Numerical Simulations of Dielectrophoresis

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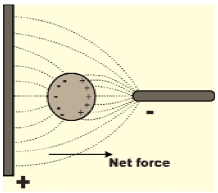
Dielectrophoresis

Basic Concept

The subject of separating microsize particles with different properties is always of great interest. Among those methods, dielectrophoretic separation devices are most commonly used as trap-and-release filters or particle sorters. Dielectrophoresis is the phenomenon that a polarizable particle will move in a converging electrical field. If the field is homogeneous, there will be no net force on the particle. If the field is however heterogeneous, the particle will have net force in the direction towards higher field strength. If the particle is surrounded by a medium that is more polarisable, the medium will have a larger motion in the direction of higher field, hence pushing the particle in the direction towards lower field strength

If the motion is in the direction towards higher field strength, it is referred to as positive dielectrophoresis (pDEP), while the case of motion towards lower field strength is called negative dielectrophoresis (nDEP). Following is the picture of pDEP.



Important Parameters and Equations

For a spherical particle, the variation in the magnitude of the force with frequency is given by the real part of the Clausius-Mossotti factor. The full expression for the time-averaged DEP force for a sphere particle is

$$Fdep = \pi\epsilon_m\epsilon_0 a^3\beta\nabla|\mathbf{E}|^2 \quad (1)$$

Here, a is the radius of particle. β is the real part of the Clausius-Mossotti factor, which is defined as

$$\beta = Re[\frac{\tilde{\epsilon}_p - \epsilon_m}{\tilde{\epsilon}_p + 3\tilde{\epsilon}_m}] \quad (2)$$

$\tilde{\epsilon} = \epsilon - \frac{\sigma}{\omega}j$ Here, ω is the frequency of AC field. In micro flows, the inertia effect could be neglected. If the interactive forces and Brownian force are also neglected , we then get the simplest and most commonly used model as follow:

$$F_{dep} = -F_{drag} \quad (3)$$

from which,together with the formular for sphree drag force for a sphere,

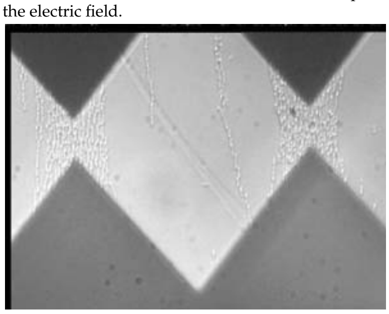
$$F_{drag} = 6\pi\mu a u \quad (4)$$

we get how to compute the speed of particles

$$6\pi\mu a u = \pi\epsilon_m\epsilon_0 a^3\beta\nabla|E|^2 \quad (5)$$

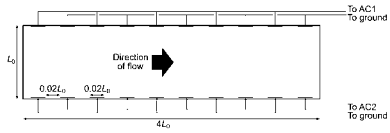
Experimental Fact

Below are experiment photo to show how the biological cells move under dielectrophoretic force.The cells shows that the particles form the famous 'peal chains', because they repulse each other in the direction perpendicular to the electric, and attract each other in the direction parallel to the electric field.



Superpositioned Dielectrophoresis

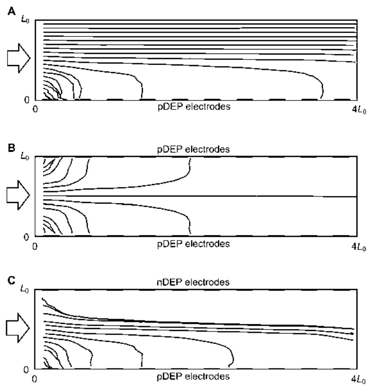
Several strategies may be employed to increase the trapping efficiency. In our simulation [2], superpositioned electrical fields have been used for trapping particles more efficiently.That means, if an additional AC field with a different frequency is applied on the system, it is possible to have one field with nDEP, and another frequency introduce nDEP. We assumed the experiment setup is like following



