Polymer additives induced axial-aligned small-scale structures in a turbulent von Kármán swirling flow

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The weakening of the vortical structures is found to be one of the key characteristics of drag reduced wall-bounded turbulent flows by polymer additives. Even in homogeneous isotropic turbulence, one can observe the significant inhibition of the vortical filaments, resulting in a decrease in kinetic energy dissipation. A large number of direct numerical simulations have been performed, revealing the interaction between the polymers and the fluid flow[1]. There is, however, a lack of detailed experimental studies especially on the influence of polymers on small-scale turbulent flow structures. In this study, we measure the three dimensional velocity field in the central region of the von Kármán swirling (VKS) flow using the Tomographic PIV system. Our results confirms that the flow at the center is axisymmetric and slightly anisotropic. After addition of small amount of long-chain polymers, the velocity fluctuation was greatly suppressed and the statistical as well as transient results were altered. The energy dissipation rate is measured without any assumptions on the local isotropy and is found to be consistent with the previous results in terms of the trend of decay[2]. In addition, the joint-PDFs of the two invariants of the velocity gradient tensor (Q and R) are very different from that of the Newtonian case. As instantaneous snapshots are further examined, the vortical structures are found to be more rare and more aligned with the axial direction of the flow, indicating that the flow is more anisotropic than that in the Newtonian case. The eigen-frame characteristics of the rate of strain tensor complemented by the flow visualizations are discussed in detail, our results revealing that with the polymer additives the flow becomes pseudo-two-dimensional. The fact that in the polymeric VKS flow the vortical structure becomes longer, thicker and more parallel to the mean flow resembles that was observed in the wall-bounded turbulent flows[1].

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