EXPERIMENTAL STUDY ON HEATED DRAG-REDUCING SURFACTANT SOLUTION FLOWS

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ABSTRACT

In the present study, we experimentally studied the characteristics of thermal as well as hydrodynamic turbulent structures, turbulence transports for momentum and heat, turbulence production and diffusion in drag-reducing surfactant solution flow. Our purpose is to clarify the mechanism of heat transfer reduction (HTR) as well as drag-reduction (DR) from the viewpoint of the interferences of drag-reducing additives with turbulence.

The experimental facility is shown in Fig.1. The channel has length of 10m and inner cross-section of $0.04\times0.5\mathrm{m}^2$. Measurement station locates at 0.8m (20*H*, where *H* is channel height) downstream from the front edge of heating section, corresponding to 9.0m (225*H*) downstream from the channel entrance. A dilute aqueous solution of a cationic surfactant cetyltrimethyl ammonium chloride (CTAC), with 30ppm weight concentration of CTAC, is used as drag-reducing fluid. Velocity measurements are performed with a two-dimensional LDV and the temperature fluctuation in the thermal boundary layer is measured with a fine-wire thermocouple probe. Measurements are made for three different Reynolds numbers, Re=1.5×10^4, 2.5×10^4 and 3.5×10^4 (based on the bulk velocity, height of the channel, and viscosity of solvent). Sampled are the synchronized signals of velocity and temperature fluctuations in the thermal boundary layer.

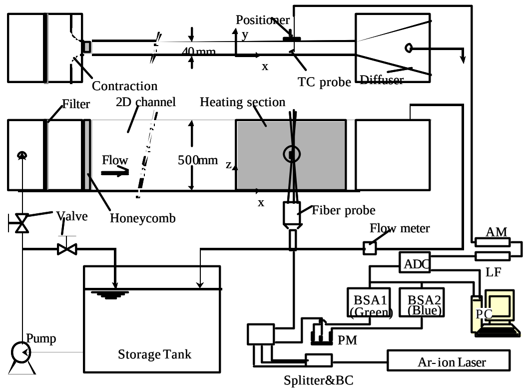

Fig.1 Schematic diagram of experimental facility

Typical hydrodynamic characteristics of the drag-reducing surfactant solution flow are obtained, such as the modification of log-law layer of U^+, enhancement of the peaky structure of u^+ profile, depression of v^+, and depression of $-\overline{uv}$. The depression of $-\overline{uv}$ is known as Reynolds shear stress deficit, which results in DR. Quadrant analysis of $-\overline{uv}$ indicates that the drag-reducing CTAC additives inhibit the process of ejections and sweeps, but do not affect the processes of both outward and wall-ward interactions of fluid. For a heated drag-reducing surfactant solution flow, at high DR or HTR level, a large temperature (Q) gradient layer appears when $y^+<50$, which can also be thought of the modification of Q^+ profile similar to that of log-law layer of U^+ profile. The peaks of both profiles of q^+ and $\overline{u^+q^+}$ are enhanced in the CTAC solution flow comparing with those in the water flow. Near the heated wall, u and q have comparatively high correlation coefficient in the CTAC solution flow, which means that correlation between u and q has not been lost. The turbulent heat flux in the wall-normal direction, $-\overline{vq}$, is depressed through the whole measured range in the drag-reducing flow, as shown in Fig.2, which occurs in a similar way to that of $-\overline{uv}$, i.e., occurrence of decorrelation between v and q comparing with the occurrence of decorrelation between u and v. The depression of $-\overline{vq}$ can be similarly named as "turbulent heat flux deficit" and directly causes HTR in the drag-reducing flow. Quadrant analysis shows that the depression of $-\overline{vq}$ is resulted from both decreases of positive contributions of the second and fourth quadrant, and increase of absolute negative contributions of the first and third quadrant. The turbulence productions of turbulent kinetic energy and temperature variance are both reduced in the drag-reducing surfactant flow. Furthermore, the profiles of the eddy diffusivities for momentum and heat in the CTAC solution flows are both also decreased.

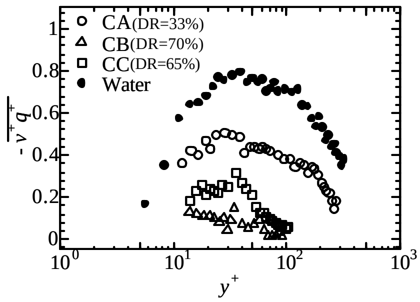

Fig.2 Wall-normal turbulent heat flux