SIZE BASED PARTICLE SEPARATION USING ACOUSTIC MICROSTREAMING AND ALCAT PUMPS

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ABSTRACT

The separation and/or extraction of particles and cells based on size is an essential step in the life sciences. Here we demonstrate a novel platform that is capable of simultaneously performing on-chip pumping and trapping/separation of particles based on size. We demonstrate that the trapping efficiency can be controlled by varying the voltage applied to the external transducer. Furthermore, we demonstrate the enrichment of 5 µm polystyrene particles from 10 µm particles.

KEYWORDS

Particle/cell trapping, particle/cell separation, acoustic microstreaming, point of care

INTRODUCTION

In the life sciences the ability to separate and/or extract particles and cells based on size is an essential step for research, diagnostics and therapeutics.[1, 2] Microfluidic based separation techniques offer many advantages, including the processing of small sample volumes, faster sample processing, lower cost and enabling development of portable platforms.[1, 2] Although numerous methods of separation have been demonstrated, a platform that is capable of simultaneously pumping and separating particles based on size will be important in realizing a true point-of-care system.

Acoustic microstreaming within microfluidic devices have the capability of generating a significant amount of trapping force.[3] Air Liquid Cavity Acoustic Transducers (ALCATs) are dead-end side channels that are in the same plane as the microchannels themselves. When the device is filled with liquid, ALCATs trap bubbles creating an air-liquid interface that can be excited by an external acoustic energy source. The oscillations of the membrane will generate a first-order periodic flow which will induce a steady second-order microstreaming flow. Based on the angle of the ALCATs, the acoustic microstreaming generates a bulk flow in the microchannel (Figure 1).

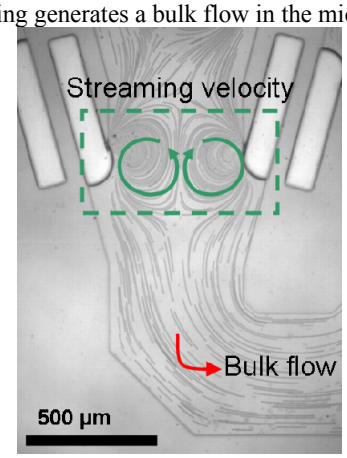

Figure 1: Streak image of ALCAT pump: Due to the angle of the ALCATs to the main channel a bulk flow is generated in addition to the acoustic microstreaming flow.

The vortices generated are also capable of trapping particles and cells.[4] This is due to the fact that shear gradient lift forces within the vortices cause particles to flow towards the center of the vortex.[5] This shear gradient lift force is dependent on the size of the particles, with larger particles experiencing a greater force. In fact, the shear gradient lift force scales between a^3 and a^4, where a is the particle diameter.[5] Therefore, the balance between viscous forces of the "bulk flow" and the "trapping vortices" will enable selective trapping (or sorting) of particles based on size.

EXPERIMENT

The microfluidic device is fabricated using standard soft lithography techniques using PDMS and bonded to a 200 µm thick glass coverslip using plasma. The device is allowed to recover its hydrophobic properties overnight in a 120°C oven. 30 µL of polystyrene bead solution (solution density ≈ bead density = 1.050 g/cm^3) is pipetted in the inlet and a vacuum is pulled at the outlet to fill the channel up to the indicated area in Figure 2. The device is coupled to a piezoelectric transducer using ultrasound gel. A 44 kHz square wave is applied to the piezoelectric transducer which pumps the fluid from the inlet to the outlet as well as traps the particles in the vortices. The voltages applied to the piezoelectric transducer determine both the bulk flow velocity and the acoustic microstreaming velocity simultaneously which result in different particle trapping efficiencies. The particle suspension is removed from the

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outlet and the bead concentration is determined using a hemocytometer and compared to the inlet concentration.

Two separate experiments were performed. First, in order to characterize particle trapping, solutions of either 5 µm or 10 µm beads at a concentration of ~1000 particles/µL were flowed through the system. The ratio of the outlet to inlet concentrations was calculated to obtain a trapping curve. Second, to demonstrate particle separation by size a mixed solution of polystyrene beads (5 µm and 10 µm of ~1000 particles/µL each) was placed at the inlet and a similar process as above was used to determine the outlet concentration. The data was used to characterize the extraction efficiency of 5 µm particles from 10 µm particles.

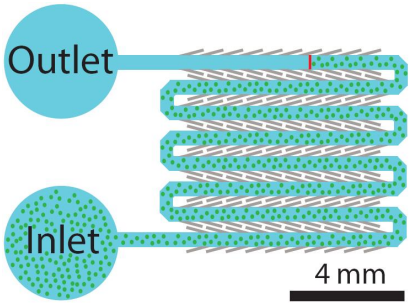

Figure 2: Design of ALCAT trapping device: Particle solution is pulled via applying vacuum to the outlet reservoir until solution arrives at the location indicated by the red line. Device is then placed on a piezoelectric transducer using ultrasound gel.

