Design, Fabrication and Experimental Study of Spiral Microchannel Particle Separator on Centrifugal Microfluidic Platforms

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ABSTRACT

Nowadays there are a lot of tendencies to use analytical micro-systems in the field of molecular and microbial diagnostics, because of benefits such as less required space, reduced sample and reagent consumption and reduced analysis time. The rotational microfluidic is a sub-branch of the microfluidic systems which by using centrifugal forces, causes the fluid to flow in the networks enclosed in disk-shaped rotating systems. These networks can carry out chemical or biological tests and lead to create more capable devices replaced with current regular devices for medical diagnosis. One of the most commonly used elements in microfluidic systems is the separation element. This element is used to separate particles in the sample by considering mechanical, chemical and electrical specifications. In this study, a novel geometry designed to separate particles passively in microfluidic systems. The spiral microchannel geometry imports the local centrifugal force caused by the curvature of the channel in addition to the centrifugal and the Coriolis forces, to affect the particles and increase the efficiency of the separation. The particle separation process in the proposed channel was studied. The results of the experiments showed high separation efficiency, which indicates the high potential of this element in the separation process.

KEYWORDS

Microfluidic, Centrifugal Microfluidics, Lob on Disc, Spiral microchannel, Separation.

1. Introduction

Current research in the field of molecular and microfluidic diagnostics shows a tendency to develop small integrated diagnostic tools or analytical microsystems. The main motivation for developing these tools is rooted in the many benefits of such systems such as the need for low space, reduced sample and reagent consumption, reduced analysis time and automation. Lab-on-disc is one of the main branches of this technology and has shown unique advantages in blood analysis. The microfluidic disc uses a centrifugal force to drive the fluid. The fluid channels are chambers embedded in a disc-shaped plastic bed, and the disc is mounted on a rotating motor to evaluate its performance[1].

Separation of different substances is one of the requirements of biochemical and biological tests in microfluidic systems. The substances may include small molecules such as metabolites, large molecules such as proteins and nucleic acids, or larger items such as cells and solids that need to be separated from their surroundings[2]. In general, the methods used in the separation process are divided into two passive and active categories[3], usually using differences in the chemical, physical or electrical properties of the separation material.

In this study, for the first time, a spiral element in centrifugal microfluidic systems is used to perform the separation process of suspended particles. The design and fabrication of this model are very simple and the separation process is passive. This idea is a completely hydrodynamic method that performs the separation process in minimal time, without damaging the particles, without the use of external force and adding complexity to the system.

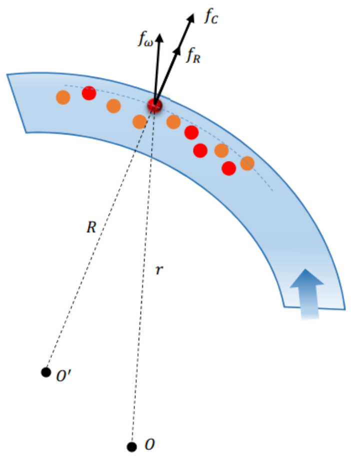

Figure 1. Schematic of the forces applied to the fluid containing particles in the curved element

2. Methodology

By rotating the microfluidic disc at constant acceleration, two centrifugal and Coriolis volumetric forces occur. By applying the spiral geometry, both Coriolis and centrifugal forces participate in the separation process simultaneously. On the other hand, due to the curvature of the channel, a centrifugal force is created which can assist the centrifugal forces and Coriolis caused by disc rotation. Therefore, according to Figure 1, the applied forces cause the fluid to move toward the outer wall of the microchannel. If the transmission volume consists of different phases, each phase having a higher density will receive a larger share of the resulting force and thus be directed to the outer wall. In this way, the different phases of the fluid are separated.

The microfluidic network designed in this study consist of an inlet chamber, a spiral microchannel for the separation process, and a branch at the end of the microchannel for transferring the separated suspension to separate collecting chambers.

There are various methods for fabricating microfluidic discs at the laboratory level used in different research centers. These methods include multilayer disc methods, microthermal forming techniques, and lithography techniques. The method used in this study is a multilayer method. The disc was built after three-dimensional design in the Solidworks program in these five layers, including three layers of polycarbonate plastic and two layers of pressure-sensitive adhesive.

