

# INERTIAL FOCUSING IN CURVED CHANNELS: TOWARDS PRECISION BIOFLUID PROCESSING

J. Martel<sup>1</sup> and M. Toner<sup>1</sup>

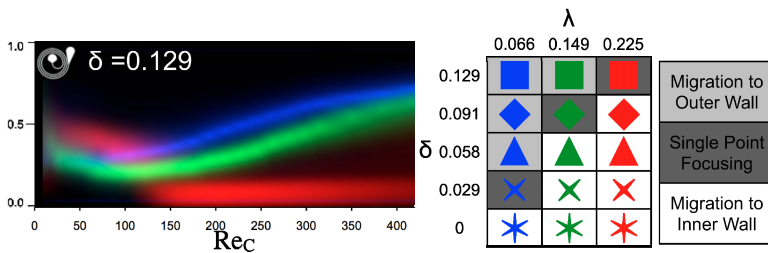
<sup>1</sup>Massachusetts General Hospital, Charlestown, MA

The field of inertial focusing has been rapidly expanding in recent years with great emphasis on the application of the phenomenon to the separation of biological particles. Despite this wealth of research, there have been very few detailed descriptions of the behaviors in terms of the capabilities for separation and the underlying physics behind the behaviors. This work will present the decoupled effects of curvature and Reynolds number on the equilibrium behaviors of inertially focused. Two behaviorally distinct regimes are discovered and the transition between these regimes is shown to be ideal focusing to a single lateral and vertical equilibrium position. These results are used to validate a finite element model created to simulate such flows and predict equilibrium positions as well as expand the results to more varied geometries. Applications of the phenomenon to fungal infection detection and concentration of bioparticles will also be presented.

**Introduction:** Inertial focusing is a fluid dynamic phenomenon where at a particle Reynolds number  $\sim 1$ , particles flowing through a microfluidic device will migrate across streamlines to predictable equilibrium positions within the channel cross-section. In straight rectilinear channels the balance of forces will cause 2-4 equilibrium positions depending on the aspect ratio of the channel. One way of reducing this number of equilibrium positions and ultimately cause separation of particles by size is through the addition of curvature to the channel path. Inertial flows through curved channels generate a secondary flow, called Dean flow, characterized by a pair of counter-rotating vortices, which adjust the equilibrium positions compared to those in a straight channel. Previous experimental results have typically adjusted the flow rate through such devices to study the fluid dynamic behaviors but due to the nature of the flows this will affect both the Reynolds number and the Dean number simultaneously making it impossible to determine causality.

**Materials and Methods:** A combination of fluorescent streak imaging and high-speed imaging are used to measure the three-dimensional positions of particle distributions at the outlet of each of the 5 different curvature microfluidic devices all with the same cross-section (100 $\mu\text{m}$  wide and 50 $\mu\text{m}$  high). Three different polystyrene particles sizes across the range of possible biological specimen (5 $\mu\text{m}$ , 10 $\mu\text{m}$  and 15 $\mu\text{m}$  in diameter) are suspended in a mixture of 1x PBS, 0.1% Tween 20 and iodixanol of equal density to the polystyrene particles (1.05g/mL). These fluids are then pushed through the devices at high pressures (up to 1000psi) and images are taken at the outlet of the behavior at flow rates from 25 to 1200 $\mu\text{L}/\text{min}$ .

**Results and Discussion:** The behaviors witnessed are presented using Reynolds number maps, which show the particle distribution at the device outlets across the channel (0 inside wall towards center of curvature and 1 outside wall) in each column of pixels for each flow rate tested as shown in Figure 1. Detailed analysis of the positional results lead to the discovery of two regimes; 1, behavior generally towards the center of curvature with increasing Reynolds number, and 2, behavior away from the center of curvature with increasing Reynolds number. The transition between these two regimes is investigated using high-speed imaging that shows the particles at this transition are focused to a single lateral and vertical equilibrium position, while in both other regimes there are two mirrored streaks across the mid-height of the channel.



**Figure 1.** Reynolds number map of the smallest radius of curvature device behavior (left) and the regimes (right) defined by the particle confinement ratio,  $\lambda$ , and the channel curvature ratio,  $\delta$  (5 $\mu\text{m}$  - blue, 10 $\mu\text{m}$  - green and 15 $\mu\text{m}$  - red) [1].

This type of separation is shown to be suitable for the isolation of two species of yeast from white blood cells in

lysed blood as well as a means of reducing the volume of a dilute cellular sample by separating particle rich and particle free streams.

**Conclusions:** The decoupling of Reynolds and Dean numbers has provided new insight into the underlying physics of inertial focusing in curved channels. The new  $\lambda/\delta$  relationship has the potential to assist in the design of optimal inertial focusing devices for each new biological specimen drastically reducing the amount of trial and error based testing required.

## References: (Optional)

1. Martel, J.M. & Toner, M. Particle Focusing in Curved Microfluidic Channels. Sci. Rep. 3, 3340; DOI:10.1038/srep03340 (2013).