Study of liquid flow in the T-shape channel with the side wall fluctuation

Y. Pang, Z. M. Liu*

College of Mechanical Engineering and Applied Electronics Technology, Beijing University of Technology, Beijing, China
*corresponding author: lzm@bjut.edu.cn

Abstract The droplet generation in a T-shape microchannel with the main channel width of 50μm and the side channel width of 25μm for the simplified two dimension geometry, is simulated to study the effects of the forced fluctuation of the sidewall. The periodic fluctuations are applied on the side wall of the T-shape microchannel in the deformation shape of the double-clamped beam acted by the uniform force varying with the flow time and fluctuation periods, forms and positions are analyzes. For the droplet size in the simulations, the fluctuation under the uniform force varying with the time in the sine curve with the period 0.008s gives the droplet generation a slight trend to group the droplets, while other forms of wave have no obvious effects when it is forced near the junction. For the fluctuation without expansion, no matter which periods are used, the effects on droplet sizes are negligible while the velocity is increased in the downstream and the flow field varied. The position provides changes to the liquid flow, which could be shown in the velocity vector and the droplet size that the size could be increased when the fluctuation is deformed at the downstream of the junction, while the lower nomodispersity of the size also could be induced. Besides, the pressure of the flow under different wall conditions shows the indications of the droplet size when it is emerged.

Keywords: flow flied, droplet generation, forces fluctuation, droplet size

1 Introduction

Multiphase flow systems offer numerous advantages which give them the promising applications in the biotechnological and medical devices. As a result, there is a growing interest in the microfluidic techniques, especially for the formation and control of the droplets or bubbles. One of the most frequently used microfluidic geometries to produce immiscible fluid segments is a T-junction[1]-[4]. Mechanism of break-up of liquid and gas streams in T-junctions over a wide range of flow rates and viscosities of the fluids has been investigated in these researches since droplets formation in a T-junction device was first reported by Thorsen et al[5].

In the T-junction devices, the droplet or bubble generation is controlled by the shearing force and the interfacial force[6]. Based on the value of the capillary number, three main regimes of generation of droplets or bubbles are present: squeezing, dripping and jetting regimes [3][4][7][8]. The squeezing regime is observed for low values of Ca. The droplet or bubble generation occurs at the two phases intersection. In this regime, the droplets or bubbles generated have an elongated shape in the continuous phase micro-channel. The dripping regime is observed for higher values of Ca. In this regime, the droplets or bubbles generated do not occupy the entire width of the continuous phase micro-channel and are smaller than the width of the continuous phase channel[9][10]. The jetting regime is a regime of droplet or bubble generation in which the dispersed phase forms a long neck in the channel of the continuous phase. The droplet or bubble formation occurs downstream at some distance from the T junction.

In this work, we investigated the effects of the forced deformation of the sidewall during the droplet generation in a microchannel with the main width of 50μm. To indicate the effect of movable sidewall, different fluctuation models are involved in the numerical simulation.

2 Calculation model and parameters

In this simulation, the 2 dimension geometry is used to investigate the effect of the side wall deformation on the droplet generation in the T-junction microchannel. The immiscible liquids are pumped into the microchannel through the water inlet and oil inlet respectively, and then merge at the right angle to generate the droplet (shown in Fig.1(a)), where water is set as the disperse phase and perfluoropolyether oil is set as the continuous phase. The horizontal length of the channel is 960μm and the lengths of both inlets are 150μm. Widths of the side channel and main channel are 25μm and 50μm respectively.

In this model, liquids properties are shown in Table 1. The hydrophobic boundary condition is applied to all the solid wall with the contact angle of 140° and non-slip boundary is set for walls. The liquid flow in the microchannel is the laminar flow with the 0.00889m/s inlet velocity of the velocity inlet condition for both inlets and 0 Pa pressure outlet condition for the outlet. In order to figure out the influence of the side wall deformation, a fluctuation with time is applied at the main channel's wall of the opposite side of water inlet. The deformation period, type and the applied position are varied to investigate the effect of them on the droplet generation. The basic type of the fluctuation can be described by the Eq. (1)

$$w = \frac{1}{24 \times 3^{-13}} q x (l^3 - 2 l x^2 + x^3) \tag{1}$$

Where, w is the y-direction deformation, x is the x-direction position of the sidewall as shown in Figure 1(b), l is the length of the fluctuant part on the wall (l=120μm) and q varies with time t and is controlled by the period T with the following equation.

