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Simulation of a Magnetophoretic Device for the Separation of Colloidal Particles in Magnetic Fluids

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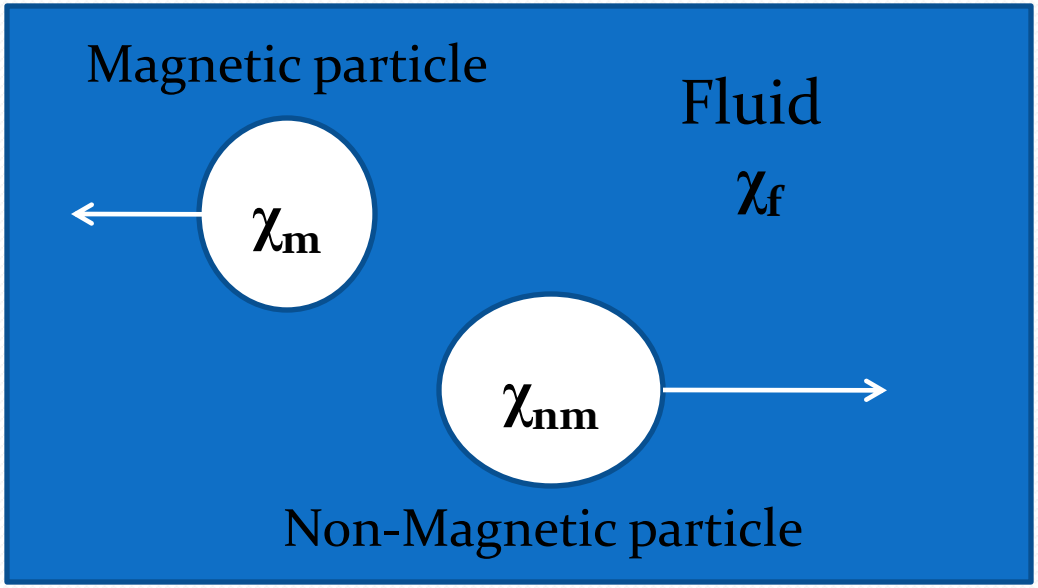
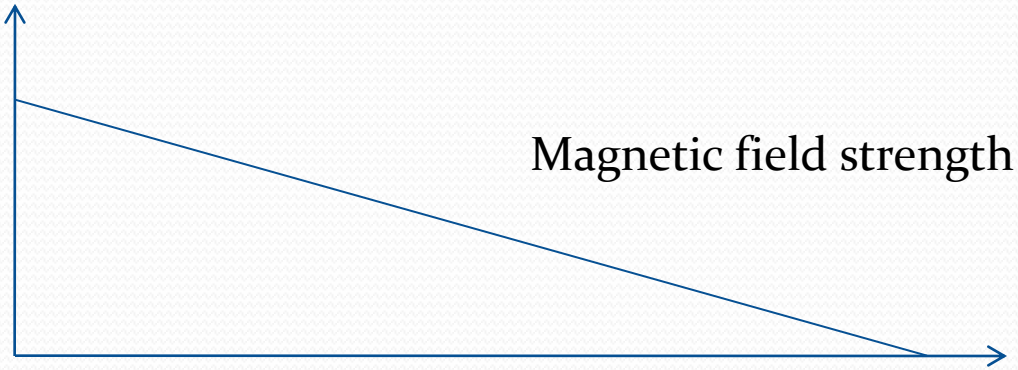
What is magnetophoresis?



$\chi_m > \chi_f > \chi_{nm}$



How can it be used in separation?

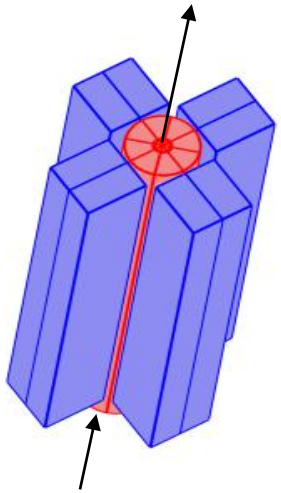
- Magnetophoretic mobility is proportional to square of the diameter

$$\mu_m = \frac{\Delta\chi D^2}{18\eta}$$

- Separating non-magnetic particles immersed in magnetic fluids based on size difference
- Different than the class of magnetic separation in which the particle magnetic susceptibility is either higher or made higher than the surrounding fluid
- Requires a subsequent step for the removal of the magnetic fluid through filteration

