This work specifically aims to provide a fundamental framework, with some experimental validation, for understanding droplet emulsion dynamics in a microfluidic channel with an applied electric field. Electrification of fluids can result in several different modes of electrohydrodynamics (EHD). Several studies to date have provided theoretical, experimental, and numerical results for stationary droplet deformations and some flowing droplet configurations, but none have reported a method by which droplets of different diameters can be separated, binned and routed through the use of electric fields. It is therefore the goal of this work to fill that void and report a comprehensive understanding of how the electric field can affect flowing droplet dynamics.

This work deals with two primary models used in electrohydrodynamics: the leaky dielectric model and the perfect dielectric model. The perfect dielectric model assumes that fluids with low conductivities do not react to any effects from the small amount of free charge they contain, and can be assumed as dielectrics, or electrical insulators. The leaky dielectric model suggests that even though the free charge is minimal in fluids with low conductivities, it is still enough to affect droplet deformations. Finite element numerical results of stationary droplet deformations, implemented using the level set method, compare well both qualitatively (prolate/oblate and vortex directions), and quantitatively with results published by other researchers. Errors of less than $7.5\%$ are found when comparing three-dimensional (3D) numerical results of this study to results predicted by the 3D leaky dielectric model, for a stationary high conductivity drop suspended in a slightly lower conductivity suspending medium. Droplet formations in a T-junction with no applied electric field are adequately predicted numerically using the level set finite element technique, as demonstrated by other researchers and verified in this study. For 3D models, droplet size is within $6\%$, and droplet production frequency is within $2.4\%$ of experimental values found in the microfluidic T-junction device. In order to reduce computational complexity, a larger scale model was solved first to obtain electrical potential distributions localized at the channel walls for the electrode placement configurations.

Droplet deceleration and pinning is demonstrated, both experimentally and numerically, by applying steep gradients of electrical potential to the microchannel walls. As droplets flow over these electrical potential “steps,” they are pinned to the channel walls if the resulting electric forces are large enough to overcome the flowing inertial forces and viscous drag. The electric Euler number, Eue, the ratio of inertial to electric forces, is used to quantify the magnitudes of each of these forces required to pin a droplet, and is consistent with a cubic dependency on the drop diameter. For larger drop diameters, effects of viscous drag and interfacial tension become more prominent, deviating from the cubic dependency. Droplet deceleration and pinning can be exploited to route droplets into different branches of a microfluidic T-junction. In addition, using steep electrical potential gradients placed strategically along a microchannel, droplets can even be passively binned by size into separate branches of the microfluidic device. These characteristics have been identified and demonstrated in this work.

Major: Mechanical Engineering

Educational Career:
Bachelor's of Mechanical Engineering, BS, 2005, University of Central Florida
Master's of Mechanical Engineering, MS, 2008, University of Central Florida

Committee in Charge:
Ranganathan Kumar, Chair, Mechanical and Aerospace Engineering
Alain Kassab, Department of Mechanical and Aerospace Engineering
Weiwei Deng, Department of Mechanical and Aerospace Engineering
Bhimsen Shivamoggi, Department of Mathematics

Approved for distribution by Ranganathan Kumar, Committee Chair, on October 15, 2013.

The public is welcome to attend.