$$q = \sin(2\pi / T \cdot t) \tag{2}$$

Based on this fluctuation, some other fluctuation models are simulated, where the modified q is compiled with the different time periods (T=0.004s, T=0.008s, T=0.016s) or equations (such as Eq.(3)).

$$q = \begin{cases} \sin(2\pi / T \cdot t), t \le T/2 \\ 0, T/2 < t \le T \end{cases} \tag{3}$$

Table 1. Properties of the immiscible liquids

Liquids	Density(kg/m^3)	Viscosity(Pa · s)	Surface tension (N/m)
water	998.2	0.001003	0.04
oil	1880	0.11468	

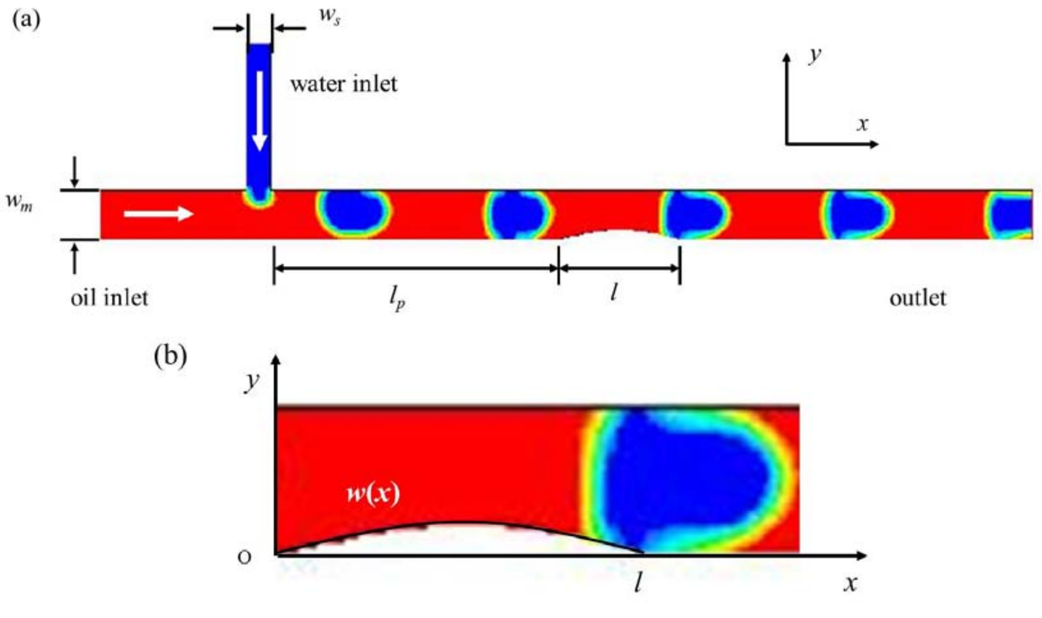


Figure 1. Model of the T-junction microchannel. (a) Snapshot of droplet generation in the T-junction microchannel; (b) details of the sidewall deformation

3 Results and discussions

To determine the influence of the deformation, the droplet size and flow flied are measured through the image sequences of the droplet generation. Since the simulation is the 2 dimension, the droplet size can be indicated by the area of the every disperse phase droplet.

3.1 Droplet generation under different time periods of sidewall deformation

When the fluctuation is applied at the position of l_p=0 with the model of Eq.(3), three kinds of time period are simulated in this research to document the influence of them on the droplet generation. The scatter diagram of the droplet size in these three cases are shown in Figure 2(a), where the size under the time period of 0.004s shows the better monodispersity compared with those under the 0.008s and 0.016s. However, the average size in the same case does not show the obvious trend with the varying time period besides the lower error bar of 0.004s from Figure 2(b).

