Determination of Optimum Flow Passages for Blood Diagnosis Chip

S. P. Wadkar, Shubham S. Mahajan and Shubham S. Kale

***Abstract*—This article involves blood and biomarker fluid flow study, which flows through microfluidic channels of blood diagnosis chip. Purpose of this study is to find out the optimum flow path design and configuration of baffles. The 3D CAD model of biochip with different fluid passage configurations and baffle design was developed. Simulation of blood and biomarker fluid flow was performed using CFD software. From the results of the analysis, configuration having highest Reynold's Number and lower flow velocity in the trench region was found.**

***Index Terms*—biochip, biomarker, CFD, microfluidics, turbulence intensity**

I. Introduction

BLOOD diagnosis is performed to find out presence of pathogens which are responsible for various diseases such as Malaria. Blood contains plasma which makes up about half of the contents in it. This plasma contains certain bacteria which allows detection of pathogens in the blood. Hence all the conventional methods of blood diagnosis like centrifugal method, size dependent particle separation method etc. separate plasma or serum from blood which is used for further testing.

The working of biochip is based on Self-Integrated Microfluidics Blood Analysis System also known as SIMBAS chip, which uses flow paths patterned underneath

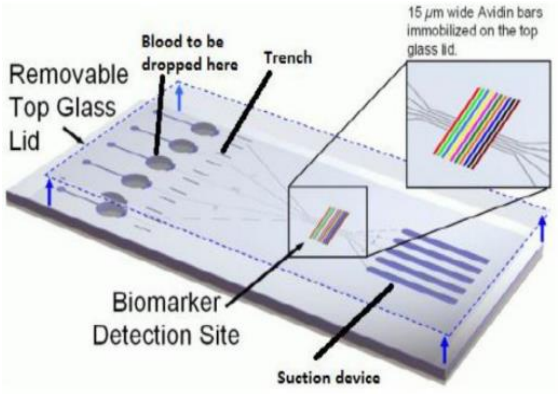

Fig. 1. SIMBAS chip

microfluidic channels which are about the width of a human hair. When whole blood is dropped onto the chips inlet, the relatively heavy red and white blood cells settle down into the trenches, separating from the clear blood plasma. The blood moves through the chip in a process called degas-driven flow [1].

Here the blood, merely two drops of 10 mm diameter each are dropped in the portion shown in Fig. 1.

This blood flows through the trench. Here plasma, RBC's and WBC's are separated by the density difference. RBC's and WBC's being heavier settle down whereas plasma being lighter floats and is used for further testing. Self-powered Integrated Microfluidic Blood Analysis System (SIMBAS) aims to replace laborious sample preparation steps by integrating blood plasma separation and multiplexed assays on the same device.

Separated plasma from the trench flows through the flow channel, this flow channel causes the flow of the plasma below the surface which is coated with the proteins (biomarkers) which react with the antibodies in the plasma. This reaction either causes some color change or fluorescence effect over this protein coated surface, which can be observed. The flow required here is obtained by degas driven flow. Here the suction device is like sponge. This device is placed in vacuum so that the air in it is taken out and when this device is connected to the flow channel it causes the flow because of suction effect.

The flow must be simulated in such a way that the velocity of the fluid in the trench where reaction occurs should be minimum so that sufficient reaction time for the fluid and biomarkers in available. Also, the turbulence intensity should be minimum or Reynolds Number should be higher so that uniform reaction occurs over the complete trench area.

II. Literature Review

It is possible to have a blood testing device which is handy, cheap and portable which requires the lesser quantity of blood and gives the results in short time [4]. Developing efficient microscale separation methods that are offering greater control over cell population distribution will be important in realizing true point-of-care (POC) lab-on-a-chip (LOC) systems [5]. Degas-driven flow is a novel phenomenon used to propel fluids in polydimethylsiloxane PDMS based microfluidic devices without requiring any external power. This method takes advantage of the inherently high porosity and air solubility of PDMS by removing air molecules from

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the bulk PDMS before initiating the flow [6]. PDMS based microfluidic devices without requiring any external power. This method takes advantage of the inherently high porosity and air solubility of PDMS by removing air molecules from the bulk PDMS before initiating the flow [6]. Lab-on-a-chip (LOC) systems can be thought of as the natural generalization of the existing electronic integrated circuits and microelectromechanical systems (MEMS) [7]. Microfluidic devices often achieve fluid transport with few mechanical components, which can significantly reduce an assay's complexity and power consumption over its macroscale counterpart [8]. "Micro total analysis systems" (microTAS) or "labs-on-a-chip" (LOC) are becoming reality where entire chemical analyses in miniaturized volumes are performed with high sensitivities and in shorter time spans [9].

