Understanding Active Complex Fluids

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Abstract

Active complex fluids are novel fluid systems whose microstructure actively exerts stresses on the immersing fluid or other immersed structures. Examples arise in both the biological and physical science realms. They include motile suspensions of bacteria or algae, and cellular systems where microtubules interact with immersed motor proteins. Motivated by what is performed by these biological systems notably large-scale transport and mixing, scientists are rapidly developing synthetic swimmers and active elements that are actuated by chemical reactions, light fields, and magnetic and electric fields. These compound element systems are naturally multiscale as it is activity by the microstructure that yields large-scale dynamics. The macroscopic dynamics couples back and determines particle distribution and conformation. I will discuss new theory and simulation tools we have developed for understanding these systems. This includes: (1) microscopic models of how the single active elements move and exert stresses on either the surrounding fluid or an immersed structure; (2) efficient simulators that couple thousands of these microstructural elements together when immersed and moving in a Stokesian fluid; and (3), new first-principles continuum theories allow simulation on larger scales, and which allow analysis and prediction. The latter is based on successful kinetic theory approaches developed for complex fluids that reciprocally couple the distribution of particle conformations to the macrocopic fluid flow.

Our numerical experiments and theory on suspensions of active particles show that both particle shape and mode of actuation determine whether macroscopic hydrodynamic flows can develop. If they do, we show that the flows exhibit a "stretch-fold" dynamics are efficient for mixing. Our theory predicts bifurcations to instability (that yields mixing) and we show their existence in discrete many-particle simulations. The latter "giant-number fluctuations", a hallmark of a strongly interacting particle system. We are currently examining how these fluids can be manipulated by the geometry of confinement so as to yield pumping or to suppress instability. Time allowing, I will discuss models and simulations of a *pulling fluid*, a multiple scale fluid-structure system arising in cellular biophysics. Here, immersed biopolymers couple with motor-proteins suspended in a cytoplasmic fluid so as to drag large nuclear complexes across a cell. We develop a special immersed boundary method for simulating this problem, and show that the confining geometry of the system largely guides the experimentally observed dynamics.

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