Increasing throughput in dielectrophoretical micro- and nanoparticle separation

Georg R. Pesch, Fei Du, Yan Wang, Michael Baune, Jorg Thöming

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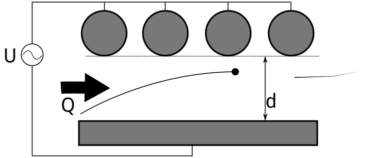
≫ Separation of micro- and nanoparticles



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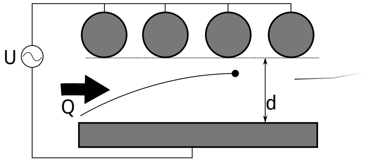

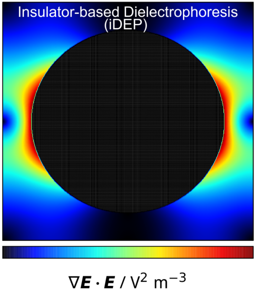

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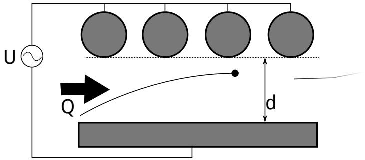

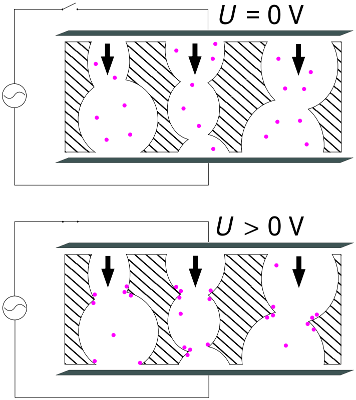

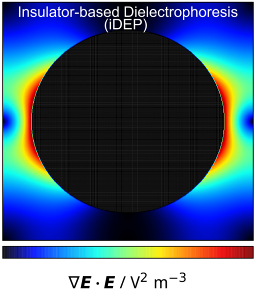

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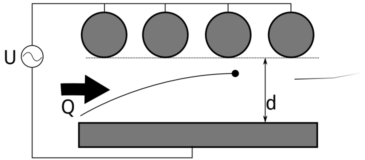
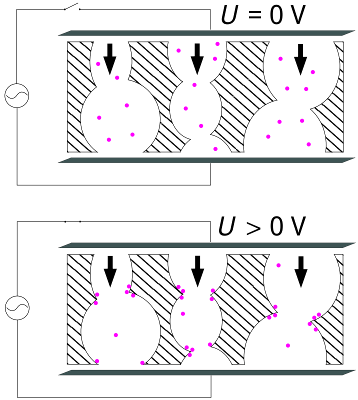
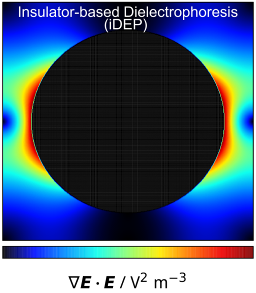




1. Dielectrophoretical filtration



2. Increase electric field disturbance by structure in iDEP and DEP filtration

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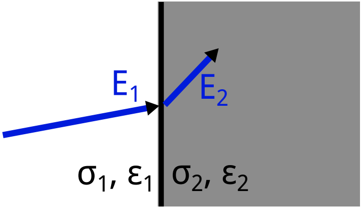
≫ Induced field inhomogeneities

Insulator-based DEP:

- different dielectric properties between materials
- induced electrical field inhomogenities



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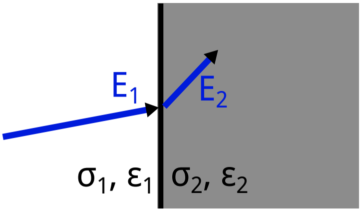
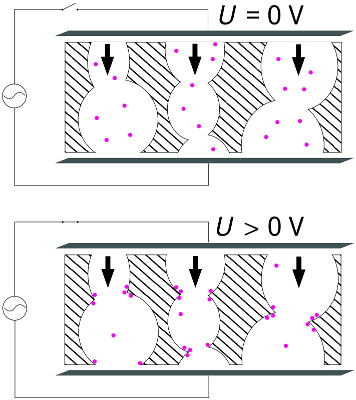


