Spring 2013

Magnetophoretic Particle & Cell Manipulation In Ferrofluid Flows Using Two Magnets

Jian Zeng

Magnetophoretic Particle & Cell Manipulation In Ferrofluid Flows Using Two Magnets

Jian Zeng

Adviser: Dr. Xiangchun Xuan

Clemson University – Department of Mechanical Engineering, Clemson SC

Focusing

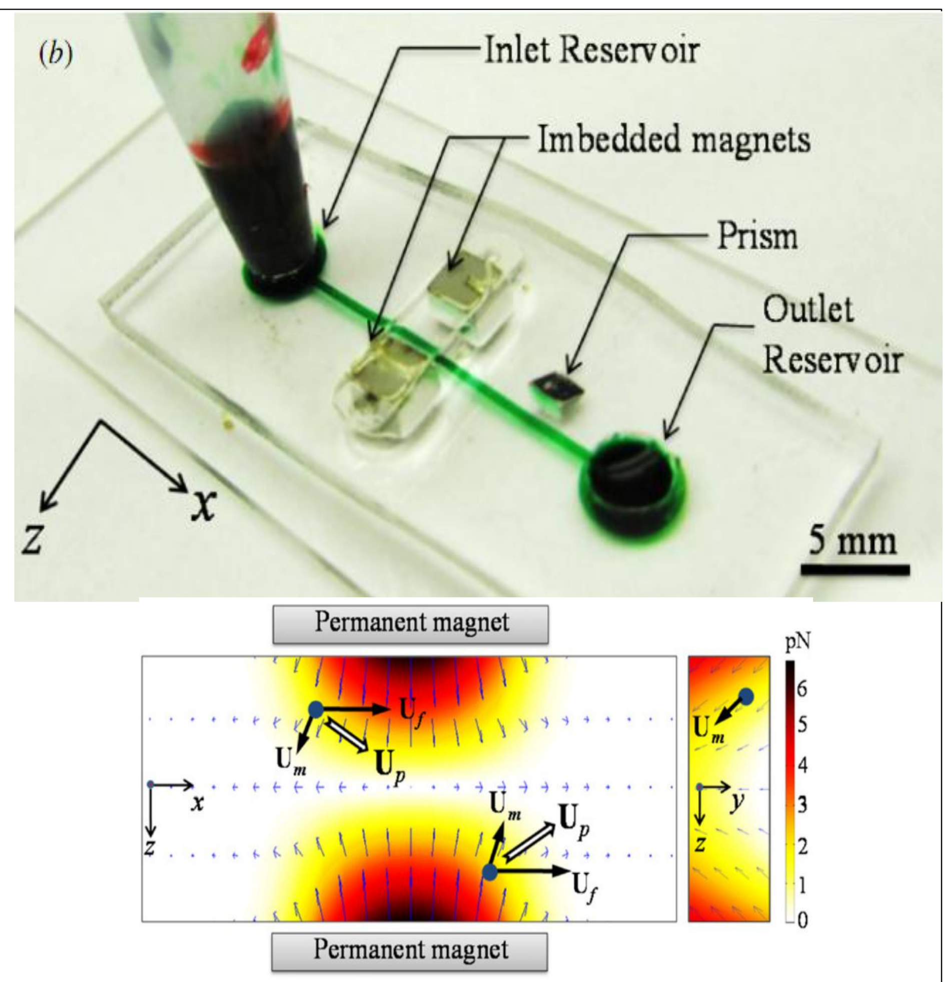
Introduction

- Particle focusing required for detection, counting, & sorting
- Imbedded pair magnets produce equal/opposing magnetic fields
- Diamagnetic particles suspended in ferrofluid experience negative magnetophoresis
- Flow speed effects vs. focused stream width
- 3-D focusing achieved and extended for use on live yeast cells
- Considered magnetic & fluid field effects on particle

$$\mathbf{U}_p = \mathbf{U}_f + \mathbf{U}_m$$

$$\mathbf{F}_m = \mu_0 V_p [(\mathbf{M}_p - \mathbf{M}_f) \bullet \nabla] \mathbf{H}$$

