§38. Buoyancy Effect of High Prandtl Free-surface Turbulent Flow

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In this study, Direct Numerical Simulations (DNS) were employed to investigate the buoyancy effects on the heat transfer and turbulent structure in high Prandtl number turbulent flows simulated the liquid wall concept in nuclear fusion applications. Numerical simulations were conducted for two cases in the stable or neutral stratified open-channel flow. Governing equations in this study were Navier-Stoke equations used the Boussinesq approximation, continuity equation and the energy equation and numerical procedure was base on Yamamoto et al[1]. Computational domain is 6.4 *h*, *h*, 3.2*h* for stream, vertical and spanwise directions respectively, where *h* denotes flow depth. The computations were carried out with 8585216 grid points (256 × 131 × 256, in stream, vertical and spanwise directions) for the Reynolds number: $u_\tau h/\nu$ is 200 in both cases and Richardson number: $Ri=\beta g \Delta Th/u^2_\tau$ is 27.6 in the stable case, where u_τ is the friction velocity, ν is the kinetic viscosity, β is the thermal coefficient of volumetric expansion, g is the gravitational force, ΔT is the temperature difference between the free-surface temperature ($T_{surface}$) and the bottom wall temperature (T_{wall}), receptively. Boundary conditions for velocity fields is periodic condition in stream and spanwise directions, no-slip condition at the bottom wall, free-slip condition at the free-surface, respectively. For the temperature fields, periodic condition in stream and spanwise directions and constant temperature at the free-surface and the bottom wall (in this study, $T_{surface} > T_{wall}$) is imposed, respectively.

Figure 1 shows the mean temperature: Θ^+ and turbulent intensity: θ^+ profiles, where $Y^+(=h^+ - y^+)$ is the distance from the free-surface. Near free-surface, the conductive sublayer, where mean scalar profile is follows to the formula; $\Theta^+=Pr\ Y^+$, exists and mean temperature profile in $Pr=5$, stable case is laminarized compared with neutral cases, because the stable stratification constrained the near free-surface turbulent motion. On the other hands, the scale and peak of the turbulent intensity in stable case is larger and wider than the neutral cases. This is why that high temperature fragments which scale Δ^+ is from 5 to 30 are existed in high Pr fluid (Fig.3) and buoyancy acts on these fragments. But the turbulent motion by the buoyancy is opposite to the heat transfer direction. As the results, heat transfer was constrained and turbulent intensity was increased near free-surface. Figure 2 shows this buoyancy effects on the velocity fields. In stable case, vertical turbulent intensity is bigger than neutral case at the high wave number region corresponded to the high temperature fragments scale.

References
1) Yamamoto, Y. et al., 8th European Turbulence Conference (2000) 231.

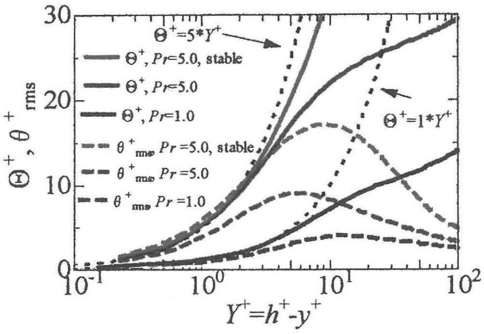

Figure 1. Mean scalar and fluctuation profiles near free-surface

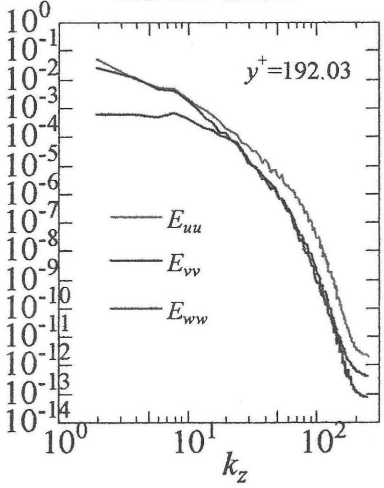

Fig.2-1 1D energy spectra (Near surface, Spanwise,Neutral)

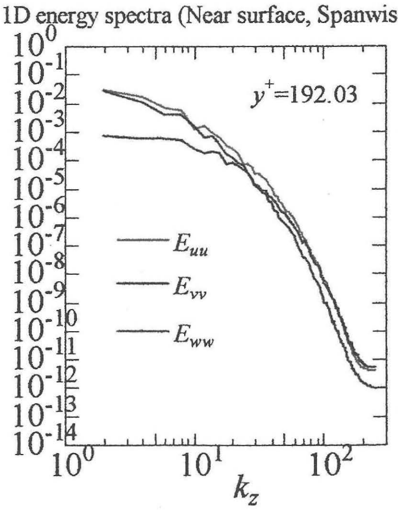

Fig.2-2 1D energy spectra (Near surface, Spanwise,Stable)

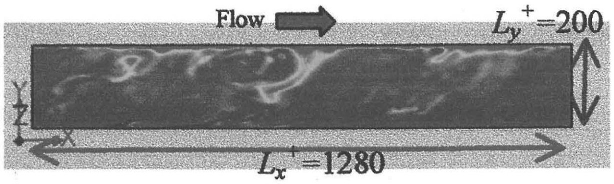

Fig.3 Instantaneous temperature field

Side view 0.1(Blue)< θ^*<0.9(Red)