Simulation of Microfluidic Blood Cells Micro-Separator

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Introduction:

Lab-on-chip (LOC) provide new possibilities for cheaper, faster and more efficient ways to analyse very small volumes of biological samples such as blood cells. These devices integrate all laboratory tasks on a single microfluidic chip. Most widely cells separation methods include paramagnetic or super-paramagnetic beads [1]. However, the excessive labeling used in magnetic separation could harm cell's structure. In this work we present a microfluidic micro-separator to separate red blood cells (RBC) and white blood cells (WBC), in their native state, without the need of magnetic beads.

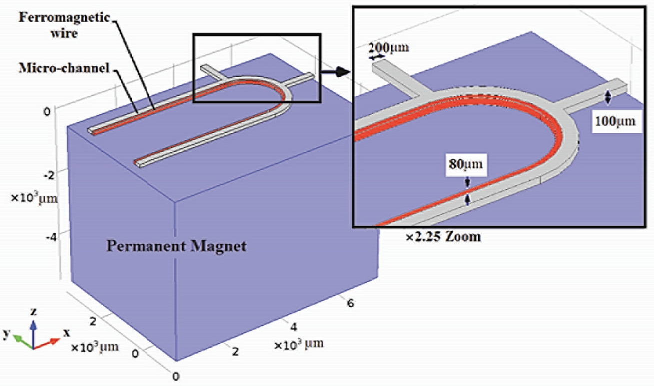

Figure 1. Model description of the microfluidic blood cells micro-separator.

Computational Methods:

Magnetophoretic force is proportional to the volume of the cells. Thus, the difference in the magnitude of the magnetophoretic forces provides a means to establish the separation of WBCs/RBCs based on the differences in their volumes.
The magnetophoretic force is given by the following equation [2]:

$$F_{MAP} = \left(\chi_p - \chi_m\right).(V_m(\nabla.B)B)/\mu_0$$

We used the calculated magnetic field for a permanent magnet an the fluid flow velocity inside the microchannel to solve the recently-developed model for blood separation using hydrodynamic and magnetophoresis (MAP).

The hydrodynamic velocity flow vector U_{hyd} can be determined by solving the Stokes equation for laminar flow in the microchannel [3]. And the viscous force can be estimated using the particle velocity and the fluid viscosity at the instant position of the cell is given by:

$$F_{vis} = 6\pi\eta r\, U_{hyd}\, C_w$$

The no-slip condition is set on all the microchannel boundaries, except for the outlets, where zero pressure is imposed, and for the inlet, where the value of fluid velocity is fixed.

The simulation strategy accounts for the following steps:

- Demonstration of the geometry and materials parameters.
- Multiphysics simulation with both the magnetic field and the fluid flow modules in the microchannel.
- Use the produced data to investigate the particles trajectories using particle tracing module.

Results:

The ferromagnetic wire joined to the inner wall of the microchannel is magnetized due to the high magnetic field of the permanent magnet. It is expected that RBCs (paramagnetic particles) would experience a MAP force pushing them away from the ferromagnetic wire and thus they would be directed to outlet-1 and outlet-2 respectively. Meanwhile, the dipole moment of the WBCs will induced F_{MAP} that will attract to the inner wall and they would follow the fluid flow toward the outlet-3.

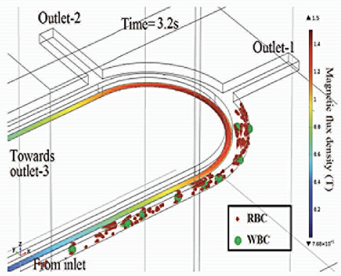

Figure 2. Cells trajectory at t=3.2s.

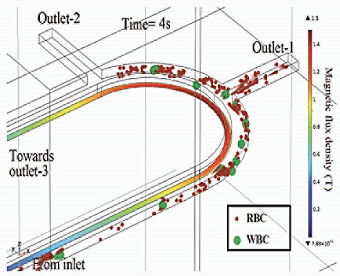

Figure 3. Cells trajectory at t=4.0s.

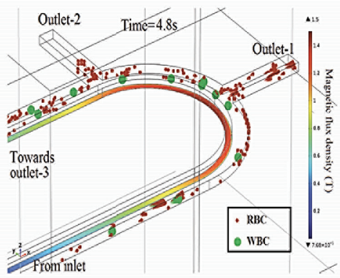

Figure 4. Cells trajectory at t=4.8s.

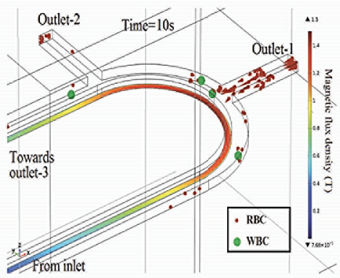

Figure 5. Cells trajectory at=10s.

From the above figures (2 to 5), it can be inferred that the RBC/WBC separation starts in the area of the channel beside outlet-1 where a portion of RBCs are pushed toward outlet-1 by the hydrodynamic force as they drifted by the high velocity fluid flow because they are relatively smaller then WBCs. However, WBCs continue their movement along the micro-channel because of the MAP force resulted by the highly magnetized ferromagnetic wire that helps WBCs to be pulled toward the inner wall of the channel.

Conclusions:

The blood cells Micro-separator provides a continuous RBC/WBC separation using MAP and hydrodynamic forces. This micro-separator can be used for many applications including lab-on-chip , point of care diagnosis micro-systems, and processing very small sample volumes. The next step in this project is to fabricate the device and show cells separation on the biochip through experimental approach.

References:

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2. H. Seo al., Hybrid cell sorters for on-chip cell separation by hydro-dynamics and magnetophoresis, J. Micromech. Microeng., 20(9), p. 095019, (2010)
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