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Behavior of Droplets in Microfluidic System with T-Junction

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***Abstract*—**Micro droplet formation is considered as a growing emerging area of research due to its wide-range application in chemistry as well as biology. The mechanism of micro droplet formation using two immiscible liquids running through a T-junction has been widely studied.

We believe that the flow of these two immiscible phases can be of greater important factor that could have an impact on out-flow hydrodynamic behavior, the droplets generated and the size of the droplets. In this study, the type of the capillary tubes used also represents another important factor that can have an impact on the generation of micro droplets.

The tygon capillary tubing with hydrophilic inner surface doesn't allow regular out-flows due to the fact that the continuous phase doesn't adhere to the wall of the capillary inner surface.

Teflon capillary tubing, presents better wettability than tygon tubing, and allows to obtain steady and regular regimes of out-flow, and the micro droplets are homogeneoussize.

The size of the droplets is directly dependent on the flows of the continuous and dispersed phases. Thus, as increasing the flow of the continuous phase, to flow of the dispersed phase stationary, the size of the drops decreases. Inversely, while increasing the flow of the dispersed phase, to flow of the continuous phase stationary, the size of the droplet increases.

***Keywords*—**Microfluidic system, micro droplets generation, T-junction.

I. Introduction

DURING recent years, the field of microfluidics has greatly diversified: it allows the transport of very small fluid volumes (nanoliter) through channels of micrometer diameter. This miniaturization is increasingly used to build a wide range of tools with applications, for example, the use of micro droplets as chemical reactors in which one can study several phenomena [1].

To make best use of these droplets in the field of chemistry, it is necessary to understand the experimental conditions of their formation [2]-[7] and flow in micro- channels.

It is well known that the droplets are obtained by two immiscible phases in contact, the aqueous (dispersed phase), and continuous phase which is the oil.

The formation of a droplet is governed by the shear applied by the continuous phase of the dispersed phase. This will distort the shear interface between the two fluids to the generation of a droplet [8].

Several geometries can lead to the generation of droplets but in this work we used a T-junction geometrical device. This is the first technique for producing droplets periodically and controlled within micro channels which has been proposed by Thorsen et al. [9]. The flow of continuous phase in the main channel and the dispersed phase are brought together into the main channel by a perpendicular to the later sub channel. It invades the main channel and eventually drops off [10].

II. Materials and Methods

Oil with surface tension of 33.3 mN/m at 25 °C measured by LAUDA TD 3was used as the continuous phase and an aqueous solution containing a food dye was used as dispersed phase. The food dye is used as a marker in order to observe the droplets.

The microfluidic system comprises of two capillary tubes, each carrying one phase. The system is equipped with tow syringe pumps (AgiliaInjectomat® and Vial Medical ®). These two capillaries are connected via connectors to a T-junction where occurs the formation of droplets. Recent circulate within a third capillary also connected to the T-junction via a fixed connection and under an optical microscope equipped with a CCD camera.

Two types of capillary tube (Table I) were used in order to optimize the correct microfluidic system to produce uniform droplets.

The size of droplets was measured using the software Image J image processing.

TABLE I
Characteristics of Capillaries

Symbol	Internal diameter (µm)	Pressure (psi)
Tygon	640	1650
Teflon	500	700

These different flow regimes are observed for flow rates of continuous phase between 0.5 and 5 ml/h and flow of dispersed phase between 0.3 and 2 ml/h.

In more, a disturbing phenomenon has been observed; it consists of the coalescence of drops as shown in Fig. 1.

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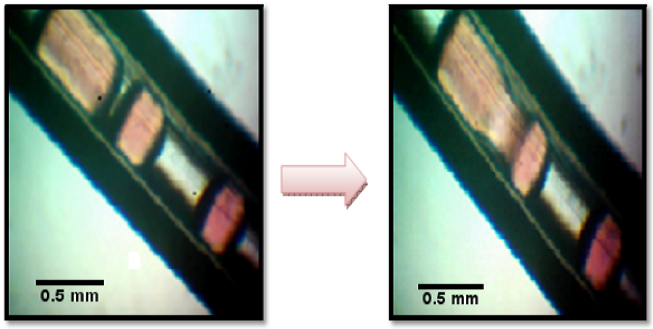


Fig. 1 Coalescence of two drops

Using Tygon capillary and for different flow rates of the continuous phase and the dispersed phase of non-regular flow regimes have been observed [11].