Dielectrophoretical filtration:

- Scattering material is highly porous, i. e., a filter



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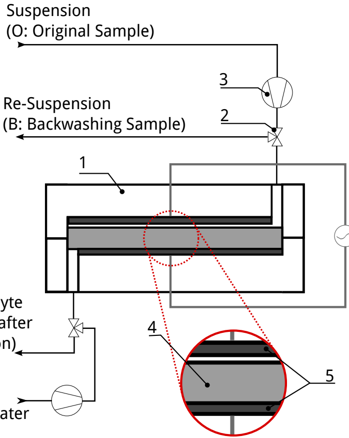

1. separation cell, 2. valve, 3. pump, 4. filter,
5. electrodes

- Separation of layer-by-layer assembled nanocapsules from polyelectrolyte of identical charge.

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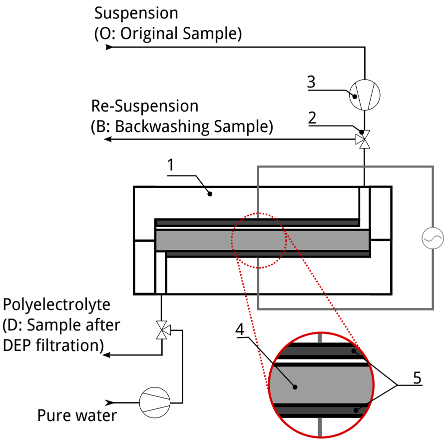

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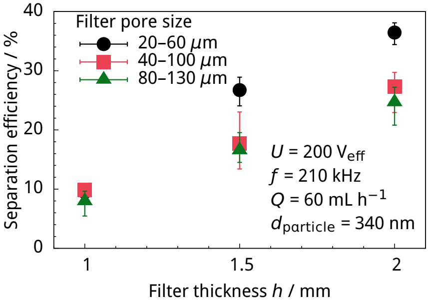

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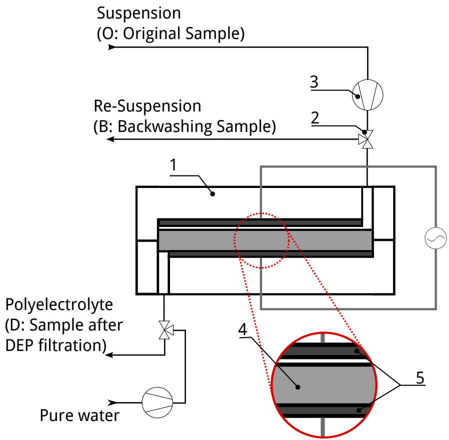

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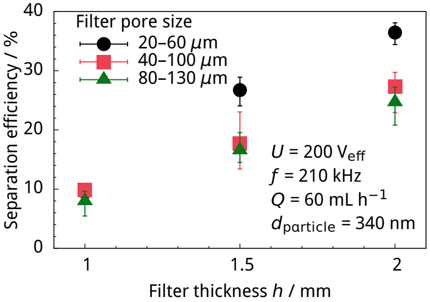

Extrapolation: 100 % separation at 6 mm thickness

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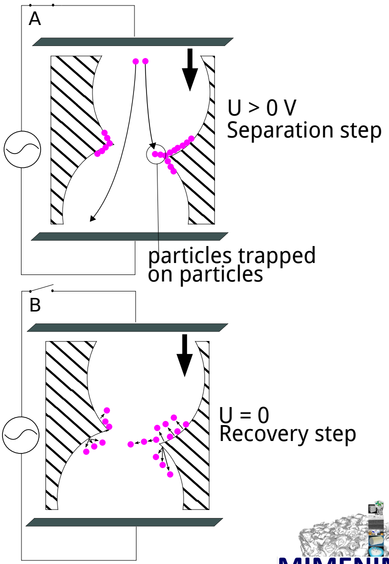
≫ Dielectrophoretical filtration

