Analytical-numerical investigation of unequal sized droplets of dilatants' fluid in T-junction with unequal length branches

Ahmad Bedram

F Ph.D. in Mechanical Engineering, Faculty of Imam Ali, South Khorasan Branch, Technical and Vocational University (TVU), Tabas, Iran, Email: bedram@chmail.ir

ABSTRACT

In this paper we performed an analytical and 3D numerical investigation for breakup of non-Newtonian droplets in a non-Newtonian carrier fluid. The system geometry is T-junction with unequal length branches that can generates unequal sized droplets. Analytical and 3D numerical results of this research have good agreement with each other. We investigated variation of many quantities during the breakup process such as: flow rate ratio of branches, velocity ratio of branches, droplet length in each branch, whole length of droplet, vorticity, pressure and effective viscosity. The analytical results of this paper reveal the variation of flow rate ratio of branches, velocity ratio of branches, droplet length in each branches and whole length of droplet during the breakup process. The results showed the flow rate ratio of branches and the velocity ratio of branches is constant during the breakup process. Also we observed the droplet length in each branches and whole length of droplet increase linearly during the breakup process. The results showed vorticity near the surface of the droplet is 3 to 7 times the vorticity of the inside of the droplet, therefore the mixing of the materials of the droplet inside increases. Also the maximum vorticity is before reaching the droplet to the center of junction.

KEYWORDS

Non-Newtonian fluid, Assymetric T-junction, Analytical solution, Numerical simulation, 3D,

1. Introduction

Microfluidic processes have various applications in many industries [1-5] such as pharmaceutical and chemical. There are several methods for breakup of droplets. A T-junction with unequal width branches can breaks a droplet to unequal parts [6]. A wave can also produces a droplet from a flowing fluid in a channel [7]. Another method is using a T-junction with valve that can produces unequal sized parts from an initial droplet [8]. Analytical solution also is presented for T-junction with valve [9].

In this research breakup of an initial non-Newtonian droplet to unequal size parts using a T-junction with unequal length branches is investigated. Research method is analytical solution and 3D numerical simulation.

2. Research Method

The system geometry is showed in Fig. 1. The boundary condition of inlet of the system is "velocity constant" and the boundary condition of the system outlets are "pressure constant". 3D numerical simulation is done by a Volume Of Fluid[1] algorithm.

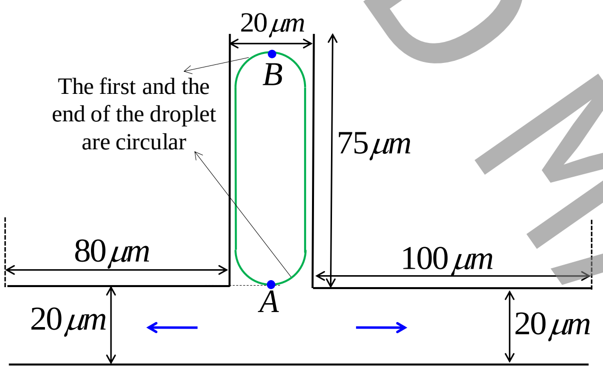

Fig. 1. The geometry of T-junction with unequal length branches. The droplet is approaching the junction center. The depth of the geometry (perpendicular to the paper) is 6 μm. The initial drop length (The distances of points A and B) is 70 μm.

A benchmark problem [10] considered for validation of numerical simulation results. Fig. 2 shows the comparison of our numerical and benchmark problem results that a good agreement is seen.

[1] VOF

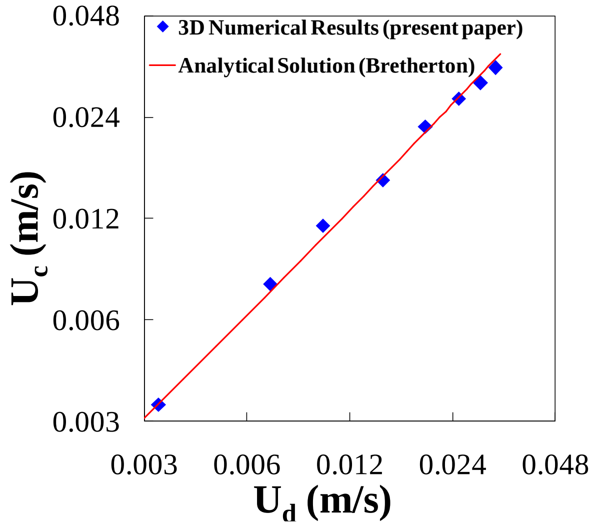

Fig. 2. Comparison of Brethertons equation [10] for droplet speed in the circular tube by the 3D numerical simulation results of the present research. The horizontal and vertical axes have logarithmic scale.

