Numerical Simulation of Polymeric Flow in Contraction Channels: Wall Slip and Channel Size Dependent Effects

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1 Introduction

In the study of flow in the micro channel, it should be noted that the behaviors of flow in a micro channel deviate from that in macro channel. It has been reported that the flow of polymer solution in a micro contraction channel shows a different trend in vortex growth as compared to that in a macro contraction channel. In our preliminary work, we have shown that the wall slip should be the important factor governing the different vortex growth for the flow in macro and micro contraction channels.

In the present work, we performed further analysis on the effects of different slip velocity-shear stress functions on the behaviors of polymeric flow in 4:1 macro and micro contraction channels. We consider simple power law models, in which slip velocity v_s is related to shear stress τ_w as follows:

$$v_s = a\tau_w^n \qquad (1)$$

where a and n are constant parameters. Four models are considered and referred as SM1 ($v_s = 1.0 \cdot 10^{-5}\tau_w^{0.5}$), SM2 ($v_s = 1.5 \cdot 10^{-5}\tau_w^{1.0}$), SM3 ($v_s = 2.0 \cdot 10^{-5}\tau_w^{1.5}$), and SM4 ($v_s = 1.0 \cdot 10^{-4}\tau_w^{0.5}$). In the range of considered shear rates, the slip velocities are about in the same order for SM1, SM2, and SM3, while about ten times higher for SM4.

2 Results and Discussion

The effect of various slip models is presented in Fig. 1. As noted in our preliminary work, the wall slip introduces different vortex growth for the flow in macro and micro channels. The effect of wall slip is not significant for the flow in macro channel, while becomes significant for the flow in the micro channel.

Fig. 1 (*upper*) shows that the different slip models introduce the different trends in vortex growth. For the flow in the micro channel at low shear rates, significant reduction in vortex length can be observed for SM1 ($n = 0.5$), while no reduction is observed for SM2 ($n = 1.0$) and SM3 ($n = 1.5$), except at very low shear rates (SM2). In contrast, at high shear rates, the slip slightly increases the vortex length for SM1, SM2 and SM3. Introducing a relatively strong slip, as for SM4, results in reduction of vortex length at both low and high shear rates. Referring the experimental results, it should be interesting to note that for one type of fluid, vortex length for micro channel is higher, while for the other fluids, the vortex is lower as compared to that for macro channel. From the above results it is reasonable to consider that the slip velocity-shear stress function should play an important role in determining whether the vortex length for the flow in micro channel is lower or higher as compared to that in macro channel.

The different trend in vortex growth is related to the different effect of the various slip models on the velocity field. The various slip models introduce the different levels of slip at the upstream and downstream regions, which result in different bulk flow behaviors. At low shear rates, as shown in Fig. 1 (*lower*), even though all slip models (SM1, SM2, SM3, SM4) modify significantly the velocity in the downstream region, no significant modification can be observed in the upstream region for SM2 and SM3. Consequently, no significant modification in vortex can be observed for SM2 and SM3 at low shear rates. At high shear rates, the wall slip and shear thinning effects result in the decrease or increase of vortex depending on the strength of the slip.

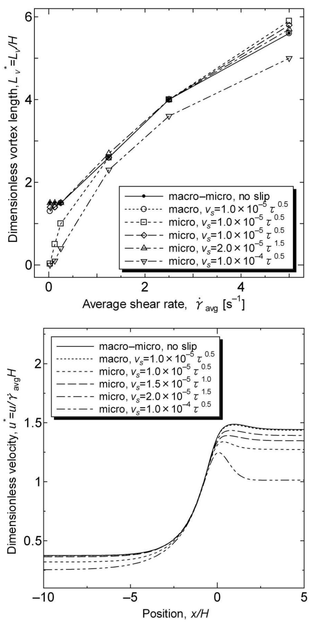

Figure 1: Effect of various slip models on vortex growth (*upper*), and profiles of velocity in the flow direction at centerline at $\dot{\gamma}_{\mathrm{avg}} = 0.25\ \mathrm{s}^{-1}$ (*lower*).