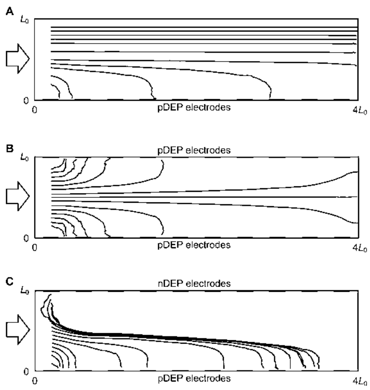
The dimensionless channel height is L_0, the width of the electrodes and the distance between the electrodes were $0.02L_0$,the radii of the ellipsoid E.coli are $r_1 = 0.0279L_0, r_2 = r_3 = 0.0068L_0$.While in the simulation, we regarded $r_1 = r_2 = r_3$. Laminar flow is assumed to bring the particles passing through the channel.

Simulation of Trapping Efficiency

Based on the parameters above, we compare three kind of geometries, A,B,C. A only have pDEP force in bottom, B has pDEP both in the cell and bottom, and C has nDEP in the cell and bottom. We simulated E.coli, which is generally regarded to be conducting and the cell membrane is assumed to be insulating. We compute two kinds of solutions. One is, the particle trajectories in a medium conductivity solution:



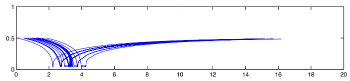
From the figure above, we can see, that in this case, B type can get highest trapping efficiency rate.(about 98 percents) Another solution is high conductivity solution.



From the figure above, we know type C is the most efficient geometry, the trapping efficiency is about 100 percents. The simulation was calculated by finite element method in FemLego.[1] 3D meshes and unstructured tetrahedral elements were used.

Simulation of Trap-release

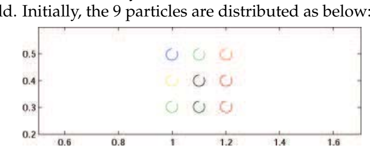
Dielectrophoresis trap-and-release devices utilize the nDEP and pDEP in different time, by changing the frequency of AC field [3]. We also simulated this situation.Following figure is the trace of 20 particles in the micro channel being trapped and released by the DEP forces.



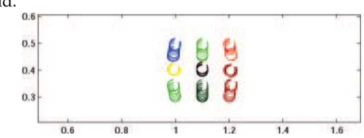
Also, different geometries of electrodes distribution are important, and they has been simulated.

Simulation of inter-particle DEP

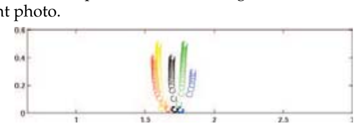
In order to simulate the 'peal chains', interactive forces due to dielectrophoretic dipole between particles must be included. Also a repulsive force between two particles when they collide need to be introduced. Below we simulated 9 particles uniformly distributed in the uniform electric field. Initially, the 9 particles are distributed as below:



After some time, the nine particles moved and formed three short chains in the electric field direction and repulse each other in the direction perpendicular to the electric field.



This shows that the interactive dielectrophoretic force we computed make sense. Then we simulated 5 particles in nonuniform electric field like dielectrophoresis sorter devices typically use. 5 particles are distributed in the middle of channel, and they are attracted to the bottom where electrode edge gives the highest pDEP. We can still see that they form two 'peal chains' ,which agrees with the experiment photo.



However, while the particles are elliptic, which is the general case in biology cells, the inter-particle DEP computation would become much complicated. Moreover, the hydrodynamics forces between particle and fluid were also neglected in our computation, which also needs to be added to our model in future.

Work Distribution

The modeling and simulation work are done by the first and second authors. Third and fourth authors contributed to the idea of simulation in trapping effiency.

Acknowledgement

Financial support from the Swedish Research Council (VR) is gratefully acknowledged. We also acknowledge Minh Do-Quang, Walter Villanueva and Jerome Hoepffner for helpful discussions.

Reference

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[2] Aldaeus,F.,Lin,Y.,Roeraade,J.,Amberg,G., Electrophoresis,2005,accepted.

[3] Aldaeus,F.,Lin,Y.,Roeraade,J.,Amberg,G.,"Multi-stepped Dielectrophoretic Saparation",to be submitted.