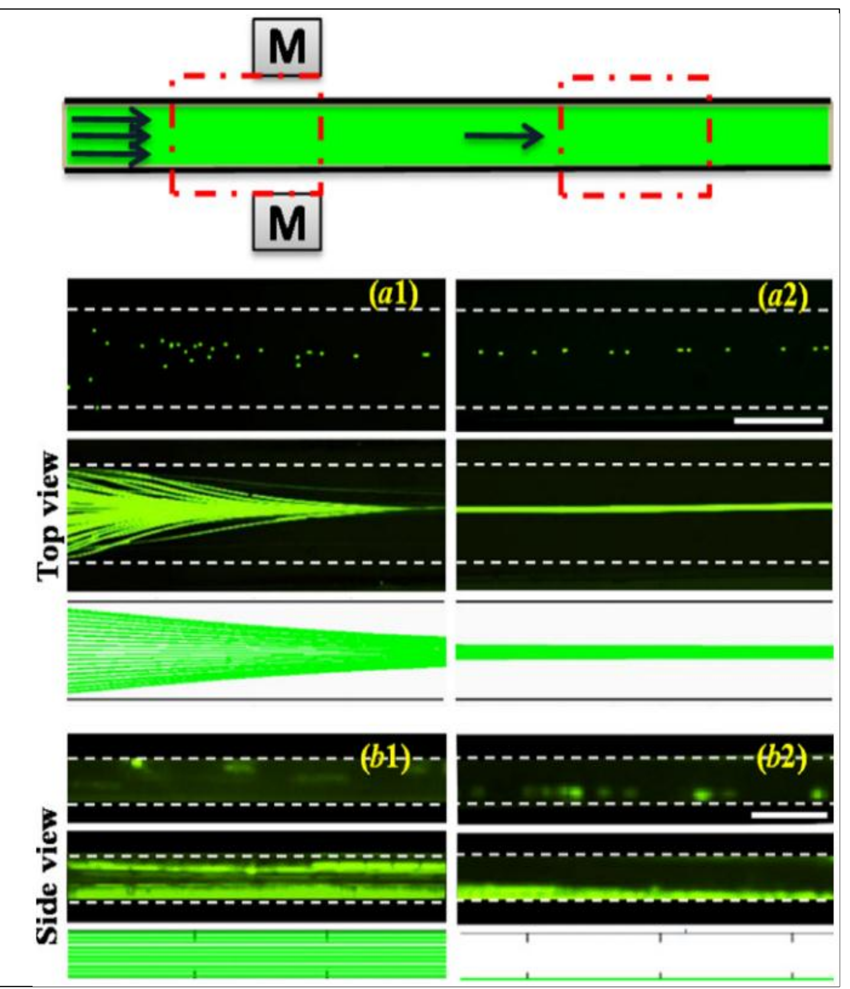
$$\mathbf{M}_f > \mathbf{M}_p , \mathbf{F}_m < 0$$



Results

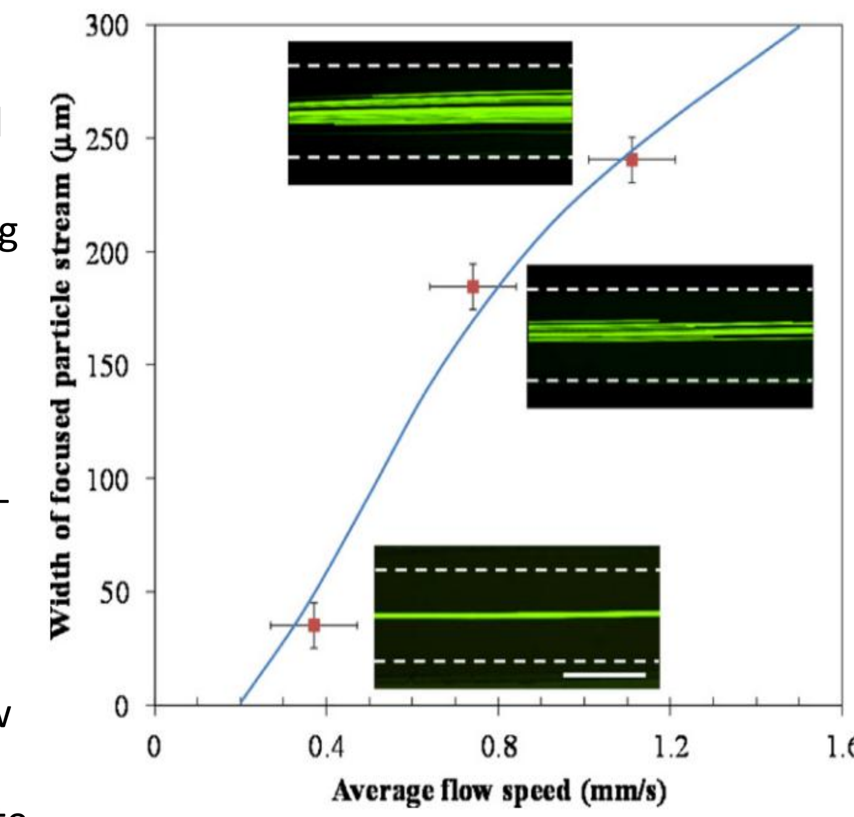
- B222 NdFeB magnets imbedded
- 5µm polystyrene particles
- 0.25 x EMG408 ferrofluid
- 0.4 mm s^{-1} flow speed
- Width + depth focusing realized
- Increased flow speeds weaken focusing effect

