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Simulation of droplet generation in flow focusing glass microfluidic device

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Droplet formation in flow-focusing microcapillary devices
Multi-phase flow, especially two-phase flow, occurs frequently in a wide range of applications such as microchemical technology, biotechnology, microelectromechanical system (MEMS), micrototal analysis system (MTAS). For all these applications, it is crucial to control and predict flow behaviors, such as flow pattern, bubble or slug size and their velocity, which are function of parameters such as the geometry and size of microfluidic devices, gas or liquid flow rates and fluid properties.

The popular geometry for the production of bubbles and droplets are flow-focusing devices (Fig. 1). Highly uniform bubbles and droplets can be generated in these devices. However, the bubble formation mechanism at microscale remains still not very clear, which is dependent on the geometry of microfluidic device, in particular the wall and the interfacial effects.

Simulation Methodology

To understand the flow behaviour in the vicinity of the 3D orifice where droplets are formed, a detailed computational fluid dynamics (CFD) based simulation of the two phase flow for the 3D device was performed STAR CCM 6.04.14 software. The volume of fluid (VOF) model in three-dimensional form was used, which enables capturing and tracking the precise location of the interface between the fluids.

A single continuity Equation 1 and the momentum Equation 2 are solved continuously across the computational domain. The VOF method accomplishes interface tracking by solving an additional continuity-like Equation 3 for the volume fraction of the primary phase, which yields the value of \( \Omega_G \) while \( \Omega_L \) is computed as 1 - \( \Omega_G \). The body force term (\( F \)) in Equation 2 is responsible for taking into account the surface tension and contact angle effects, and it is computed in Star CCM by use of the continuum surface force (CSF) model.

\[
\frac{\partial \rho}{\partial t} + \nabla (\rho \vec{v}) = 0 \tag{1}
\]

\[
\frac{\partial (\rho \vec{v})}{\partial t} + \nabla \rho (\vec{v} \cdot \nabla \vec{v}) = -\nabla P + \rho \vec{f} + \nabla \cdot \tau \tag{2}
\]

\[
\frac{\partial \Omega_G}{\partial t} + \nabla (\Omega_G \vec{v}) = 0 \tag{3}
\]

Results and discussion

Quadrilateral elements were used with the paved meshing scheme and the entire flow domain is then meshed using more than one million size controlled hexahedral cells with a spatial resolution (Fig. 2 and Fig. 3). Typical images of computer simulation results for volume fraction of phases and velocity profile at \( Q_{\text{water}} = 10 \text{ ml/h} \) and \( Q_{\text{DCM}} = 1.2 \text{ ml/h} \), and \( d_{\text{orifice}} = 200 \mu m \) are shown in Fig. 4 (a) and (b), respectively.

Conclusions

The 2-phase flow behaviour in the vicinity of a 3D orifice is modelled using VOF method and Star CCM simulation software. The initial velocity and volume fraction results are presented. Further work is required to complete the simulation process of the droplet formation.

References