For the hydrophilic type of the capillary Tygon some droplets produced had a tendency to adhere to the capillary inner-wall and this is due to the high affinity between the dispersed phase and the hydrophilic capillary wall Tygon.

Clinging to the wall, drops are hindered which causes them to coalesce with the drops continue.The phenomenon of Rayleigh-Plateau is shown in Fig. 2 [12].

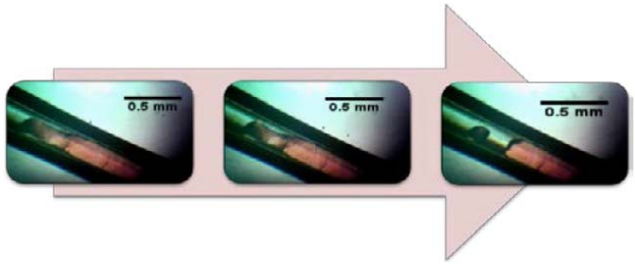


Fig. 2 Rayleigh- Plateau

This instability is related to the phases that have the greatest interfacial tensions. From the calculated values of interfacial tensions between different continuous phases and the dispersed phase, the couples silicone / water and paraffin / water are the largest values. That is why this instability was observed only with silicone oil and paraffin oil.

Moving from a capillary Tygon to Teflon capillary with wettability properties offers a more favorable difference compared to the flow regimes observed.

The drops obtained with Teflon capillary and for a the continuous phase flow ranging from 1 to 6 ml/h f of the dispersed phase ranging from 0.2 to 1 ml/h have uniform size and are separated from the same distance which gives regular regimes such as in Fig. 3.

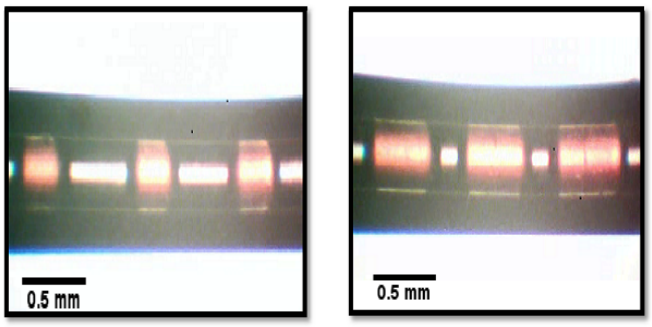


Fig. 3 Regular regime obtained for (Qc= 1ml/h, Qd=0,6ml/h) on the left end for (Qc=6ml/h, Qd=0,4ml/h) on the right

After having achieved these regimes of drops, their sizes were characterized in order to monitor their evolution as a function of the flow rate variation of the two phases.

We observe, as described in the literature, that the droplet size increases as function of flow rate increase of the dispersed phase for a fixed value of flow rate of the continuous phase and decreases with increasing the flow rate of the continuous phase to a fixed flow value of the dispersed phase (Fig. 4).

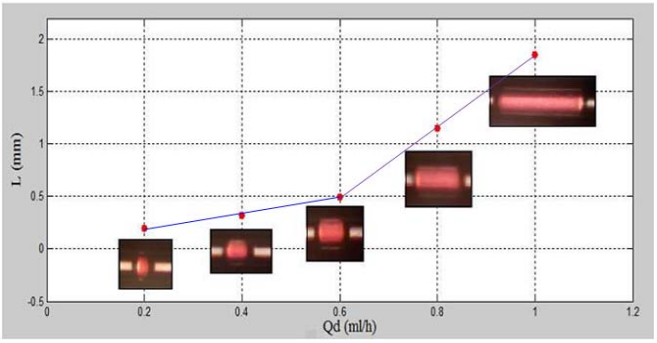


Fig. 4 Evolution of the droplet size versus the flow rate of the dispersed phase with Qc = 1ml/h

At fixed flow rate of the continuous phase, the length of the drops increases with respect to the increase of the flow rate of the dispersed phase.

From the figures obtained, we can divide the flow values of the dispersed phase into two zones. In each of them, changes the length of the drops is an increasing straight. The two lines have different slopes. We note that the abscissa of the intersection of the two lines is 0.6 ml/h, notes Qd*.