III. Biochip Configurations

Flow passage was designed based on the required velocity of plasma at the entry to the rectangular shaped trench. The diameter of the flow passage is 2mm and overall thickness of

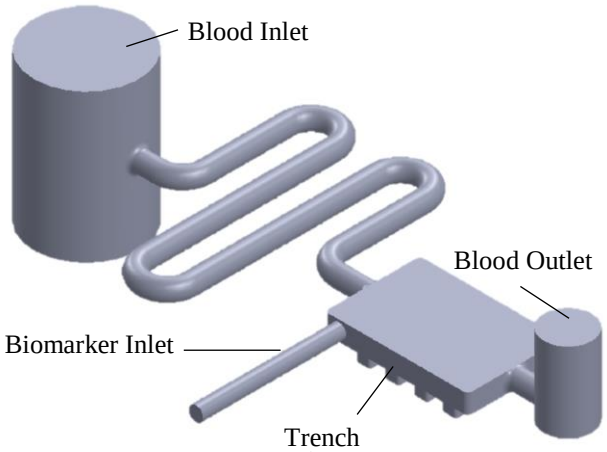

Fig. 2. Computer aided design data for analysis

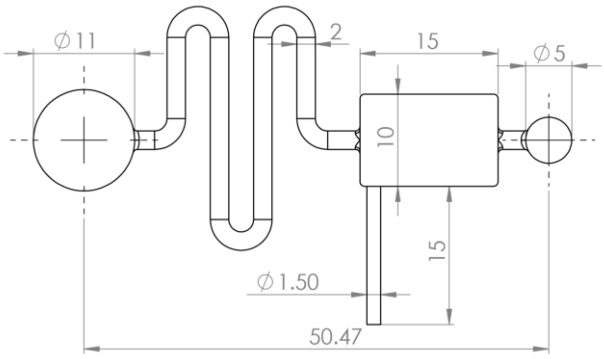

Fig. 3. Dimensions of biochip in millimeters

the biochip is around 20mm. Other dimensions are as shown in Fig. 3. The dimensions of the biochip were kept larger because of the manufacturing constrains for making an experimental validation model, which is to be performed in future study.

The CAD model of blood and biomarker fluid was created and meshing was done using ICEM-CFD software. Volume meshing parameters were defined and mesh was created with prism layers using Robust(Octree) method.

The design of trench area should ensure that the flow velocity to be low, which ensures sufficient reaction time

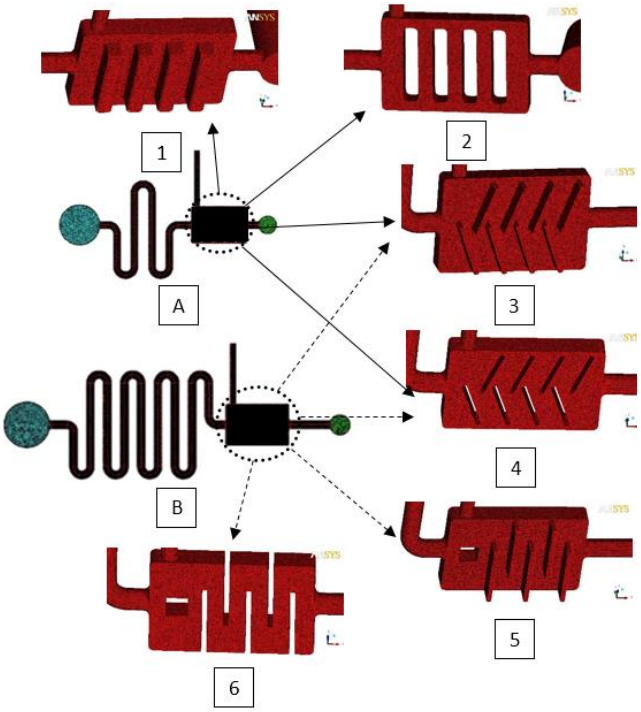

Fig. 4. Configurations considered for analysis.

between blood and biomarker fluid. By varying the number of turns and trench design having different types of slots and baffles, eight configurations were considered for this study as shown in Fig. 3.

