COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE 117 (2014) 20–29

journal homepage: www.intl.elsevierhealth.com/journals/cmpb

An efficient passive planar micromixer with ellipse-like micropillars for continuous mixing of human blood

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ARTICLE INFO

Article history:
Received 23 January 2014
Received in revised form
28 May 2014
Accepted 29 May 2014

Keywords:
Micromixer
Passive mixing
Splitting and recombination
Computational fluid dynamics

ABSTRACT

In this paper, a passive planar micromixer with ellipse-like micropillars is proposed to operate in the laminar flow regime for high mixing efficiency. With a splitting and recombination (SAR) concept, the diffusion distance of the fluids in a micromixer with ellipse-like micropillars was decreased. Thus, space usage for micromixer of an automatic sample collection system is also minimized. Numerical simulation was conducted to evaluate the performance of proposed micromixer by solving the governing Navier–Stokes equation and convection–diffusion equation. With software (COMSOL 4.3) for computational fluid dynamics (CFD) we simulated the mixing of fluids in a micromixer with ellipse-like micropillars and basic T-type mixer in a laminar flow regime. The efficiency of the proposed micromixer is shown in numerical results and is verified by measurement results.

1. Introduction

For self-sampling or collection of blood by health personal related to point-of-care diagnostics in health rooms, it may often be necessary to perform automatic and painless collection of blood samples. The most important operation that needs to be done when handling whole blood is to be able to combine automatic sample collection with optimal mixing of anticoagulation liquid and weak fixatives. In particular before doing any transport of a sample or point-of-care nucleic acid diagnostics, it is very important to fix the gene expression at the time of collection. An automatic sample collection module with a painless microneedle array in combination with a micromixer is proposed for the blood collection in typical nurse or health rooms.

In general, micromixers can be classified into active micromixer and passive micromixer. In the mixing process, active micromixers require external disturbance effects such as pressure, temperature, electrohydrodynamics, dielectrophoretics, electrokinetics, *etc.* Hence, the structures of active micromixers are often complicated. In contrast to active micromixer, a passive type requires no external energy. The normal mixing process within a passive micromixer is slow and entirely dependent upon molecular diffusion [1–3]. The mixing of the passive microfluidic mixer is based on several main principles: (a) laminar flow, which is used in the T-mixer [3,4]; (b) chaotic mixing by eddy formation [5]; (c) splitting and combination [6]. Previous studies of micromixer [6–9] show that fast and homogenous mixing can be achieved in the micromixer with SAR concept by increasing the contact

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http://dx.doi.org/10.1016/j.cmpb.2014.05.007

interface of fluids. But some of them are complicated and require complex microfabrication processes because of their three dimensional micro structure [1].

In this paper, a simple and low cost SAR micromixer with ellipse-like micropillars was proposed. The SAR structures of the flow channels result in the split of the main stream at the beginning of the micropillars and the reduction of the diffusion distance of two fluids. Besides, the mixing strength is increased at the end of the micropillars with the impingement effects when one stream is injected into the other. The efficiency of the micromixer was examined by theoretical methods including Finite Element Method. Simulation results are presented with the laminar flow regime, in which a low Reynolds number is applied, $0.048 \leq Re \leq 2.381$. For the experimental characterization of the mixing performance, SAR micromixer was fabricated by using replica molding method. Because of simple structures with two-dimensional ellipse-like micropillars, our proposed SAR micromixer does not require the complex microfabrication process. Hence, the cost of making our proposed SAR micromixer is lower than other micromixers with complicated three dimensional micro structures. Furthermore, we compare the experimental mixing performance of the designed channels to the simulated results.