The mechanism of droplet formation is coupled phenomena elongation effect of dispersed phase and the shear applied by the continuous phase at the interface (Fig. 5) [13].

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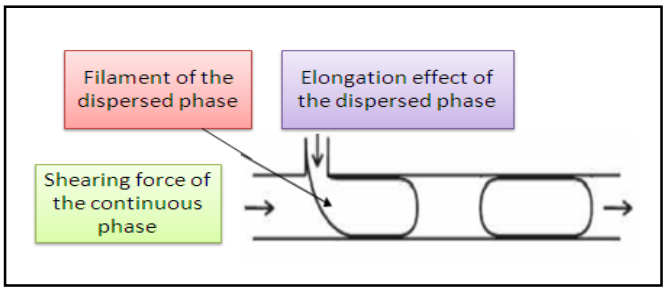


Fig. 5 Detachment mechanism of a drop

When the flow rate of the dispersed phase is less than Qd*, the shear force exerted by the continuous phase is enough to cause the detachment of the drop of the filament dispersed phase. The shear force is predominant in this interval. When the flow rate of the dispersed phase is greater than Qd *, the shear force exerted by the continuous phase of the filament of the dispersed phase is not enough to cause detachment of the drop of the filament. The phenomenon of drop formation is controlled by the flow of the dispersed phase, therefore by the effect of the elongation of the dispersed phase which stage dominant in this interval.

At the opposite, when the ratio of flow rates decreases the droplet size increases as shown in Fig. 6.

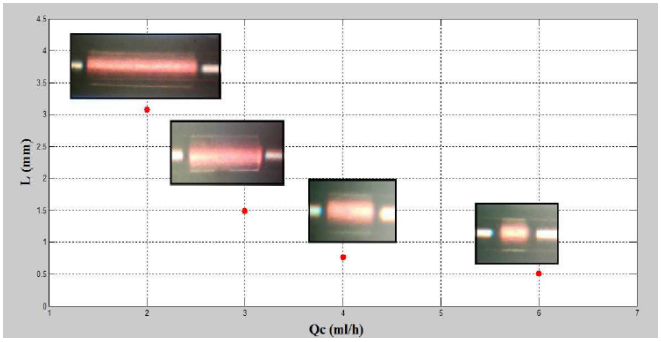


Fig. 6 Evolution of the droplet size as a function of the flow rate of the continuous phase with Qd = 0.6 ml/h

The length of the droplets is reduced with increased throughput of the continuous phase. The values of flow of the continuous phase can be divided into two intervals. In each interval the variation of the length of the drops is decreasing. Both lines have two different slopes.

We note that the abscissa of the intersection of two lines which we denote Qc* is 4 ml/h. When the flow of the continuous phase is less than Qc*, The shear rate increases but slightly allowing the dispersed to lie at the intersection phase. The effect of elongation is predominant in this interval.

When the flow of the continuous phase is greater than Qc*, The shear rate is becomes more important. The droplet didn't have enough time to grow. The rate of shear outweighs the effect of the elongation of the dispersed phase.

The ratio of flow is useful for determining which droplets: pinch, drip, or jet [14]. The values of the ratios obtained in the course of manipulations show that we situate in the squeezing regime.

III. Conclusion

The understanding of the physical processes that affect the formation of drops is desirable because the production of uniform drops, regular has many applications.

Through this study we have chosen the most appropriate type of hair and the range of flow rates of the two phases in which regular diets generation drops is obtained.

The results of this study can be summarized as: The capillary Tygon with hydrophilic inner surface, does not allow regular flows, and due to the continuous phase that does not adhere to the capillary inner wall. In contrast, the capillary Teflon, which has better wetting properties, allows regular stable flow regimes with uniform droplet size to be obtained.

The droplet size is directly dependent on the flow of both continuous and dispersed phases. Thus, by increasing the flow rate of the continuous phase to flow in the fixed dispersed phase, the droplet size decreases. Conversely, increasing the flow rate of the dispersed phase at the fixed rate of the continuous phase, the droplet size increases.

Nomenclature

Q_d : flow of dispersed phase (mL/h)
Q_C : flow of continuous phase (mL/h)
L : length of the drop (m)

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