Particle separation in straight channel based on size, shape and post shape using dielectrophoretic Deterministic Lateral Displacement (e-DLD)

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Degree Sought: Master

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Overview

Dielectrophoresis (DEP), a linear electrokinetic transport mechanism, can be used to concentrate and sort cells, viruses, and particles. An electrokinetically driven deterministic lateral displacement (e-DLD) device is proposed for the continuous, two dimensional fractionation of particles in microfluidic platforms. The suspended particles are driven through an array of regularly spaced posts by applying an electric field across the device. In recent published papers, it has been shown that particle separation in DLD systems is induced by cumulative and separative effect of particle-obstacle non-hydrodynamic interactions, whose presence is independent of the driving field.

Motivation

- Prove the directional locking phenomena using Lagrangian Tracking Method.
- Find parameters(forcing-angles, electric field) which have the highest separation efficiency based on particle size.
- Find the separation feature when using different shapes of particle and different post shapes.

Numerical Formulation

1. Boundary condition

1). The electric field outside the EDL (Electric Double Layer) is governed by the Laplace equation because the net charge outside the EDL is zero:

$$\nabla^2\phi=0 \qquad (1)$$

where ϕ is the electric potential.

2). The electric potentials applied on the inlet and outlet are, respectively:

$$\phi = 0 \quad \text{on the inlet AB} \qquad (2)$$

$$\phi = \phi_0 \quad \text{on the outlet CD} \qquad (3)$$

3). All the other rigid surfaces are electrically insulating:

$$\vec{n}\cdot\nabla\phi = 0 \qquad (4)$$

where $\vec{n}$ is the unit normal vector pointing from the boundary surface into the fluid.

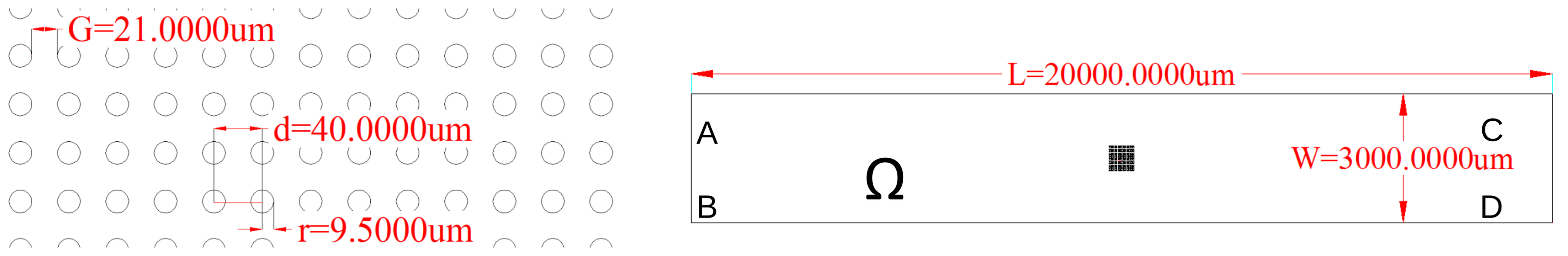
2. Governing equations of fluid field

The fluid motion can be modeled by the Stokes equations without any electrostatic body force, described as:

$$\rho\frac{\partial\vec{u}}{\partial t} - \mu\nabla^2\vec{u} + \nabla p = 0 \quad \text{in } \Omega \qquad (5)$$

$$\nabla\cdot\vec{u} = 0 \quad \text{in } \Omega \qquad (6)$$

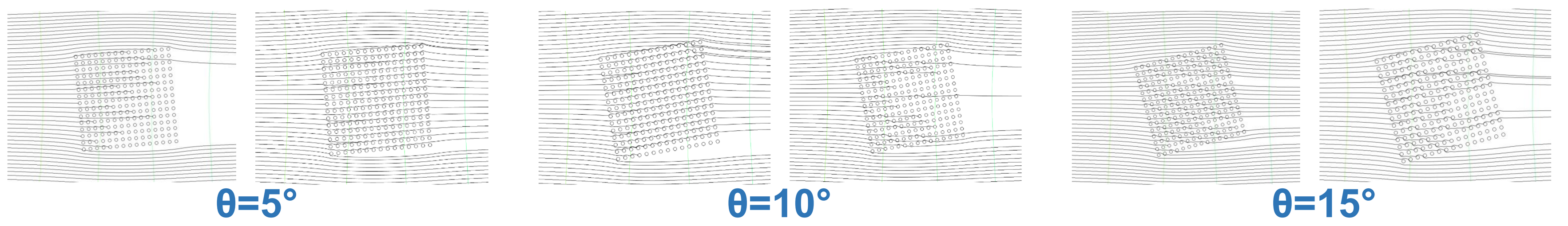
Where $\vec{u}$ is the fluid velocity vector and p is the pressure. Both the fluid velocity and the pressure are initially zero in the computational domain. The pressure at the inlet and the outlet are both zero so there is no pressure imposed.



