

# SCALING EFFECTS IN A MICROMACHINED ELECTRICAL FIELD-FLOW FRACTIONATION ( $\mu$ -EFFF) SYSTEM WITH INTEGRATED DETECTOR

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## ABSTRACT

This work examines scaling effects in a miniaturized electrical field-flow fractionation ( $\mu$ -EFFF) system with an integrated electrical detection scheme and presents a new electrical model for operation of the system. Critical parameters in the  $\mu$ -EFFF system are examined including the electrical time constant, retention, plate heights, and resolution. This work is significant since it increases the theoretical understanding of EFFF, a powerful system used in the separation and analysis of colloids, emulsions, and other suspensions, and validates the theory with experiment. Biological particles of interest testable using EFFF include proteins, DNA, liposomes, organelles, viruses, and polymers for use in biochemistry, cell biology, bioengineering, and pharmaceuticals. EFFF uses an electric field perpendicular to the separation direction to separate particles based on size and charge.

## INTRODUCTION

While EFFF theory indicates that the system would be improved by reductions in channel size, the extent of the improvement and experimental validation has been limited until recently when microfabrication techniques were applied to develop a miniaturized system. General EFFF theory assumes that all parameters, other than channel dimensions, remain constant as the system is miniaturized. If this is not the case, miniaturization of the system may be of limited value. Thus understanding how parameters in the system scale is of critical importance in characterizing the value and abilities of a miniaturized system. This paper shows how some of these parameters scale and what some of the anticipated advantages are for a miniaturized system. The  $\mu$ -EFFF system used in this analysis and for the experiments was described in [1], and the detector was described in [2].

## RESULTS AND DISCUSSION

The retention ratio (ratio between the void and elution volumes), is independent of channel dimensions for FFF systems. If channel dimensions change by a factor  $s$ , the void volume for the miniaturized system drops by  $s$ . Thus to accomplish the same level of retention in the miniaturized system requires  $s$  times less time! Figure 1 shows a separation in the  $\mu$ -EFFF that took 5 times less time with higher resolution.

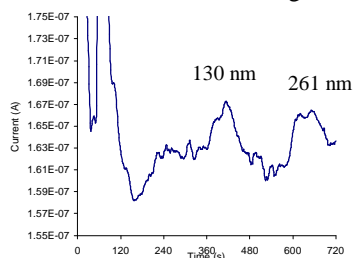


Figure 1. Separation of 130 and 261 nm particles with on-chip detector

The equation for resolution in EFFF systems was derived previously [1] and showed that resolution in EFFF systems is inversely proportional to channel height. Thus resolution in the system also improves as the system is miniaturized. One measure of

the efficacy of a separation system is plate height. Theoretically, plate height scales with the channel height *squared*. Thus, improvement is expected in this area, assuming that instrumental plate height contributions are minimized. When experimental plate heights are compared, the instrumental components of plate heights were reduced by half in the on-chip detector system compared to the off-chip system and macro systems. The non-equilibrium component of plate height was also reduced in accordance with theory. The reduction was less than anticipated when compared to macro systems due to difficulty in reducing sample sizes and making system connections.

Figure 1 shows a high-resolution separation done in the  $\mu$ -EFFF system. While there is a significant amount of noise, peak broadening has been reduced and resolution doubled. The effective field in this separation is about 0.5% of the applied field, which is lower than for macro systems. Taking into account that the electrodes in this system are gold, which has a much higher standard electrode potential than the graphite used in macro systems, we anticipate that effective fields will scale as expected.

Of interest is the use of AC fields in the EFFF channel to perform separations based on transport rates. The factor that determines whether AC fields will ever be practical is the electrical time constant.

An electrical model for the channel is shown in Figure 2. Using this model, we find that time constant should vary directly with  $s^2$  if  $s$  is a dimensional scaling factor. Experiment, though, seems to indicate that  $R_f$  is dependent on material considerations rather than geometry, so the total scaling effect on the RC time constant is greater than  $s$ , but less than  $s^2$ . The measured time constant for the system was about 4 seconds, which is much less than the typical 50 seconds for macro systems, but not as fast as predicted by our model. Thus, the possibility of using variable fields is much higher, but high frequencies are still unachievable.

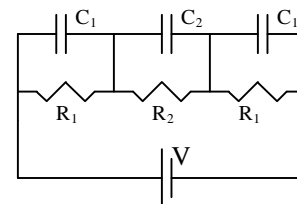


Figure 2. Electrical model of EFFF channel showing capacitances and resistances associated with the double layers ( $C_1$ ,  $R_1$ ) and the main channel volume ( $C_2$ ,  $R_2$ ).

## CONCLUSION

The majority of the parameters relevant to EFFF systems have been shown to improve when the system is miniaturized. Thus, even higher resolution separations are anticipated as miniaturized systems are refined and improved.

## REFERENCES

- [1] B. K. Gale, K. D. Caldwell, and A. B. Frazier, *IEEE-TBE*, V. 45, N. 12, pp. 1459-69, 1998.
- [2] B. K. Gale, K. D. Caldwell, and A. B. Frazier, *Proc. SPIE*, V. 3515, pp. 230-42, 1998.