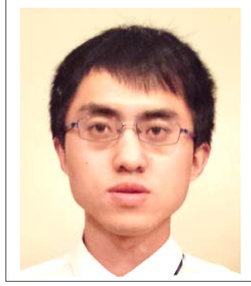

Continuous-flow sheathless diamagnetic particle separation in ferrofluids

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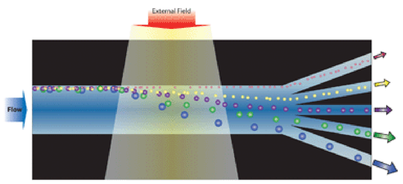
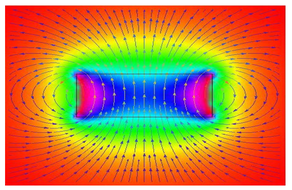
1. Motivation

- Lab on a micro-scale chip (LOC)
  - Lower fabrication costs
  - Lower fluid volumes consumption
  - Increase speed of reaction
  - Better performance with lower power

2. Study background

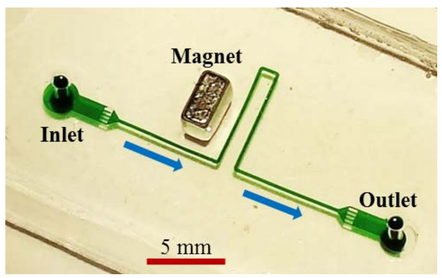


- Separating particles from a binary or more complex mixture is important in many chemical and biomedical applications
- Magnetic field (external field)
  - Simple, low-cost, non-invasive, no heating (if permanent magnet), free of surface charges and pH
- Continuous sheathless separation
  - Sheath fluid were used in the majority of the reported diamagnetic particle separations to pre-focus the particle mixture



- Sheath-free separation is achieved in this work by a single magnet through a U-shaped channel

3. Experimentation



- 0.5×EMG 408 ferrofluid
- 5 μm and 15 μm diamagnetic particles
- 800 μm magnet distance
- 800 μm gap between two branches of the U-turn

4. Simulation

$$\nabla \cdot \mathbf{u} = 0$$

$$\rho \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla p + \eta \nabla^2 \mathbf{u} + \mathbf{f}_m$$

Magnetic body force acting on ferrofluid

Particle velocity → $\mathbf{u}_p = \mathbf{u} + \mathbf{u}_m + \mathbf{u}_{gb}$

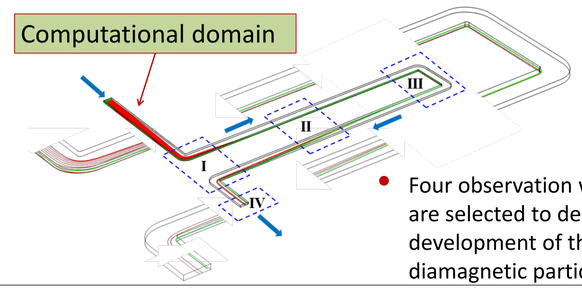
- Negative magnetophoresis

$$\mathbf{u}_m = -\frac{2\mu_0 a^2 \mathbf{M}_f \cdot \nabla \mathbf{H}}{9\eta f_D}$$

- Gravity-buoyancy action

$$\mathbf{u}_{gb} = \frac{2a^2(\rho_p - \rho)}{9\eta f_D}\mathbf{g}$$

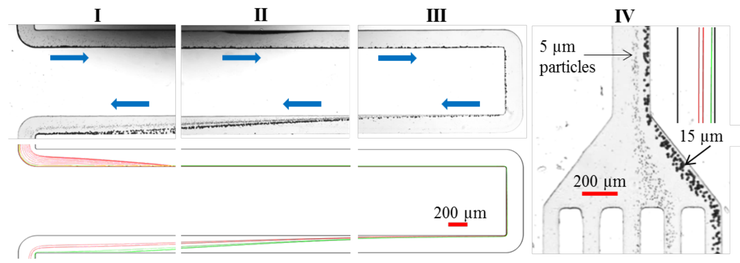
- 3D view of the numerically predicted trajectories of 5 μm (green lines) and 15 μm (red lines) diamagnetic particles



- Four observation windows I-IV are selected to demonstrate the development of this diamagnetic particle separation

