2D Simulation of dielectrophoretic multi-particle motion using Boundary Element Method

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ABSTRACT

Dielectrophoresis (DEP) is one of the most common techniques employed in microfluidic bio-particle manipulation. DEP can be defined as the movement of particle(s) within a fluid under the action of an electric field (which is non-uniform in the flow domain). This motion of particle(s) is achieved due to the interaction of each particle's dipole with the electric field gradient.

The simulation of DEP poses a loosely coupled multiphysics problem: the solution of the electric field with finite-sized particles in the flow domain reveals the DEP force acting on each particle which is imposed as an external force on that particle in the flow problem, solving the particle velocities, including also the angular velocity due to the moments created on the surface of the particle.

Solution of such a problem is not an easy task, even for 2D using domain-meshing problems, since the mesh should be updated with the motion of the particle(s). Such an update of mesh results in numerical errors, which mostly leads to non-converging or non-accurate results. This problem becomes more severe in a multi-particle problem where the particles can get too close to each other as they move.

Noting that in microfluidics, the flow problem reduces to that of the Stoke's flow, and the electric field can be solved using Laplace equation, the boundary element method can be employed to solve both problems.

In this study, a DC-DEP and AC-DEP problem is solved using boundary element method, first solving the electric field through Laplace equation, which is used to obtain the DEP force on the particle. This force is then inserted in the Stoke's flow equation as an external force driving the particle with the flow. Since boundary element method is a numerical method that only requires the meshing of the boundaries of the domain, the simulation needs no remeshing other than translation and rotation of the particles in the flow, assuming that the particles are rigid. Solution of deformable particles is not studied in this scope.

In the flow, multi-particle tracking is performed through proper boundary conditions, the particle-particle and particle-channel interaction is inherent in the solution. In time integration, first order forward difference (explicit) is used for simplicity and fast solution. At each time step, the positions of the particles are updated using the velocities obtained and the time increment. The simulations are performed in 2D space, but the formulation is valid for both 2D and 3D.

Several comparisons are made, with single particle and multi-particles in DC-DEP, AC-DEP and travelling wave DEP problems. Also, obtained solutions are compared with literature and solutions using Lagrangian Tracking Method, when possible.