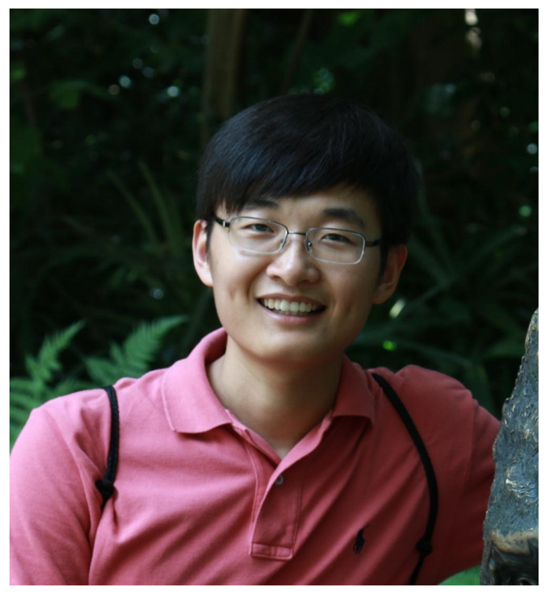

High-throughput label-free particle separation in viscoelastic fluids via elasto-inertial focusing

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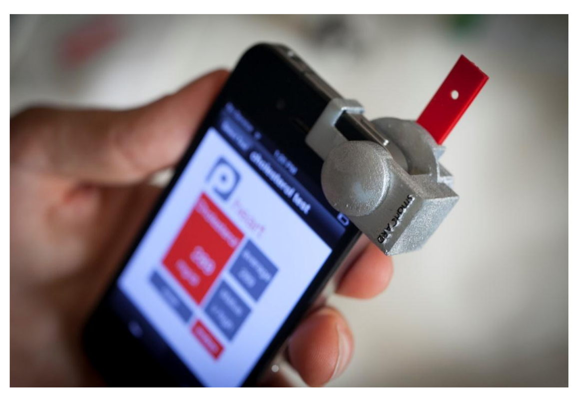
1. Motivation

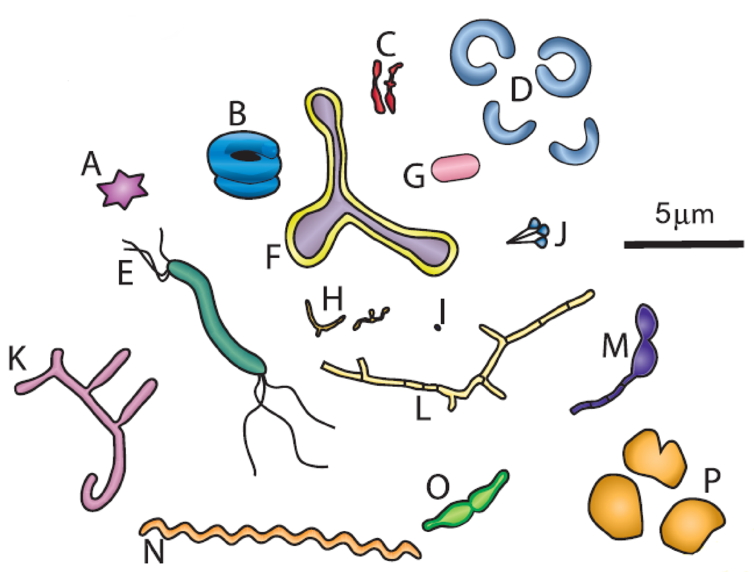
- Lab-on-a-Chip (LOC)
  - Developed for chemical and biomedical application
  - Reduces a laboratory to the size of a credit card
  - Compatibility with biological analysis



Smartphone camera clip-on and app for at-home cholesterol testing, MedCityNews, 2013