A special test machine (CD Imager K1000) was used to evaluate the disc design and the tests. The device consists of two parts: hardware and software. In the hardware part, a servo motor with a maximum velocity of 7200 rpm and high rotational accuracy is responsible for controlling the drive movement in clockwise and counterclockwise directions at different velocities. A microscope is located at the top of the disc where its position can be changed using two linear motors on different areas of the disc. There is also a color camera for recording microscope images on the system.

3. Results and Discussion

The designed disk was tested to check the performance of the microfluidic network at 400 rpm. To examine more precisely the behavior of the particles and how the separation process was carried out, Photographs were taken from three sections of the channel (inlet, middle and outlet). Figure 2a shows the channel inlet when rotating the disk. As can be seen from the images, the particles are scattered in the fluid and do not show any deviation or arrangement. Figure 2b shows that the particles in the sample gradually deviate toward the outer wall of the channel. The accumulation of particles at the wall is clearly visible, but there is still a large number of particles dispersed in the channel, with no clear boundary between the particles and the fluid. The deviation of the particles is due to their higher density than the fluid environment, so they receive a greater share of the amount of forces available for separation and will naturally be influenced by the direction of the force and will have to change course.

Figure 2c shows the pictures of the end of the channel before reaching the branch. As you can see the particles stacked on the outer wall, the phase separation process is well done and the boundary between the particles and the liquid is clearly defined. It can be concluded that centrifugal and Coriolis forces eventually overwhelm the particles and divert them in their direction to the outer wall of the channel. Therefore, due to their higher density, the particles fall below the fluid and move slowly along the wall. This process continues until the point of division. At this point, the flow is divided into two branches and each enters a separate chamber. Images from the split point show that the particles collected near the wall reach the particle collecting chamber as they move along the wall (Figure 2d). However, the fluid flow continues in the spiral direction of the channel and eventually enters the second chamber intended for fluid collection (Figure 2e).

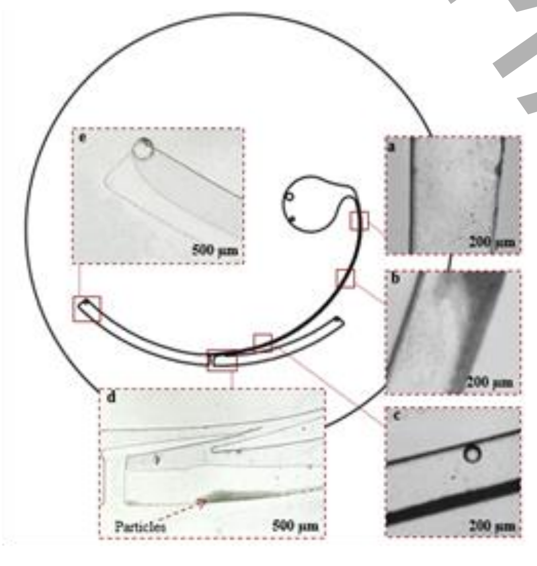

Figure 2. Performance evaluation of designed microfluidic network

The examination of Fig 2 shows that very few particles have entered the fluid collection chamber, so the obtained fluid is expected to have a good purity. After the separation process is complete and the excess particles are separated from the fluid, the pure fluid collected can be used for further experiments in the microfluidic network. For example, this element can be used in biological experiments to isolate blood plasma.

4. Conclusions

In the present study, a new technique for separation elements has been used which is simple and highly efficient and avoids the complexity of microfluidic networks. In this element, a spiral microchannel is used for the separation process, which utilizes three separation mechanisms simultaneously (centrifugal and Coriolis force caused by disk rotation and centrifugal force caused by the spiral channel). The sample is affected by these forces as it passes through the microchannel and gradually separates its phases and moves to a specific chamber by reaching the branch at the end of each channel. Experiments were conducted to evaluate the proposed design, all of which successfully separated the particles from the fluid.

In general, it can be said that this method is a valid method that can separate different particles according to the need and with acceptable efficiency. Since this is a completely hydrodynamic method and minimizes sample damage it can be used in specific applications, especially biological applications.

5. References

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