Flow and clogging of capillary droplets

Corey O'Hern
Yale University (USA)

Capillary droplets form due to surface tension when two immiscible fluids are mixed. We describe the motion of gravity-driven capillary droplets flowing through narrow constrictions and obstacle arrays in both simulations and experiments. Our new capillary deformable particle model recapitulates the shape and velocity of single oil droplets in water as they pass through narrow constrictions in microfluidic chambers. Using this experimentally validated model, we simulate the flow and clogging of single capillary droplets in narrow channels and obstacle arrays and find several important results. First, the capillary droplet speed profile is nonmonotonic as the droplet exits the narrow orifice, and we can tune the droplet properties so that the speed overshoots the terminal speed far from the constriction. Second, in obstacle arrays, we find that extremely deformable droplets can wrap around obstacles, which leads to decreased average droplet speed in the continuous flow regime and increased probability for clogging in the regime where permanent clogs form. Third, the wrapping mechanism causes the clogging probability in obstacle arrays to become nonmonotonic with surface tension. At large values of the surface tension, the droplets are nearly rigid and the clogging probability is large since the droplets cannot squeeze through the gaps between obstacles. With decreasing surface tension, the clogging probability decreases as the droplets become more deformable. However, in the small surface tension limit, the clogging probability increases since the droplets are extremely deformable and wrap around the obstacles. The results from these studies are important for developing a predictive understanding of capillary droplet flows through complex and confined geometries.