- Implemented on live yeast cells (*Saccharomyces cerevisiae*)
- Diameter of Yeast cells average that of 5µm sphere particles
- Viability tested positive (>90%) after cells passed focusing



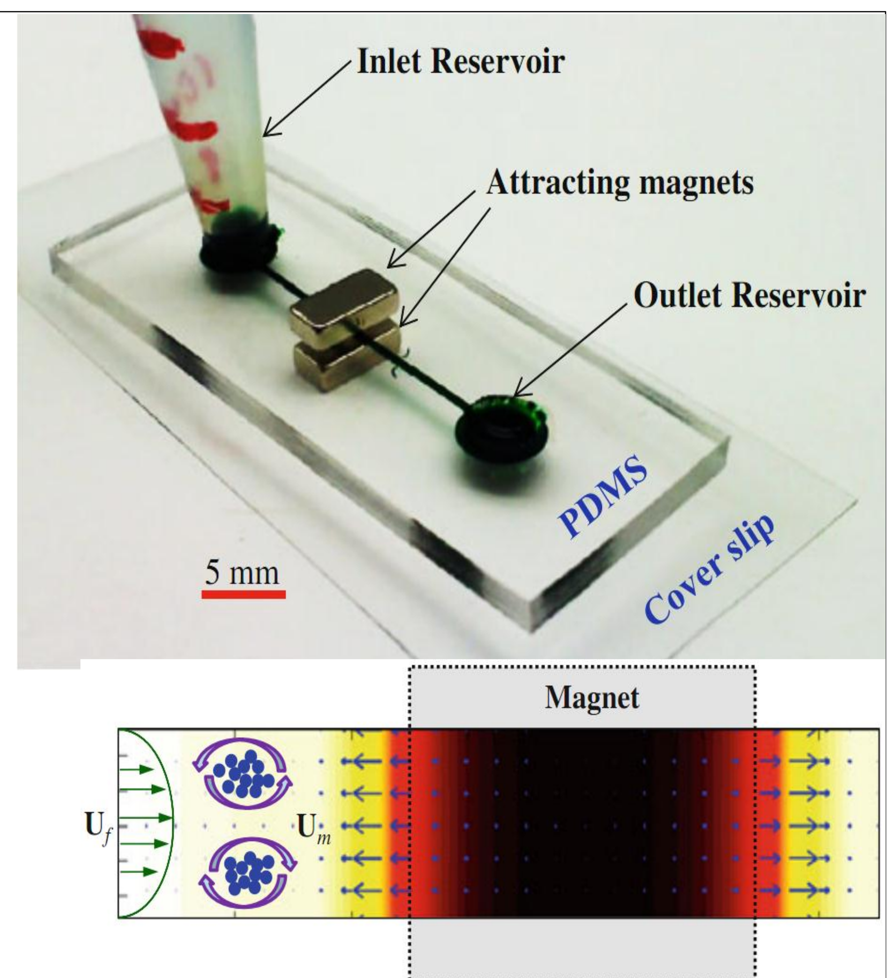
Conclusion

- Developed technique for embedding two opposing magnets within microchannel device for use in particle/cell focusing via negative magnetophoresis
- 3-D focusing accomplished and verified through top-view and side-view using prism
- Focusing accuracy enhanced when flow speed decreased as magnetophoretic rate of deflection increases



