High pressure inertial focusing for separation and concentration of bacteria at high throughput

F.J. Cruz and K. Hjort

Engineering Sciences, Uppsala University, Ångström Laboratoriet, Uppsala, Sweden

javier.cruz@angstrom.uu.se; klas.hjort@angstrom.uu.se

Abstract. Inertial focusing is a phenomenon where particles migrate across streamlines in microchannels and focus at well-defined, size dependent equilibrium points of the cross section. It can be taken into advantage for focusing, separation and concentration of particles at high through-put and high efficiency. As particles decrease in size, smaller channels and higher pressures are needed. Hence, new designs are needed to decrease the pressure drop. In this work a novel design was adapted to focus and separate 1 µm from 3 µm spherical polystyrene particles. Also 0.5 µm spherical polystyrene particles were separated, although in a band instead of a single line. The ability to separate, concentrate and focus bacteria, its simplicity of use and high throughput make this technology a candidate for daily routines in laboratories and hospitals.

Keywords. Particle separation, Bacteria separation, Inertial focusing, Microfluidic channel, High pressure.

1. Introduction

Inertial focusing is a phenomenon where particles migrate across streamlines in microchannels and focus at well-defined, size dependent equilibrium points of the cross section. In a straight system it is caused by the balance of two forces [1], Fig. 1.

![Figure 1. Main forces on a particle in a straight microchannel.](image-url)
a shear lift force directed towards the walls of a channel due to the shape of the velocity profile ($F_L$ SHEAR GRADIENT) and a wall lift force directed towards the center due to interactions of the streamlines with the wall ($F_L$ WALL EFFECT). The net lift ($F_L$) force was predicted by Asmolov [2].

$$F_L = \frac{4\rho C_L U_f^2 a_p^4}{D_h^2} \quad \text{Eq. 1}$$

where $\rho$ is the fluid density, $C_L$ is the lift coefficient which is a function of the particle position across the channel cross-section and the channel Reynolds number, $U_f$ is the average flow velocity, $a_p$ is the particle diameter and $D_h = \frac{4(hw)}{h+w}$ the hydraulic diameter of the channel, with $h$ its height and $w$ its width. In curved channels the Dean flow enhances the lateral motion of particles and reduces the focus length [3].

We previously showed a set of scaling factors (Table 1) that maintain the magnitude of the lift forces and allow the transformation of a system that works for a certain size of particles into a system that successfully focuses smaller sizes. We also supported the idea with experimental results showing alignment of 1 µm particles and Escherichia coli (E. coli) in a spiral microchannel. However, the high pressure was on the limit for the E. coli. Its viability was similar before and after being focused at 50 µl/min (70 bar). However, at 100 µl/min (150 bar) 90% of the bacteria died. [4]

Table 1. Scaling law to transform a design that works for certain particle size to target another size. [4]

| Scaling Relations | Particle size | Height | Width | Flow rate | Focus length | Average speed | $\Delta P$ |
|------------------|---------------|--------|-------|-----------|--------------|---------------|------------|
| Scale factor     | X             | X      | X     | X         | X            | X\(^{-1}\)       | X\(^{-2}\) |
3. Results
A design of straight channel with varying width showed excellent results already at 50 µl/min and approx. 30 bar, Fig. 2.

![A General view of a straight channel (4.6 mm in length) with varying width (B) Performance with 1 µm particles at 50 µl/min. (C) Performance with 0.5 µm particles at 50 µl/min (D) Analysis of the intensity signal. (E) Separation of 1 (green) and 3 (red) µm particles at 150 µl/min and approx. 100 bar.](image)

**Figure 2.** (A) General view of a straight channel (4.6 mm in length) with varying width (B) Performance with 1 µm particles at 50 µl/min. (C) Performance with 0.5 µm particles at 50 µl/min (D) Analysis of the intensity signal. (E) Separation of 1 (green) and 3 (red) µm particles at 150 µl/min and approx. 100 bar.

4. Discussion
The design with straight channels with varying width is still under evaluation, Fig. 2. A preliminary study showed not only a faster alignment of 1 µm particles than in curved models but it also required less pressure for the same flow rate. It could also concentrate 0.5 µm particles to a narrow band enabling their separation.

The design can be shortened relieving some pressure drop. The system is expected to focus 1 µm particles at 50 µl/min demanding around 20 bar.
The separation between 1 and 3 µm is quite large, allowing for further discrimination of intermediate sizes.

5. Conclusion
In this work we used straight microchannels that vary their width. The new design aligned 1 µm particles faster that the spiral model and required less pressure. Furthermore, although not completely aligned, 0.5 µm particles were concentrated in a band and were separated from the main stream.

The ability to separate, concentrate and focus bacteria, its simplicity of use and high throughput make this technology a candidate for daily routines in laboratories and hospitals.

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