External Field Induced Flow Patterns in Microscale Multiphase Flows

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Introduction: The study of multiphase flows inside the microfluidic devices have received much attention recently because of its variety of application related to heat and mass transfer, mixing, microreaction, and emulsification [1]. Many researchers have concentrated on the influence of flow rate of the fluids, fluid properties such as surface or interfacial tensions, contact angle and viscosity of the liquids on the interfacial morphologies and their transitions [2]. The results suggest that a host of interesting flow patterns can be achieved by controlling the fluid properties (interfacial tension, viscosity) and flow conditions (flow rate).

Use of COMSOL Multiphysics: In the present study, we explore the pathways to control the flow morphologies of a liquid-liquid multiphase flow employing an external electrostatic field. The oil-water multiphase system is modelled employing the commercial software COMSOL MULTIPHYSICS. The electrohydrodynamics (EHD) of the multiphase system is numerically resolved employing Navier-Stokes equations of motion coupled with the Maxwell stresses together with enforcing the appropriate boundary conditions.

The geometry of the problem is shown in the Figure 1 in which two perpendicular inlets are put on the left hand side for the oil and water. The fluids flow out from the right hand side. The electric field is enforced through the top and bottom walls at the right hand side.

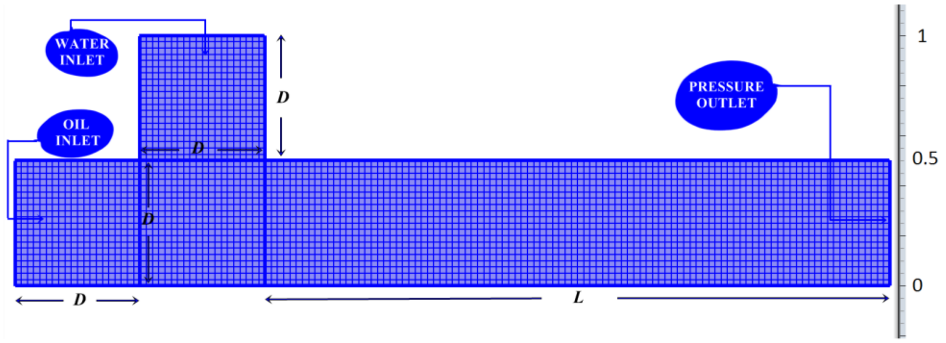

Figure 1. The geometry of a T-junction microchannel. Here L = 2.5 mm and D = 0.5 mm. The mesh employed for the numerical simulations has a typical size of 40 nodes/mm length.

Results: The results reported in the Figure 2 and 3 show that EHD can very effectively tune the multiphase flow patterns. Importantly, these figures suggest that when the electric field is enforced on an oil-water two-phase multiphase configuration, the interfaces can deform into some very unique patterns, which are in general not observed in the pressure driven two-phase flows.

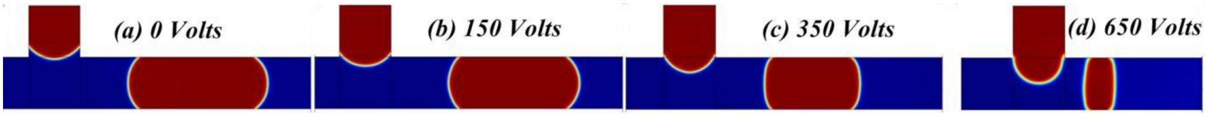

Figure 2. Effect of voltage on the plug size. Here the electrodes are placed across the entire length of channel (L) from T-junction.

For example, in Figure 2, the electrode covers the entire downstream portion of the channel (L) from T-junction. The figure suggests that the plug size shrinks to form a drop like morphology with increase in the applied voltage.

Figure 3. Deformation in a 'plug' patter is observed when it passes through an applied field (500 Volts) at different time intervals.

In Figure 3 the electrodes are positioned 1 mm away in the downstream from the T-junction. The figure shows that the contact angle of the oil-water interface changes as it enters the applied field. The images also show some unique interfacial morphologies as the plug enters the electric field. The images show that (a) water plug approaching the electrode, (b) flattening of plug nose as it enters the field, (c) the rear of the plug enters the field, and (d) the rear plug also flattens while the plug nose departs.

Conclusions: This study reveals the EHD can indeed influence in changing the flow morphologies in the microscale multiphase flow, which holds the promise of a wide variety of applications in MEMS/NEMS technology, micro-mixing, µTAS or Lab on a chip devices, sea water desalination, chemical and biological applications.

References

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