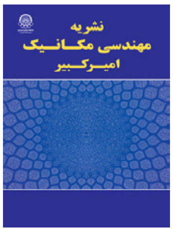

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(7) (2021) ***-3
DOI: 10.22060/mej.2020.18250.6783

Control of droplet size in a two-phase microchannel using PID controller: A novel experimental study

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ABSTRACT: Precise droplet generation with controllable precise size is the target of this research. For this purpose, a flow focusing micro-channel is constructed using photolithography. Two syringe pumps are used, one for injecting discrete phase flow (DI water) and another for injecting continuous phase flow (oil). The Meros high speed camera is used for recording the image of droplets, and a fast image processing algorithm is used to calculate the size of the droplets. To regulate the size of the droplet, the PID controller is used due to its ease of implementation and robustness. The flow rate of the continuous phase flow is the control input and the size of the droplets is the output of the closed-loop system. Experimental tests are done by considering three desired droplet diameters, i.e. 100, 140 and 160 μm. To show the disturbance rejection characteristic of the designed closed-loop system, the flow rate of the discrete phase flow is changed stepwise. Due to this disturbance, the transient response of the system changed, but the controller attenuates this disturbance and regulates the system to the desired size. The experimental tests show that the designed closed-loop microfluidic system can generate droplets with desired precise size.

Review History:

Received: 2020-04-11
Revised: 2020-09-20
Accepted: 2020-10-25
Available Online: 2020-12-02

Keywords:

Microchannel
Active control
PID controller
Two-phase flow
Micro-droplet

1- INTRODUCTION

Microfluidic digital equipment has attracted a lot of attention to laboratory applications. By isolation of water droplets containing biological and biochemical components in an oily environment, reactors can move without discretization and contacting each other [1-2]. The required energy needs to transport to the surface of the droplet (discrete phase) to create a droplet from continuous water. This energy may be from the hydraulic pressure of the fluid which is called passive droplet generation. However, if external energy enters to create a droplet, it is called active droplet generation [3].

Micro-channels used to generate droplets have various shapes. Among them, the two shapes used the most in droplet generation are T-shaped microchannel [4-5], and concentrated flow focusing channels [6-7]. The flows in both phases are controlled either by using syringe pumps, which generate constant flows for each phase or by using pressure regulators that provide the required pressure in each phase [8]. While the droplet is being generated, the energy coming from syringe pumps or pressure controller separated droplet from a discrete flow.

2- METHODOLOGY

To implement the control strategy and generating precise micro-droplets the experimental setup is built at first. The experimental setup consists of a microchannel, two syringe pumps, a high-speed camera, and a PID controller all of which are described in the following subsections.

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2-1- Microchannel

The mold of the microchannel was built first by photolithography. To build a microchannel, the built mold is put in a plastic container. Then the 6-millimeter layer of a mix of PDMS and hardener is poured into the SU-8 mold, and it is kept at 90 °C. When the PDMS is polymerized, it is separated from the mold and its additional parts are cut. By separating the PDMS from the mold a transparent microchannel is built. The geometry and the dimensions of the microchannel are presented in Fig. 1.

2-2- Syringe pumps

To create flows of each phase, two syringe pumps from two different manufacturers are used. LAMBDA-VIT-FIT(HP) pump is used for the discrete phase and the Zistrard suction-injection pump (model ISP94-1) for the continuous phase. In this research, the LAMBDA pump has a constant flow rate, and the Zistrard pump is used to control the droplet size by adjusting the flow ratio.

2-3- Fluids

In this research, a mixture of liquid paraffin (Paraffin oil; CAS Number: 8012-95-1) and 10% Span 80 (Span80; CAS Number: 1338-43-8) is used for the continuous phase and

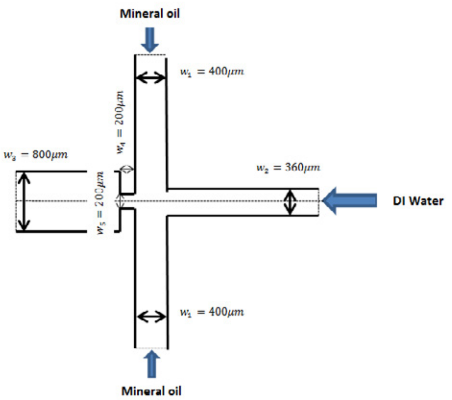

Fig. 1. Dimensions of the microchannel built to control the size of generated droplets