3. Results and Discussion

Fig. 3 shows our analytical and numerical results of flow rate ratio in branches. As seen, analytical and numerical results have very good agreement. The flow rate ratio is constant during the breakup process.

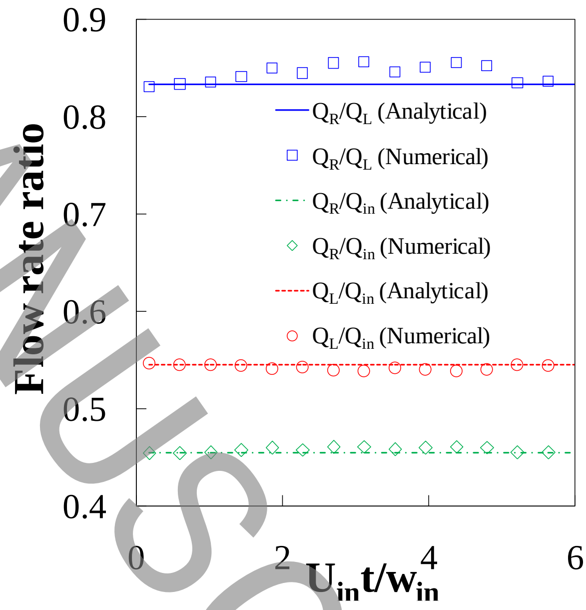

Fig. 3. Analytical and numerical results for the ratio of the right branch flow rate to left branches flow rate (Q_R/Q_L) and the ratio of the right branch flow rate to inlet channel flow rate (Q_R/Q_{in}) and the ratio of the left branch flow rate to inlet channel flow rate (Q_L/Q_{in}) during the breakup process.

Fig. 4 shows breakup process of the droplet in T-junction with unequal length.

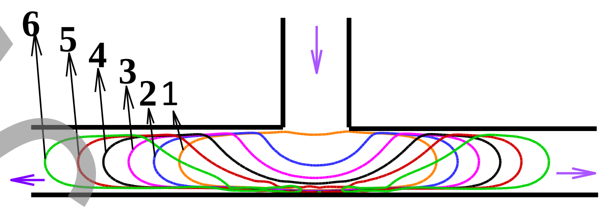

Fig. 4. Droplet breakup process in the T-junction with unequal length branches. After breakup, the smaller droplet enters the right branch and the larger droplet enters the left branch.

Fig. 5 shows five sections of droplet during the breakup process that the results of this sections presents in the next figures.

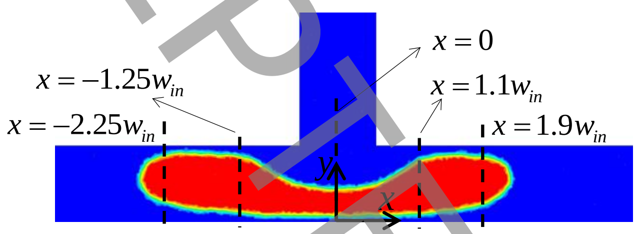

Fig. 5. The droplet image during the droplet deformation in the center of junction. Five sections from droplet are selected to report the results.

Fig. 6 shows the pressure of fluid in five different sections of droplet during the droplet deformation in the center of junction. As seen, the pressure in the center of junction has its maximum.