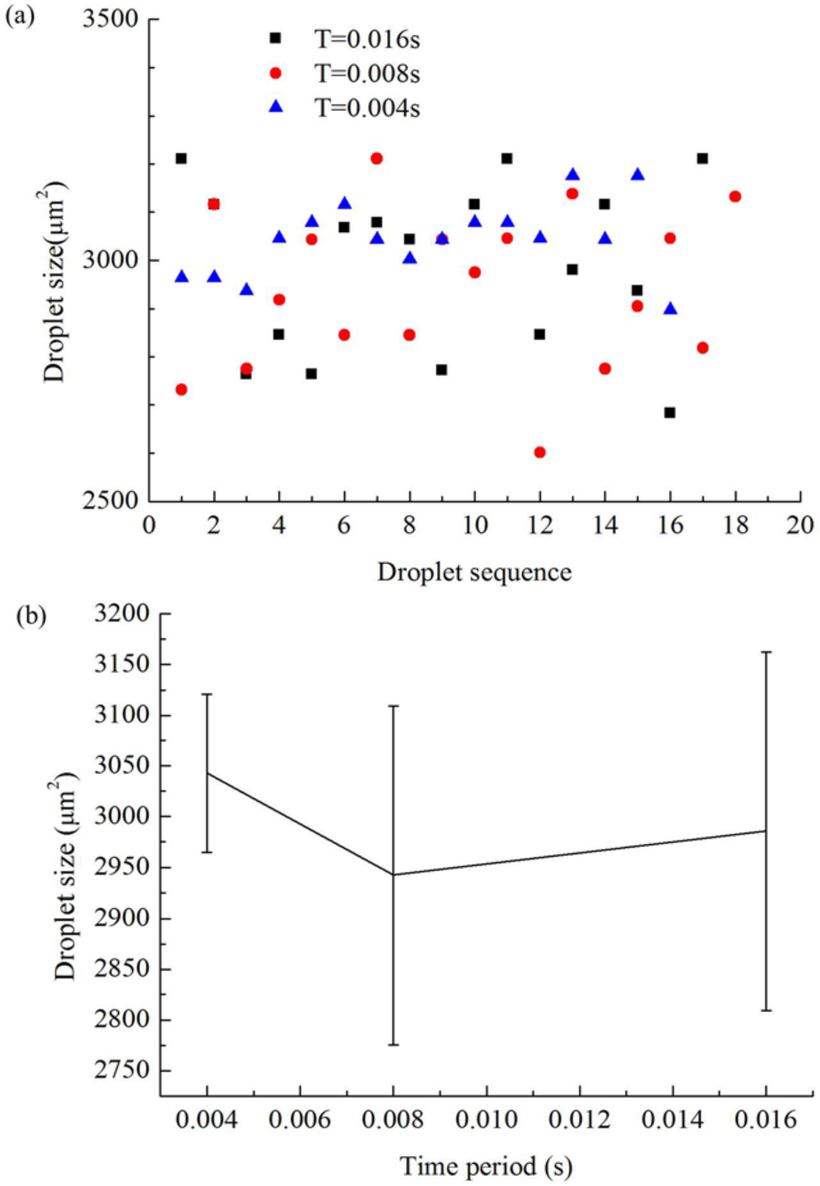
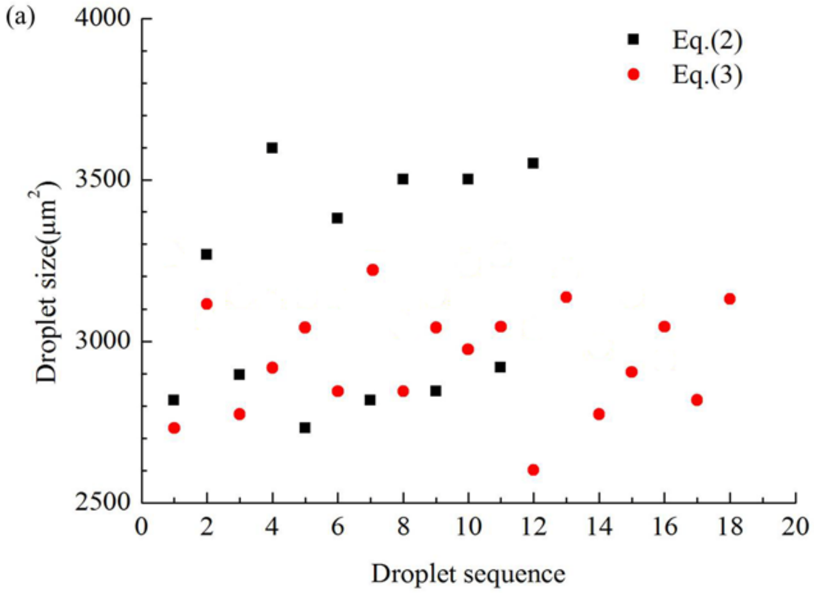


Figure.2 The droplet size under different period. (a) Scatter diagram of droplet size; (b) average droplet size

3.2 Droplet generation under different force forms of sidewall deformation

Besides the time period of the fluctuation, the different forms of q also give some the variation to the fluctuation model. With the period of 0.008s, q of Eq.(2)-Eq.(3) are simulated at the position of l_p=0. From the scatter diagram of these cases, the fluctuation of Eq.(2) gives the wider range of the droplet size.

