

A PERFORMANCE COMPARISON OF POST- AND RIDGE-BASED DIELECTROPHORETIC PARTICLE SORTERS

Rafael V. Davalos, Blanca H. Lapizco-Encinas, Gregory J. Fiechtner, Anup K. Singh, Blake A. Simmons, Yolanda Fintschenko, and Eric B. Cummings
Sandia National Laboratories, P.O. Box 969, MS 9036, Livermore, CA 94551

1. Introduction

Sample concentration is an essential step for the detection of pathogens in a microfluidic platform. Dielectrophoretic architectures have been developed to support particle sorting and sample processing in microfluidic systems. We present a comparison of measured performance of insulating-post-based (2-D) and insulating-ridge-based (2-1/2-D) dielectrophoretic particle filter/concentrators and experimental observations and analysis of issues facing each architecture. In batch mode, saturation of the dielectrophoretic traps limits the selectivity and device capacity that can be achieved simultaneously. Saturation limits the effectiveness of such filters when target particles are present in low concentrations compared to similar background particles, typical when processing samples to extract pathogens. We report the degree of saturation as a function of applied field and collection period.

After trapping particles for the desired collection period, elution takes place by decreasing the magnitude the applied DC field. For post-based arrays, trapping occurs in potential wells in multiple locations within the microfluidic channel. The corresponding elution volume is large. Therefore, we have also explored batch-mode operation using insulating-ridge-based concentrators. Here, ridges selectively deflect particles to potential-well-traps located in a confined spatial region, corresponding to elution volumes that are reduced greatly. The reduced elution volume is achieved with the penalty of a limited saturation volume when compared to that achieved in post-based arrays.

Keywords: dielectrophoresis, electrokinetic flow, concentrator, sample preparation

2. Experimental

Experiments were conducted in a microfluidic chip consisting of patterned channels isotropically etched to a 10- μm depth in borosilicate glass [1-3]. Microchannels are straddled by two reservoirs that have a diameter of ~ 1 mm and a depth of ~ 1 mm. The distance between the reservoirs is 10.2 mm. For the post arrays, the array area is located in the middle of the microchannel, 2.9 mm from each port. The arrays consist of circular posts with 200- μm diameters, spaced 250 μm from center-to-center. The channel and reservoirs were filled with a solution consisting of DI water, NaOH, and KCl to obtain 7.5-8.0 pH and 1.0- or 2.0- $\mu\text{S}/\text{mm}$ conductivity. Platinum electrodes are placed in the reservoirs and an electric field is applied.

Lyophilized *Escherichia coli* (strain BL21) are obtained from Stratagene (La Jolla, CA). Cell cultures are grown at 37 $^{\circ}\text{C}$ using standard culture techniques to obtain cells in late log phase and labelled with Syto[®] 11 (Molecular Probes, Inc., Eugene, OR) dye (excitation/emission 508/527 nm). The concentration factor of *E. coli* in the microchannels is evaluated by performing experiments with an initial dilution of 1×10^5 cells/ml that are concentrated and subsequently released in the following manner:

- (a) A pressure-driven flow (~ 100 Pa) was applied continuously.
- (b) An electric field was applied and the cells were trapped in the post array.
- (c) The *E. coli* cells were released from the dielectrophoretic traps as a plug of cells.

For each of these three stages, a 250-frame, arbitrarily selected movie was recorded. The rate at which particles escape the device while the electric field is applied was estimated by counting the number of cells that pass through the outlet. The number of concentrated cells was calculated by counting the number of cells in the movie frame with the highest population. The concentration factor is defined as the ratio of the cell flow rate evaluated at the frame containing the plug of concentrated cells as they elute the post array to the rate at which cells flow pass the outlet (before the electric field is applied).

3. Results and discussion

Figure 1 (a) shows the operation of a post-based device that is batch-concentrating *E. coli* near full saturation. The flow is electrokinetically driven from left to right with an applied mean field of 75 V/mm. Because all traps are saturated, particles escape the device, a condition we call "breakthrough." This behavior is reasonably predictable and called "normal saturation." In contrast, Fig. 1 (b) shows the operation of the same device at the same voltage as Fig. 1 (a). In this case, the particles accumulate significantly only in the first row of the posts. These densely collected particles are an electrokinetic packing that blocks upstream particles from propagating into the device. Such "anomalous saturation" never exhibits breakthrough and loses nearly all selectivity. With judicious operation, devices can saturate normally, but factors influencing the saturation behavior are comparatively subtle. Typically, 98% of the *E. coli* are trapped within the device under normal saturation conditions.