Small biomedical chip, ©BMNL Group

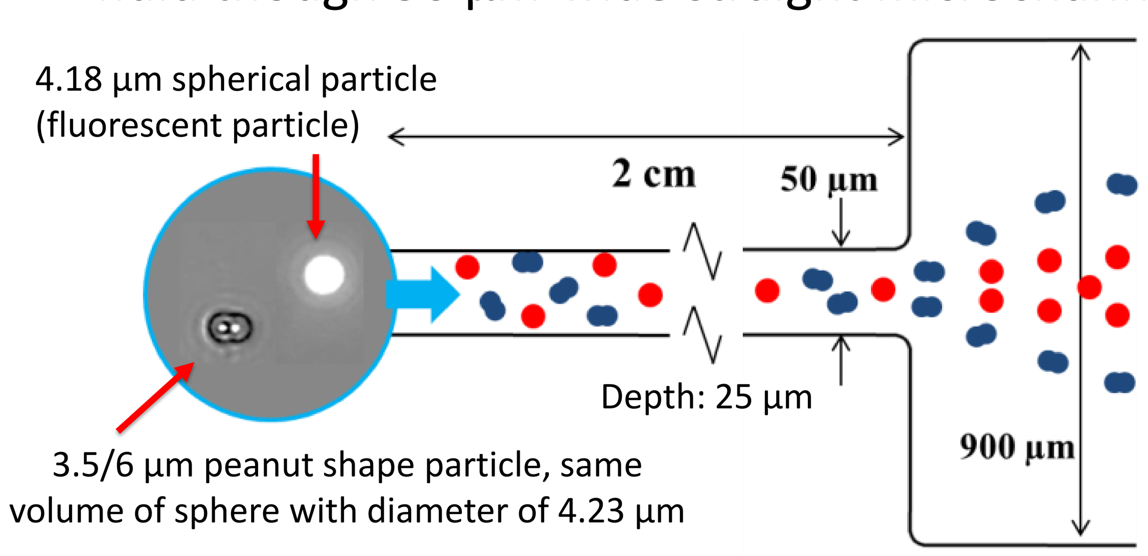
- Bodily fluids (e.g., blood and saliva) and polymer solution exhibit non-Newtonian behaviors such as viscoelasticity that few people studied
- Cells and bacteria have different sizes and a variety of shapes, which can be used as markers of sorting



Microbiol. Mol. Biol. Rev. 2006

2. Experimental design

- Size/shape-based separation in non-Newtonian fluid though 50 µm-wide straight microchannels



Schematic diagram of shape-based separation

- Size-based separation is in a similar 50 µm-wide channel for spherical particles with diameters of 3 and 10 µm

3. Intellectual Merit and Broader Impacts

- We explore the elasto-inertial flow with Reynolds number near order 1 and Weissenberg number (Wi=shear rate · relaxation time=$\dot{\gamma}\cdot\lambda$) near order 10
- This approach is continuous, passive, simple in channel design and in control, and high purity (>95%)
- It can be used in applications of particle/cell separation and diagnosis for spheres with different sizes or those with similar volume but different shapes

4. Theory

- Non-Newtonian fluid
  - Different from Newtonian fluid
    - Viscoelastic effect
    - Shear-thinning/thickening effect (weak in this project)
  - In our experiment, non-Newtonian fluids were prepared by dissolving 1000ppm Poly(ethylene oxide) (PEO) powder (average molecular weight is 2e6)
  - Oldroyd-B model is widely used to model dilute PEO fluid

3D Stationary model was built in CONSOL

$$\rho(\mathbf{u}\bullet\nabla)\mathbf{u} = \nabla\bullet(-p\mathbf{I} + \mu\left[\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right] + \mathbf{T})$$

$$\mathbf{T} + \lambda\overset{\nabla}{\mathbf{T}} = \eta\left[\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right]$$

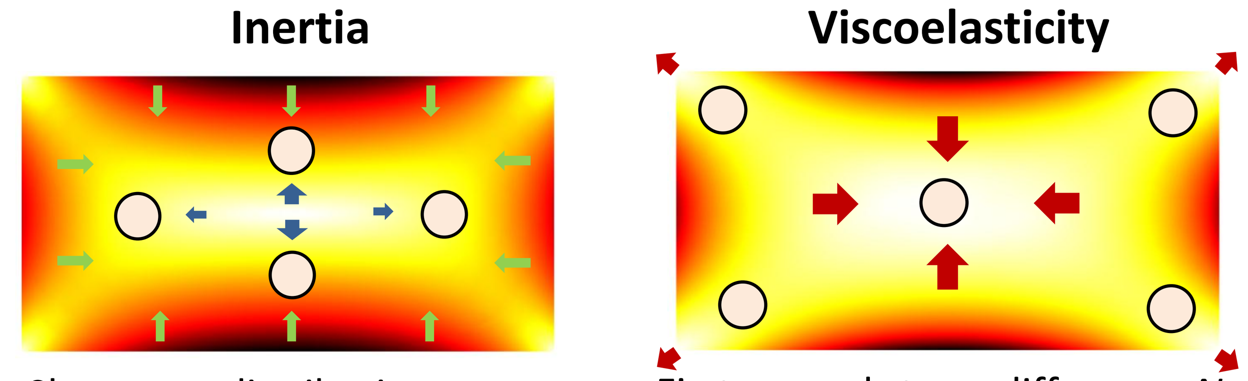
Extra Stress

where

$$\overset{\nabla}{\mathbf{T}} = \frac{\partial\mathbf{T}}{\partial t} + (\mathbf{u}\bullet\nabla)\mathbf{T} - \left[(\nabla\mathbf{u})\mathbf{T} + \mathbf{T}(\nabla\mathbf{u})^T\right]$$