Nevertheless, when droplet sizes of Eq.(2) are picked out, the separated group could be recognized with an average droplet size and lower standard deviation respectively as shown in Figure 3(b). The effect of droplet group could grow out of the obvious two form of the side wall deformation which make the main channel wide and thin alternately.



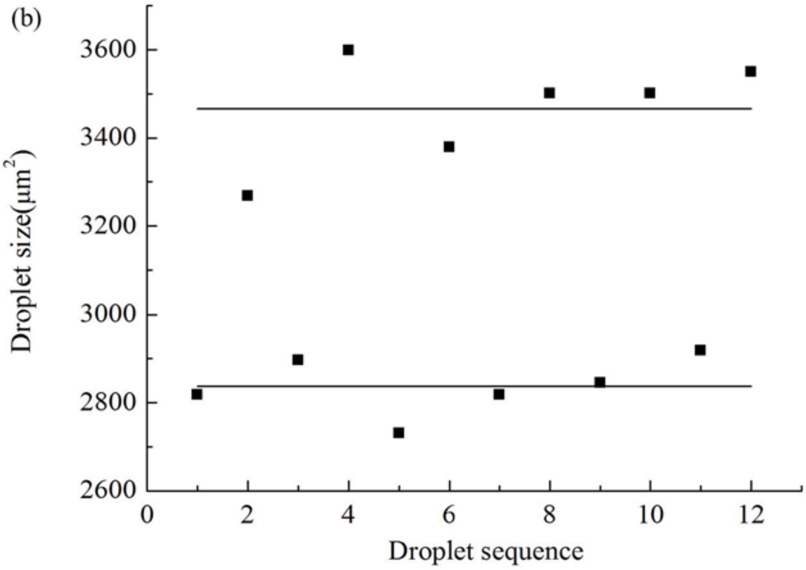


Figure.3 The droplet size with different types of q. (a) Scatter diagram of droplet size; (b) Scatter diagram and average

droplet size of each group for Eq.(2) case.

3.3 Droplet generation under different positions of sidewall deformation

The applied position of the fluctuation is the other parameter which is investigated in this research. Two models of period 0.004s with the Eq.(3) are simulated at the position of l_p=0 and l_p=300μm respectively. The average droplet sizes of these two models show some difference but not a huge distinction that the l_p=300μm case makes the droplet larger.

The velocity vector graphs of droplets when the moving side wall is crushing into the channel are shown in Figure(4(b)-(c). From the velocity vector of both cases, the downstream fluctuation gives higher velocity to the front of the droplet while the l_p=0 case forces it to the back part of the droplet.