- Easy recovery of trapped particles by switching off the electric field
- Separation of particles 2 orders of magnitude smaller than filter pore size
  - Comparably low pressure loss
  - No filter cake formation / Fouling



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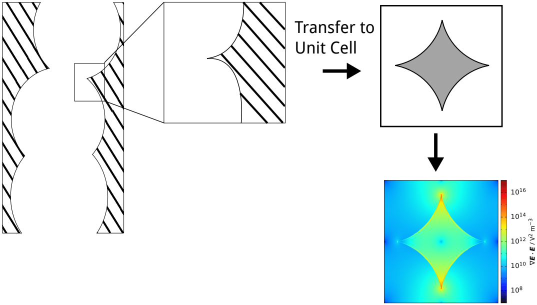
≫ How to intensify E field distortion? ($\nabla|E|^2\uparrow$)



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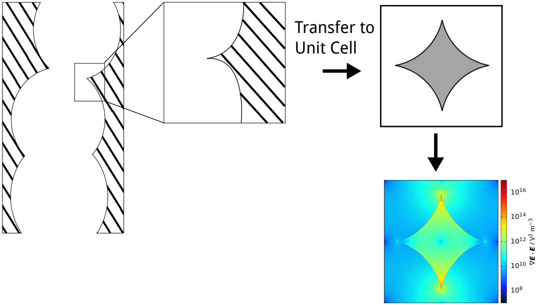
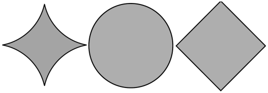


- Geometry



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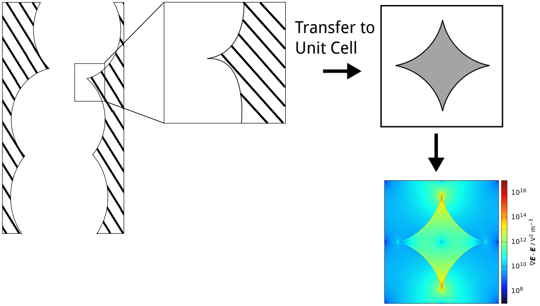
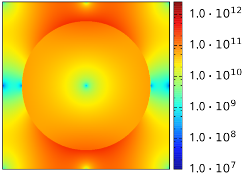
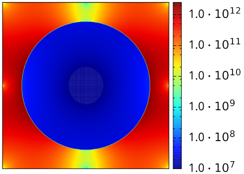


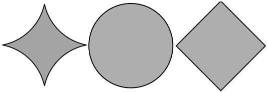


Less polarizable structure



More polarizable structure

- Geometry



- Material

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≫ Scattering of the electric field

Poisson's equation

$$\nabla\left(\varepsilon^{*}\nabla\phi\right)=\rho$$
$$\boldsymbol{E}=-\nabla\phi$$

ϕ – electric potential, $\rho = 0$ for charge free space

- $\varepsilon^{*}=\varepsilon_0\varepsilon_r - j\frac{\sigma}{\omega}$

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- $\varepsilon^* = \varepsilon_0\varepsilon_r - j\frac{\sigma}{\omega}$
- Neumann BC for insulating boundaries

$$\frac{\partial\phi}{\partial\boldsymbol{n}} = 0$$

- Dirichlet BC for electrodes

$$\phi = U_0$$

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- Scattering of electrical field lines at material interfaces:

$$\boldsymbol{E}_1 \times \boldsymbol{n}_1 = \boldsymbol{E}_2 \times \boldsymbol{n}_2,$$
$$\varepsilon_1^*\boldsymbol{E}_1 \cdot \boldsymbol{n}_1 = \varepsilon_2^*\boldsymbol{E}_2 \cdot \boldsymbol{n}_2$$

- **Tangential** components are **continuous** across interface
- **Normal** components **changes value** according to ε^*.