5. Results

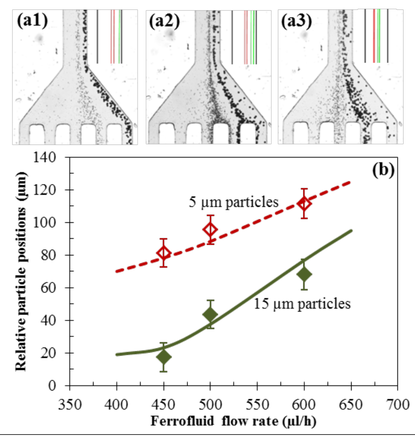
- Demonstration of diamagnetic particle separation



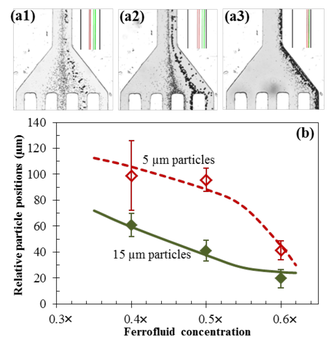
Comparison of experimental images and numerical predictions. Initially mixed particles in the ferrofluid are first focused to a narrow stream flowing. They later undergo a continuous separation by size.

- Parametric effects on diamagnetic particle separation
  - Effect of ferrofluid flow rate

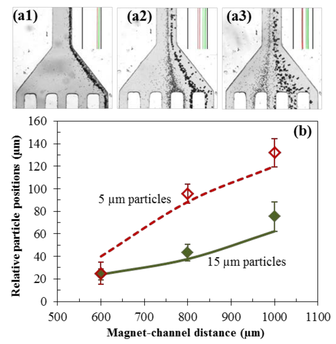
1. Comparison of the relative positions of the two separated particle streams between experiment (symbols) and simulation (lines)
2. Error bars account for spans of particle streams (symbols)



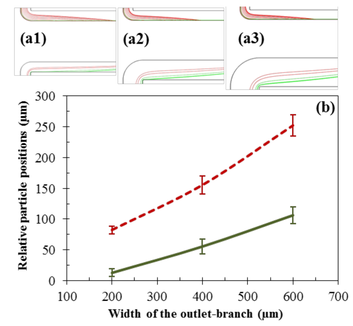
- Effect of ferrofluid concentration



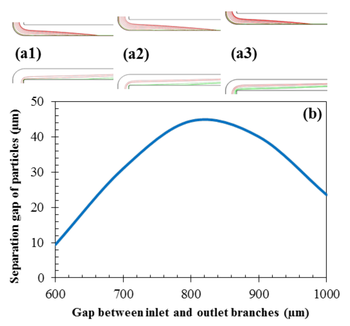
- Effect of magnet-channel distance



- Effect of outlet-branch width

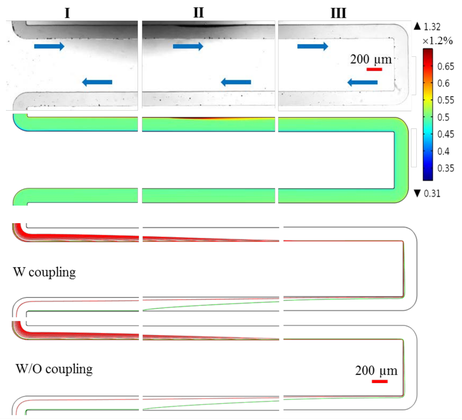


- Effect of outlet-branch width



The parametric study will aid in the optimal design of future U-shaped microchannels for the best separation. Particularly interesting is that increasing the outlet-branch width can significantly enhance the particle separation.

- 2D full model considering concentration fields (coupling)



1. Comparison of the experimentally recorded (top row) and the numerically predicted concentration fields (bottom row)
2. Comparison of the predicted trajectories with (top row) and without (bottom row) consideration of the coupling between ferrofluid flow and concentration fields

6. Conclusion

- We have demonstrated a continuous-flow sheathless diamagnetic particle separation in a ferrofluid through a U-shaped microchannel
- 3D numerical model are found to agree well with the experimental observations in a systematic study of the effects of multiple parameters. Moreover, we have used the validated numerical model to investigate the geometrical effects of the U-turn.

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Reference: Liang, Litao, and Xiangchun Xuan. "Continuous sheath-free magnetic separation of particles in a U-shaped microchannel." Biomicrofluidics 6.4 (2012): 044106.