Dielectrophoresis Analysis of Particles and Cells in a Microfluidic Channel

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OBJECTIVES

The objective is to understand the behaviour of particles (polystyrene (PS) beads and biological cells) as they go through a microfluidic channel, while under the influence of a dielectrophoretic force. Fluid dynamic modeling was used to understand their behaviour, the relationship between the frequency dependent Clausius-Mossotti Factor (KCM), their deflection in the channel and the entrance and exit heights of the cells. This work will lead to a label free device for rapid analysis of the physiological state of cells.

BACKGROUND/THEORY

The microfluidic device consists of two glass slides with a channel between them to allow for cells in a fluid medium to run through. A dielectrophoretic (DEP) electrode is placed in the center of the microfluidic channel, which produces a uniform electric field. On either side of the electrode, are sensors that can detect the height of the cell.

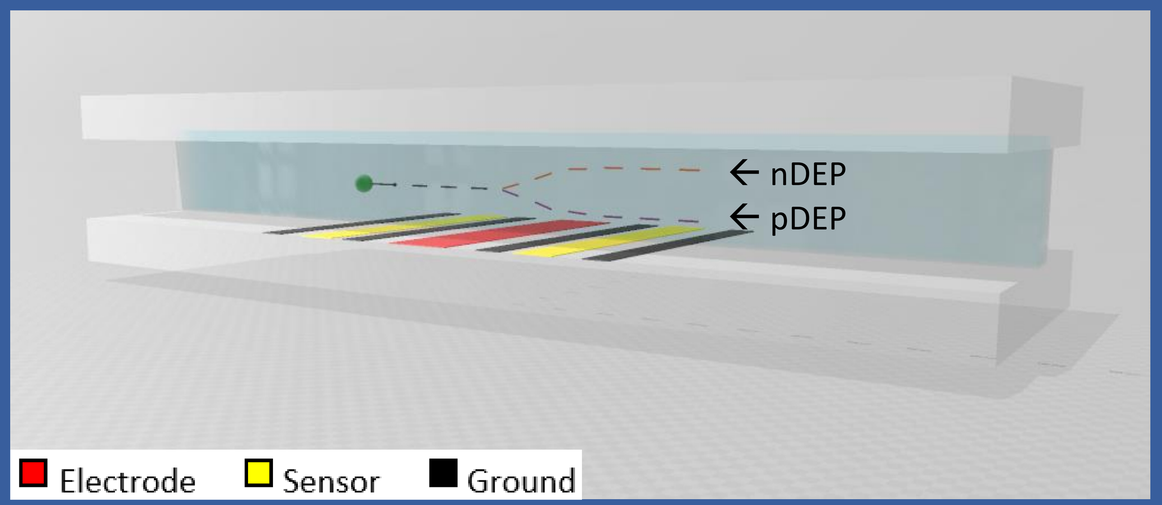


Figure 1: 3D model of the microfluidic channel.

The frequency of the signal is directly related to the Clausius-Mossotti Factor (KCM). Having a signal with a negative or positive KCM will correlate with the DEP force and is referred to as an nDEP and a pDEP, respectively.

MATERIALS/METHODS

In order to find the relationship between the heights and the KCM, the microfluidic channel was simulated using COMOL Multiphysics Software. The heights before and after the electrode for a range of entrance heights and KCM's.

The microfluidic channel was designed with a height of 40um sandwiched between the two glass slides. Initially 10.2um diameter polystyrene beads in de-ionized water medium was simulated as they mimic biological cells. Results were compared with experiments performed with a 6MHz 4Vpp voltage and the 10.2um PS beads.

Fluid Dynamic Simulations of Cell Trajectories

Simulation

A 2D plot of simulations was created to show the particles (cells) trajectories as they experience a dielectric force. For a nDEP force the height of the cell increases, and with a pDEP force it decreases. When there is no DEP, the cell remained at the same height.

