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Design and Fabrication of a Droplet Generator Microfluidic Device by Stereolithography 3D Printing

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ABSTRACT

Droplet formation is an important process for different types of biological analysis. In this work, a water-in-oil droplet-generating microfluidic device was designed, fabricated and tested. The microfluidic chip was fabricated by stereolithography 3D printing and its performance was evaluated using syringe pumps. In the following hyperlink you can find complementary visual material about the project: DRIVE FOLDER

1 INTRODUCTION

The goal of developing Lab-on-a-Chips (LOC) is to transfer laboratory procedures to small devices to reduce the cost of the process and possibly increase the accuracy and precision of analysis. LOC devices can integrate microfluidic channels and micro-electromechanical systems (MEMS) for different biological applications. One of the most common procedures used in biological research is the generation of microdroplets. This technique can be employed in a variety of studies, including Flow Cytometry [1], Spectrometry [2], and applications such as drug encapsulation and drug delivery [3]. Each application requires different parameters for droplet formation, such as size, material, generation speed, and distance between droplets. The most important thing is to ensure the creation of discrete volumes with the use of immiscible phases [4]. Currently, there are very sophisticated models, but they require high-resolution equipment. In this project, we designed and fabricated a microfluidic device capable of generating droplets from two inputs, similar to T-models [5], to maintain symmetric forces for more complex applications, such as double emulsion [6].

2 OBJECTIVES

- Design a microfluidic droplet-generating device for Lab-on-a-chip applications.
- Understand the working principle of stereolithography 3D printing.
- Fabricate the microfluidic device using the stereolithography 3D printing method.
- Evaluate the performance of the microfluidic emulsification system.
- Quantify the droplet production for different flow values of the dispersed and continuous phases.

3 DEVICE DESIGN

Two 50 x 25 mm devices were designed using the CAD software Onshape. The dimensions of the channels were 1.2 mm for the first device and 1.5 mm for the second. The microfluidic device presents two inlets for the injection of two immiscible phase fluids (Figure 1). Inlet A is for the dispersed phase fluid (water), while inlet B is for the continuous phase fluid (oil). The droplets are generated when the two fluids converge in the contraction area. Finally, the generated droplets are channeled through

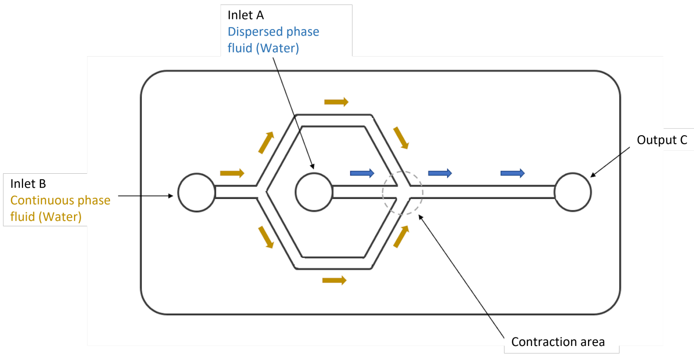

Figure 1. Microfluidic device design

the microfluidic cavity that ends at outlet C. All inlets and outlets for syringe connection have a diameter of 4 mm.

4 DEVICE FABRICATION

We imported both designs as STL. files into Preform, a 3D printing software that uses automatic algorithms to configure the print organization, orientation, and support structures [7]. First, it is important to define the ideal orientation for the fabrication of the device to ensure the correct formation of the channels. The first device was printed vertically and Preform generated the support structures for the printing process (Figure 2a). Secondly, we determined the 3D printing parameters in Preform, including the 3D printer (Form 2), the material (V4 resin), and the layer thickness (0.100mm) (Figure 2b).

