Lipid vesicles, as ubiquitous in biological systems, are essentially droplets that are enclosed by a phospholipid bilayer. They are potentially capable of delivering macromolecular drug particles into cells through membrane fusion, which is not possible with the traditional means of drug delivery. Vesicles are similar to red blood cells regarding their membrane properties and their morphology and dynamics in both open and confined flow environments. Their suspension provides a tractable model system for developing quantitative models for blood flow in vessels and further for understanding the micro-hydrodynamics of blood disease such as malaria and coagulopathy.

When a vesicle is deformed by a shear flow, the coupled effect of the bilayer’s fluidity, incompressibility and bending stiffness endows the vesicle with rich dynamics (tank-treading, tumbling and swinging), which strongly depends on the internal/external fluid viscosity ratio and the non-sphericity of the shape. The phase diagram of the motion and the particle stresslet can be accurately predicted by a direct numerical simulation based on the Stokes-flow boundary integral equation. The simulations have also revealed the existence of new classes of general three-dimensional periodic orbits, which resemble but are fundamentally different from the Jeffrey's orbit of a rigid ellipsoid.

In a non-dilute suspension, the vesicle-vesicle interactions delay the flow transition from tank-treading to tumbling, and in turn affect the suspension’s shear viscosity and normal stress differences. The microstructure of the suspension varies qualitatively with the viscosity ratio; in particular, at high viscosity contrasts the vesicles tend to aggregate in the flow vorticity direction. I will further discuss the suspension in confined geometries such as in a Couette flow and in a pressure-driven channel flow. The near-wall clear fluid region and the layered cellular structure next to it are much similar to the plasma cell-free layer in microcirculation; they are formed through the balance between a stresslet-induced wall lift velocity and a counter-flux due to inter-particle repulsion or suspension temperature.