- ε^* is frequency dependent, so is scattering

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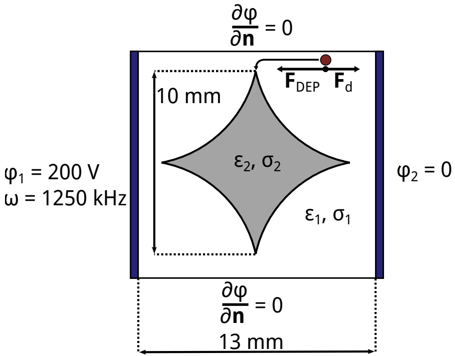
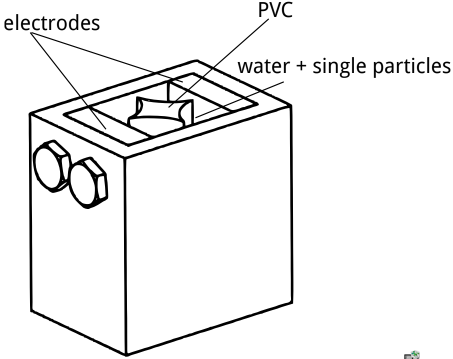
≫ Simulation geometry

Simulation study to understand influence of material and structure:



Experimental setup to validate simulation results (Comparison of particle trajectories and velocities)



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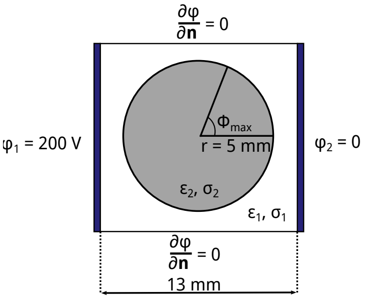
≫ Influence of frequency/material



- **Water:**
  $\varepsilon_1 = 80,\ \sigma_1 = 5.5 \cdot 10^{-6}$ S/m
- **BaTiO$_3$:**
  $\varepsilon_2 = 10000,\ \sigma_2 = 10^{-12}$ S/m

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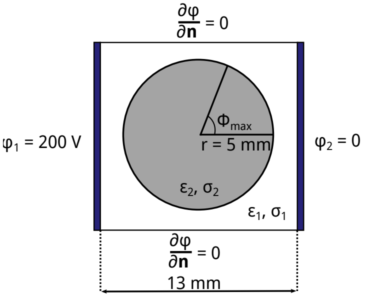

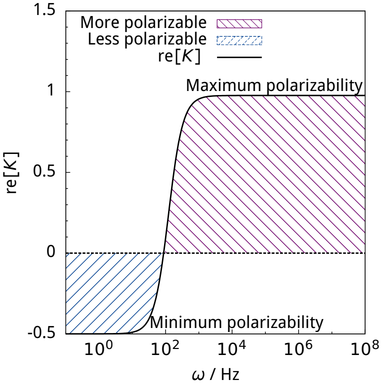

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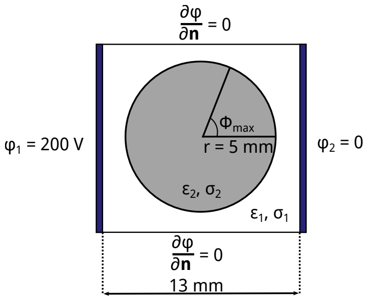

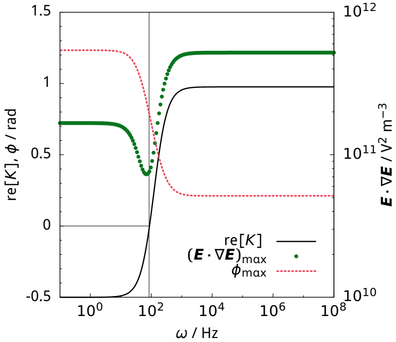

- **Water:** $\varepsilon_1 = 80,\ \sigma_1 = 5.5 \cdot 10^{-6}$ S/m
- **BaTiO$_3$**: $\varepsilon_2 = 10000,\ \sigma_2 = 10^{-12}$ S/m
- $\Phi_{\max}$ points towards maximum $(\boldsymbol{E} \cdot \nabla)\boldsymbol{E}$ on the surface

