step heat fluxes lower than the value. With the increase in the heat flux from that corresponding to $t_L \cong 1.2ms$, the experimental data decrease along the line with the gradient of –2 given by Eq.(2). However, as the step heat flux increases, the solutions of the lifetime for the higher range of step heat flux decrease not along the line given by Eq.(2) but along the extrapolated line of Eq. (1). The solutions of the lifetime given by using SUPER-2D are in good agreement with the experimental data measured by Shiotsu et. al. [3] except those for the high heat fluxes corresponding to $t_L \le 1.2ms$.



Figures 2 shows the velocity distributions and the temperature distribution at the λ transition in the duct with A_d/A_h=2.0 for various step heat fluxes. For the higher step heat flux such as $q_s \ge 9$ W/cm², the λ transition has occurred before the vortex has been fully established near the heated surface. The total fluid in the duct is almost static up to the occurrence of the λ transition, although the heat is carried by the internal convection. With decrease in the step heat flux, the vortices of total fluid are seen to appear and develop above the heated surface. For the step heat fluxes higher than 9.0 W/cm², the thermal boundary layer near the heated surface is relatively. Therefore, it is assumed that the heat transfer would be approximately regarded as one-dimensional heat flow. The lifetime of the step heat input in the region agrees with that for the one-dimensional solutions as shown in Fig.3. For the step heat fluxes lower than 9.0 W/cm², the vortex is generated and develops in He II before the λ transition occurs. The temperature distribution with the two-dimensional expansion can also develops sufficiently as shown in Fig. 3. The values of the lifetime departs from the curve predicted by Eq.(1) to the longer direction with decrease in the step heat flux from 9.0 W/cm². It is assumed that this departure would be due to the effect of the two-dimensional heat expansion.

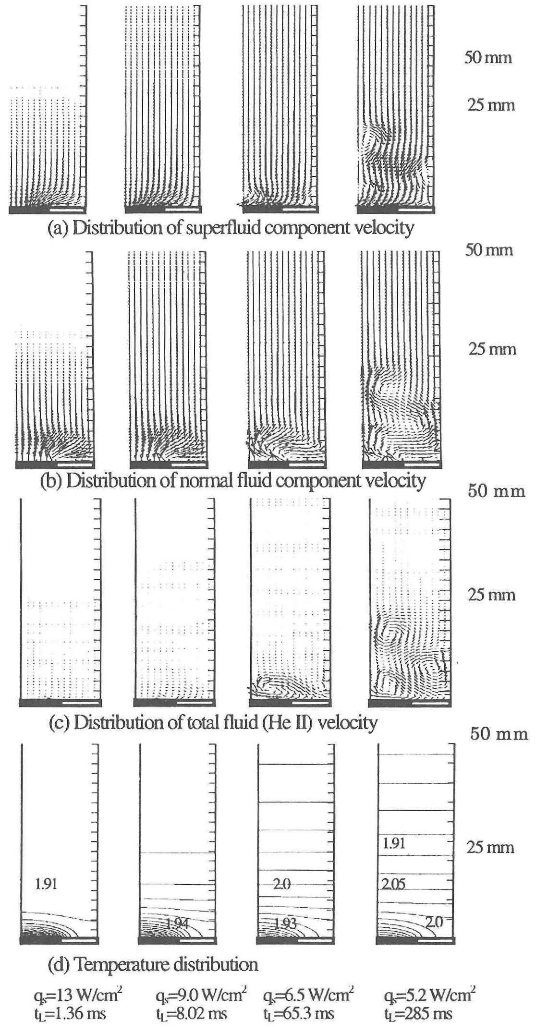


Fig.3 Distribution in a duct with A_d/A_h for T_B=1.9 K for various step heat fluxes at λ transition

Refirences

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