Figure 2 shows the concentration factor obtained for *E. coli* cells in a corduroy array. Here, particles are deflected along the ridge, reaching a potential well near the wall, where they are then trapped. The concentration factor is ~6000, reaching saturation after a mean electric field of 80 V/mm is applied for ~16 s.

To test operation of the device well before the onset of saturation, experiments were conducted using mean fields of 50 V/mm, 75 V/mm, and 100 V/mm for 1 or 2 minutes, conducted for each configuration for eighteen measurements. The results are summarized in Table I, demonstrating concentration factors that are all above three orders of magnitude and that increase with applied electric field. Results summarized in Table II demonstrate that the concentration factor increases with the collection period, indicating that the collector has not reached saturation or a performance limit, even for up to 32 min at 75 V/mm, corresponding to concentration factors of > 6000.

Table I. Concentration as a function of applied field for 1 and 2 minutes.

Mean Field (V/mm)	1 min		2 min	
	Concentration Factor	Concentration Factor	Concentration Factor	Concentration Factor
	mean	deviation	mean	deviation
50	1640	229	2427	184
75	2029	284	2733	281
100	2071	71	3208	389

Table II. Concentration as a function of duration at 75 V/mm.

Duration (min)	Concentration Factor
1	2029
2	2733
4	3097
16	4598
32	6172

4. Conclusions

The post-based iDEP device was used to trap *E. coli* with up to 100% removal efficiency and release a ~6000X concentrated plug of cells. Because of the low initial concentration, the particle traps remained far from saturation during this test. While saturation dramatically complicates the

operation and limits the selectivity and repeatability of the post-based device, the corduroy device demonstrated an approach that allows concentration to saturation in a localized region with minimal effect on selectivity and the global flow-field. This approach also localized the particle trap to a compact region near a channel wall, facilitating efficient elution. The corduroy iDEP concentrator demonstrated concentration by more than 3 orders of magnitude in 16 seconds, limited by saturation.

Acknowledgements

This work was performed by Sandia National Laboratories for the United States Department of Energy under Contract DE-AC04-04AL85000. The authors acknowledge funding from Sandia Laboratory Directed Research and Development grants. The authors thank Allen Salmi for technical assistance in assembling the experimental apparatus, and Judy Rognlien for preparing *E. coli* samples.

References

- [1] E. Cummings and A. Singh, *Analytical Chemistry* **75**, 4724-4731 (2003).
- [2] B. H. Lapizco-Encinas, B. A. Simmons, E. B. Cummings and Y. Fintschenko, *Analytical Chemistry* **76**, 1571-1579 (2004).
- [3] B. H. Lapizco-Encinas, B. A. Simmons, E. B. Cummings and Y. Fintschenko, *Electrophoresis* **25**, 1695-1704 (2004).

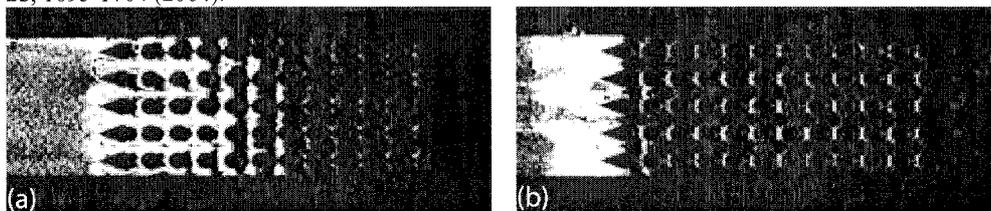


Fig. 1. Demonstration of Saturation Behavior in a Post Array. (a) Image captured after 71 seconds of operation; particles saturate traps, and then flow downstream, saturating traps at downstream locations. The entire array is filled with particles for longer periods of operation, when particles break through the downstream edge of the post array. (b) Image captured after 90 seconds in the same microchannel as for (a). Particles anomalously saturate the traps located at the front row of posts, ultimately forming an electrokinetic barrier to further downstream particle flow.

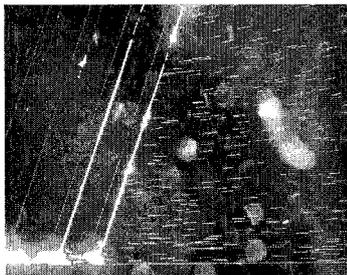


Fig. 2. Demonstration of Saturation Behavior in a Corduroy Array. (Fluorescence image of 2- μm polystyrene microspheres in a fully saturated corduroy DEP concentrator. The ridges in the 20- μm -deep by 3-mm wide glass channel are 13- μm tall and 100- μm wide. The electrokinetic particle flow is from right to left at ~ 1 mm/s, produced by a field of 80 V/mm. With the high inlet particle concentration, the device saturates with particles in ~ 16 s, providing a $\sim 6000\text{X}$ concentration factor.