Schematic of the channel and post array

Results

1. Directional locking phenomena using Lagrangian Tracking Method (LTM)



θ=5° θ=10° θ=15°

It is clear that at certain range of forcing angles, the bigger particle will be locked in the single column, while smaller particle follow the flow field direction. Since Lagrangian tracking method is not accurate enough to get any quantitative conclusion, ALE modeling is needed to validate the phenomena above. The lines in picture are simulated streamlines.

2. Particle separation by size using Arbitrary Lagrangian-Eulerian Method (ALE)

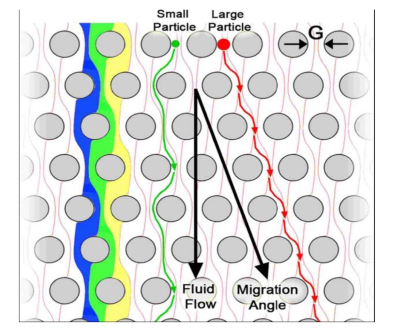
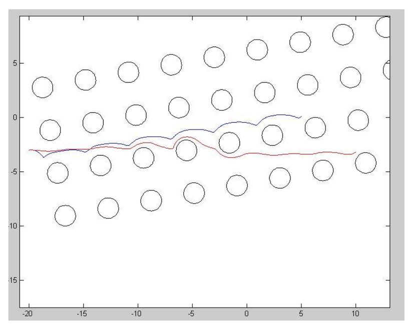
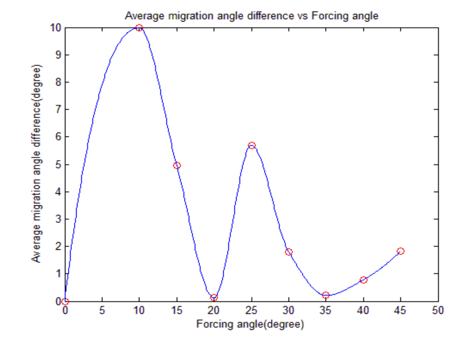


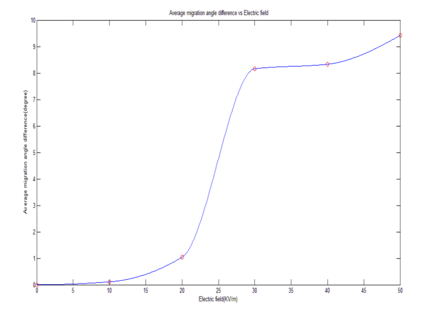
Illustration showing the separation method. a small particle, green, is able to follow the fluid flow, while the large particle, red, is excluded from the. leftmost streamline in each gap. This causes the large particle to move at an angle to the flow fluid.



Using COMSOL with MATLAB, the trajectory of both particles can be plotted, in which blue trajectory represents bigger particle and red trajectory represents smaller particle (θ=25°，E=30KV/m)



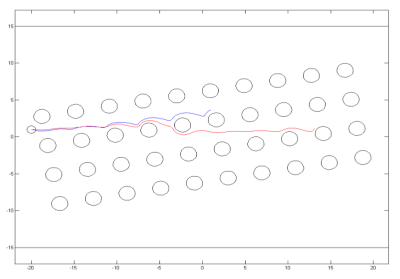
Average migration angle(α)changing with forcing angle(θ)



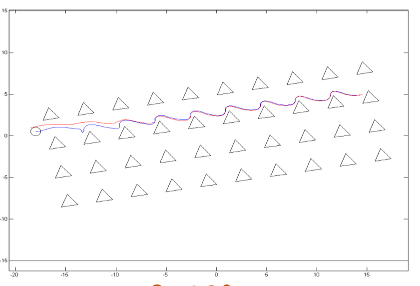
Average migration angle(α) changing with electric field(E)

