TEMPERATURE-BASED TUNING OF MAGNETIC PARTICLE SEPARATIONS

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ABSTRACT

We present temperature control as a simple yet highly efficient means of improving particle separations in on-chip free-flow magnetophoresis. Increased temperatures resulted in a decrease in solution viscosity, which in turn yielded greater particle deflection distances and increased the separation resolution of two particle populations. This inexpensive and effective technique would also be of great benefit to other continuous flow processes involving the deflection of particles.

KEYWORDS: Magnetophoresis, Magnetic microparticles, Continuous flow, Temperature dependence, Viscosity

INTRODUCTION

Magnetic microparticles are becoming increasingly popular as solid supports for biomedical processes within microfluidics due to their high surface-to-volume ratios, range of surface functionalities, and ease of manipulation via magnetic fields [1]. Hence, they are now commonly used for on-chip bioassays and separation procedures. Previously, we have demonstrated on-chip free-flow magnetophoresis as a continuous flow method of particle separation. Such continuous flow methods eliminate many of the laborious and time-consuming aspects of batch magnetic separation systems where particles must be washed and resuspended several times to ensure complete separation. Here, we investigate the effects of temperature on buffer solution viscosity and hence particle deflection.

THEORY

In on-chip free-flow magnetophoresis, laminar flow streams of buffer solution are generated in the x-direction across a microfluidic chamber [2]. Magnetic particles are introduced into the chamber, with an external magnetic field applied perpendicular to the direction of flow. This causes the particles to deflect laterally, in the y-direction (Figure 1a). Particles of different sizes and magnetic contents are deflected to different degrees, which results in their separation as they cross the chamber. The extent of deflection can be described as the velocity of the particles in the y-direction towards the magnet, $\mathbf{u}_{\mathbf{mag}}$ (Eq. 1). This is affected by the radius (r) and magnetic content (V_m) of the particles, the magnetic field ($(\mathbf{B}\cdot\nabla)\mathbf{B}$), the difference in magnetic susceptibilities between the particles and the medium ($\Delta\chi$), and the viscosity of the medium (η). Viscosity, in turn, is inversely related to temperature. Hence, increasing the temperature of the buffer solution in the system decreases its viscosity, creating less drag on the particles and allowing them to be deflected further in the y-direction.

978-0-9798064-2-1/µTAS2009/$20©2009CBMS

$$\mathbf{u}_{\mathbf{mag}} = \frac{\Delta\chi V_m (\mathbf{B}\cdot\nabla)\mathbf{B}/\mu_0}{6\pi\eta r} \tag{1}$$

EXPERIMENTAL

The microfluidic chip design (Figure 1b) featured a 6 x 6 mm^2 separation chamber, with 16 buffer inlet channels, a single particle inlet channel, and 16 outlet channels. The chip was fabricated in glass to a depth of 20 μm. Buffer solutions and particle suspensions were introduced via reservoirs glued over the inlet holes, with negative pressure applied at the outlet to draw the solutions through the chip. The magnetic field was generated by a 10 mm x 5 mm NdFeB disc magnet placed on top of the chip, halfway across the separation chamber. The temperature of the system was controlled by placing the chip on a Peltier element (Figure 1c). Particles were visualised using a zoom overhead CCD camera.

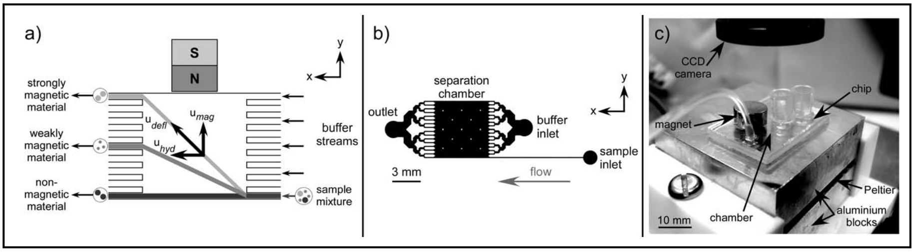

Figure 1. (a) Principle of free-flow magnetophoresis: magnetic particles are deflected across a separation chamber by a magnetic field. (b) Schematic of the chip design, featuring 16 buffer inlet channels, a single particle inlet channel and 16 outlet channels. (c) Photograph of the chip placed on a Peltier heater for temperature control.

