Comsol multiphysics simulation of micro fluidic system for blood sample analysis

N.J.R. Muniraj[1] and K.Sathesh[2]

[1]Tejaa Shakthi Institute of Technology for Women, Coimbatore, India

[2]Department of ECE, Karpagam College of Engineering, Coimbatore, India.

ABSTRACT

The effective analysis of blood samples is a pressing issue in the modern world. This can be addressed by lab on a chip system. This paper deals with the design of several systems for supplying oxygenated blood (star chip) and to mix blood cells for analysis (lamella mixer).we have used comsol multiphysics(Matthias K.Gobbert, (October,2007)) to simulate these structures and to optimize their design.

Introduction

Labs on chip a systems assist the quick transfer from design board to production. Comsol multiphysics (Matthias K.Gobbert, (October, 2007)) offer a great way to optimize the performance of the structure. Thus reducing the time between testing and production. For blood sample analysis there is a need for star chip and lamella mixer optimized for the particular purpose.

Description of various systems:

Infuser (star chip):

This involves the design of star chip that feeds oxygenated blood to the mixer. Controlling pressure is an accurate way to introduce a quantity of blood at certain velocity to some piece of equipment. Figure1 shows the 2D geometry of star chip.

This exercise arbitrarily sets geometry and conditions of microchannel (Abraham D,2002) lab on a chip. The pressure at the five inlets and outlet is time controlled so blood flows in a smooth way. At any particular instant one of the inlet flow dominates it could be significant from more than one inlet. The pressure of the outlet is set to zero.
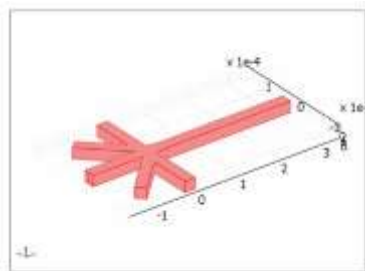

Figure1: 2D Model geometry for a star-shaped infuser with five inlets and one outlet

The example models only blood flow whose velocity is of the magnitude that suggests laminar behavior. In order to find the numerical solution we must solve navier stokes equation in time domain. The boundary conditions for the inlets and outlets assume a set pressure Where ρ denotes density (Kg/m3), u is the velocity (m/s), η denotes dynamic viscosity (Pa.s), and P equals pressure (Pa).

Cell lyser (lamella mixer):

At the micro scale level this model demonstrates the mixing of blood cells using laminar layer flow. In order to characterize the mixing behavior we use Reynolds number (Douglas brune, 1993).

Where ρ is the blood density, u is flow velocity, L is a characteristic length, and η is the blood's dynamic viscosity. Turbulent mixing takes place when Reynolds number is typically high. The width of the channel is in the range of 100μm and velocity is approximately 1cm/s.

The mixer has several lamella of microchannel (Abraham D, 2002) and the blood cells are being mixed and alternated for every second layer. Pressure forces the blood to travel in the channels from back to front. 2D geometry of lamella mixer is shown in figure2.
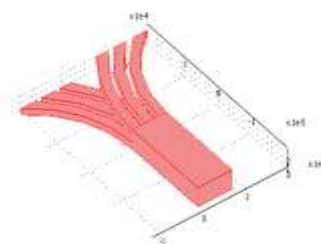

Figure 2: Geometry of a lamella mixer (mixing chamber not visible)

We can solve the blood flow in channels and in the chamber with the incompressible navier stokes equation.

Where ρ is blood density, u= (u, v, w) is the flow velocity field, P is blood pressure, I is the unit diagonal matrix, η is the

Tele:
E-mail addresses: njrmuniraj@yahoo.com, sathesh_kce@yahoo.com

blood's dynamic viscosity and F= (fx, fy, fz) is a volume force affecting the fluid.

The following convection-diffusion (Nataliya M,2007) equation describes the concentration of the dissolved substances in the blood.

Where c is concentration, D is diffusion coefficient, R is the reaction rate.

Result:

Star chip:

The velocity field in a microchannel(Abraham D,2002) infuser through the middle of geometry. The plot shows the pressure at the walls. Figure3 shows the simulated 3D geometry of star chip and figure 4 shows the output plot.
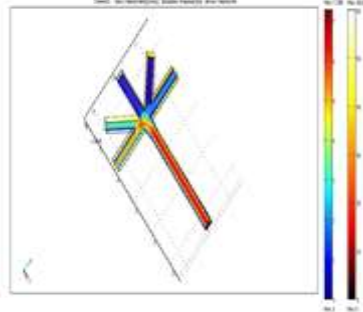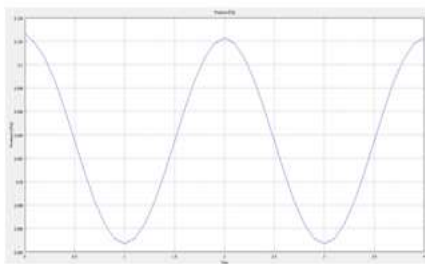

Figure 3: simulation of star chip

Figure 4: Pressure as a function of time at a point located just before the outlet

Lamella mixer:

Mixing starts when the fluid enters the mixing chamber. At the entrance there is a clear separation of the concentration, but this diminishes toward the end of the chamber. On the sides of the mixing chamber where the flow velocity is smaller the mixing is better than at its center. The figure 5 represents the simulation of lamella mixer (k) and figure 6 and figure 7 shows the output plot.
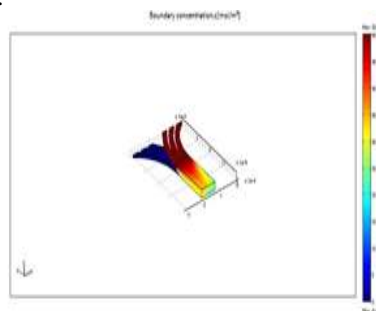

Figure5: simulation of lamella mixer

Concentration profile along a line in the Z direction in the middle of the mixing chamber at various distances from the microchannel with the input concentration as 25 and Y coordinate values changed from -5e-5 to -22e-5.
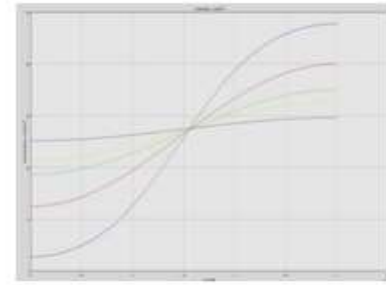

Figure 6: Concentration plot on the boundaries of the lamella mixer

Concentration profile in the middle of the in the middle of the mixer around Z direction at various distances with input concentration as 25 and Y coordinate value is beyond -22e-5.
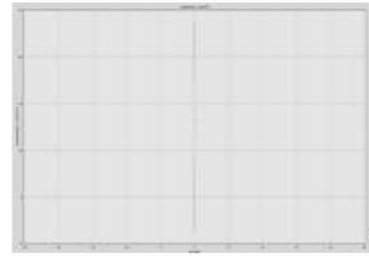

Figure 7: Concentration plot on the boundaries of the lamella mixer

Conclusion

Comsol multiphysics(Matthias K.Gobbert, (October,2007)) is a valuable and powerful tool when designing non trivial lab on structures, as it helps identify key parameters for the performance of the device and optimize them.

References

Abraham D. Stroock, Stephan K. W.Dertinger, Armand Ajdari, Igor Mezić, HowardA. Stone and George M. Whitesides (2002) Chaotic Mixer for Microchannel, Science, New Series, 295, 647-651.

Acheson, D. J. (1990), Elementary Fluid Dynamics, Oxford Applied Mathematics and Computing Science Series, Oxford University Press, ISBN 0198596790

Batchelor, G. K. (1967), Introduction to Fluid Dynamics, Cambridge University Press, ISBN 0521663962.

Douglas brune, Sangtae kim (May1993),Department of Chemical Engineering, University of Wisconsin, Madison WI 53705, Proc. Natl. Acad. Sci. USA Vol. 90, pp. 3835-3839,.

Landau, L.D. Lifshitz, E. M. (1987), Fluid mechanics, Courseof Theoretical Physics, 6 (2nd revised ed.), Pergamon Press, ISBN 0 08 033932 8, OCLC 15017127

Matthias K.Gobbert, (October, 2007), Introduction to comsol multiphysics.

Nataliya M. Ivanova (October 31, 2007), Exact Solutionsof Diffusion-convection eqations.

Fox, R.W., McDonald A.D., Phillip J. Pritchard ,Introduction to Fluid Mechanics, 6th ed (John Wiley and Sons) ISBN 0 471 20231 2 page 348.

Streeter, V.L., (1962) Fluid Mechanics, 3rd edn (McGraw-Hill)

William A. Tucker and Leslie H. Nelken,(1982).Chapter 17 in Handbook of Chemical Property Estimation Methods, Warren J. Lyman, William F. Reehl and David H. Rosenblatt, editors, American Chemical Society.

Matthias K.Gobbert, (October,2007), Introduction to comsol multiphysics.

Nataliya MIvanova (October 31, 2007) ExactSolutions of Diffusion-convection eqations.

Fox, R.W.,McDonald , A.D., Phillip J. Pritchard ,Introduction to Fluid Mechanics, 6th ed (John Wiley and Sons) ISBN 0 471 20231 2 page 348.

Streeter, V.L., (1962) Fluid Mechanics, 3rd edn (McGraw-Hill)

William A. Tucker and Leslie H. Nelken,(1982).Chapter 17 in Handbook of Chemical Property Estimation Methods, Warren J. Lyman, William F. Reehl and David H. Rosenblatt, editors, American Chemical Society.

Design Parameters
Table1: Constants description

Name	Expression	Description
eta	3e-3[Pa*s]	Dynamic viscosity
rho	1.06e3[kg/m^3]	Density of blood
p0	25[Pa]	Pressure offset
p1	5[Pa]	Pressure amplitude
omega	pi[rad/s]	Angular velocity

Design Parameters
Table2: constants description

Name	Expression	Description
p0	5[Pa]	Driving pressure
rho	1.06e3[kg/m^3]	Density of blood
eta	3e-3[Pa*s]	Dynamic viscosity of blood
c0	25[mol/m^3]	Input concentration
D_i	1e-10[m^2/s]	Isotropic diffusion coefficient of the substance in blood