μ: solvent viscosity η: polymer viscosity $\mu_0 = \mu + \eta$

- Particle equilibrium positions for sphere



Shear rate distribution on the cross section (Newtonian Re~o(>1))

First normal stress difference N_1 (σ_{xx}- σ_{yy}) distribution (Oldroyd-B model, Wi~o(10))

Note: the background shows the simulated shear rate/first normal stress difference intensity (the redder the higher).

Wall lift force: pushes the particles away from the walls

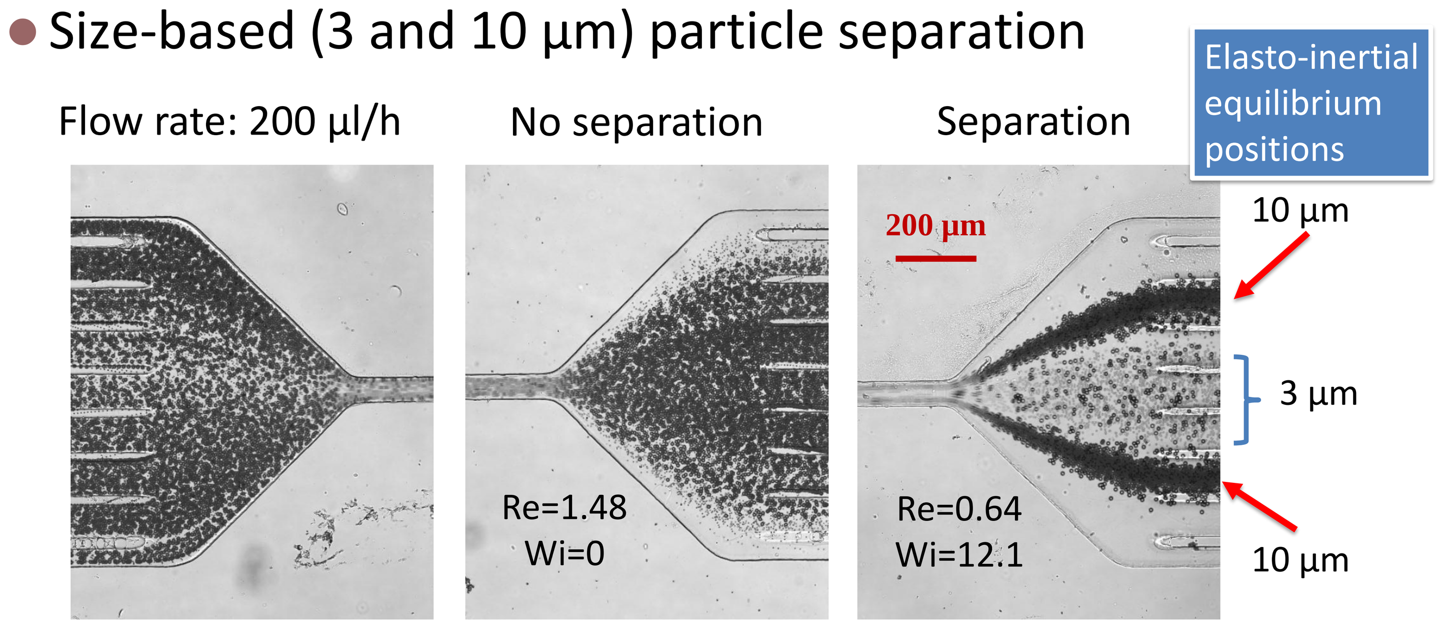
Shear rate force: pushes the particles away from the low shear rate regions

Viscoelastic lift force: pushes the particles towards the low first normal stress difference regions.