Configuration A1 has two turns with straight slots, A2 has two turns with straight baffles, A3 has two turns with inclined slots, A4 has two turns with inclined baffles, B3 has five turns with inclined slots, B4 has five turns with inclined baffles, B5 has five turns with square and straight slots, B6 has five turns with square and straight baffles.

IV. Problem Definition and Computational Simulation

Boundary conditions are defined as:

Inlet pressure P_i = 1.01325 bar (absolute)

Outlet pressure P_o = 0.9 bar (absolute)

The objective is to find out best configuration for which the velocity and turbulence intensity should be minimum to ensure that there is enough time for the reaction to take place and there is proper mixing of fluid while reaction takes place. Pressure at the outlet of chip must be less than the pressure at the inlet to prevent backflow of fluid.

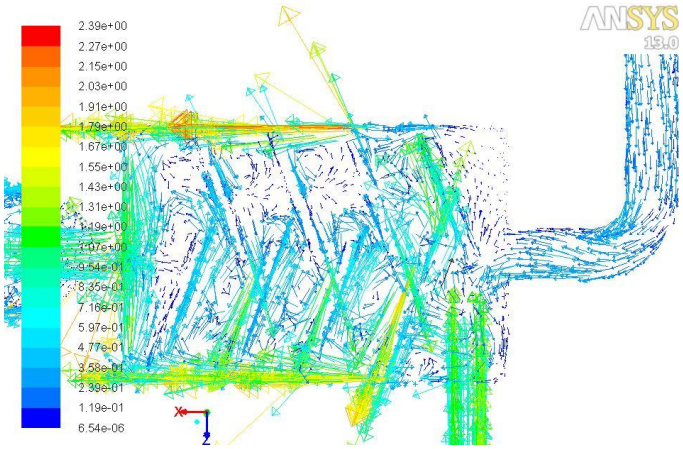

Fig. 5. Velocity vector plot for A4 configuration

The CFD analysis was done using FLUENT software to

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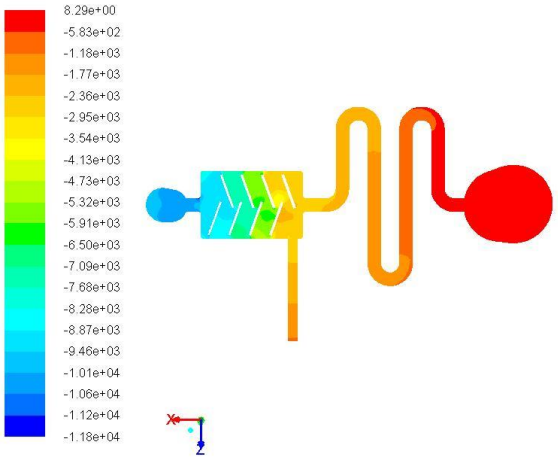

Fig. 6. Pressure plot for A4 configuration

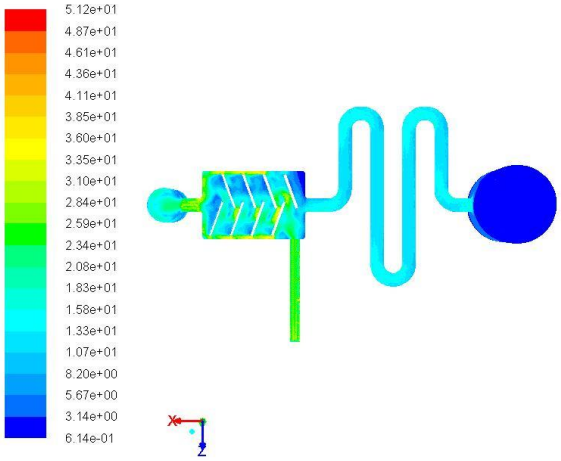

Fig. 7. Turbulence Intensity plot for A4 configuration

find the velocity contours, turbulence intensity contours and path lines. Different configurations mentioned above were analyzed and best configuration was found.