RESULTS AND DISCUSSION

Initially, the deflection behaviour of 2.8 μm particles (Dynabeads M-270 Epoxy) was investigated over a temperature range of 5 to 50 °C (Figure 2a). The particle deflection distance in the y-direction was much greater at higher temperatures than at lower temperatures, with the particles being deflected six times further at 50 °C than at 5 °C. The observed deflection paths compared well to theoretically calculated trajectories, as shown in Figure 2b. With this trend clearly established, the effect of temperature on particle separation was investigated for a mixture of 2.8 μm and 1 μm (Dynabeads MyOne) particles at 50, 20 and 5 °C (Figure 3). Increasing the temperature of the system resulted in an increase in the deflection distance of both populations, though the effect was more pronounced on the larger particles due to their greater magnetic content. At 5 °C the deflection of the two particle populations overlapped significantly, whereas at 50 °C the populations were completely separated.

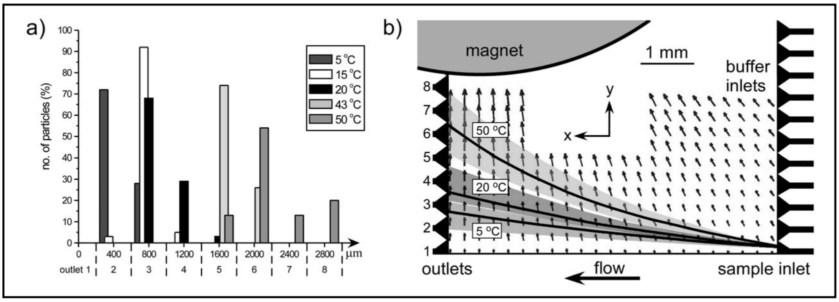

Figure 2. (a) Deflection of 2.8 µm particles between 5 and 50 °C. (b) Theoretical (solid black lines) and experimental (shaded regions) particle trajectories. The vector arrows indicate the direction and gradient of the magnetic field.

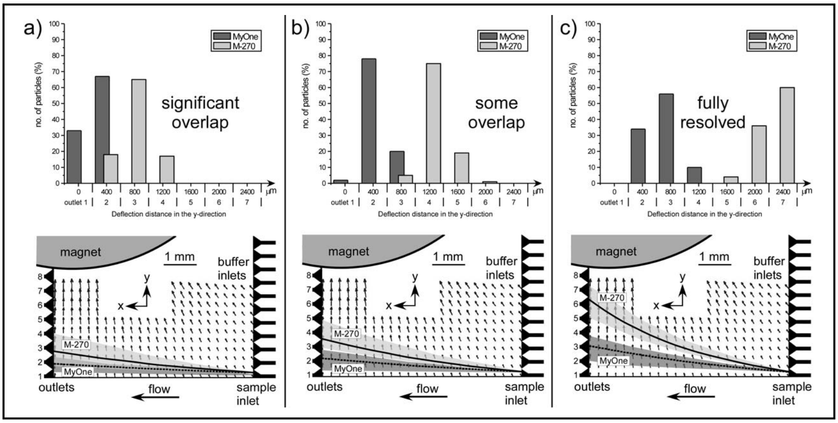

Figure 3. (a) Separation of 2.8 µm (M-270) and 1 µm (MyOne) particles at (a) 5 °C, (b) 20 °C, and 50 °C.

CONCLUSIONS

We have demonstrated the important role that temperature plays in the continuous flow deflection of magnetic particles. Increasing the temperature of the system greatly improves separation resolution, and could be be used to fine tune the deflection paths of desired particle types. This technique would be of great benefit to many continuous flow processes involving the deflection of particles against viscous drag.

ACKNOWLEDGEMENTS

The authors would like to thank the Engineering and Physical Sciences Research Council (EPSRC) for funding.

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