Simulated Experimental Device

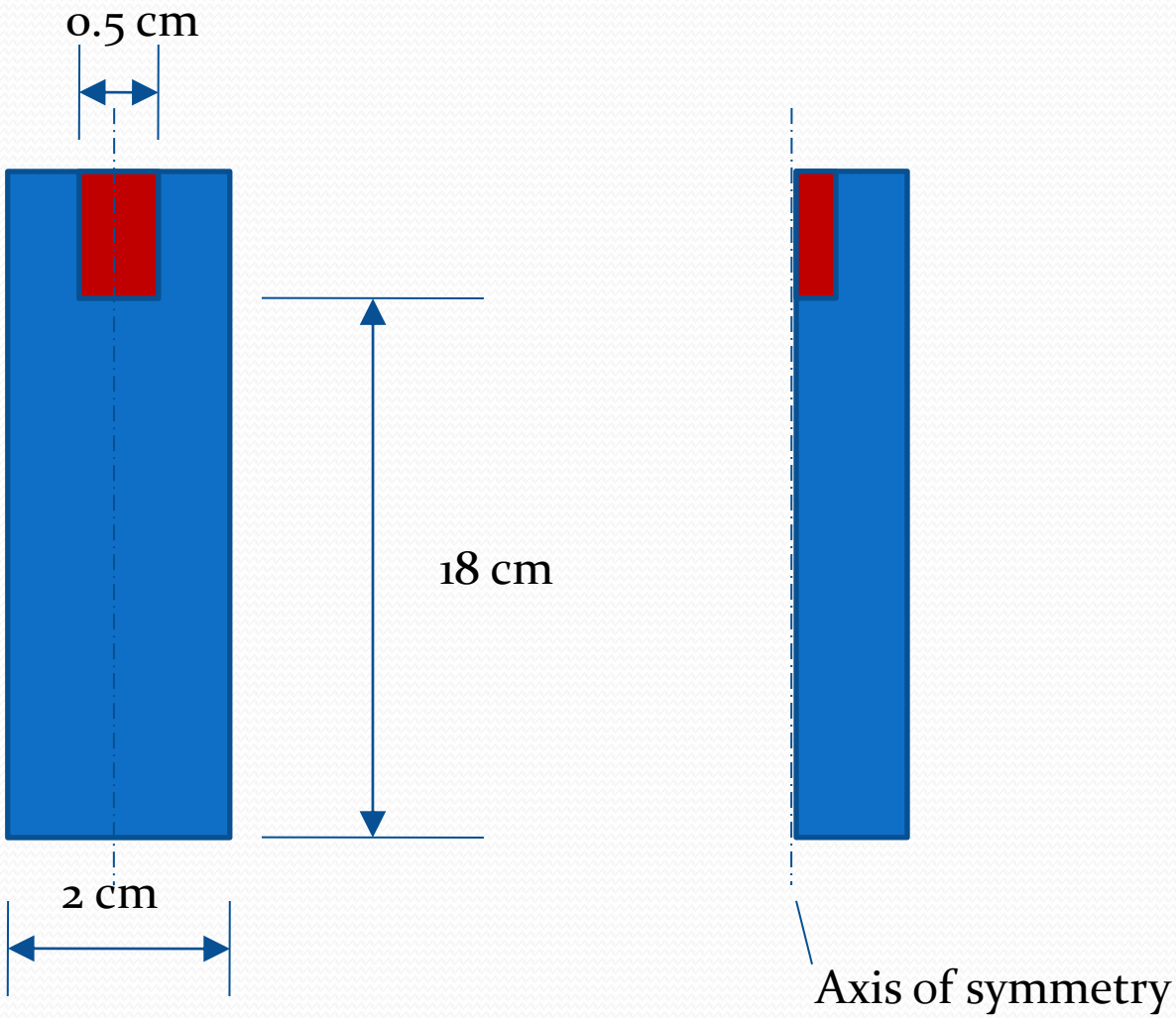
Quadruple configuration of permanent magnets



A stream that contains concentrated colloidal particles flows out from the center tube while the dilute stream flows out from the annulus.

Mixture flowing in

Separator Dimensions



Magnetophoretic Model

$$\underline{\mathbf{J}}_p = \frac{-W_f CD_{pf}}{\rho RT}\left[RT + \Psi^2 C_p\right]\underline{\nabla} C_p$$

$$-\frac{W_f CD_{pf}\bar{v}_p}{RT}\left[C_p g\left(1-\frac{\rho_p}{\rho}\right)+\frac{C_p}{\rho}\mu_o M\underline{\nabla} H\right]$$

$$\underline{\mathbf{v}}\cdot\underline{\nabla} C_p + \underline{\nabla}\cdot\underline{\mathbf{J}}_p = 0$$