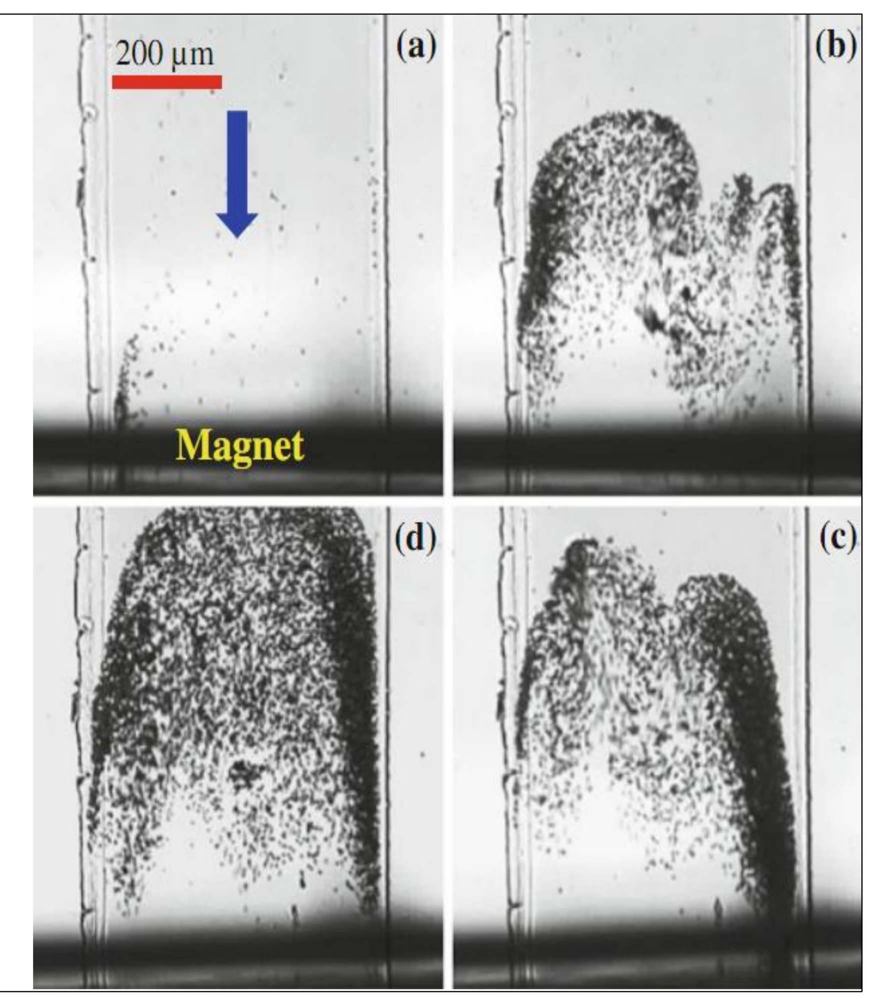
Trapping

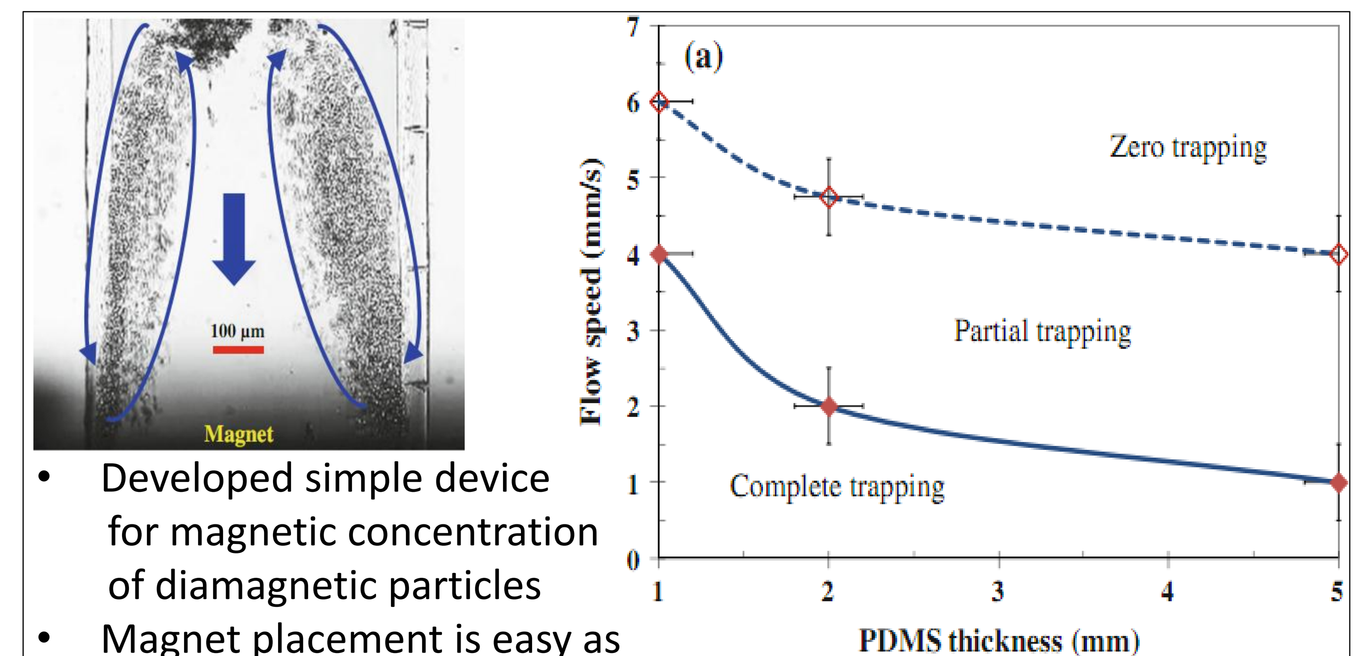
- Trapping/Concentration of micro-particles often necessary for detection applications
- Contactless methods allow the use of external forces for manipulation
- Applying magnetic field gradient produced by two attracting magnets allow for versatility, inexpensive cost, and simplicity
- Using negative magnetophoresis in this case avoids magnetic labeling of diamagnetic particles/cells
- Concentration achieved by trapping mechanism and accumulation over a short time period
- Trapping occurs: $\mathbf{U}_m \geq \mathbf{U}_f$



- B421 NdFeB magnets
- 5µm polystyrene particles
- 0.05 x EMG408 ferrofluid
- 2.0 mm s^{-1} flow speed
- Up to 15mins recorded
- Increased flow speeds weaken trapping effect
- Increased magnet placement also weaken trapping effect

- Live yeast cells trapped and concentrated over a period of 10mins
- Circulation attributed to symmetrical magnet placement
- Cell viability proved positive

