

Analytical-Numerical Investigation of Unequal Sized Droplets of Dilatants' Fluid in T-Junction with Unequal Length Branches

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ABSTRACT: In this paper we performed an analytical and 3 dimensional 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 3 dimensional 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.

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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 3 Dimensional (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 (VOF) algorithm.

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.

3. Results and Discussion

Fig. 3 shows our analytical and numerical results of flow

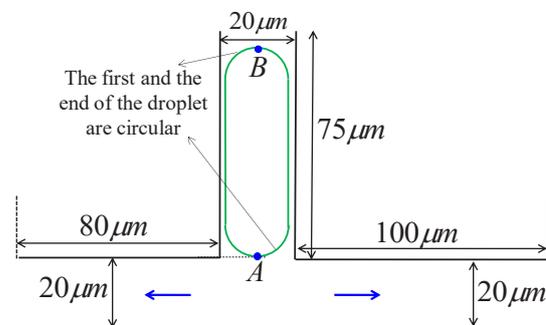


Fig. 1. The geometry of T-junction with unequal length branches. The droplet is approaching the junction center. The depth of the geometry (perpendicular to the paper) is $6\ \mu\text{m}$. The initial drop length (The distances of points A and B) is $70\ \mu\text{m}$.

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

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

Fig. 6 shows the pressure of fluid in five different sections

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of droplet during the droplet deformation in the center of junction. As seen, the pressure in the center of junction has its maximum.

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

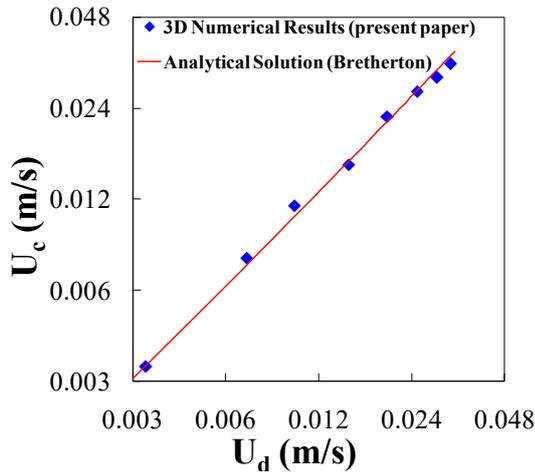


Fig. 2. Comparison of Bretherton's equation [10] for droplet speed in the circular tube by the 3D numerical simulation results of the present research. The horizontal and vertical axes have logarithmic scale.

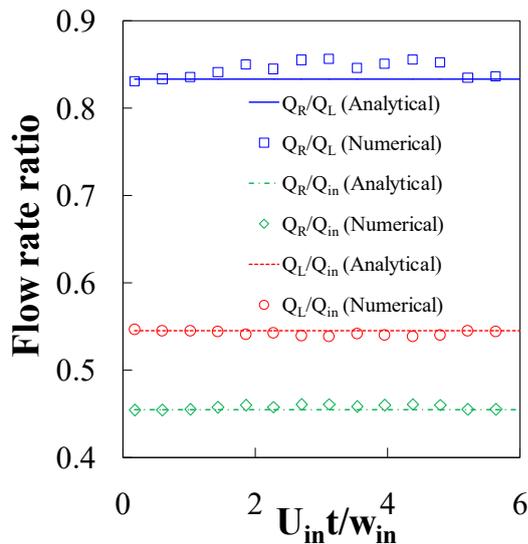


Fig. 3. Analytical and numerical results for the ratio of the right branch flow rate to left branches flow rate (Q_R/Q_L) and the ratio of the right branch flow rate to inlet channel flow rate (Q_R/Q_{in}) and the ratio of the left branch flow rate to inlet channel flow rate (Q_L/Q_{in}) during the breakup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

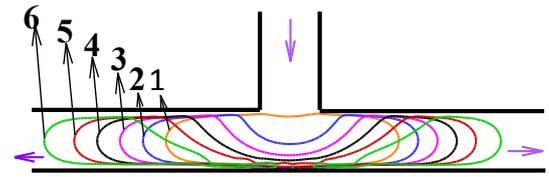


Fig. 4. Droplet breakup process in the T-junction with unequal length branches. After breakup, the smaller droplet enters the right branch and the larger droplet enters the left branch.

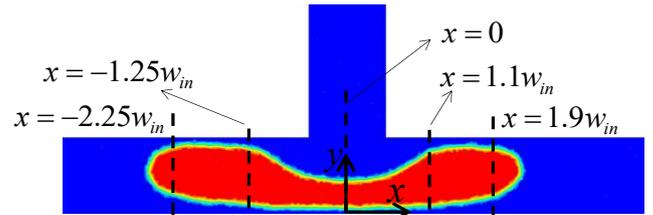


Fig. 5. The droplet image during the droplet deformation in the center of junction. Five sections from droplet are selected to report the results.

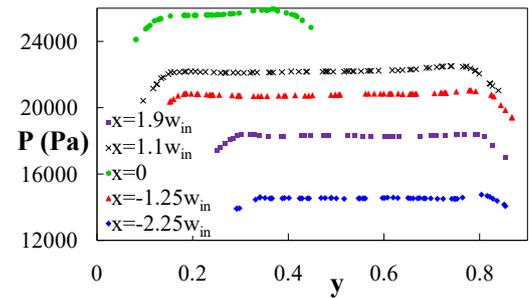


Fig. 6. The fluid pressure in five different sections of droplet during the droplet deformation in the center of junction. The five selected sections cover first to end of the droplet (Fig. 5). The location (horizontal axis) is dimensionless using the inlet channel width (w).

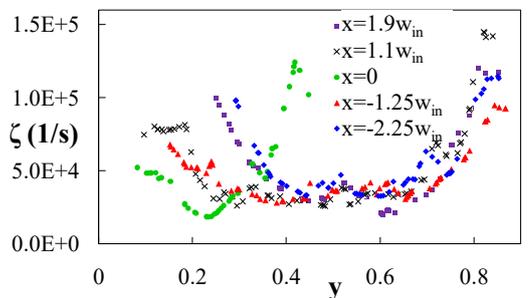


Fig. 7. Vorticity in five different sections from first to end of the droplet (Fig. 5 shows the sections) during the droplet deformation in the center of junction. The location values that are shown in horizontal axis are dimensionless using the inlet channel width.

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.

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