- Stronger electric field distortion if particle is better polarizable ($\mathrm{Re}[K] = 1$)
- Particle exhibits minimum of polarization if $\mathrm{Re}[K] = 0$
- $((\boldsymbol{E} \cdot \nabla)\boldsymbol{E})_{\max}$ switches position

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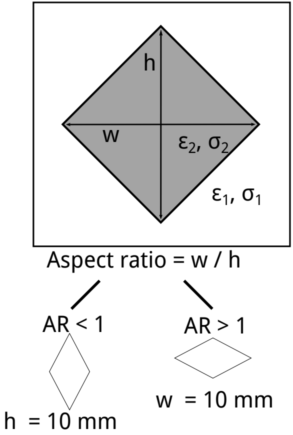
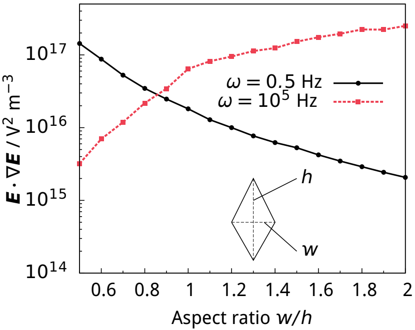
≫ Influence of geometry





- Optimal AR dependent on frequency

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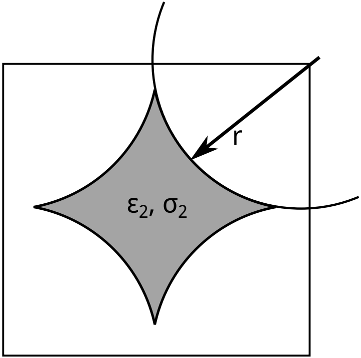

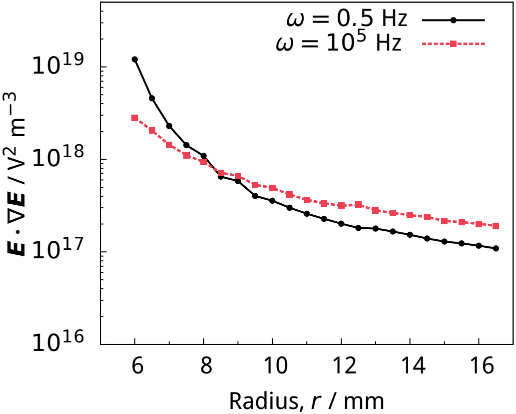

- $((\boldsymbol{E}\cdot\nabla)\boldsymbol{E})_{max}$ increases with decreasing radius (sharper tip)
- Effect is more pronounced if structure is less polarizable

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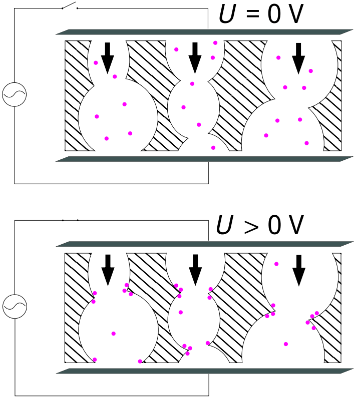
≫ Conclusion



- Separation of small particles in comparably large pores
  - No fouling
  - Low pressure loss
- Easy recovery

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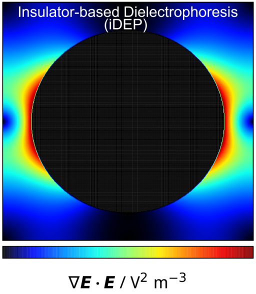
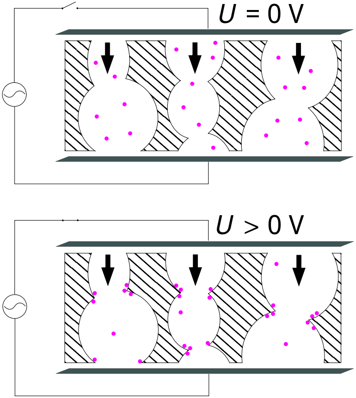
≫ Conclusion





- Scattering of electric field is influenced by structure and material
- Particle movement can be optimized with ideal design parameters