In order to simplify calculation, the size of micro channel is reduced to 1mm long and 300 um wide, the post array is reduced to 4×10. The electric field is 50 KV/m. The particle's Zeta potential is 32 mV and the wall's is 80 mV, two different sizes of spherical particle (5um and 10um) are being used. I choose **average migration angle (α)** to be the criterion of separation efficiency. I drew diagrams using MATLAB which shows the trend that average **migration angle(α)** changing with **forcing angle (θ).** It is clear that when **θ=10°,** α becomes the biggest. Then keep θ=10° fixed, using MATLAB, the diagram that average migration angle changing with electric field is obtained. It is obvious that when **E=50KV/m**, the separation efficiency is the best which has the maximum migration angle α about 10°.

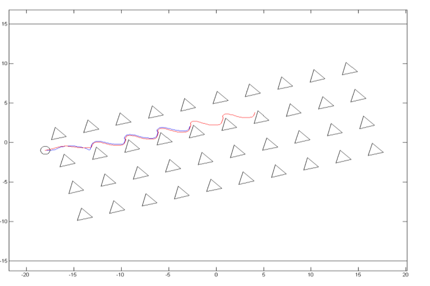
3. Particle separation by size with triangular post



Cylindrical post, θ=10°



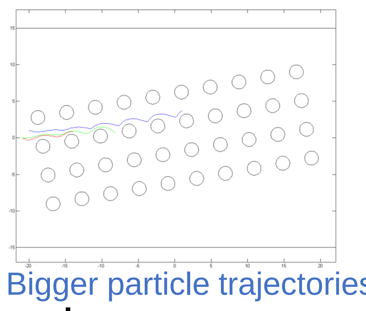
θ=10°



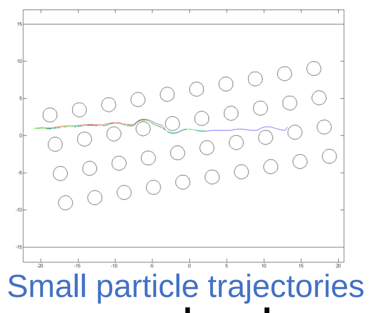
θ=15°

When two differently sized particles following the same streamline enter the constriction and negotiate a post, no diffusion involved, a particle smaller than a defined **critical diameter** (D_c) will remain in the first streamline, alternatively, a particle larger than D_c is displaced into the next streamline. In this simulation, every parameter is the same (θ=10°, E=50KV/m, G=21um), except changing the post shape to triangular. Interestingly, instead of following the electric field, the smaller particle is locked in the single column in post array when θ=10°, and also θ=15°, which means when having the same gap G and θ, the critical diameter of triangular posts will have smaller D_c than cylindrical posts.

4. Particle separation by shape using elliptic and spherical particle



Bigger particle trajectories



Small particle trajectories

In this simulation, keep every parameter the same and volume of the particle the same, using elliptic particle and spherical particle. The elliptic particle's initial orientations are following the flow direction and being perpendicular to the flow direction. For bigger particle, the separation may happen since the elliptic particle is not locked in single column, that may because the hydrodynamic diameter is smaller for elliptic particle; for smaller particle, there is no sign of separation.

Conclusion

- Simulations have showed the best forcing angle θ is about 10° which suggests the use of relatively small forcing angles to optimize the resolution. Using the best forcing angle, the electric field that has the best resolution is found------ 50 KV/m, which indicates the use of relatively strong electric field.
- When having the same gap G and θ, triangular posts will have smaller critical diameter D_c than cylindrical posts. For the same gap G and θ, an array using triangular posts can separate smaller particles.
- When having the same volume, the elliptic particle may have a smaller hydrodynamic diameter than spherical particle, and the initial orientation of the elliptic particle also influence elliptic particle motion.

Reference: 1. Srinivas Hanasoge. Electrokinetically-driven deterministic lateral displacement for the particle separation in microfluidic devices. Microfluid Nanofluid (2015) 18:1195–1200

2. Shizhi Qian, Ye Ai. Electrokinetic particle transport in micro-nanofluidics. (2012)

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