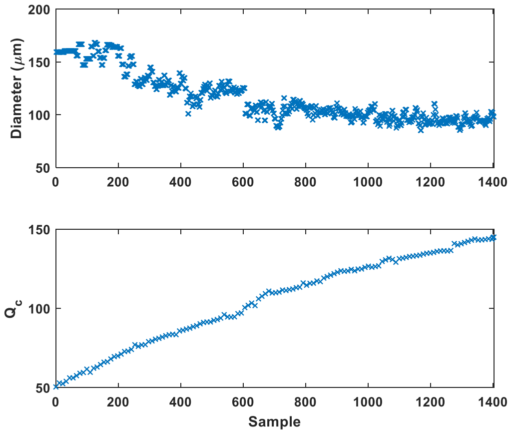

Fig. 2. Diagram for the desired diameter of 100 versus time-step, and diagram of the continuous flow (oil) versus time-step (control command) (*RSME*=5.27)

double-distilled water is employed as the droplet generating phase.

2-4- Image processing program

To measure the size of the droplets, an image processing program was used. This program consists of four stages including taking photos, cutting photos, making them binary and recognizing droplets. After that, the diameter of the droplet is measured based on the number of pixels. Finally, based on its ratio to the width of the channel, the diameter is measured based on a micrometer.

2-5- Controller loop

Finally, after connecting the camera, pumps, and computer, a control algorithm is designed. A PID controller is used to control the system and reaching the desired size of the droplets. The reason is the simplicity of the setup and its strength, which makes it popular among most controllers. In the proposed feedback control loop, the flow rate of the continuous phase is the control input, and the droplet size is the output.

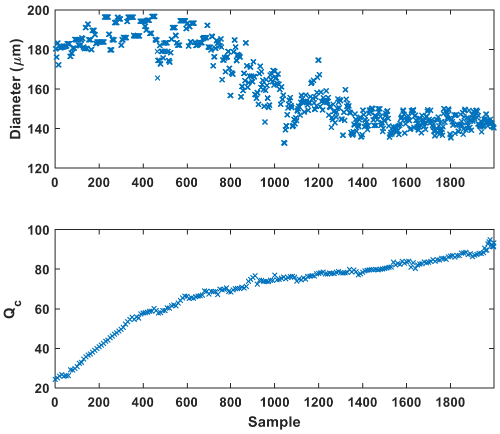

Fig. 3. Diagram for the desired diameter of 140 versus time-step, and diagram of the continuous flow (oil) versus time-step (control command) (*RSME*=3.4)

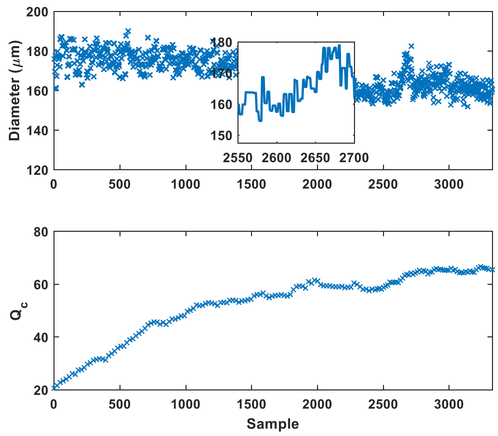

Fig. 4. The effect of the disturbance and the response of the controller (*RSME* = 0.48).

3- RESULTS AND DISCUSSION

To show the performance of the controller, two different droplet sizes to desired droplet size ratio (D/D_d) are chosen. The flow rate of the discrete flow (double-distilled water) was set at 145.2 mm^3/min by the syringe pump. By increasing the continuous flow rate and consequently decrease in flow ratio, the diameter of the droplets has an increasing trend at first which is due to the delay between the exerted flow and its effectiveness on the channel flow. The fluctuation around the setpoint is assessed by RMSE.

Figs. 2 and 3 show the performance of the control feedback loop in generating droplets with precise size. As shown in these Figures, the PID controller can set the size of the droplets to the desired value.

To show the performance of the closed-loop system in dealing with disturbances, we change the flow rate of the discrete phase, which was assumed to be constant. Fig. 4 shows the performance of the system in which the closed-loop control system can overcome the disturbances and uncertainties in the system.

4- CONCLUSIONS

The results of the experiment showed that the designed and built closed-circuit microsystem was capable of creating droplets with various diameters with high accuracy and robustness. Some fluctuations were observed in the experimental tests which were related to the vibrations of the electric motor and mechanical accessories of the syringe pump. The future work of the researchers would be to remove these fluctuations by MEMS approaches.

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HOW TO CITE THIS ARTICLE

*S. Motaghi, M. Nazari, N. Sepehri, A. Mahdavi , Control of droplet size in a two-phase microchannel using PID controller: A novel experimental study, Amirkabir J. Mech Eng., 53(7) (2021): ***-3.*

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