**Novel design of magnetophoretic microdevices for extracorporeal sepsis treatment**

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**Highlights**

* Magnetic bead separation from human whole blood is analyzed
* CFD approach is used for modeling magnetic bead magnetophoresis from blood
* Effect of fluid flow rates in the recovery of magnetic beads is modeled
* We report the rational design of magnetophoretic microfluidic devices

**1. Introduction**

The removal of disease-causing agents from bloodstream is considered to be the most direct conceivable treatment for infectious illness such as sepsis. In this regard, the coupling of functionalized magnetic microparticles and continuous flow microfluidic devices has attained outstanding attention for the extracorporeal toxin and pathogen isolation from blood. The laminar flow pattern developed in microfluidic devices allows co-flow of parallel streams with stable interface, while the magnetic beads provide the selective adsorption of the target substance on their surface and promote their recovery by external magnetic fields generated by rare-earth magnets [1, 2]. Nevertheless, the performance of such magnetophoretic-microfluidic devices has not been addressed yet because of the complexity of their mathematical description.

**2. Methods**

The current study presents both the experimental and computational based design of a two-phase continuous-flow extracorporeal magnetic blood cleansing microdevice for maximizing bead recovery while keeping impaired blood quality. In such system, a suspension (0.2 g·L-1) of fluorescent magnetic microparticles (4.9 μm) in Human Whole Blood (HWB) and a buffer solution are continuously injected through different inlets of a Y-Y shaped glass microchannel. The deflection of the particles and their collection in the buffer stream is achieved through the application of an external magnetic field by a permanent rectangular (10 x 5 x 3 mm3) neodymium (NdFeB) magnet parallel to the microchannel. Experimentally, the use of fluorescent beads allows the quantification of the particle recovery by fluorescence microscopy, using a custom Matlab code for image analysis. For the numerical analysis, a Computational Fluid Dynamics (CFD)-based Eulerian-Lagrangian approach, using the commercial software FLOW-3D, linked to a Fortran code for magnetic field and forces calculations was employed. The numerical method reported here involves magnetic and fluidic models that describe the motion of the beads and can be used to study critical details of the separation process, including the trajectories of individual particles and the stability of the blood/buffer interface.

**3. Results and discussion**

The complete bead recovery and fluids separation at the channel outlet requires a careful study of both magnetic and fluidic forces. For that purpose, a dimensionless number (J) that relates the variables that affect such forces (i.e. bead and fluids properties, magnetic field applied, selected flow rates) was employed.

The influence of fluids flow rates on both flow patterns and capture efficiency of the microseparator, expressed as particle recovery, is illustrated in Fig. 1. Because of the rheological properties of HWB, low flow rates of approximately 0.005 μL·s-1 are required to obtain high recovery (higher than 90%). This flow rate leads to similar values of magnetic and fluidic forces (J-value of 1.2) and corresponds to an average velocity of 0.65 mm·s-1 and a residence time of 3s, which is low enough to prevent diffusion of blood components to the buffer stream, thus ensuring that these low flow rates can be safely used since the properties of the blood are not affected. The experimental results fitted adequately to simulated data provided by the theoretical model (error lower than 10%).

**Figure 1.** Magnetic bead recovery (experimental and theoretical approaches) from human whole blood as a function of the applied flow rate.

The improvement of the system performance requires the treatment of high contaminated blood volumes. Thus, several channel lengths (2, 5 and 10 mm) and cross sections were computationally tested in order to find the best geometrical conditions that allow the use of higher flow rates while achieving high bead recovery.

**4. Conclusions**

The theoretical and experimental methodology developed in this work provide insight into the design of magnetophoretic-microfluidic devices for biomolecules separations and can be adapted to a broad range of magnetically-enabled microfluidic applications.

**Acknowledgements**

Financial support from the Spanish Ministry of Economy and Competitiveness under the projects CTQ2015-72364-EXP/AEI and CTQ2015-66078-R is acknowledged. C. González-Fernández thanks the Concepción Arenal postgraduate research grant from the University of Cantabria.

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