A Comparison of the Continuous and Discrete Approach for Liquid Manipulation

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Abstract

The objective of this paper is to achieve a complete and rapid efficient mixing of numerous sample in micro-scale devices of microfluidic system. The principle of microfluidics is extensively used in a number of fields such as biomedical, healthcare, biochemical, drug research and other applications. These microfluidic devices with mathematical simulations are appropriately utilized in systematic designed process. In this paper a comparative study of continuous [1] and discrete fluid mixing [2] has been studied to improve the mixing efficiency. All the simulations have been carried out with COMSOL Multiphysics® software and the LiveLink™ for Matlab®. It has been observed that the discrete flow has a better mixing efficiency compared to the continuous flow. Also the discrete type fluid flow has certain advantages over continuous fluid flow like re-configurability, low reagent volume, all the control parameters are in electrical domain and more importantly the devices have no mechanical components. Consequently, the discrete droplet mixing has been verified experimentally with Thin-Film-Transistor (TFT) technology[3],[4].
The computational analysis of the continuous micro-channel fluid flow has been executed (figure 1) by using a mixing based model where two different physics in model wizard has been selected. In the physics of 'Single Phase Fluid Flow', the 'Laminar flow' model has been selected for flow analysis. Similarly, in the physics of 'Chemical Species Transport', 'Transport of Diluted Species' has been selected. Further, the model has been simulated by considering 'Stationary Solution'. In particular modelling is done by considering the fluid as an incompressible Newtonian liquid in micro channels to be mixed. This can generally be described by the Navier-Stokes equation [22] and continuity equation.

In contrast, discrete type fluid flow (figure 2) (assuming the fluid flow as incompressible flow and neglecting the inertial term i.e. Stokes flow). AC/DC, Fluid Flow and Chemical Species Transport physics interfaces are used for simulation in COMSOL® platform. In particular, we use Electric Current (ec), Laminar Two-Phase Flow, Moving Mesh (tpfmm) for simulation of Lippmann-Young equation i.e. change in contact angle for droplet deformation, additionally Level Set (tpf) with Electric Current (ec) for simulation of droplet transport and Convection-Diffusion Equation (cdeq) for mixing two droplets having different concentration. The surface velocity is calculated by Laminar Two-Phase Flow. Moving Mesh (tpfmm) using Navier-Stokes equation is then coupled with level set method for transporting. Convection diffusion equation is used for mixing the droplets. The result shows much higher mixing efficiency for discrete fluid flow compared to continuous fluid flow.

Finally, the simulated data is verified with experimental results for discrete type fluid flow. Thin Film Transistor (TFT) array is deducted from lower glass of liquid crystal display (LCD), is used for discrete liquid manipulation as figure 3, which is very unique in nature, because of its larger array with thousands of independent microelectrodes, active multiplexed addressing, reusability, planar addressing method, low threshold voltage and negligible Joule heating effect. In consequence, a significant contact angle modulation efficiency 54.61% is experimentally achieved with only 7.4% deviation from simulated data (figure 4).

Reference

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[3] "Programmable large area digital microfluidic array with integrated droplet sensing for bioassays," Hadwen, B., et al. Lab on a Chip, 3305-3313 (2012).
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Figures used in the abstract

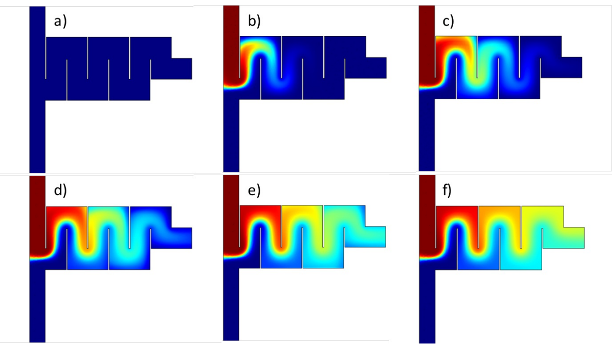

Figure 1: (a-f) Representing the mixing concentration for continuous mixing.

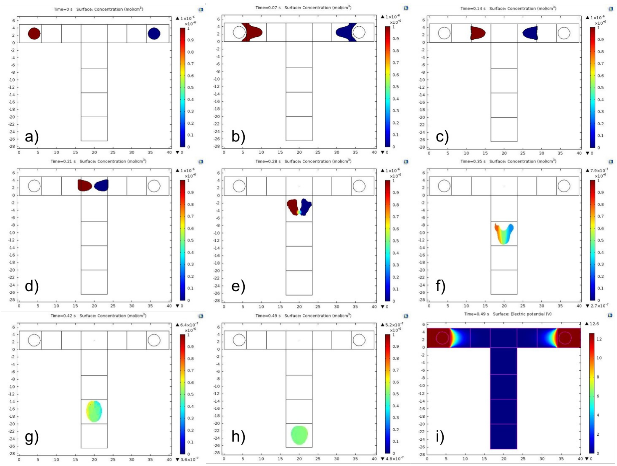

Figure 2: (a-h) Representing the mixing concentration for discrete mixing i) The electric field simulation of 1st and 2nd electrodes.

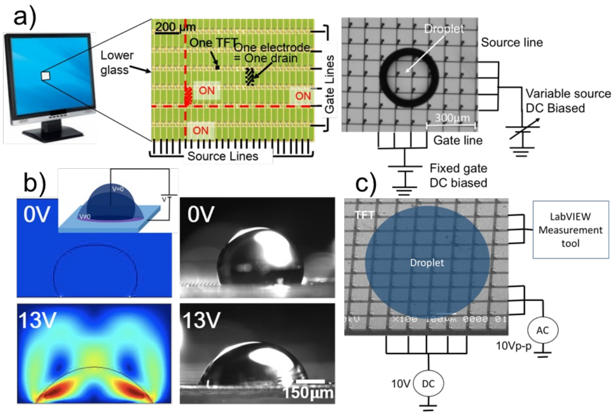

Figure 3: a) TFT deducted from LCD b) Surface wettability of liquid droplet on COMSOL and TFT c) Experimental setup.

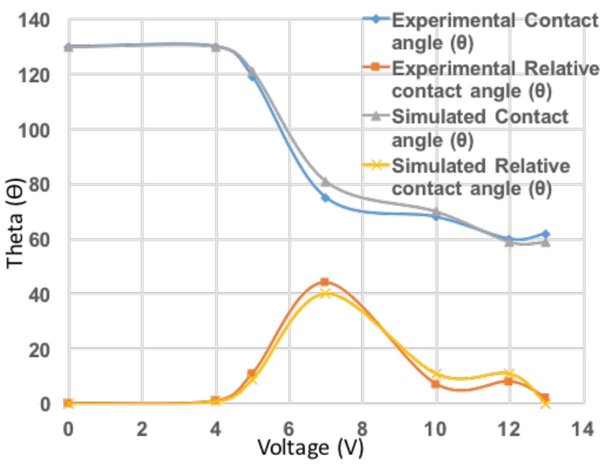

Figure 4: Experimental results deviate 7.4% from simulated data.