Localization of stirring flows: the effect of the yield stress

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ABSTRACT

Viscoplastic fluids (VPFs) are a class of non-Newtonian fluids that behave like solids when the applied shear stress is less than a threshold value called the yield stress ($\widehat{\tau}_y$). When the shear stress exceeds the yield stress, VPFs flow like fluids. Mixing VPF is a ubiquitous problem in many disciplines. Pharmaceutical, polymer, and food processing are examples where mixing plays a vital role in the quality of the final product. We investigate the mixing of a dye in a 2D circular domain of radius $\widehat{R}$ filled with a VPF. The stirring strategy is to move a circular stirrer along a circular path with a constant velocity ($\widehat{r}_o\widehat{\Omega}$, where $\widehat{r}_o$ is the radius of the path and $\widehat{\Omega}$ is constant). The material initially contained in one half of the flow domain is marked by a (passive) dye, described by a concentration field governed by an advection-diffusion equation. The flow domain and the initial condition are illustrated in Fig. 1, where the red and blue colors represent the dyed and dye-free fluid. When the fluid is Newtonian, mixing is enhanced by periodic vortices that spread away from the stirrer. The recirculation zone expands steadily and monotonically (see Fig. 2 for an illustrative example). Keeping the stirring strategy constant, we investigate the effect of viscoplasticity on the evolution of mixing and fluid flow. When the fluid has a yield stress, the kinetic energy decays more rapidly away from the stirrer. Expectedly, the recirculation zone is confined to a finite domain around the stirrer (see Fig. 2 for an illustrative example). We classify the different mixing regimes, characterize the limit cases and discuss the transition between different mixing regimes.

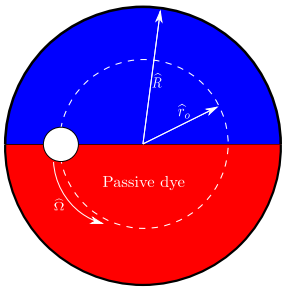

Figure 1: Schematic of the domain geometry and the initial condition

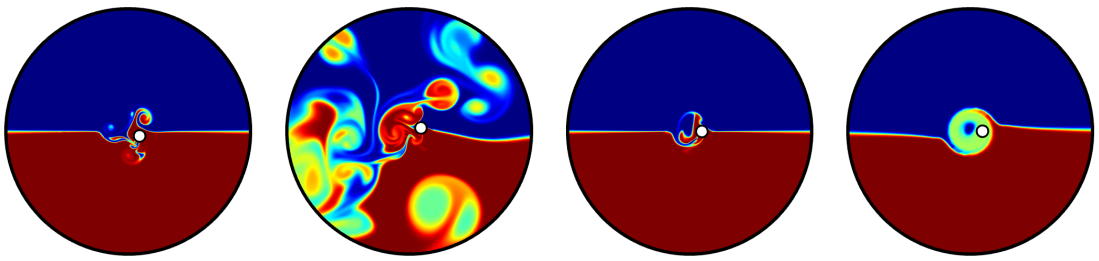

Figure 2: Illustrative examples of the time evolution of the concentration field for a Newtonian fluid (a,b) and a VPF (c,d).