Polymer Migration Mechanisms in Microfluidics

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We use Brownian Dynamics and Stochastic Rotation Dynamics simulations to demonstrate polymer migration mechanisms in microfluidics in geometries of size comparable to that of the polymer molecule. Besides simple size exclusion mechanisms, which include both sieving and volume bypass effects, three other migration mechanisms are explored. These are 1) deformation-hydrodynamic coupling, including wall-hydrodynamic interaction, which causes polymers to drift away from the wall towards the center of a straight channel; 2) depletion-convection coupling, in which depletion layers in thin channels are convected across wide side chambers, creating a one-sided diffusion barrier to polymers or colloids that leads to depletion from the entire side chamber, and 3) stream-curvature-induced migration, in which polymers traveling along curved streamlines migrate towards the center of curvature.

To demonstrate these mechanisms, we study polymer migration in 1) a periodic pressure-driven contraction channel with the width of its narrow region comparable in size to the polymer's radius of gyration and in 2) a pressure-driven flow in a grooved channel that is significantly wider than the polymer. In the contraction geometry, sieving takes effect at low Weissenberg number $Wi < 1$, where Wi is based on the flow rate in the narrow region of the contraction channel. Due to tight confinement in the narrow region, at moderate Wi ($1 \sim 15$), wall-hydrodynamic migration is negligible in the contraction flow, but has been shown by Graham and coworkers [1] to be important in the grooved channel. For $Wi > 1$, in the contraction geometry, polymers migrate towards the centerline, due to a combination of streamline-curvature-induced (SCI) migration and depletion-convection coupling. The depletion-convection-induced migration depends on the thickness of the depletion layer in the narrow region, and becomes weaker at increasing Wi because of polymer stretching and alignment near the wall.

The effect of SCI migration is clearly demonstrated in a grooved channel by letting the polymer sample each of two different regions of the flow field with oppositely directed streamline curvature; in each case the polymer migrates towards the center of curvature. We further show that the SCI migration is controlled by Wi. We propose a method of polymer separation based on SCI migration in a periodic pressure-driven contraction channel for polymer separation, and quantify the separation using the central limit theorem.

[1] J.P. Hernández-Ortiz, Hongbo Ma, J.J. de Pablo and M.D. Graham, "Concentration distributions during flow of confined flowing polymer solutions at finite concentration: slit and grooved channel," *Korea-Australia Rheology Journal* **20**, 143-152 (2008).