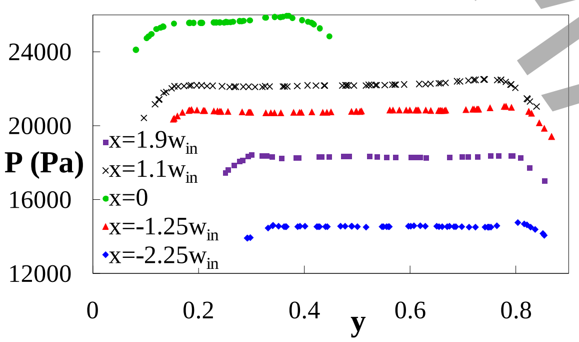

Fig. 6. The fluid pressure in five different sections of droplet during the droplet deformation in the center of junction. The five selected sections cover first to end of the droplet (Fig. 5). The location (horizontal axis) is dimensionless using the inlet channel width (*w*).

Fig. 7 shows the vorticity magnitude of fluid in five different sections of droplet during the droplet deformation in the center of junction.

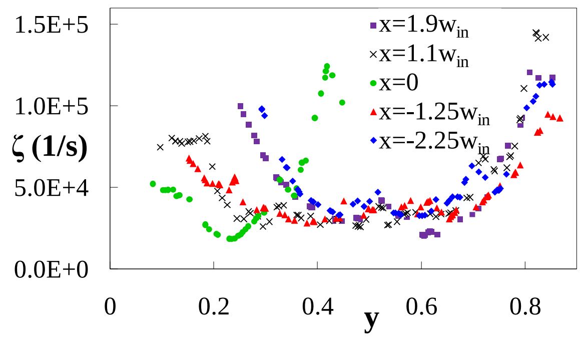

Fig. 7. Vorticity in five different sections from first to end of the droplet (Fig. 5 shows the sections) during the droplet deformation in the center of junction. The location values that are shown in horizontal axis are dimensionless using the inlet channel width.

4. Conclusions

In this paper breakup of a non-Newtonian droplet in a non–Newtonian continuous fluid using T-junction with unequal length branches investigated. We used 3D numerical simulation (VOF algorithm) and analytical solution for presenting the results. The analytical and numerical solutions have good agreement. Also the numerical results compare with an analytical benchmark problem and an excellent agreement seen. The results show that the flow rate ratio is constant during the breakup process.

5. References

[1] B. L. Khoo, G. Grenci, Y. B. Lim, S. C. Lee, J. Han, C. T. Lim, Expansion of patient-derived circulating tumor cells from liquid biopsies using a CTC microfluidic culture device, *Nature protocols*, 13(1) (2018) 34-58.

[2] Q. Xiong *et al.*, Magnetic nanochain integrated microfluidic biochips, *NATURE COMMUNICATIONS*, 9(1743) (2018) 1-11.

[3] F. S. Ruggeri *et al.*, Microfluidic deposition for resolving single molecule protein architecture and heterogeneity, *NATURE COMMUNICATIONS*, 9(3890) (2018) 1-12.

[4] L. D. Maio, F. Dunlop, Sessile Drop on Oscillating Incline. *Journal of Applied Fluid Mechanics*, 11(6) (2018) 1471-1476.

[5] J. Q. Feng, A Computational Study of High-Speed Microdroplet Impact onto a Smooth Solid Surface, *Journal of Applied Fluid Mechanics*, 10(1) (2017) 243-256.

[6] A. Bedram, A. Moosavi, Droplet breakup in an asymmetric microfluidic T junction, Eur. Phys. J. E, 34(78) (2011) 1-8.

[7] X. Hu, T. Cubaud, Viscous Wave Breaking and Ligament Formation in Microfluidic Systems,

PHYSICAL REVIEW LETTERS, 121(044502) (2018) 1-5.

[8] A. Bedram, A. E. Darabi, A. Moosavi, S. Kazemzade, Numerical Investigation of an Efficient Method (T-Junction With Valve) for Producing Unequal-Sized Droplets in Micro- and Nano-Fluidic Systems, Journal of Fluids Engineering, 137(031202) (2015) 1-9.

[9] A. Bedram, A. Moosavi, S. Kazemzade Hannani, Analytical relations for long-droplet breakup in asymmetric T junctions, PHYSICAL REVIEW E, 91(053012) (2015) 1-11.

[10] F. P. Bretherton, The motion of long bubbles in tubes, J. Fluid Mech., 10(2) (1961) 166-188.

↑ please level both columns of the last page as far as possible. ↑