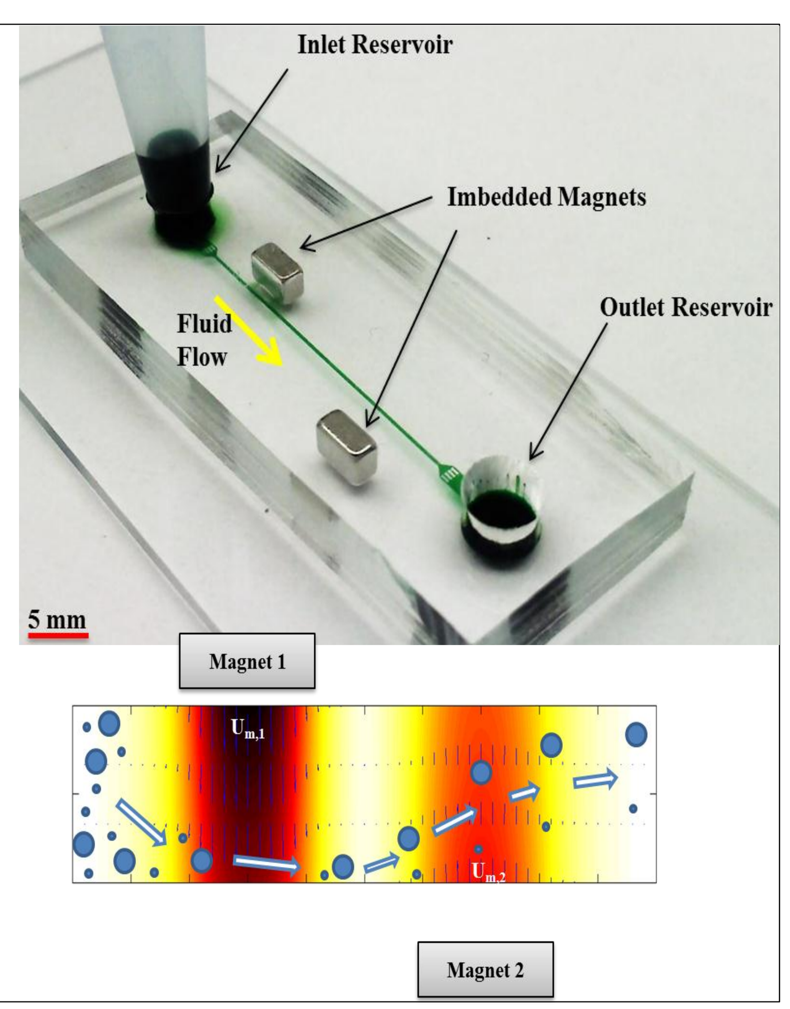


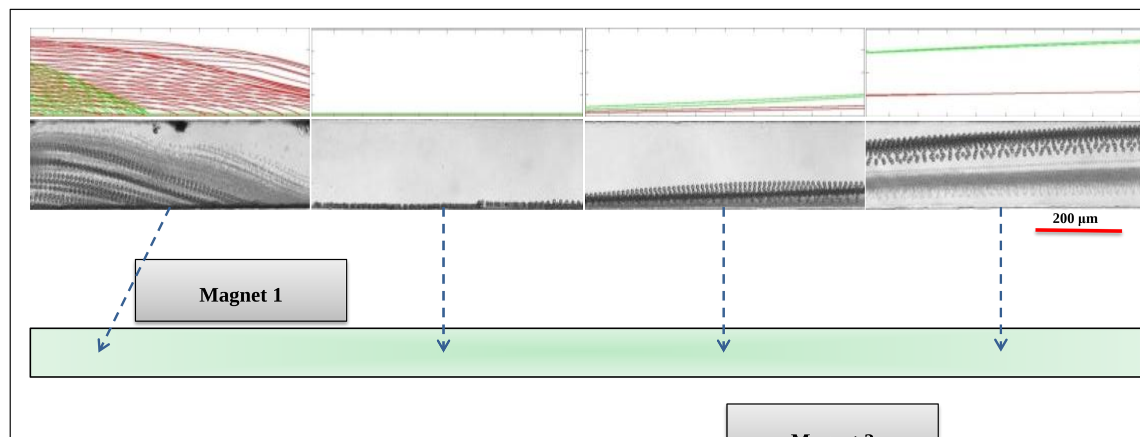


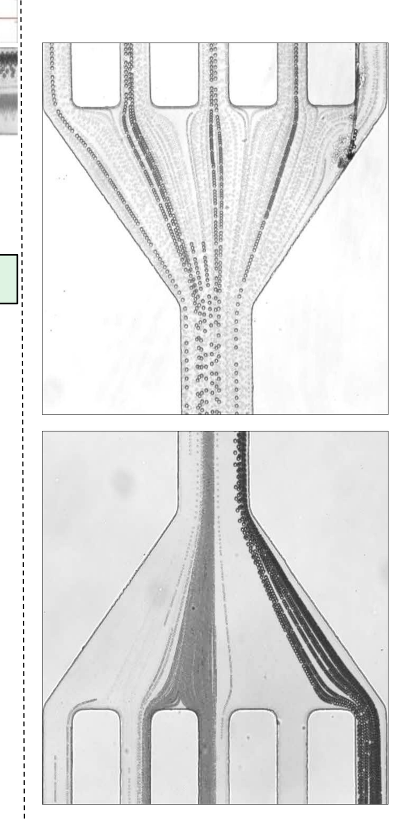
- Developed simple device for magnetic concentration of diamagnetic particles
- Magnet placement is easy as they are naturally attractive
- Concentration results verify this straightforward mechanism
- Trapping effectiveness varied by flow speed and magnet distance
- Magnetic field removal by manually pulling away magnets
- Magnetic nanoparticle accumulation will need to be taken into consideration in future numeric modeling to describe behavior