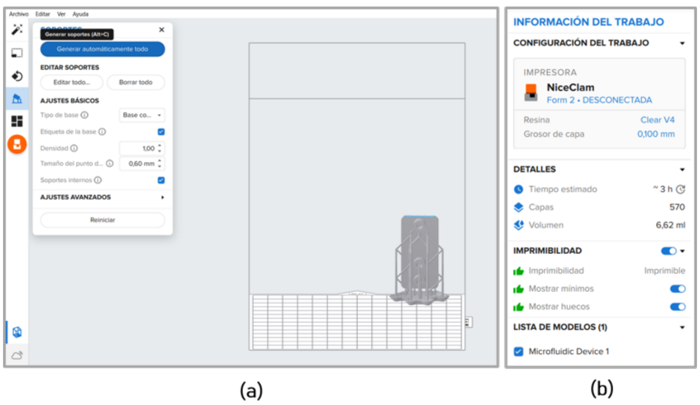

Figure 2. 3D Printing process configuration in Preform: a) Support structures generation. b) Printing parameters

Finally, the device was fabricated by stereolithography 3D printing. This method consists of the solidification of UV-sensitive resins by means of an incident beam. The beam scans the resin surface according to the 3D model and forms a solidified layer. The printing platform descends to generate a new layer, and the process is repeated until the entire part is fabricated [8]. Once the device was printed, isopropyl alcohol was used as a solvent to clean the excess unsolidified resin [9]. Then, the device was placed in a UV curing oven for 30 minutes to complete the polymerization process and improve its mechanical properties (Figure 3).

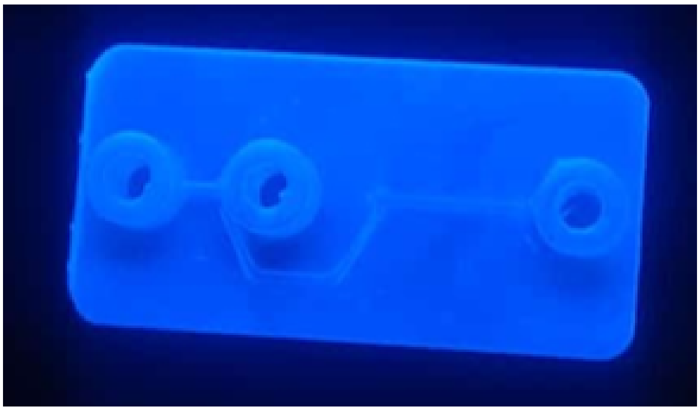

Figure 3. Microfluidic device in a UV Curing Oven

5 DESIGN VALIDATION

In the case of the first device, one of the channels was clogged after printing. This may have been due to the small size of the channels (1.2 mm) and the resolution of the printer. Microdroplet generation was tested using water (with blue dye) and oil. Syringe pumps were used to flow the solutions through the microchannel (Figure 4). Because the first device had only one functional channel, emulsification was always water-in-oil (water droplet generation), despite alternating both fluids as continuous and dispersed phases.

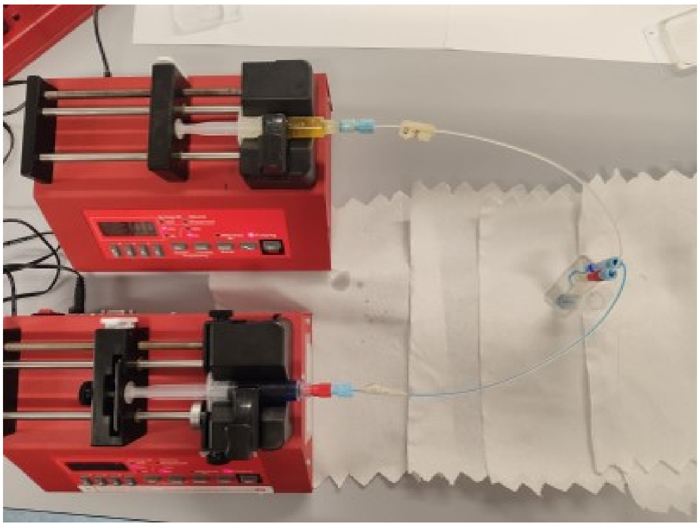

Figure 4. Droplet generation system with syringe pumps

For this experiment, the continuous phase (water) was introduced at a constant flow rate of 3 ml/h, while the flow rate of the dispersed phase (oil) varied from 2 ml/h to 6 ml/h, with spacings of 0.5 ml/min. It was observed that the droplets generated were smaller as the flow rate increased. In addition, the spacing between droplets was also larger. Table 1 summarizes the rate of droplets generated per second during each flow change of the dispersed phase. Figure 5 shows a graph of the droplet generation rate (drops/sec) as a function of the oil flow (ml/h). It can be observed that more drops are generated as the flow rate increases.