RESULTS AND DISCUSSION

Results of the particle trapping characterization are shown in Figure 3. This data demonstrates that larger particles are trapped with higher efficiency within the microstreaming vortices compared to smaller particles. Smaller particles tend to occupy larger orbits within the vortices making them more likely to be influenced by viscous forces due to the bulk flow. This allows them to be released more readily to the outlet. However, increasing the voltage applied to the piezoelectric transducer simultaneously increases the bulk flow velocity and the microstreaming velocity allowing larger particles to be released to the outlet as well, although to a lesser extent.

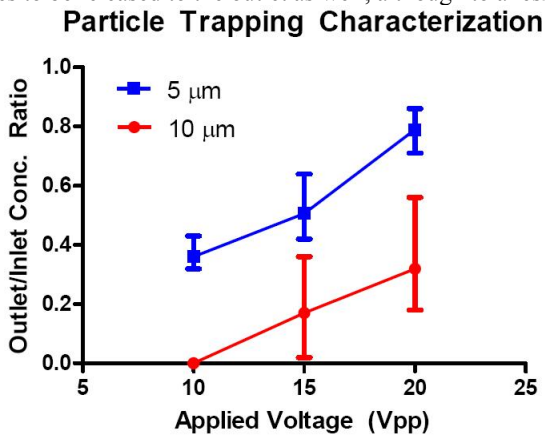

Figure 3: Characterization of particle trapping. Particle trapping decreases linearly as the applied voltage is increased. Data also demonstrates that larger particles are trapped more readily compared to smaller particles.

Results of particle separation by size are shown in Figure 4. Here, we observe that 5 µm particles can be efficiently extracted from 10 µm particles. The data shows that at an applied voltage of 15 V_{pp} there is approximately a 9-fold enrichment of 5 µm particles from a solution of 5 µm and 10 µm particles with an initial concentration ratio of 1:1.

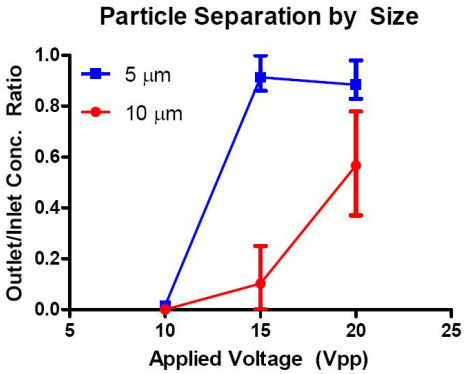

Figure 4: Results of particle separation. Smaller particles can be efficiently enriched from larger particles. Approximately a 9-fold enrichment of 5 μm particles from a solution of 5 μm and 10 μm particles (1:1 ratio of concentration) can be achieved at 15 V_{pp} applied voltage.

The almost two fold increase in concentration of 5 μm particles at the outlet for the particle separation by size experiments (Figure 4) compared to the particle trapping characterization experiments (Figure 3) at 15 V_{pp} could be attributed to the fact that as more 10 μm particles get trapped and occupy more space within the vortices, this contributes to more 5 μm particles flowing into the outlet well. Figure 5 shows a micrograph of particle separation with an applied voltage of 15 V_{pp}.

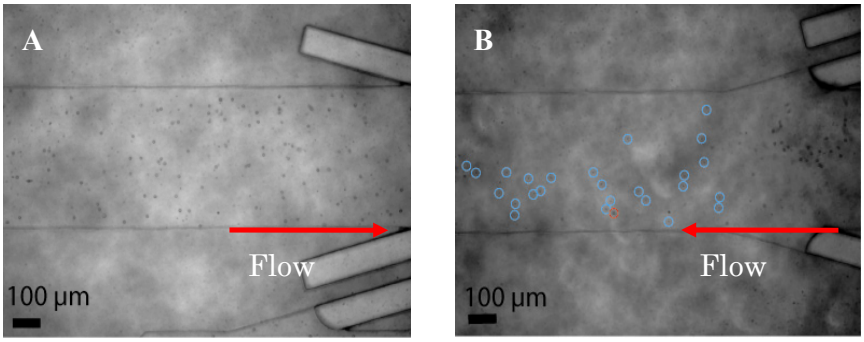

Figure 5: Micrograph of particle separation with applied voltage of 15 V_{pp}. A) Inlet - Mixed population of 5μm and 10μm particles. B) Outlet – 5μm particles (blue circles) flow through to the outlet with a few 10μm particles (red circle)

CONCLUSION

We demonstrate the ability to utilize the acoustic microstreaming generated by the on-chip ALCAT pump platform to perform particle separation based on size on μL sample volumes. The observation that smaller particles occupy larger orbits within the microstreaming flow allows for the enrichment of 5 μm particles from 10 μm particles by a factor of 9. We aim to characterize this separation platform to determine how differences in solution density vs. particle density will impact separation efficiency. Furthermore, the authors will aim to characterize the platform for cell separation based on size.

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