Fateen, 2002

Non-dimensional Model

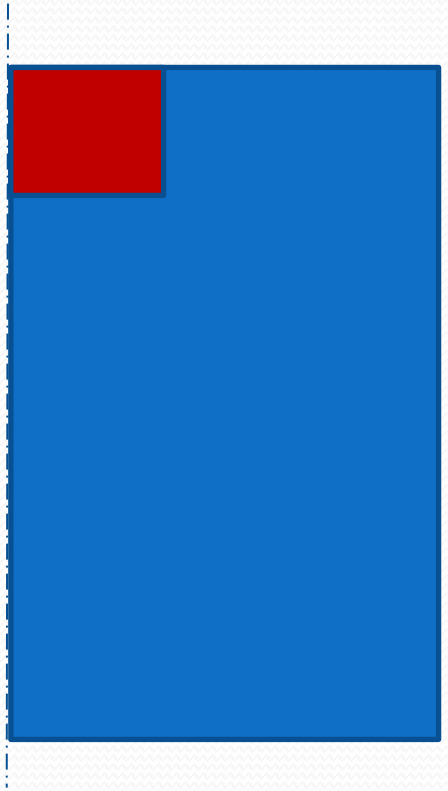
$$(\tilde{v}_z(\tilde{r}) - \tilde{g}) \frac{\partial \tilde{C}_p}{\partial \tilde{z}} =$$

$$\frac{1}{\tilde{r}} \frac{\partial}{\partial \tilde{r}} \tilde{r} \left[\tilde{D} + \tilde{\Psi}^2 \tilde{C}_p \right] \frac{\partial \tilde{C}_p}{\partial \tilde{r}}$$

$$+ \frac{1}{r} \frac{\partial}{\partial r} \tilde{r} \tilde{\beta} \tilde{M} \frac{d\tilde{H}}{d\tilde{r}} \tilde{C}_p$$

Boundary Conditions

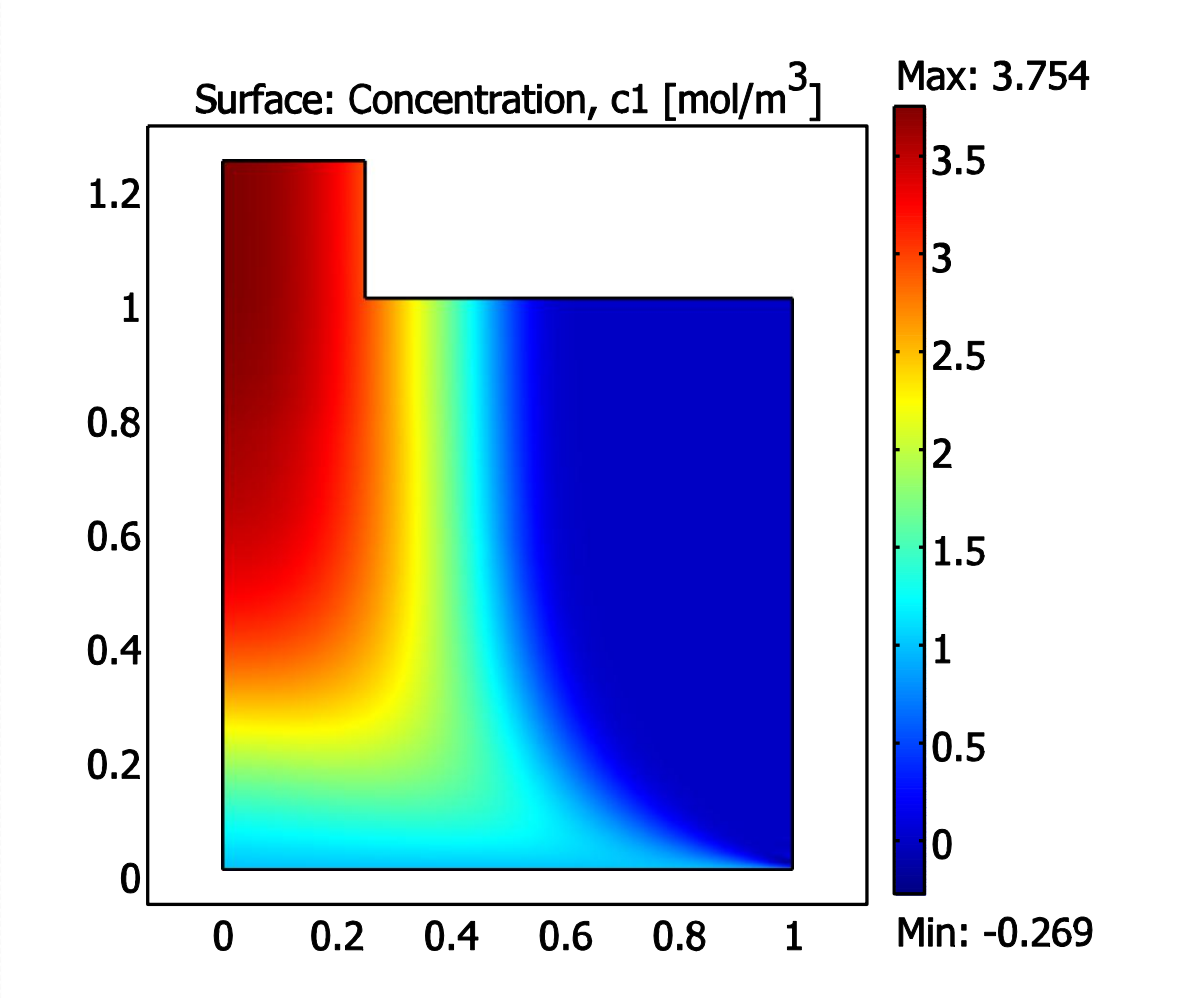
- Initial concentration at the inlet
- Convective flux at the outlet
- Symmetrical axis and wall

