§5. Study on Turbulent Control of Supercritical Helium in Cooling Channel for Superconducting Magnet System

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Supercritical helium (SHe) that the temperature is lower than critical temperature, $T < T_c$, and the pressure is larger than the critical pressure, $p > p_c$, is often employed to cool down the superconducting magnets for high energy physics and nuclear fusion. It is important to understand not only the heat transfer characteristics but also the vortical structures generated in the flow field in order to predict various phenomena generated in the cooling systems. In addition, the vortical structures play an important role in the heat and flow characteristics to perform turbulent control for enhancement of heat transfer characteristics.

Several transport coefficients near the critical point change drastically, for example heat capacity at constant pressure, c_p, and isothermal compressibility, κ_T, defined by the density-density auto-correlation function is diverged near the critical point since density fluctuation with respect to the space becomes large. Therefore, the thermal diffusivity, $D = \lambda/\rho c_p$, defined as a function of the inverse of c_p becomes very small. If some kind of body force such as buoyancy does not act on such fluid which has low thermal diffusivity, the heat transfer characteristic becomes decreasing. However, it is known that the heat transfer characteristic improves by the existence of piston effect near the critical point in the closed system. In addition, thermal plume such as pseudo-boiling occurs due to the buoyancy under the gravitational field.

In this study, spatially developing direct numerical simulations were performed for the natural convection heat transfer between vertical parallel plates with several numbers of riblet in order to find the passive turbulent control method and to clarify the dependence of channel shape geometry with respect to the transition processes. The results in the case of open system, $< p(\mathbf{r}, t) >\simeq const$, are introduced in this paper. The heat transfer coefficients obtained from simulations are compared with several experimental results to confirm the validity of the calculation. From the view point of the vortical structure, the laminar-turbulent transition process in the case of the standard vertical plate system with no riblet is compared with that in the case of the channel with riblet.

Fig.1 and Fig.2 show the vortical structure in the case of vertical channel without riblet and with short riblets, respectively. The vortical structure in this figure is identical to positive value of the second invariant of the velocity gradient tensor, $\partial_j u_i$ [1]. Actually, in the case of without riblet system the roll up structures of the temperature field are generated due to Kelvin-Helmholtz instability which occurs near the heated surface because of the buoyancy and clearness of the boundary between high temperature domain and low temperature one owing to low thermal diffusivity near the critical point. The vortical structures corresponding to roll-up temperature field is horizontal vortex tube as shown in the downstream side of the Fig.1. In this case developed turbulent field occurs at about 1.8 sec due to the instability of the horizontal vortex tube itself. There are two kinds of instability in the case of non-structure such as riblet in the channel. Kelvin-Helmholtz instability is generated as the first step to laminar-turbulent transition. After that the two dimensional horizontal vortex tube becomes unstable because of the frozen in motion caused by Helmholtz theorem. As a result, this secondary instability makes complicated three dimensional field after vortex tubes are twisted. On the contrary, the horizontal vortex street does not occur in the case of with riblets system. This is because the natural convection is disturbed near the leading edge of the riblets. As a result, as can be seen from Fig.2, the presence of riblets near the leading edge of the channel could facilitate the transition to developed turbulent field.

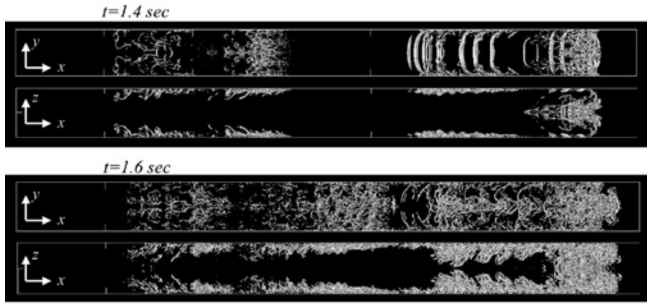

Fig. 1: Vortical structure in the case of vertical channel without riblet.

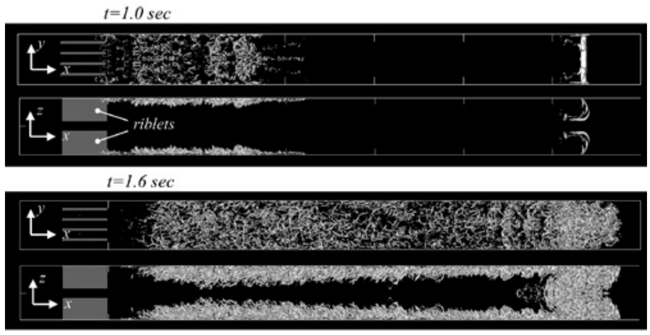

Fig. 2: Vortical structure in the case of vertical channel with riblets.

1) Hunt, J.C.R., Wray, A.A. and Moin, P., *Center for Turbulence Research* CTR-S88, p. 193, 1988