186f Nonlinear Particle Segregation Instabilities in Micro-Vortices and Burger Dynamics

Diana S. Hou, Zach Gagnon, and Hsueh-Chia Chang

Particles are experimentally shown to be attracted into cylindrical micro-vortices, with dimensions smaller than 1 mm, generated by AC electro-kinetic flow driven by micro-electrodes. The particles are observed to aggregate into an annular cylinder and, depending on the conditions, can disperse into the interior to form a nearly well-packed particle cylinder undergoing rigid rotation. Both annular and solid cylinders then suffer a symmetry-breaking instability and break up into funnel-shaped slugs which migrate along the axis and coalesce into more concentrated slugs. Eventually, only one slug remains with a length comparable to the vortex radius and it migrates down the axis in another symmetry-breaking bifurcation involving particle transport along the axis. We are utilizing these various particulate segregation instabilities to concentrate and trap bacteria and viruses. A theory has been formulated for the various bifurcations observed in the particulate patterns. The formation of the annulus is attributed to positive dielectrophoretic motion of the particles towards a point with maximum electric field intensity. Since a closed streamline passes through this point, the aggregated particles are quickly homogenized along the closed-streamline to form an annulus. Subsequent invasion into the vortex interior is driven by shear-induced migration towards the low-shear rate region and diffusion towards low concentration. The extent of particle invasion into the vortex is determined by a dimensionless parameter χ that measures the relative magnitude of DEP attraction to the original closed streamline on the periphery and shear-induced migration inward. Closed-streamline averaging produces a cross-streamline transport equation that describes the evolution from an annulus to a cylinder as the particles migrate inwards. Filled cylinders appear beyond a critical χ. A long-wave expansion of the streamline-averaged particle transport equation and the associated flow equation produces a Burger equation that describes the secondary bifurcation for the cylindrical breakdown. The various funnel-shaped slugs are shown to be described by the triangular shock solutions of the Burger equation, which also break reflection symmetry along the axis. The coalescence dynamics of the Burger shocks, which is well-studied in the literature, are also shown to adequately describe the observed slug interaction. The particle concentration within the large-χ cylinders is determined by the local shear rate which, in turn, is sensitively dependent on the local effective suspension viscosity and particle concentration. This positive feedback is responsible for the slug breakup and coalescence. A local increase in concentration slows down the vortex circulation. The resulting lower shear-rate attracts axial particle flux to this location and hence further increases the particle concentration. The symmetry breaking is due to the nonlinearity of the shear-induced particle migration flux, which produces a concentration-dependent axial particle velocity.