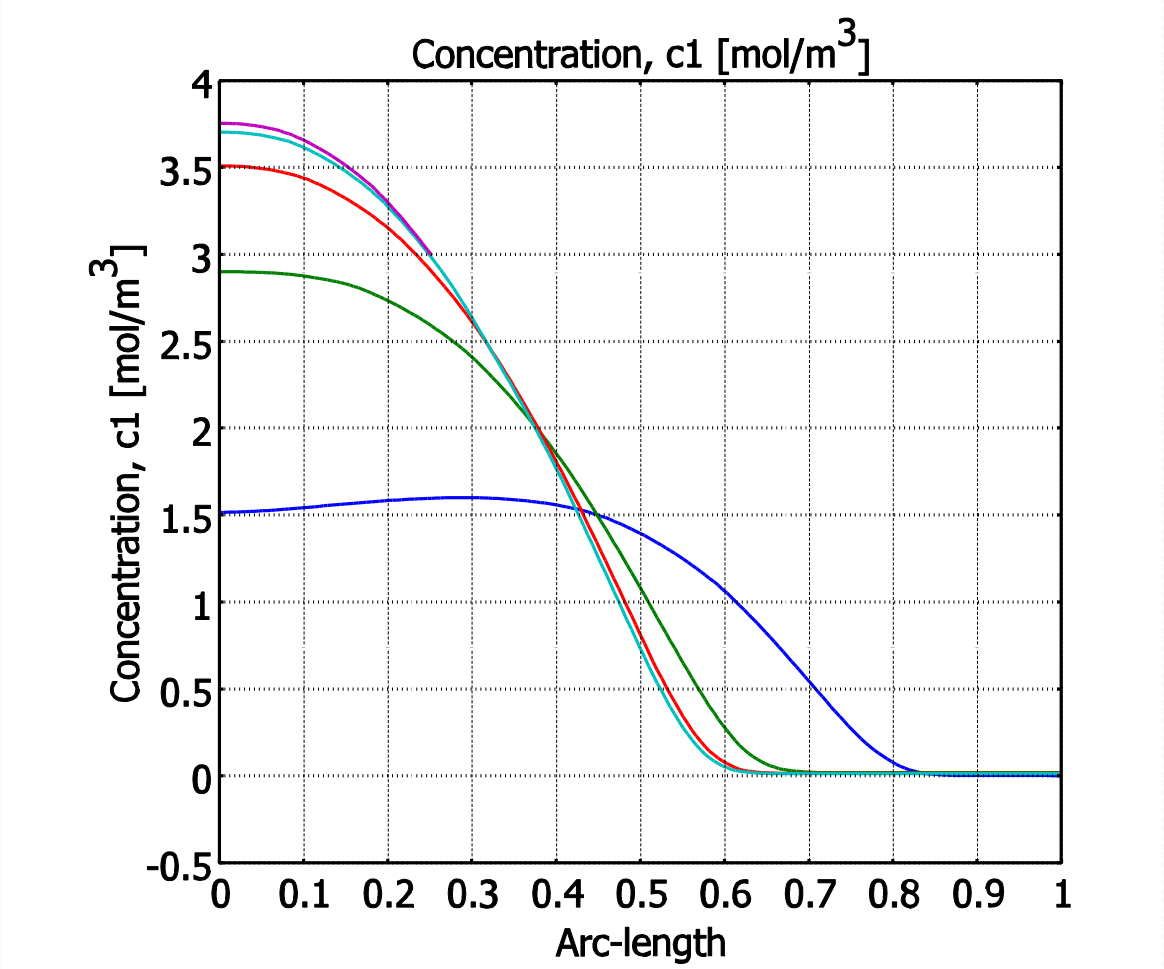


The Use of COMSOL Multiphysics

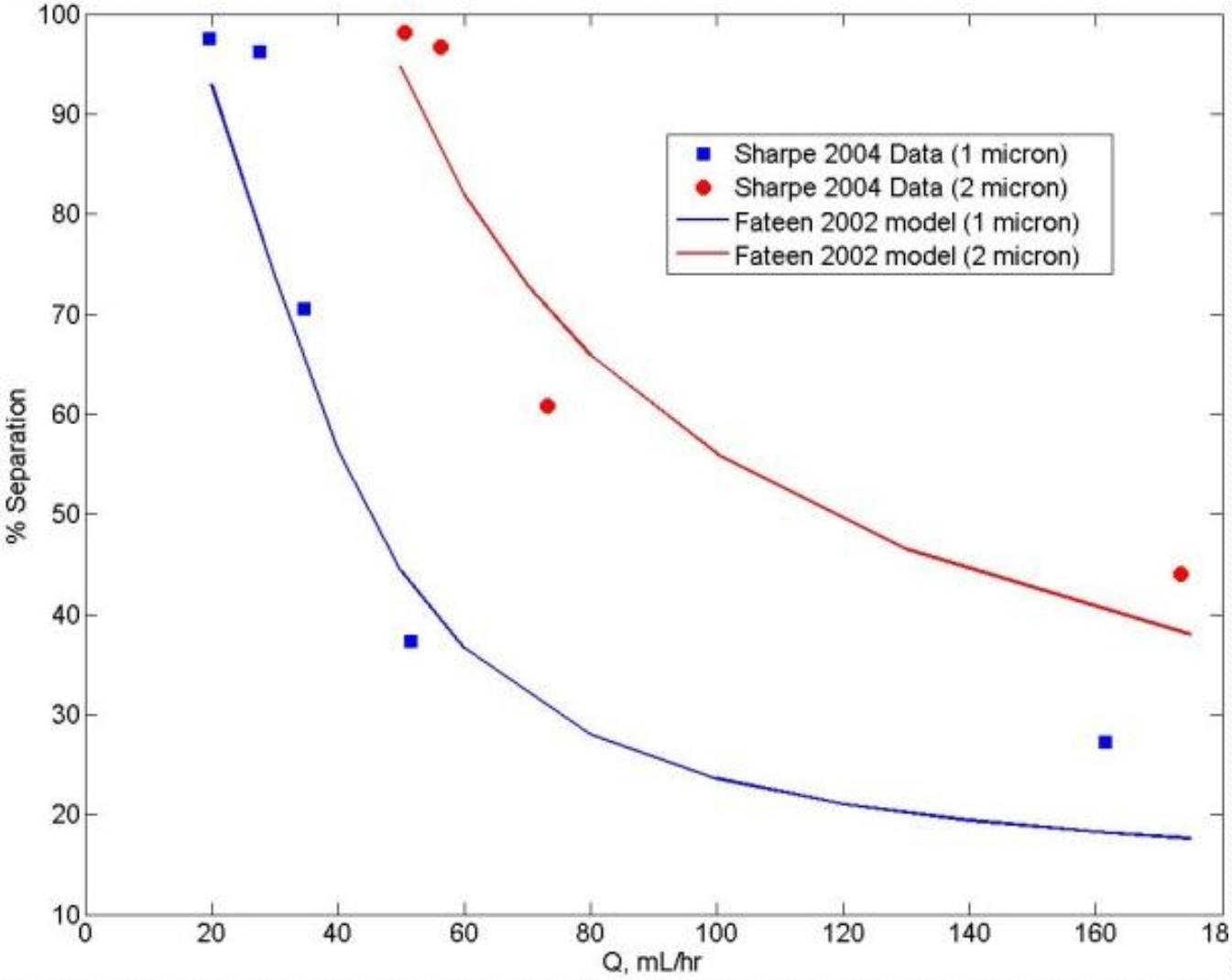
- Started from convection and diffusion module
- Edited the ‘Equation Systems’ manually to modify as per our model
- Use the artificial diffusion option for convergence