- Separation of small particles in comparably large pores
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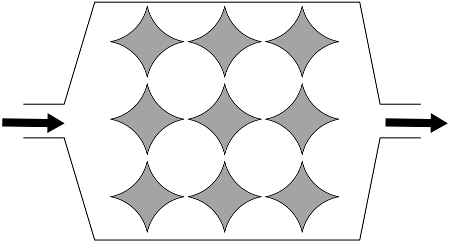
≫ Outlook



- Higher trapping in flow devices with optimized structure and material
- 2D filter model

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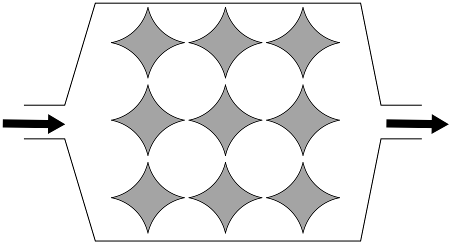
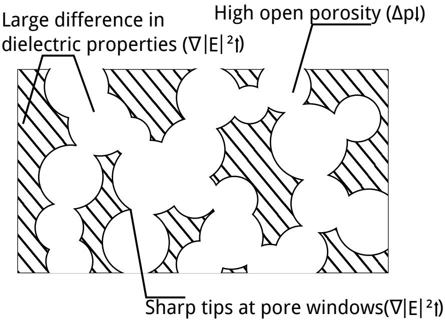
≫ Outlook





- Higher trapping in flow devices with optimized structure and material
- 2D filter model

- Transfer of knowledge to produce ideal filter

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Thank you very much for your attention!

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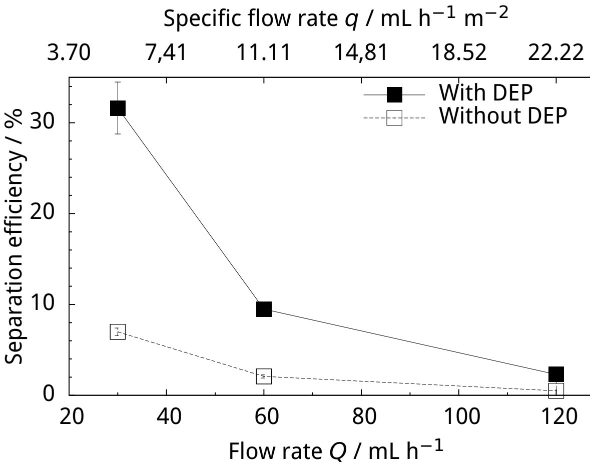
≫ Influence of flow rate on separation efficiency



f = 210 kHz, U = 200 V, d = 20–60 μm, h = 1 mm.

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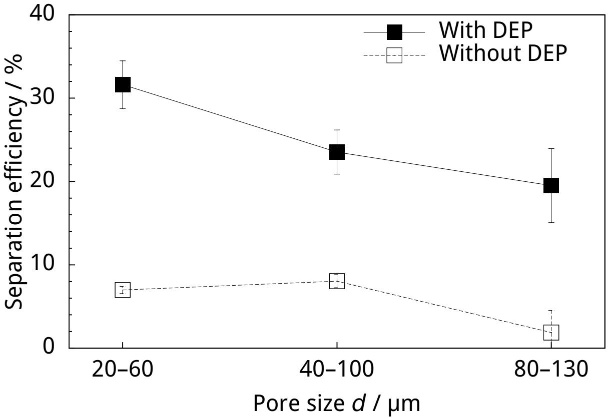
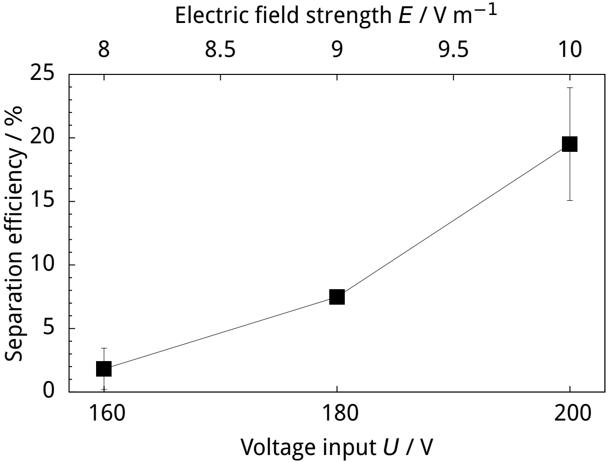
≫ Influence of filter pore size on separation efficiency



f = 210 kHz, U = 200 V, Q = 30 mL h^{-1}, h = 1 mm.

