Understanding the Physics of Droplet Electrocoalescence in a Microfluidic Device

Faisal Bilal Memon,* Bhargav Koppolu
Faculty: Sindhu Preetham Burugupally
Department of Mechanical Engineering, College of Engineering

This work details a parametric study for merging millimeter sized oil droplets, using an electric field, to simulate a mesoscale version of the microfluidic device. This was done to see if the physics of droplet merging changed when we moved from the microscale regime to the mesoscale regime.

The microfluidic device, titled TAP (Trapping and Assisted Pairing) is a cell handling platform for conducting cell-cell (plant cell-microbe) interaction studies for identifying symbiotic/parasitic relationships and to help plant biologists devise approaches to maximize the symbiotic functions and minimize the parasitic functions. This work stems from the big picture idea of smart and sustainable agricultural practices to meet the future global crop production demands in the era of ecosystem degradation and climate change. TAP leverages droplet microfluidics to efficiently electrocoalesce multiple pairs of droplets — one set of droplets containing individual plant cells and another set of droplets containing individual microbes — to initiate multiple cell-microbe interactions.

As a first step, through experiments, we analyzed the physics of meso-scale droplet merging and conducted a parametric study to analyze the effect of applied voltage and droplet gap on their behavior. This study resulted in the generation of preliminary design-charts: 1) a plot of droplet fate (whether merged or failed to merge) vs applied voltage and droplet gap, 2) a plot of the bridge width vs minimum droplet gap and applied voltage, and 3) a plot of response time of bridge formation vs applied voltage and droplet gap. We then used numerical simulations to cross-verify our experimental results, and to spot false positives. This resulted in similar design charts, based on the results of the numerical simulations.

We found that merging is delayed as the droplet gap is increased, or applied voltage is decreased. We also found that once merging is initiated, the rate of bridge formation is the same, regardless of applied voltage or droplet gap. Furthermore, we found that the bridge formation is almost instantaneous at first (within 50 milliseconds), and then asymptotes to the maximum bridge width. These observations are in good agreement with the existing literature.