409d Particle Behavior in Closed Streamline Flows: Dilute and Concentrated Suspensions

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Closed streamline flows are notoriously difficult regions to handle in mixing systems. Because closed streamlines are, in the continuum sense, material surfaces, passage of materials across the surface requires some unsteadiness. For particle-laden flows, the flow is intrinsically unsteady at the particle scale, and this work addresses how this affects mixing and demixing processes for particles suspended in a Newtonian liquid. For small solids loading, the focus is upon how the particles' finite size relative to the closed region and the unsteadiness of the flow induced by the particles affect mixing of both the liquid carrier and the particles themselves. At large solids loading, when the mixture is properly considered as a suspension with particle-induced non-Newtonian rheology, the same issues are compounded by the tendency of particles to demix to develop regions concentrated in solids. The problems are studied by a combined experimental and numerical modeling effort, with the latter including particle tracking in Newtonian fluids as well as a suspension flow model inclusive of shear-induced migration. The focus of the effort is on the flow past a cavity at low Reynolds number, where a recirculating vortex is well-known to arise for the liquid alone. The flow is generated by a slot cut from the wall of a concentric cylinder (Couette) flow driven by rotation of the inner cylinder. The closed streamline region in the cavity is studied by experimentation based in flow visualization, with the results of experiments at small and solids fraction compared to the predictions of particle- and dye-tracking computations. At large solids fraction, the predicted (from the suspension mechanical model) and observed recirculating flow are compared, with a focus on determining the rate at which material crosses to and from the zone of mean closed streamline, a quantity measured experimentally and exploring the manner by which the irreversible part of this motion takes place.