Simulation of magnetic particles in blood flow to improve failsafe particle detection of microspheres based detoxification system

Markus Gusenbauer[†]*, Giulia Mazza[†], Martin Brandl[†], Thomas Schrefl[†]

[†] Center for Integrated Sensor Systems, Danube University Krems (DUK),
Dr.-Karl-Dorrek-Straße 30 - Bauteil C, 3500 Krems
e-mail: markus.gusenbauer@donau-uni.ac.at, web page: http://www.donau-uni.ac.at/

ABSTRACT

In acute liver dysfunction therapy a microspheres based detoxification system is used for high specific toxin removal [1]. A hollow fiber membrane filter separates blood plasma from an extracorporeal blood circuit, which is led to a secondary circuit with immersed specific adsorbent microparticles. In case of filter rupture, the particles can contaminate the patient. Fluorescent magnetic particles are added to the secondary circuit in order to magnetically trap and optically detect the contaminant as a failsafe system before re-entering the patient (Fig. 1a). In preliminary work a theoretical analysis of magnetic particle accumulations at certain magnetic gradient fields from neodymium iron boron magnets was performed using a continuous Lagrangian approach [2]. The blood was represented by its viscosity, density and a given flow rate. Individual blood cell collisions with the magnetic particle compound could not be analyzed.

In order to analyze interactions of individual blood cells with agglomerating magnetic particles a newly developed simulation tool is used. Magnetic particles and blood cells are treated as individual subjects, similar to to the idea of molecular dynamics or discrete element simulations [3]. The simple Stokes drag is a good approximation for laminar flow. Here we combine magnetic particle dynamics and complex hydrodynamics computed with the lattice Boltzmann method. We extended the soft-matter simulation environment ESPResSo [4] with an immersed boundary model of individual red blood cells and magnetic particles (Fig. 1b). The objects are represented by a boundary mesh of interacting immersed boundary nodes. Magnetic interactions are calculated in the center of mass whereas the hydrodynamics and the objects elasticity are computed at the boundary nodes.

The goal of this work is a very small agglomeration plug for highly sensitive optical measurement of the fluorescent intensity. The intensity is proportional to the amount of collected particles and hence an indicator for a ruptured filter membrane (Fig. 1c). Using the developed simulation tool, the magnetic gradient field can be optimized such, that magnetic particles are collected at a small spatial region with respect to colliding blood cells and passing blood plasma (Fig. 1d).
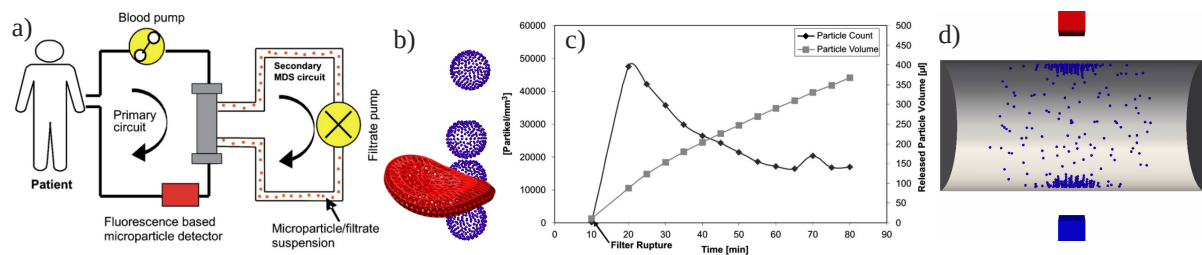
Figure 1: a) Microspheres based detoxification system. b) Interacting immersed boundary models of elastic red blood cell and rigid magnetic particles. c) Drastic increase in particle count after rupture of filter membrane. d) Agglomeration of magnetic particles at high field gradients of permanent magnets.

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