Fluid Dynamic Simulations of Cell Trajectories

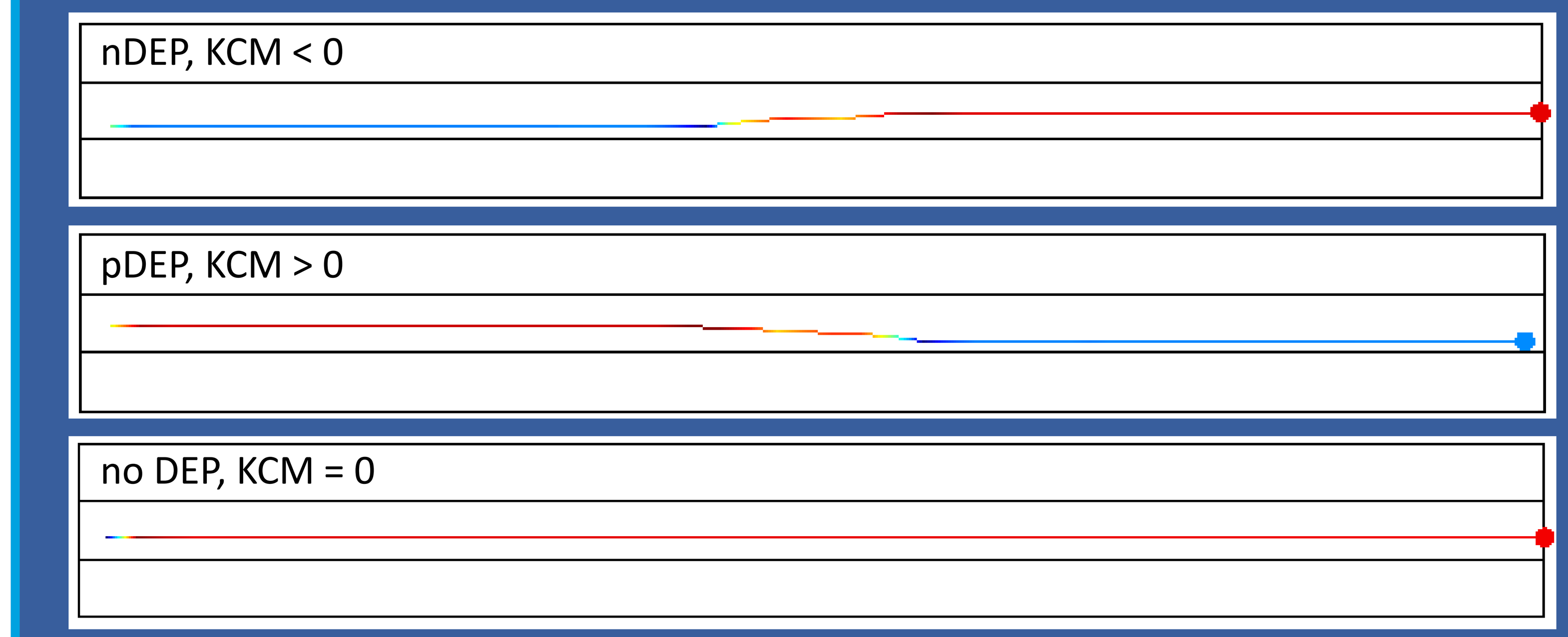


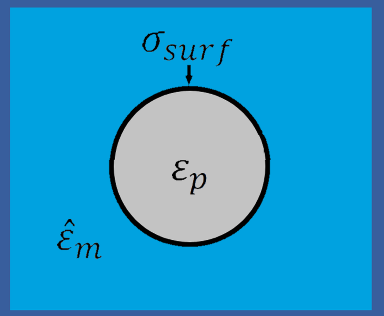
Figure 2: Example cell trajectory simulations

KCM Spectrum

Using MATLAB and the equations below, the spectrum for the KCM values, relative to frequency, is collected using the permittivity parameters for PS beads in de-ionized water. The range of possible KCM values is from -0.5 to 0.5, which is used in the simulations for particle tracking. The nDEP region is seen below the dotted line, while the pDEP region is above. The KCM for biological cells has a similar but unique spectrum.

$$KCM = \frac{\hat{\varepsilon}_p - \hat{\varepsilon}_m}{\hat{\varepsilon}_p + 2\hat{\varepsilon}_m}$$

$$\hat{\varepsilon}_p = \varepsilon_p - j\frac{\sigma_{surf}}{r\omega}$$



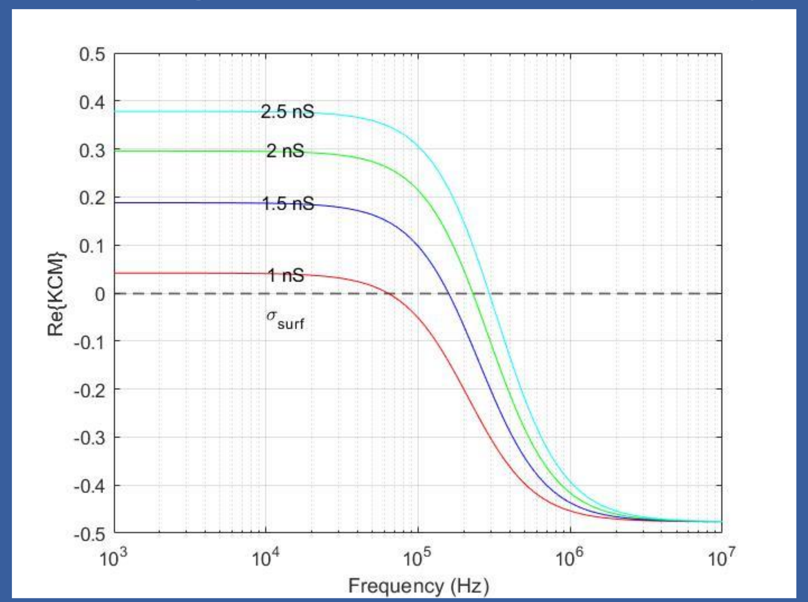


Figure 3: Spectrum for KCM vs Frequency for polystyrene beads in de-ionized water

Mapping the Heights to KCM

The heights that were gathered from simulations, were graphed to examine the relationship between the entrance and exit heights to the value of KCM. The mapping of h_1 and h_2 to KCM would then enable identification of a cell's dielectric property in an experiment.

