Numerical Prediction of Particle Dynamics Within a Cytometer. Application to Counting and Sizing By Impendance Measurement

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Abstract

Introduction
In Haematology analysis, counting and sizing of blood cells are mainly based on electrical gating through a microorifice in an orifice-electrode system. More precisely, when a particle passes through the gate, the inner dielectric medium is changed inducing a voltage drop between the two polarizing electrodes. This voltage variation, directly linked to trajectory and particle orientation, allows to work out particle volume measurement (Figure 1 shows the electrical pulses resulting two different particles). All these physical phenomena are micrometrical and occur in close system, which make their experimental observation difficult. So, to improve the resolution of sizing measurements by using electrical gating, we expose a complete numerical approach based on fluidic and electrical cross linked simulations. The presented model allows to compute the exact particle size distribution by taking into account the trajectory and the orientation of the particles through the microorifice.

Use of COMSOL Multiphysics®
Simulating the dynamic of suspended particles is a fluid-structure interaction problem, such that the flow affects the particle movement and vice versa. The model is then solved on a moving mesh by using an Arbitrary Lagrangian-Eulerian method. Numerically, to track the particle displacement, the subdomain is free to deform as determined by the boundary conditions, which are that the inlet, outlet and walls are fixed, whereas the particle is transported according to the velocity of the moving boundary derived from the Navier-Stokes equations. To control the solution, the mesh deformation stops when the quality of the mesh becomes lower than a specified value. The solution is then halted, and an automatic remeshing is performed from the deformed mesh, and the solver is restarted. This technique allows large mesh deformations and therefore the whole displacement of the particle through the aperture. A classical electrostatic model is then added to compute the impedance variation generated by the particle at each remeshing step.

Results
This approach gives important information about particles size distribution and allows to quantify the role of trajectory and orientation of particles on the size measurement. In particular, we show that the sizing can be strongly optimized by controlling the trajectory and the orientation of the

particles through the orifice. The preliminary results refer to rigid and totally insulating particles. In Figure 2, we expose an example of particle dynamics through an orifice-electrode system and the impact of the particle position on the electrical field. We also expose the deformed mesh between a remesh/started cycle. The two graphics at the bottom show a panel of computed electrical pulses generated by the passing of particles through the gate and the corresponding particle size distribution.

Conclusion

In this study, we present a fully innovative numerical approach in diagnosis engineering allowing to understand and optimize physical processes that we do not experimentally apprehend. We are currently working on substantial improvements on the particle transport model, notably including three-dimensional processing and deformability of particles under strong hydrodynamic stresses by integrating mechanical properties of the membrane. These developments will allow to simulate the hydrodynamic and rheologic behavior of red blood cells improving cell volume calculation in hematology analyzers.

Figures used in the abstract

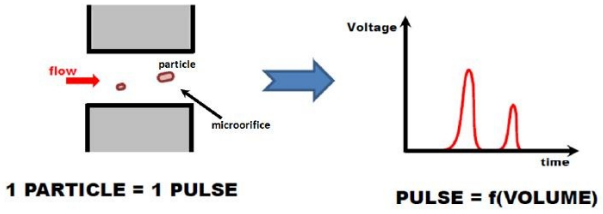

Figure 1

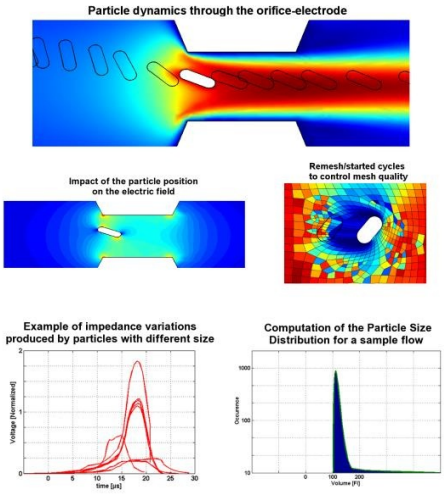
Particle dynamics through the orifice-electrode
Impact of the particle position on the electric field
Remesh/started cycles to control mesh quality
Example of impedance variations produced by particles with different size
Voltage [Normalized]
time [μs]
Computation of the Particle Size Distribution for a sample flow
Occurrence
Volume [Fl]

Figure 2