≫ Influence of voltage on separation efficiency



f = 210 kHz, Q = 30 mL h^{-1}, d = 80–130 µm, h = 1 mm.

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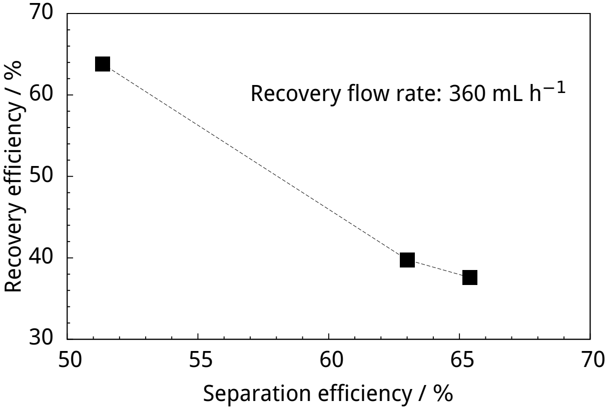
≫ Recovery of trapped particles



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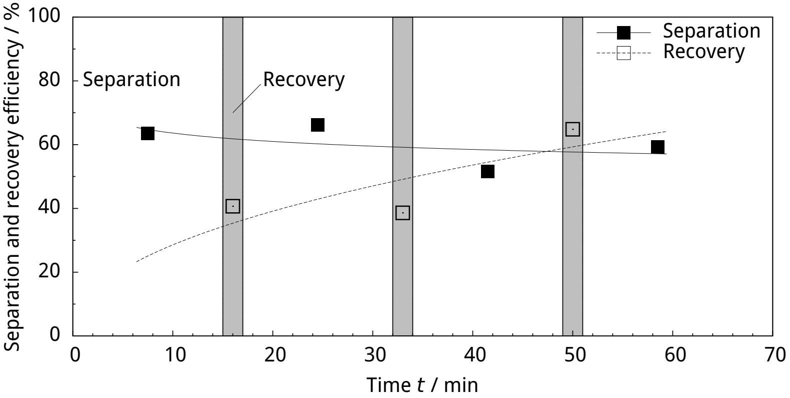
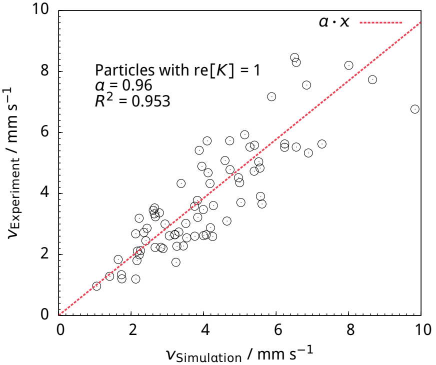
≫ Semi-continous application for particle recovery

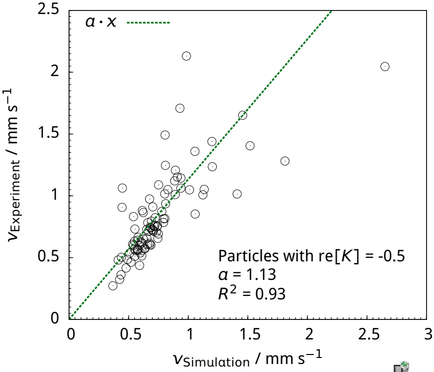


≫ Proof of simulation model

pDEP particles:
Insulating PVC post in water.
Ionic exchange catalyst particles
($d \sim 500\mu m$).



nDEP particles:
Insulating PVC post in water.
PS particles ($d = 500\mu m$).



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