Effect of Polymer Additive on Turbulent Bulk Flow: The Polymer Concentration Dependence

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INTRODUCTION

Minute amount of long-chain polymer additives can dramatically change flow properties. Examples include the well-known drag reduction in turbulent pipe/channel flows [1] and the elastic turbulence phenomenon at low Reynolds numbers [2]. The dynamics of the polymer-turbulent flow interaction are determined by three control parameters, namely the Reynolds number R_λ, the Weissenberg number Wi and the polymer concentration ϕ. In recent years, there have been a few experimental measurements of bulk turbulence in polymer solutions [3-8], which shed new light on our understanding of turbulence-polymer interaction. However, experiments systematically exploring the full parameter space are still lacking. It is therefore of great importance to carry out experiments that fully isolate the effect of the three control parameters. In this talk we report experimental results on the effect of minute high-molecular-weight polymers on bulk turbulence, i.e., turbulence far away from boundaries. We study the polymer concentration dependence of the effect of polymer additive on the flow by using the three dimensional Lagrangian Particle Tracking technique (LPT) technique with high temporal and spatial resolution. From the measured tracer particle trajectories we obtained the fluid velocities and accelerations. By keeping both R_λ and Wi unchanged and varying solely the polymer concentration ϕ, we studied the concentration dependence of the root-mean-square (RMS) acceleration a and the RMS velocity u. We found that the RMS acceleration is strongly suppressed with increasing polymer concentration, while the RMS velocity decreases slowly with concentration. Our results confirm that the suppression effect of polymer additives is much stronger on small-scale than on large-scale quantities. We further found that polymer additives enhance the anisotropy of the flow at small-scales, but do not affect the anisotropy at large-scale very much.

EXPERIMENTAL SETUP

The experiments were carried out in a von Kármán swirling flow between two counter-rotating baffled disks. The flow is generated in a cylinder with 63cm in height and 49cm in diameter. The two baffled disks both are 25cm in diameter. The LPT system consists of three Phantom v12 CMOS cameras, a Q-switched Nd:YAG laser with power of 60W and repetition frequency up to 120 kHz. The details of the LPT technique and the algorithms used here are described in [9, 10]. The polymer we used is Polyacrylamide (PAM) with molecular weight Mw = 18×10^6. The experiments were done at three different Reynolds numbers 270, 342, and 360 which corresponding to three different Wiessenberg numbers 5.9, 11.8, and 14.2. For each R_λ, ϕ was varied from 0ppm to 5ppm or 10ppm (part per million by weight).

RESULTS AND DISCUSSION

We first examine the ϕ dependence of RMS velocity u and RMS acceleration a. In Figure 1 we plot the measured u and a as functions of ϕ, normalized by the corresponding values for the cases of pure solvents. The figure shows that a(ϕ) deceases very strongly with ϕ. The figure also shows that, however, u decreases slowly with ϕ, suggesting that the polymer does not have strong effect on the large-scale property like velocity fluctuation. Our results confirm that the suppression effect of polymer additives is much stronger on small-

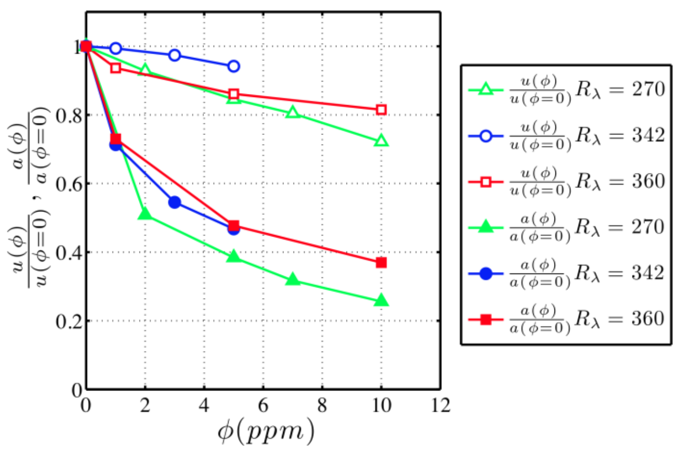

Figure 1 The polymer concentration dependence of the measured RMS velocity u and RMS acceleration a.

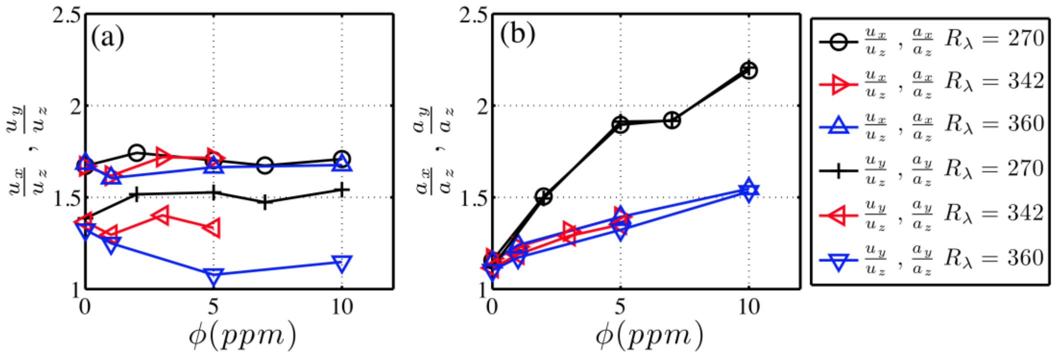

Figure 2 The ratios between RMS of different velocity components (a) and between RMS of different acceleration components (b), as functions of polymer concentration.

scale than on large-scale quantities [11]. The future work about this study is to explore larger ϕ and find out whether $a(\phi)/a(\phi=0)$ will reach a constant value or not.

We then examine the effect of polymer additives on the anisotropy of the flow by studying the ratios between different components of the RMS velocity, i.e., u_x/u_z and u_y/u_z, as functions of ϕ, as plotted in Fig. 2 (a). Similarly we plot a_x/a_z and a_y/a_z as functions of ϕ in Fig. 2(b). It is seen from the plot both u_x/u_z and u_y/u_z stays largely the same as ϕ increases, which suggests that the large-scale anisotropy/isotropy does not change much with the polymer additives. While both a_x/a_z and a_y/a_z increase roughly linearly with ϕ, especially for the R_λ =270 case, suggesting the polymer additives enhance the anisotropy of the flow at small-scales.

In conclusion, we studied the polymer concentration dependence of the effect of polymer additive on the turbulent bulk flow. We found that the fluid acceleration fluctuation is strongly suppressed with increasing concentration, while the velocity fluctuation decreases slowly with concentration. Our results show that the suppression effect of polymer additives is much stronger on small- than on the large-scale quantities. We further found that polymer additives enhance the anisotropy of the flow at small-scales, but do not affect the anisotropy at large-scale very much.

ACKNOWLEDGEMENT

We appreciate useful discussions with Guenter Ahlers and Denis Funfschilling. This work is supported by the Max Planck Society, the Humboldt Foundation, and the German Research Foundation (DFG).

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