V. Results

From the results obtained from CFD analysis for eight configurations are as shown in table I and II. Velocity and Turbulence Intensity of fluid is minimum for configuration A4. Corresponding value of Reynolds Number is also maximum for the same configuration since Turbulence Intensity is inversely proportion to Reynolds Number as given in eq. (1).

TABLE I
Results

Model	Configuration	Velocity (m/s)	Turbulence Intensity (%)	Pressure at Inlet (Pa)	Pressure at outlet (Pa)
1	A1	0.58	22.45	11.508	-13967.820
2	A2	0.70	23.60	13.978	-13172.810
3	A3	0.64	32.5	0.663	-15543.000
4	A4	0.30	14.5	8.292	-11824.900
5	B3	0.74	2.05	0.553	-11995.270
6	B4	0.39	16.3	5.917	-11253.130
7	B5	0.92	42.0	1.302	-12028.750
8	B6	0.21	14.9	1.428	-13072.980

$$Turbulence\ Intensity = 0.16\times Re^{-\frac{1}{8}} \quad (1)$$

TABLE II
Reynolds Number for Models

Configuration	Re	Configuration	Re
A1	0.06656	B3	0.13770
A2	0.04463	B4	0.86190
A3	0.00345	B5	0.00044
A4	2.19794	B6	1.76795

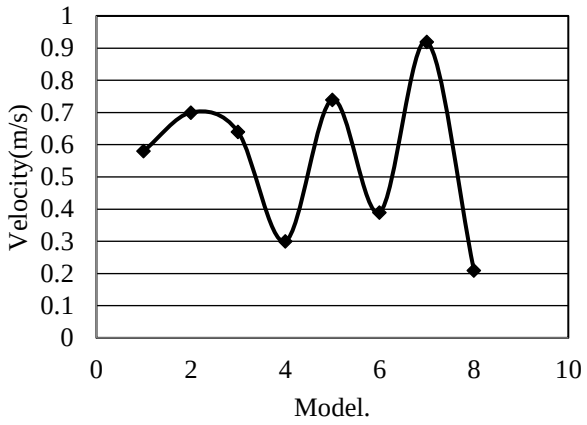

Fig. 8. Velocity plot of all configurations

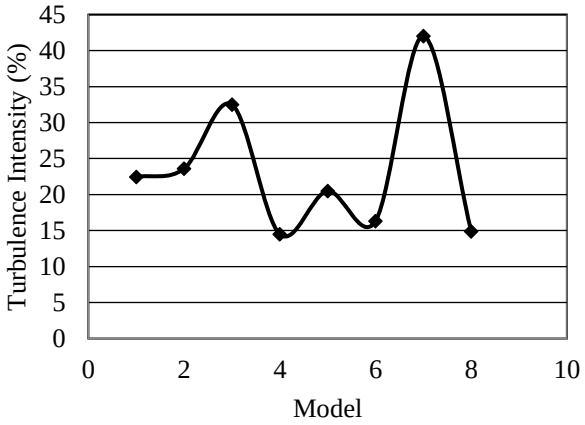

Fig. 9. Turbulence Intensity plot of all configurations

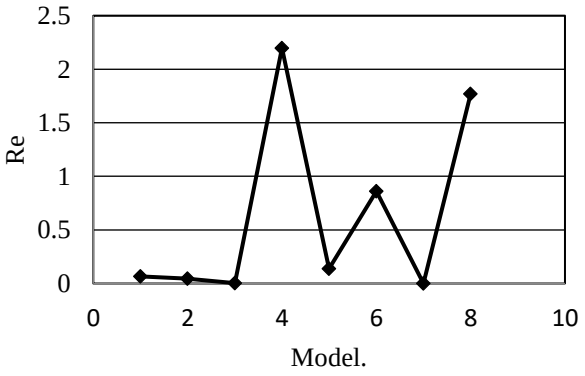

Fig. 10. Re of all configurations

VI. Conclusion

For effective diagnosis of blood sample the biochip having two turns and inclined baffles design is preferred because of lower fluid velocity and higher Reynolds Number.

Since the basic principle lies in the microfluidics, the functionality and reliability of the device can be enhanced by achieving lower dimensions in the flow passages of the model. The results above are obtained from the model whose dimensions are not too close to that desired for the proper working of the device based on microfluidics.

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