ELECTROSPRAYING MICROFLUIDIC CHIP FOR EMULSION GENERATION AND SATELLITE DROPLET SEPARATION

H.C. Lin¹, M.H. Lee¹, C.H. Yeh¹, Y.C. Chung² and Y.C. Lin¹,*

¹Department of Engineering Science, National Cheng Kung University, Tainan, Taiwan and
²Department of Mechanical Engineering, Ming Chi University of Technology, Taipei, Taiwan

ABSTRACT

This research has successfully generated the uniform emulsions in electrospraying microfluidic chip, and the satellite droplets of various sizes were separated in the separation channels by an electric field. The emulsion size is controlled by the ratio of water and oil phase flow rates, and the electric filed. The electric field affected on emulsion size when the ratio of water and oil phase flow rates is excess of 18. When the ratio is 73, the minimum emulsion size is 0.98 μm under the electric field at 5000 V/mm. The separation channels precisely differentiated the various satellite droplets in diameter from big size to small size using the electric filed.

KEYWORDS: Electrospraying, Microfluidic chip, Satellite droplet

INTRODUCTION

The flow focusing geometry is commonly used to generate droplets whose size is easily controlled by the flow rates [1, 2]. Hsuing et al. used an air control system and create a moving-wall structures to generate tiny droplets which about 20 micrometers in diameter [3]. One potential means of overcoming these limitations is the use of electrospray. The electrospraying causes the liquid surface to form the Taylor cone by an electric force and when the electric field force was excess of the surface tension, the microdroplets are generated by electrospraying method [4]. For practical applications, the immiscible liquids flowed in the channel of microscale have been reported. For example, Song et al. presented a microfluidic system that forms aqueous droplets in a continuous flow of a water-immiscible fluid [5]. Zhao et al. proposed a strategy to control the flow of immiscible liquids in microchannels by patterning surface free energies, which were applied in the fabrication of a semipermeable membrane [6]. Hisamoto et al. used an immiscible system to develop a new method of performing multi-ion sensing [7]. The proposed immiscible system maintains stable multilayer interfaces for a long distance and completes the ion pair extraction reaction inside the microchannel.

THEORY

In this research, the microfluidic chip consists of the cross-junction microchannels and parallel ITO electrodes, as shown in Figure 1(a). The separation position consists of channels and ITO electrodes, as shown in Figure 1(b). The emulsion is formed due to the hydrodynamic-focusing and electric field effect. Because the disperse phase (water phase) and continuous phase (oil phase) are immiscible, the continuous phase has compressed the disperse phase to generate the hydrodynamic-focusing. The parallel electrodes have induced the electric field effect in the cross-junction position. In addition, the generated satellite droplets were induced to generate electric force by ITO electrodes and the strength of electric force proportional to size and shift and droplet. Therefore, the different sizes of satellite droplets was separated into the individual channels according to the strength of electric force exerted on the satellite droplets as shown in enlarged Figure 1(b).

EXPERIMENTAL

The gap size of ITO electrodes is 400 μm and the width of the cross-junction microchannel is 100 μm. In the cross-junction microchannels, a central channel is water phase, and the side channels are oil phases. The water and oil were injected into the microfluidic chip and the flow rats were controlled by syringe pumps. In the materials, the water phase is DI water and the oil phase is mineral oil (6 % wt span 80) which are flowing in the microchannels. When both flowed pass through the cross-junction position in the microchannel, the Taylor cone was formed and then the droplets was gen-
generated by controlled flow rates respectively. In the experiment, flow rate of oil phase is fixed and flow rate of water phase was regulated for obtaining the emulsion of different sizes. Moreover, we applied electric field, from 0 to 5000 V/mm, to measure variation of the emulsion size. For separation of satellite droplets, we applied voltage at 200 V to separate the satellite droplets.

RESULTS AND DISCUSSION

As shown in Figure 2, the Taylor cone is appeared in cross-junction positions and the emulsion is generated. When the fixed oil phase is 6 μL/min and water phase is decreased from 1.3 to 0.08 μL/min, the emulsion size is from 43.3 to 17.7 μm. Then, the applied electric filed is increased from 0 to 5000 V/mm, the emulsion size was decreased. In the ratio of water and oil phase flow rates was excess of 18, the influence of the electric filed was obviously observed and the minimum emulsion size is 0.98 μm under the 5000 V/mm of electric field and 73 of the flow rate ratio, as shown in Figure 3. Because the size of the satellite droplet is proportional to the strength of the induced electric force, the satellite droplets of various sizes were separated precisely by various electric filed (Figure 4). The various droplet sizes (2.1, 2.9, and 3.9 μm) were successfully separated into the first, second, and third channel, respectively (Figure 5).

![Figure 2](image_url)

*Figure 2. The emulsion size was affected by the ratio of water flow rate and oil flow rate, and electric field. When the oil flow rate was fixed in 6 μL/min, the effect of electric field was observed below the 0.33 μL/min of water flow rate.*

![Figure 3](image_url)

*Figure 3. The relationship between the emulsion size and electric field under various ratios of water flow rate and oil flow rate.*

![Figure 4](image_url)

*Figure 4. The separation channels differentiated the various satellite droplets using the electric field. The satellite droplets entered into (a) channel 1, (b) channel 2, and (c) channel 3.*
CONCLUSION

We have successfully demonstrated the electrospraying microfluidic chip to produce the emulsions and separated the satellite droplets of various sizes by the electric field. The parallel electrode provided the stable electric field to obtain the Taylor cone, which could produce the micro-sized emulsions with a narrow size distribution. When increasing the electric field and ratio of water and oil flow rate, it could generate smaller emulsion size, and the minimum emulsion size was 0.98 μm. According to the size, the generated satellite droplets were precisely differentiated in the respective channels by the applied electric field. The approach will provide many potential usages for pharmaceutical applications.

ACKNOWLEDGEMENTS

The authors would like to thank the Center for Micro/Nano Technology, National Cheng Kung University, Tainan, Taiwan, ROC for access to their equipment and for their technical support. Funding from the Ministry of Education and the National Science Council of Taiwan, ROC under contract no. NSC 97-2221-E-006 -222 -MY3 is gratefully acknowledged.

REFERENCES


CONTACT
*Y. C. Lin, tel: +886-6-2762395; yuclin@mail.ncku.edu.tw