Separation

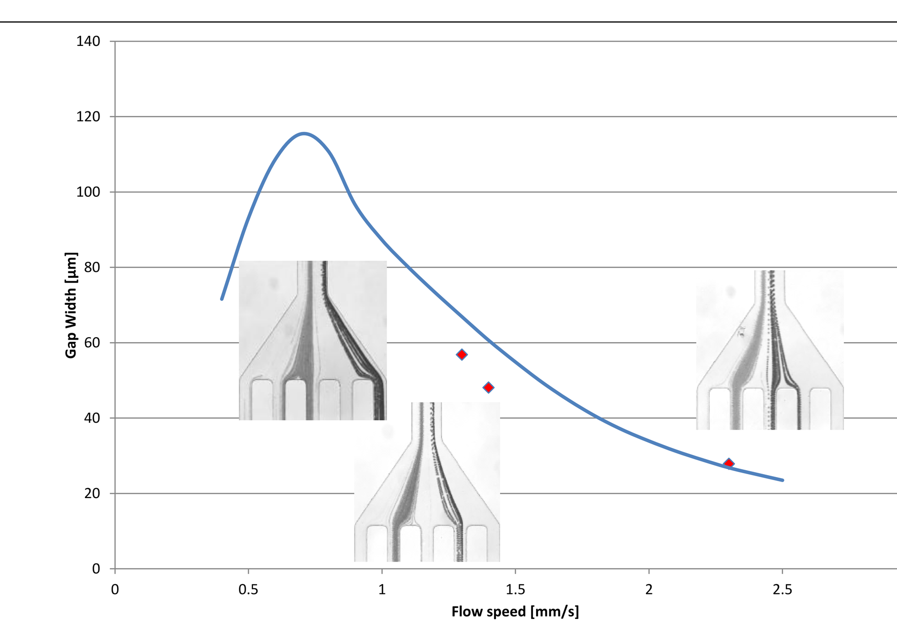
- Particle separation required in many bio-applications
- Existing methods often require complex channel designs, expensive equipment, & unwanted side-effects
- Negative magnetophoretic deflection of particles with two magnets
- 2 imbedded magnets; one provides full deflection, while the other for size-based particle separation
- Flow speed & magnet distance effects studied against separation behavior
- Live yeast cells separated from mixture of 10µm spherical particles







- B221 NdFeB magnets
- 3 & 10µm polystyrene particles
- 0.05 x EMG408 ferrofluid
- 1.2 mm s^{-1} flow speed
- 500µm - 1st magnet
- 2600µm - 2nd magnet
- Separation distinction decreases with increasing flow speeds
- Live yeast cells & 10µm particles mixed and separated showing comparable result



- Extended basic principle of magnetophoresis for size-based particle separation
- Gap width between sorted particle streams based on magnet distance and flow speed
- Once 1st magnet position is fixed for deflection of multiple sized particles, 2nd magnet can be positioned to accommodate desired separation

Acknowledgments: NSF CBET-1150670 (Xuan), Clemson University's University Research Grant (Xuan and Tzeng), Creative Inquiry Program (Xuan)

References: (1) Zeng, J., Chen, C., Vedantam, P., Tzeng, T., Xuan, X.. "Three-dimensional magnetic focusing of particles and cells in ferrofluid flow through a straight microchannel" *Journal of Micromechanics and Microengineering*, 22 105018 (2012) (2) Zeng, J., Chen, C., Vedantam, P., Tzeng, T., Xuan, X.. "Magnetic concentration of particles and cells in ferrofluid flow through a straight microchannel using attracting magnets" *Microfluidics and Nanofluidics* (2012)