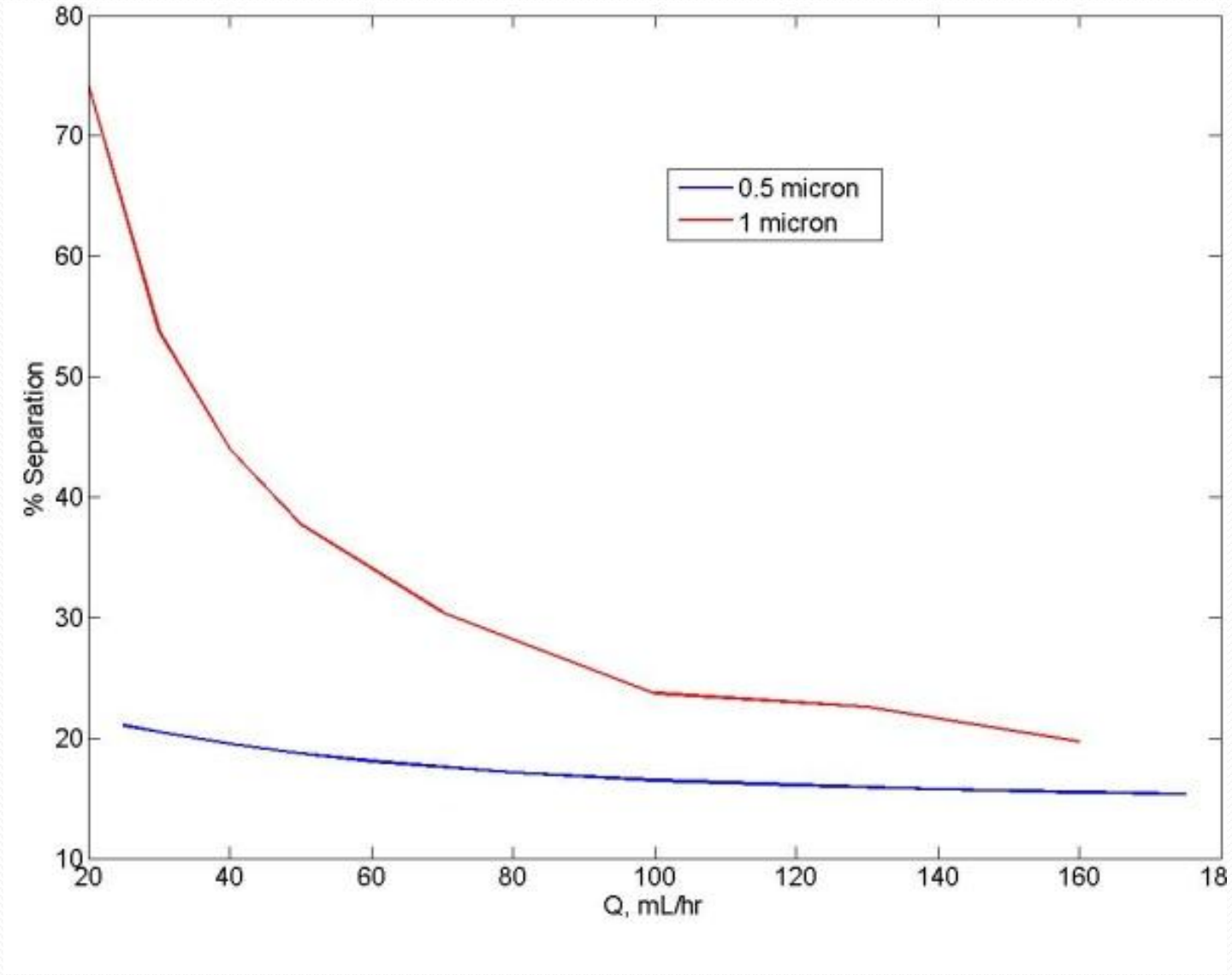
Results of 1 μ particles

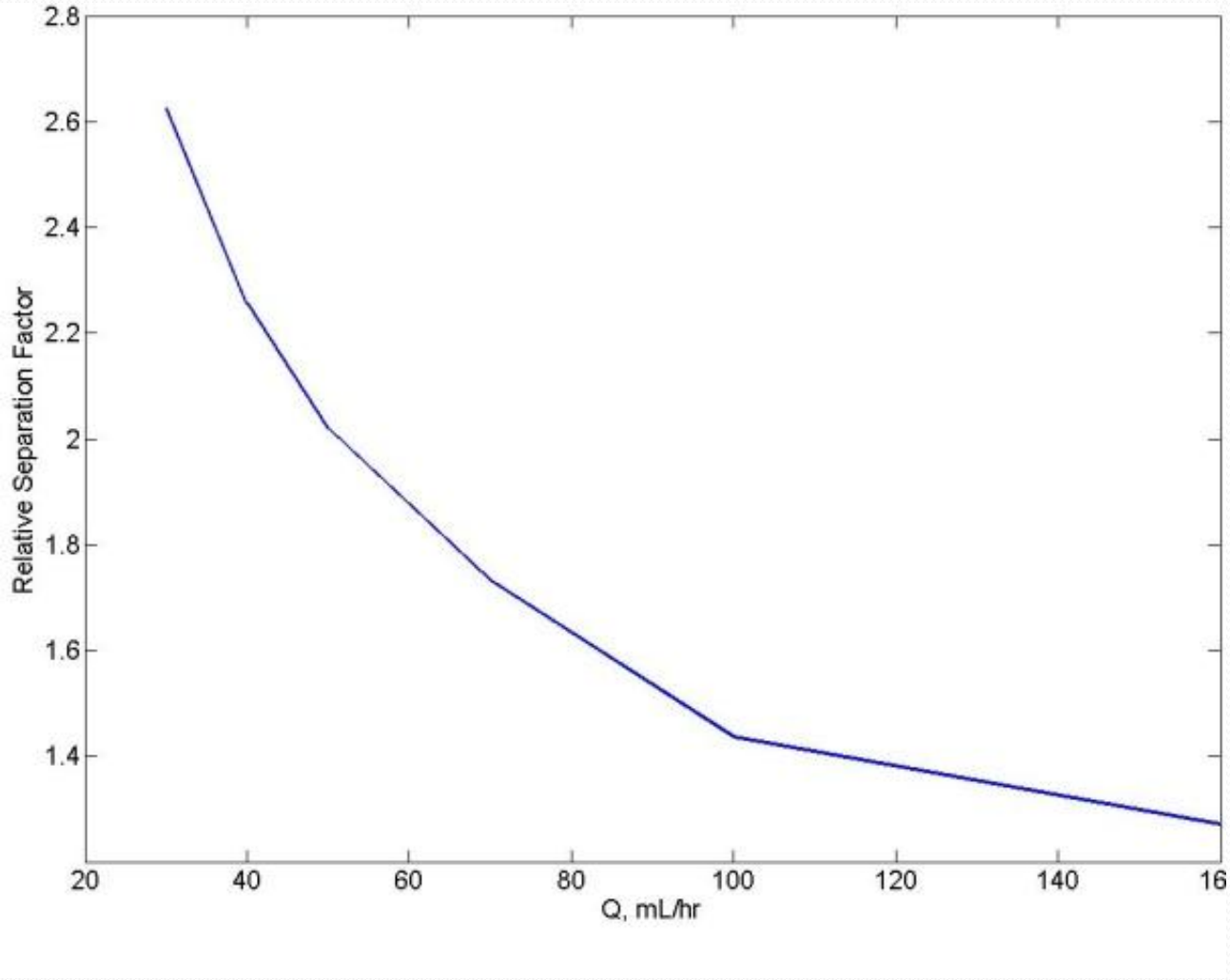



Concentration, c1 [mol/m3]
Concentration, c1 [mol/m3]
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Arc-length