$$F_{VE} \sim a^3\nabla N_1$$

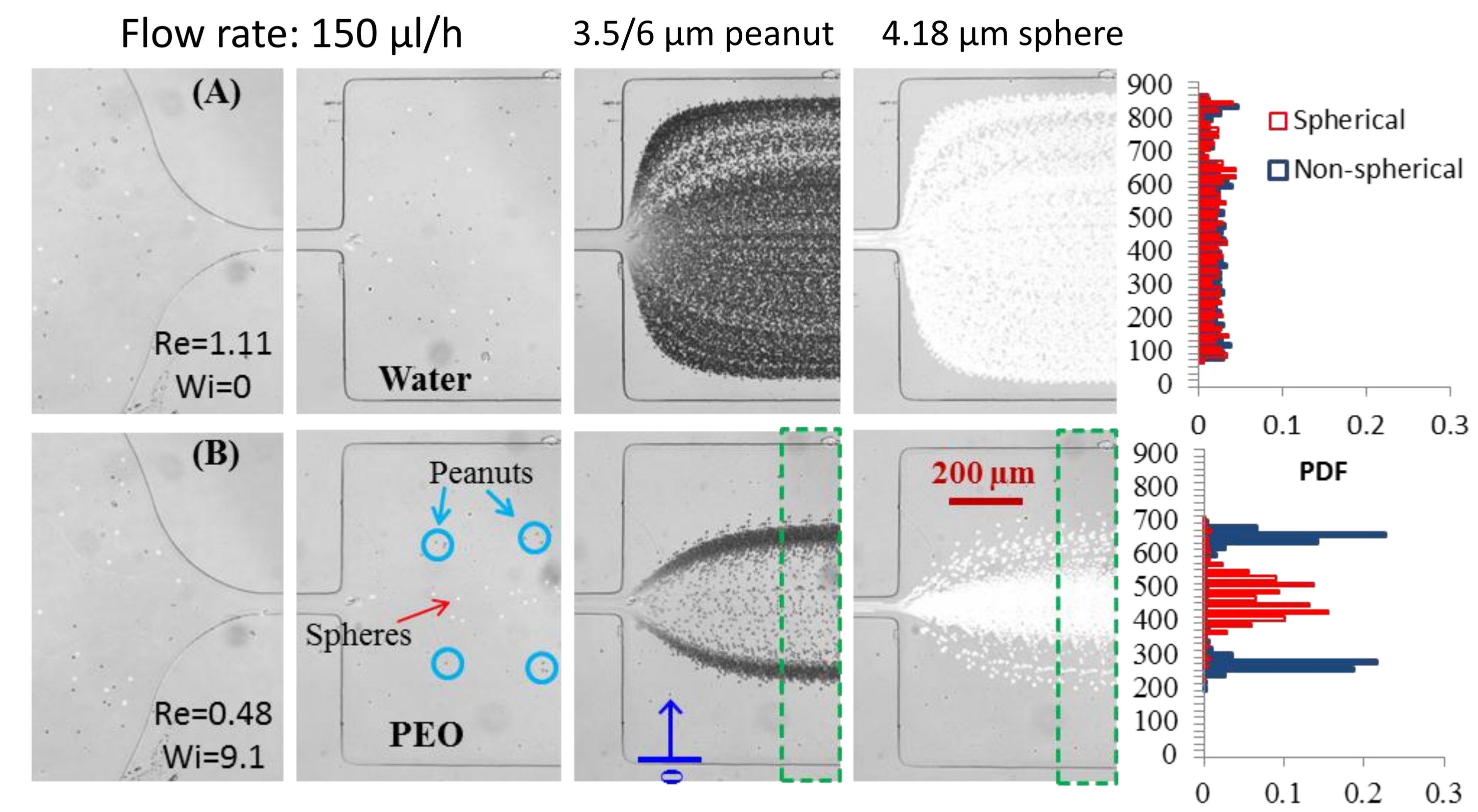
5. Results

- Size-based (3 and 10 µm) particle separation



Inlet | Outlet (Newtonian/ water) | Outlet (PEO solution, μ_0 = 2.3mPa·s)

- Shape-based (sphere and peanut) particle separation



Newtonain (row A) and 1000 ppm PEO solution (row B)

- Peanut rotates much slower in non-Newtonian fluid than in Newtonian solution
- shape-dependent elasto-inertial lift-induced particle migration is speculated to correlate with the rotation effects and as well the effective diameter of non-spherical particles

6. Conclusion and future plan

- In a range of Re~o(1), the pure inertial lift barely varies on particle motion between different sizes/shapes, but the elasto-inertial effect does
- Size and shape-based separations are achieved in viscoelastic fluid
- To further study the shape-dependent elasto-inertial lift, we are currently fabricating ellipsoidal particles of various aspect ratios for additional test; the simulation of particle-fluid interaction is in process

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