2. Micromixer with ellipse-like micropillars

2.1. Mixing unit

The term ellipse-like micropillar is an element having the shape of an ellipse. As shown in Fig. 1, a contour of the micropillar was described as the composition of two half ellipses with the left major axis semidiameter a_1, right major axis semidiameter a_2, and minor axis semidiameter b. It should be noted that the high velocity region along the two sides of the contour was larger when the length of the left half axis a_1 is not equal to that of the right half axis a_2, that is $a_1 < a_2$. The optimized values of the profile parameters are $a_1{:}a_2{:}b = 5{:}6{:}4$ [10,11].

Due to the demand for fast and homogenous mixing, the splitting and recombination concept is considered in blood mixer design. There are three steps in splitting and recombination process, flow splitting, flow recombination and flow rearrangement [2]. When the main flow reaches the ellipse-like micropillar, the flow is then split into two separated flows on the smaller channels. For an incompressible fluid, equation of continuity (mass conservation of fluid) is defined as [12]

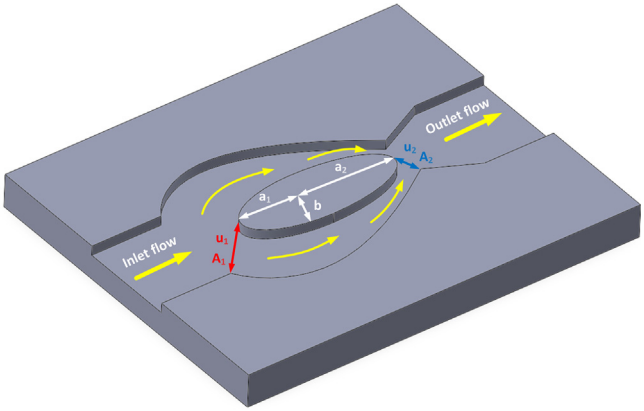

Fig. 1 – Mixing unit of SAR micromixer.

$$A_1 u_1 = A_2 u_2 \tag{1}$$

Since the cross-section area A_2 is less than the cross-section area A_1 (see Fig. 1), the local velocity u_2 will be larger than velocity u_1. This phenomenon together with the high velocity region of ellipse-like micropillar will create high velocity at the right end of the micropillar's contour. At the outlet end of the micropillar, two separated flows in small channels are recombined with high velocity. The contact interface of fluids is increased throughout each mixing unit so that the mixing effect is enhanced.

2.2. Device design

SAR micromixer ellipse-like micropillars for blood mixing includes 3 inlet channels (blood sample, anticoagulant solution, Pretect™ solution (NorChip, Klokkarstua, Norway)), one outlet channel, and some mixing units. The geometry of SAR micromixer with ellipse-like micropillars is shown in Fig. 2.

Whole blood undergoes coagulation few seconds after it has left the *in vivo* condition [13]. Therefore, the whole blood

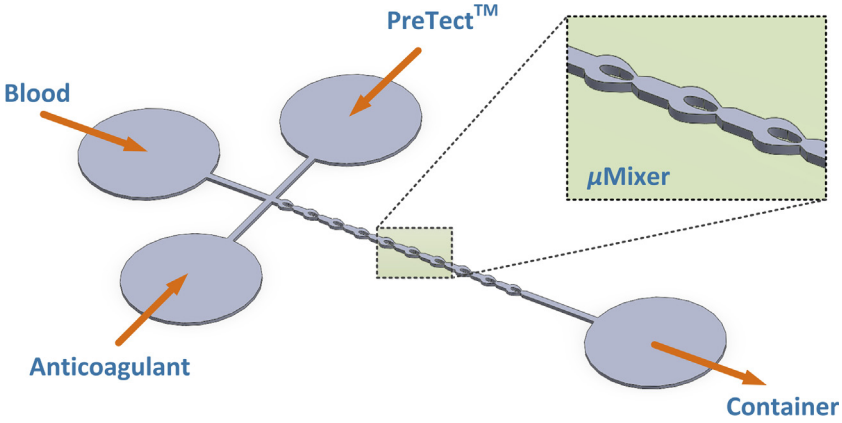

Fig. 2 – SAR micromixer for blood mixing.