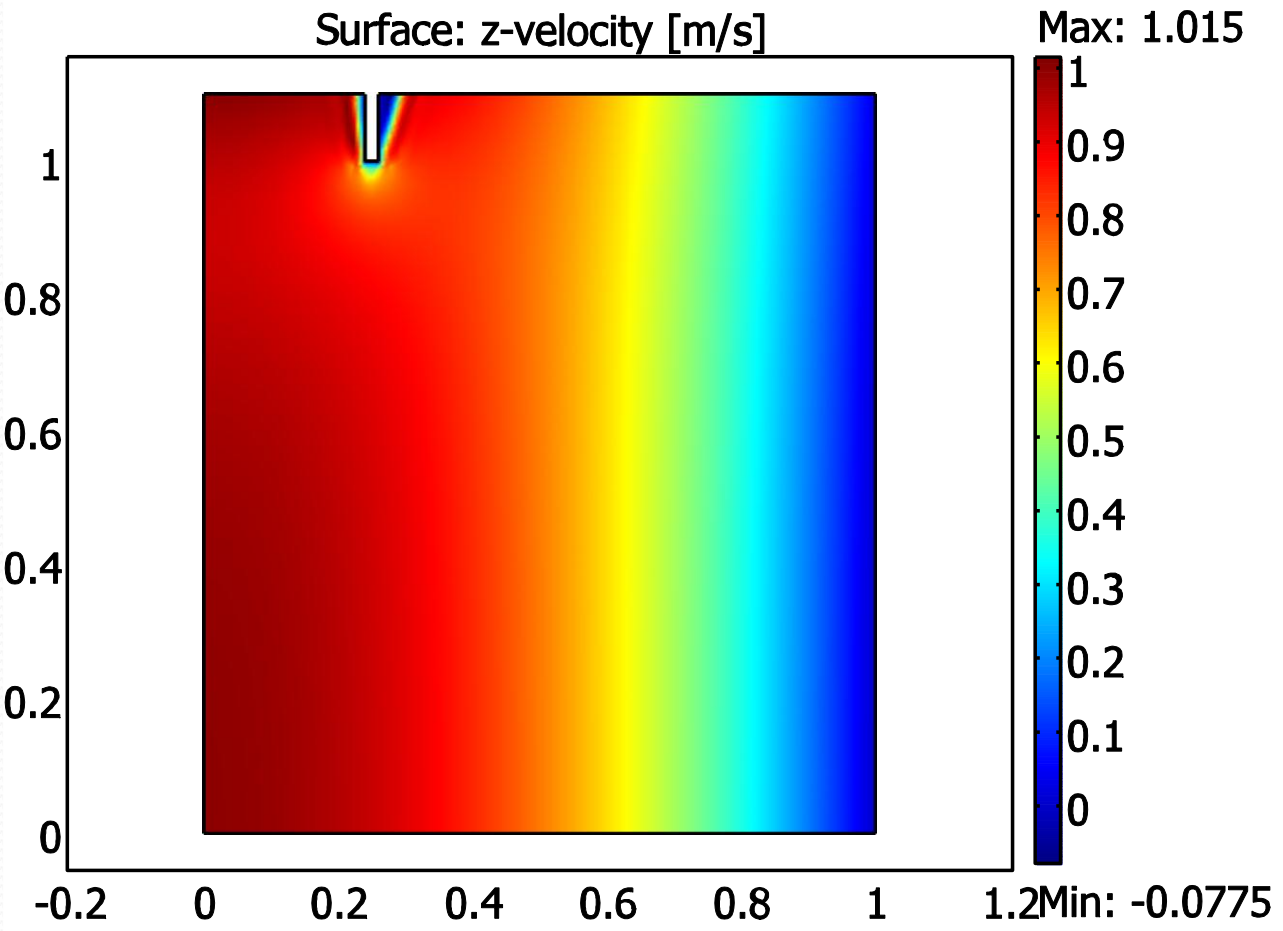
Comparison with experiment



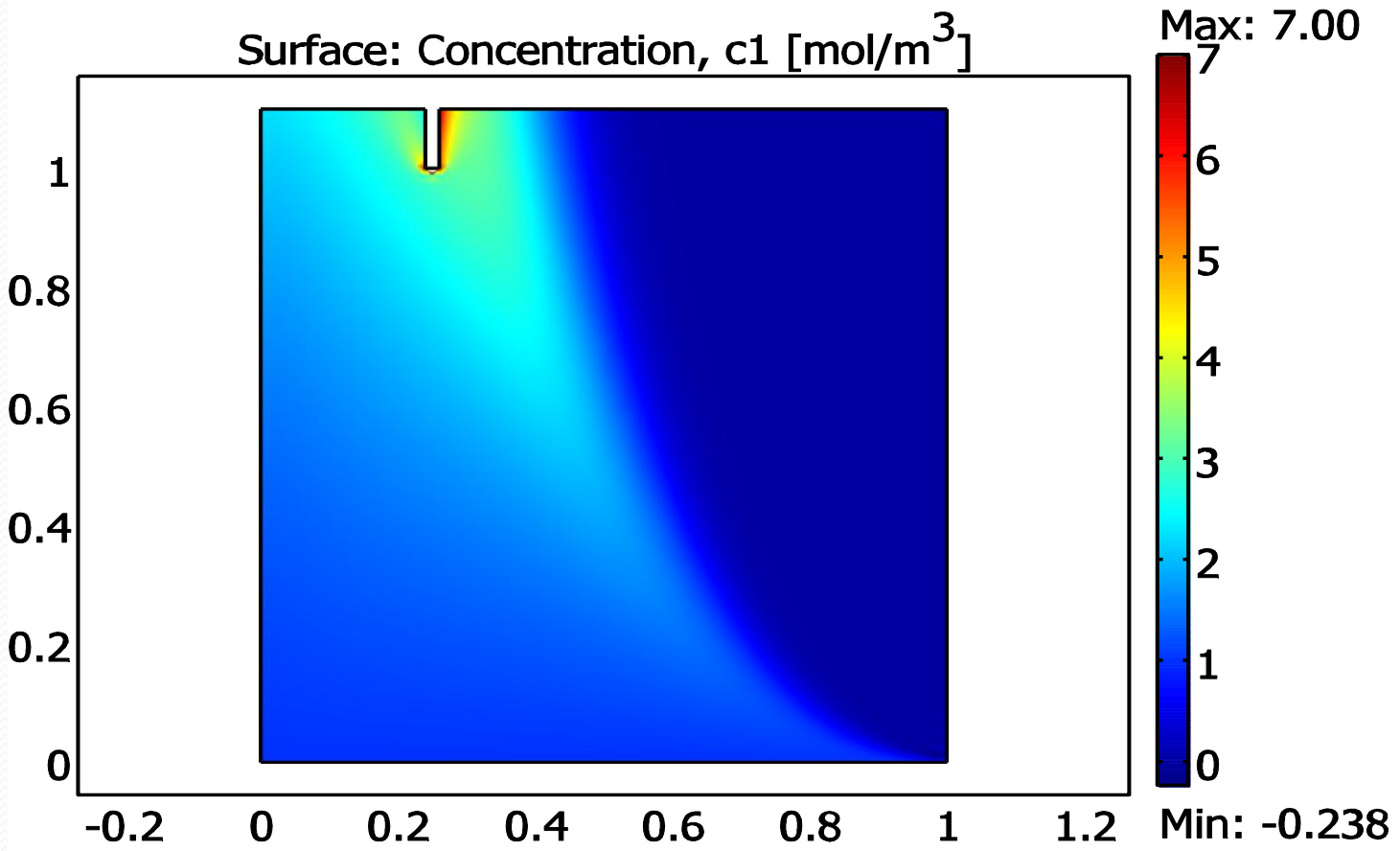

0.5 micron
1 micron
% Separation
Q, mL/hr
80
70
60
50
40
30
20
10
20
40
60
80
100
120
140
160
18


Relative Separation Factor
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
20
40
60
80
100
120
140
16
Q, mL/hr

Coupling with Navier Stokes



Similar Predictions



Discussion

- Model predicts experimental data for particle size 1 micron
- The electrostatic parameter is fitted to obtain better agreement with 2-micron experimental data

Next Steps

- Include the COMSOL Magnetostatic module to generate the magnetic field instead of using an empirical formula
- Simulate the 3D configuration to capture some of the subtle phenomena like the entrance effect
- Design different magnetic configuration to improve the separation factor