Table 1. Rate of droplet generation for different flows of the dispersed phase.

Water flow (ml/h)	Oil flow (ml/h)	Drop rate (drop/seg)
3	2	0.192
3	2.5	0.308
3	3	0.346
3	3.5	0.423
3	4	0.577
3	4.5	0.654
3	5	0.615
3	5.5	0.615
3	6	0.692

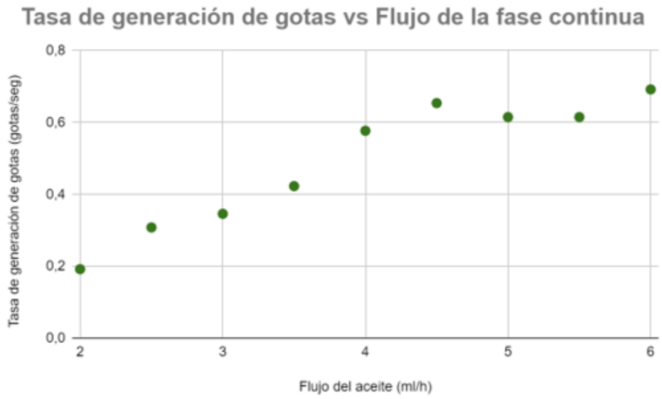

Figure 5. Droplet generation rate as a function of continuous phase (oil) flow

After these tests, a second device with 1.5 mm channels was printed. The same procedures described above were followed for cleaning the 3D printed part. This time, the device was printed with an inclined orientation, so the channels were fabricated without obstructions. In addition, a successful emulsion test was performed, according to the originally proposed design, where inlet A is for the dispersed phase fluid (water) and inlet B is for the continuous phase fluid (oil).

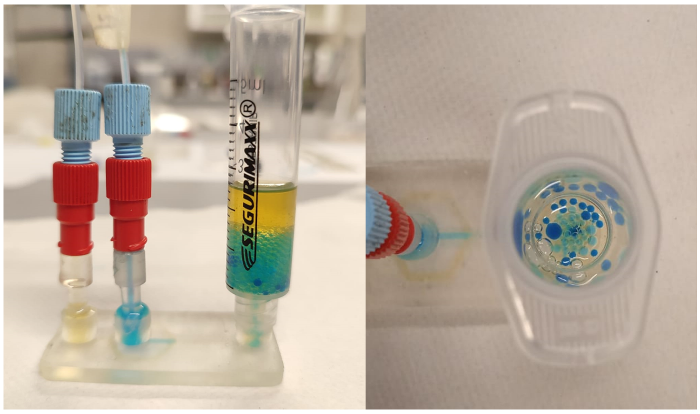

Figure 6. Test with the second microfluidic device

6 CONCLUSIONS AND FUTURE PERSPECTIVES

- Two emulsifying microfluidic devices were designed using Onshape CAD software. The applications of this design include drug encapsulation, flow cytometry, and spectrometry, among other applications in biological research.
- The operation of the stereolithography 3D printing process was understood, as well as the post-processing steps for cleaning the devices.
- Two devices were fabricated using the stereolithography 3D printing method. In the first case, one of the channels was clogged after printing. This may be due to the resolution limit of the printer. For the second case, larger channels (1.2 mm to 1.5 mm) were designed, resulting in successful fabrication. Additionally, this device was printed with an inclined orientation. This allowed a larger cutting area for layer formation and, therefore, better resolution.
- The emulsifying capability of the devices was tested using water and oil. Due to the clogging of a channel in the first device, the droplets generated were always water-in-oil, regardless of the continuous and dispersed phase fluid.
- In both tests, it was observed that the number of droplets increases as the oil flow rate increases. In addition, the droplets generated were smaller and more uniform. In the future, it is proposed to improve the design of the device by modifying the width of the contraction channel to optimize the droplet generation. In addition, to perform microfluidic flow simulations of the droplet generator geometry and implement real-time image processing of the droplets to control the generation frequency and evaluate the droplet size.

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