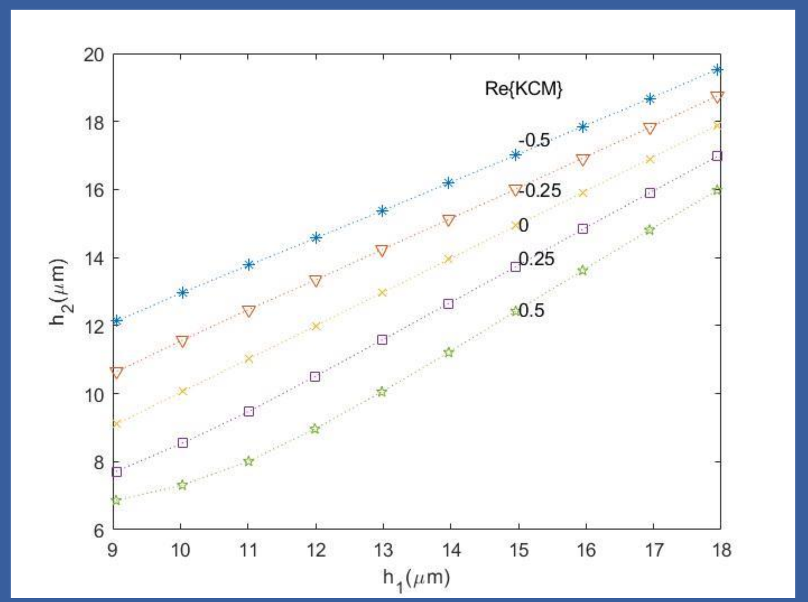


Figure 4: Simulated relationship of cell entrance, h_1, and exit, h_2, positions with its KCM.

Trial Tests using Polystyrene Microspheres

Experimental Test with PS microspheres

Experiments were performed using polystyrene microspheres flowing in the channel for an applied electrode voltage of 4Vpp. The KCM for PS beads is known to be -0.5. This was compared with the fluid dynamic simulation results.

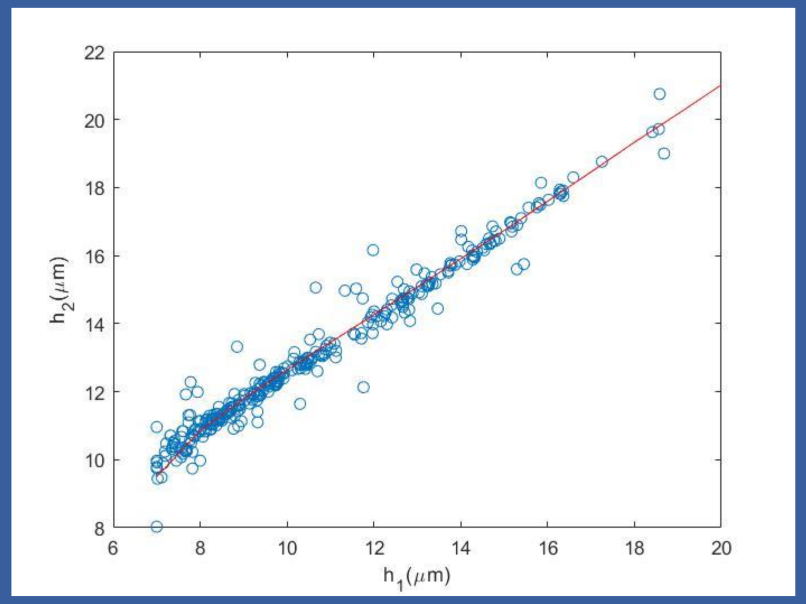


Figure 5: Experimentally measured entrance vs. exit heights of PS beads (circles) and simulation values (red line).

CONCLUSION

Biological cells experience a nDEP, pDEP or no DEP force and, raise, lower or remain at the same height in the channel, respectively. This can be used to determine the dielectric properties of the cells physiological state. The polystyrene beads follow a linear trend in the relation from there entrance and exit heights, as seen in both the simulation and experimental data. This linear relationship plateaus as it reaches the center of the channel, as well as the edges.

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