145l Complex Fluids in Motion: Elastic Instabilities in Microfluidic Devices, Advection-Diffusion-Reaction Systems, and Granular Flows

Paulo E. Arratia

Complex systems are extremely common in engineering, biology, and physical sciences. Examples include microfluidics, physiological flows, chemical & biochemical reactions, granular flows, micellar self-assembly, and mixing. Many of these systems play an important role in the success of several engineering operations and the understanding of the fundamental principles governing such systems is crucial to the design of novel products and operations.

Elastic Instabilities in Microchannels: Microfluidics is an interdisciplinary subject that can have a strong impact in the field of biology, chemistry, and engineering. In particular, the study of fluid flow in small channels has garnered much attention in the past few years. Here, the flow behavior of dilute polymeric solutions is studied in an elongational flow in a microchannel. We investigate solutions of both flexible and semi-rigid polymers and a viscous Newtonian fluid. Flow behavior is characterized by means of velocity fields obtained from particle tracking measurements, and also by dye experiments. Our results reveal time-dependent instabilities in both dye and velocity fields for dilute flexible polymer solutions; flow instabilities are not observed for Newtonian and semi-rigid polymer solutions under the same conditions. Such instabilities tend to grow as strain rate (i.e. flow rate) is increased. We propose the stretching of flexible polymers near the hyperbolic point produces extra elastic stresses that alter flow kinematics and result in flow instabilities. Furthermore, we demonstrate that these flow instabilities can be used to improve mixing of fluids in microchannels, where fluid flow in inheritably laminar and efficient mixing is difficult to achieve (with Jerry Gollub).

The Interplay of Mixing, Diffusion, and Reaction: It is generally accepted that chaotic advection accelerates reaction rates in fluid flows. The dynamics is determined by the interplay of three factors: advection, diffusion, and reaction. Here, this interplay is investigated using a fast acid-base reaction in the presence of chaotic advection and diffusion, in a thin layer of fluid. In the limit of fast chemical reactions, diffusion controls the fluxes of the chemicals into the reaction interface. We compare experimental results to theory and simulations, which indicate that after a short transient, the product concentration should increase exponentially at first due to stretching, and then more slowly due to diffusion and the collision of reaction interfaces. We demonstrate experimentally the close connection between reaction (product field) and stretching field. However, the reaction product grows more slowly than expected, possibly as a result of highly non-uniform stretching. Surprising oscillations occur on a time-scale much slower than the basic flow period, a phenomenon that is not reproduced by the usual model for fast reactions, which is isomorphic to a passive scalar problem. We discuss possible origins of the unexpected oscillations. This investigation is done in collaboration with Jerry Gollub and Zoltan Neufeld.

Simulation and Experiments in Granular Media: In many industries, particle blending is a required step and the ability to create homogeneous blends of powders and granules can affect final product quality. For example, ineffective blending of pharmaceutical products can result in dangerous variability of active concentrations in tablets and capsules. Here, we present an experimental and computational investigation of mixing and segregation of granular material in a tumbling blender. The Discrete Element Method (DEM) is used to simulate flow of spherical, free-flowing particles. Computational results are compared to blending experiments of monodisperse and bidisperse systems using spherical glass beads in a 1:1 scale. Although some discrepancies are observed, DEM simulations show good agreement with experimentally measured mixing and segregation rates for different fill levels and loading conditions. The effects of blender geometry on particle velocities and flow patterns were examined using DEM. The presence of a hopper and bin section as well as the axial offset proved to introduce greater axial mixing rates that would be expected from pure dispersion. Vibrated experiments showed better agreement than not-vibrated experiments, indicating that modeling of friction forces needs to be further improved to enhance the accuracy of DEM methods (with Fernando Muzzio, Osama Sudah, and Albert Alexander).