Comsol multiphysics simulation of micro fluidic system for blood sample analysis

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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 \( \rho \) denotes density (Kg/m3), \( u \) is the velocity (m/s), \( \eta \) 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 \( \rho \) is the blood density, \( u \) is flow velocity, \( L \) is a characteristic length, and \( \eta \) 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 \( \rho \) is blood density, \( \mathbf{u} = (u, v, w) \) is the flow velocity field, \( P \) is blood pressure, \( \mathbf{I} \) is the unit diagonal matrix, \( \eta \) is the
blood’s dynamic viscosity and \( F = (f_x, f_y, f_z) \) 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. Figure 3 shows the simulated 3D geometry of star chip and figure 4 shows the output plot.

![Figure 3: Simulation of star chip](image)

![Figure 4: Pressure as a function of time at a point located just before the outlet](image)

**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.

![Figure 5: Simulation of lamella mixer](image)

![Figure 6: Concentration plot on the boundaries of the lamella mixer](image)

![Figure 7: Concentration plot on the boundaries of the lamella mixer](image)

**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**


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

Nataliya M. Ivanova (October 31, 2007), Exact Solutions of Diffusion-convection equations.


Matthias K. Gobbert, (October, 2007), Introduction to comsol multiphysics.
Nataliya MIvanova (October 31, 2007) Exact Solutions of Diffusion-convection equations.

Design Parameters
Table 1: Constants description

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<tr>
<th>Name</th>
<th>Expression</th>
<th>Description</th>
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<td>$\eta$</td>
<td>3e-3[Pa*s]</td>
<td>Dynamic viscosity</td>
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<tr>
<td>$\rho$</td>
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<td>Density of blood</td>
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<td>$p_0$</td>
<td>25[Pa]</td>
<td>Pressure offset</td>
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Design Parameters
Table 2: Constants description

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<tr>
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<td>Density of blood</td>
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<tr>
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<td>$D_i$</td>
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<td>Isotropic diffusion coefficient of the substance in blood</td>
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