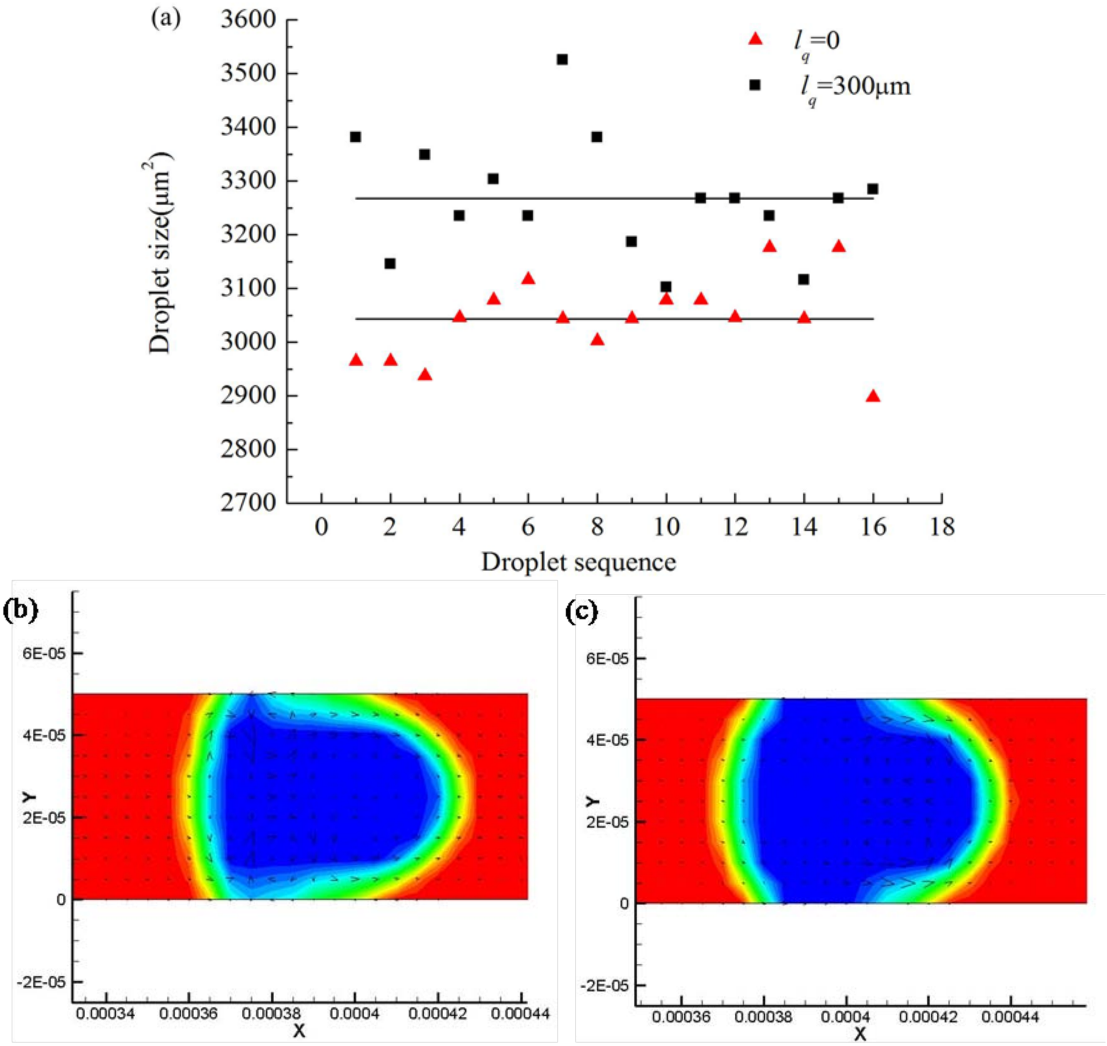


Figure 4. The droplet size under different applied position. (a) Scatter diagram of droplet sizewith the average value of each case; (b) droplet velocity vector of l_q=0; (c) droplet velocity vector of l_q=300

4 Conclusions

The effects of the forced deformation of the sidewall are numerically investigated during the droplet generation in a microchannel with the main width of 50μm. For the droplet size, the applied position shows the effect that the size could be increased when the fluctuation is deformed at the downstream of the junction but the lower nomodispersity also could be induced. The form of q in the Eq.(2) give the special influence that it can separate the droplets into two groups of different sizes every other one.

References

[1] Tarchichi N et al (2013) New regime of droplet generation in a T-shape microfluidic junction. *Microfluid Nanofluid*, vol. 14, pp45-51.
[2] Garstecki P et al (2006) Formation of droplets and bubbles in a microfluidic T-junction—scaling and mechanism of break-up. *Lab on a Chip*, vol. 6, pp437-446.
[3] Christopher G et al (2008) Experimental observations of the squeezing-to-dripping transition in T-shaped microfluidic junctions. *Physic Review E,* vol. 78, pp36-317
[4] Menech M et al (2008) Transition from squeezing to dripping in a microfluidic T-shaped junction. *Journal of Fluid Mechanics,* vol. 595, pp141–161
[5] Thorsen T et al (2001) Dynamic pattern formation in a vesicle-generating microfluidic device. *Physic Review Letter,* vol. 86, pp4163-4166.
[6] Nisisako T et al (2002) Droplet formation in a microchannel network. *Lab on a chip,* vol. 2, pp24-26.
[7] Cubaud T, Mason T (2008) Capillary threads and viscous droplets in square microchannels. *Physic Fluids,* vol. 20, pp53-302
[8] Sivasamy J et al (2011) An investigation on the mechanism of droplet formation in a microfluidics T-junction. *Microfluid Nanofluid,* vol. 11, pp1–10
[9] Gunther A et al (2005) Micromixing of miscible liquids in segmented gas–liquid flow. *Langmuir,* vol. 21, pp1547–1555
[10] Hsiung, S. K., Chen, C. T. and Lee, G. B. (2006) Micro-droplet formation utilizing microfluidic flow focusing and controllable moving-wall chopping techniques. *Journal of Micromechanics and Microengineering,* vol. 16, pp2403