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

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=γ · η) 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
    - Viscelastic 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
  - \[ \rho \left( \frac{\partial \mathbf{u}}{\partial t} - \mathbf{f} + \mu \nabla \mathbf{u} + (\nabla \mathbf{u})^T \right) = \eta \nabla \mathbf{u}^T + (\nabla \mathbf{u})^T \]
  - where
    - \( \nabla \mathbf{u} = \nabla \mathbf{u}^T + (\nabla \mathbf{u})^T \)
    - \( \mu \): solvent viscosity
    - \( \eta \): polymer viscosity
    - \( \mu_0 = \mu + \eta \)
- Particle equilibrium positions for sphere
  - Inertia
  - Viscoelasticity

5. Results
- Size-based (3 and 10 µm) particle separation
- Flow rate: 200 µl/h
- No separation
- Separation
- Inlet (Newtonian/water) Outlet (PEO solution, \( \mu_0 = 2.3 \text{mPa} \cdot \text{s} \))

6. Conclusion and future plan
- In a range of \( Re \sim 1 \), 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