Formation of droplets in microfluidic T-junction at small capillary number

Piotr M. Korczyk, Volkert van Steijn, Piotr Garstecki

Microfluidic devices can generate monodisperse droplets offering precise control over their size and contents. This has potential applications in biotechnology, material synthesis and medical diagnostics.

The T-junction is one of the simplest geometry which allows for generation of micro-droplets. It comprises two perpendicular channels forming a "T". The liquid-to-be dispersed is supplied from the side channel, flows into the main channel and obstructs the flow of the continuous phase, which then squeezes the interface until it breaks and a droplet releases into the main channel. The volume (V) of the droplets is a function of the rates of flow of the continuous phase (Q_c) and of the droplet phase (Q_d). At low values of the capillary number ($Ca = \mu v/\gamma$, where μ is the viscosity of the continuous phase, v the speed of flow and γ the interfacial tension) formation of droplets is controlled by the model, in which volume of the droplets linearly depends on the ratio between the flow rate of the dispersed phase and the continuous phase: $V = A + B(Q_d/Q_c)$, where A and B are constants. This squeezing mechanism described by Garstecki *et al.* [1] is typical to flows through confined channels ruled mainly by interfacial forces and conservation of mass.

The fact that the droplet does not occupy the whole cross-section of rectangular channels and leaves some space in corners was used by Van Steijn *et al.* [2, 3] to formulate an improved model which takes into account the flow of the continuous phase bypassing the droplet through corners of channels.

Here we demonstrate a further extension of the model, where we now lift the assumption of constant magnitude of flow through the gutters. In particular we analyze the ratio of the flow through the gutters to the flow that squeezes the growing droplet and derive a new expression for the volume of droplets that explicitly depends on the value of Ca.

We will show experimental observations of droplets generated in T-junctions with square cross-sectional channels of the width from 0.36mm to 1.2mm. Acquired experimental data indicate that: i) leakage is most relevant for square cross-sections as it maximize the lumen available for the gutter flow, ii) both the bypass flow and volume of droplets increase with decreasing Ca even for $Q_d/Q_c = const$.

The fact that flow through the gutters increases with decreasing Ca implicates that a model describing generation of droplets in square cross-sectional channels should take into account a competition between both flows of continuous phase: i) the flow squeezing a droplet and ii) the flow bypassing droplet. We will propose a model describing generation of droplets as a result of squeezing of the droplet phase thread by the flow of the continuous phase in the presence of the gutter flow depending on Ca. The Model will be compared with experimental data.

References

[1] Piotr Garstecki, Michael J. Fuerstman, Howard A. Stone, and George M. Whitesides. Formation of droplets and bubbles in a microfluidic t-junction—scaling and mechanism of break-up. *Lab on a Chip*, 6(3):437, 2006.

[2] Volkert van Steijn, Chris R. Kleijn, and Michiel T. Kreutzer. Flows around confined bubbles and their importance in triggering Pinch-Off. *Physical Review Letters*, 103(21):214501, November 2009.

[3] Volkert van Steijn, Chris R. Kleijn, and Michiel T. Kreutzer. Predictive model for the size of bubbles and droplets created in microfluidic t-junctions. *Lab on a Chip*, 10(19):2513, 2010.