§7. Study on MHD Wall Shear Turbulent Flow with Buoyancy Effect

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1. Objectives

Liquid-metals as coolant material in a fusion reactor have a significant role in the design of advanced reactors. To understand it better, investigation of thermal behavior under a magnetic field is needed, such as in the case of low Prandtl (Pr) number fluid flow with buoyancy effect. In the present study, direct numerical simulations (DNS) for low Pr number fluid flow of turbulent heat transfer with buoyancy effect has been carried out under a magnetic field. In this simulation the values of Hartmann number Ha were kept as 0, 6, 12 and Prandtl number was 0.06. Grashof numbers were 1.6 x 10^6. Using DNS the parameter such as mean temperature, turbulent heat flux, and temperature variant were quantified. The Reynolds number for channel flow based on friction velocity, viscosity, and channel half width was set to be constant as Re_τ =150. A uniform magnetic field was applied in a direction perpendicular to the wall of the channel. Using the simulation we could see that with an increase in heat transfer, thermal plume by the effect of buoyancy filled the entire region of the channel. In case of an applied magnetic field, it was seen that the turbulence became asymmetric with increasing of the magnetic field, although the thermal transport was also increased by the buoyancy effect of the thermal plume.

2. Numerical method for direct numerical simulations

In our simulation model a uniform magnetic field B_0 defines the y-axis perpendicular to the streamwise direction that defines the x-axis as shown in Fig. 1. Our DNS code is a hybrid of spectral finite difference method. And for the normalization of the temperature equation, a constant positive temperature difference between the bottom and top walls was used. The gravitational acceleration in the y-direction gives rise to an unstable buoyancy effect. Furthermore, the wall normal component imposes the additional body force according to Bossinessq-approximation. The Grashof number was varied as shown in table 1. All variables and parameter in the governing equations were normalized by the channel half-width δ, the friction velocity and. The Reynolds number was kept fixed at 150; the number was based the friction velocity and channel half width. The fluid then flowed with a constant pressure. The Neumann condition for the electrical potential was adopted at the wall which meant the existence of insulation was assumed here. The Hartmann numbers were set to be 0, 6, and 12. These numbers were based on the values of the magnetic field, the kinematic viscosity, the electrical conductivity and the channel half-width. Table 1 summarizes the values of Prandtl number, Reynolds number, and Hartmann number. Periodic boundary conditions were applied to the streamwise (x) and spanwise (z) directions. For the wall-normal direction (y), a non-uniform mesh spacing was employed that was specified by a hyperbolic tangent function. A non-slip condition at the wall was applied to the velocity components. The Prandtl number was 0.06 as is for Lithium, and this number was selected for the working fluid used for this computation.

Table 1 Computational parameters

Re_τ	Pr	Ha	Gr	Region	Grid number
150	0.059	0	1.6x10^6	$5\pi\delta$x2δx$2\pi\delta$	128x128x128
150	0.059	6	1.6x10^6	$5\pi\delta$x2δx$2\pi\delta$	128x128x128
150	0.059	12	1.6x10^6	$5\pi\delta$x2δx$2\pi\delta$	128x128x128

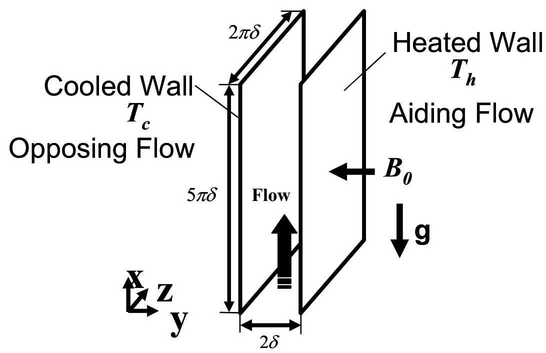

Figure 1 Computational domain.

3. Results

Streaky structures are shown in Fig. 2. With buoyancy effect and magnetic field, many structures exist near both walls. At Ha =0, the structures with buoyancy effect are merged, become asymmetric, the phenomenon is known as thermal plume. In the case of strong magnetic field, the two scale structures by the thermal plume are only shown. The structures have two meandering scales at Ha = 12.

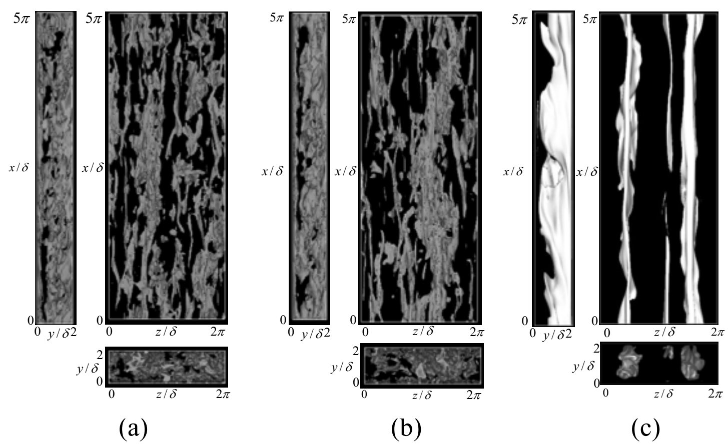

Figure 2 Contour of low-sped streaks; (a) Ha = 0, (b) Ha = 6, (c) Ha = 12