COMSOL
CONFERENCE
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Simulation of the Geometric Design Parameters' Impact on the Performance of EHD Ion-Drag Micropump

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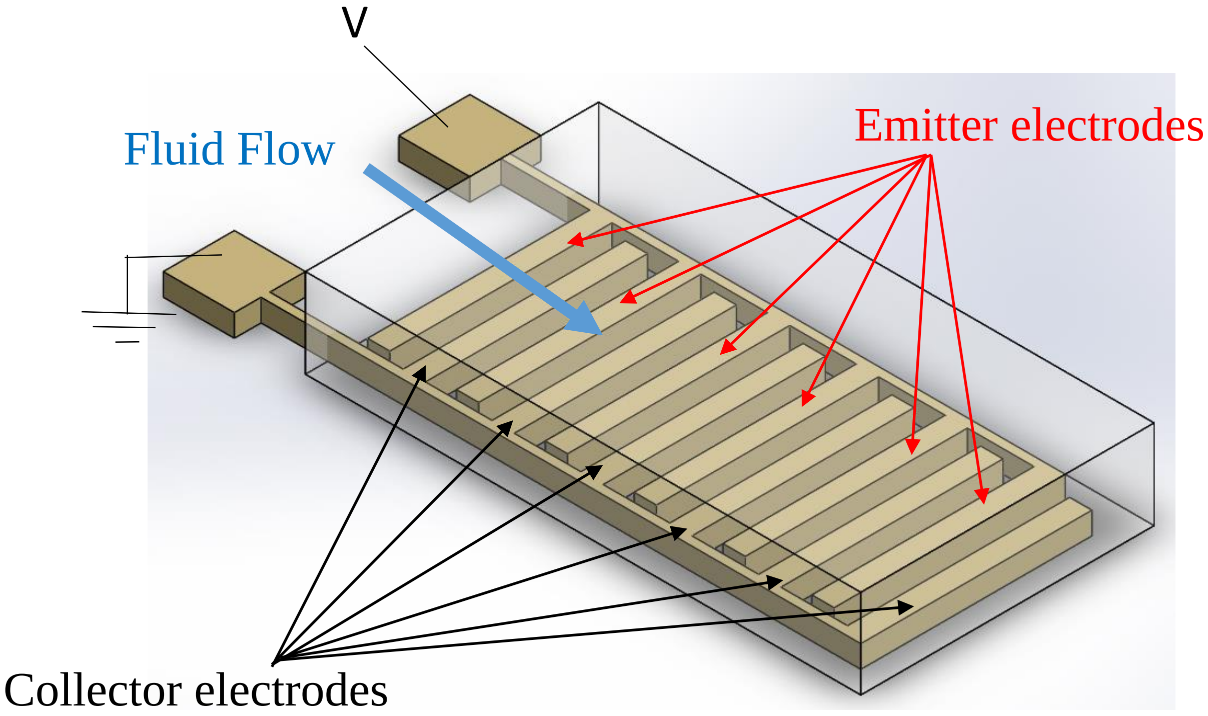
Micropumps

- Micropumps importance and applications
  - Generate fluid motion in microsystems
  - Compact size, ability to pump precise volume of fluid
  - Applications Ex.: Electronics cooling, Biomedical applications.
- Classification
  - Mechanical Micropumps (moving parts)
    - Ex: Piezoelectric, Shape memory alloy
  - Non-Mechanical Micropumps (no moving parts)
    - Ex: Magnetohydrodynamic, Electrochemical, Electrohydrodynamic (EHD)

EHD Pumping

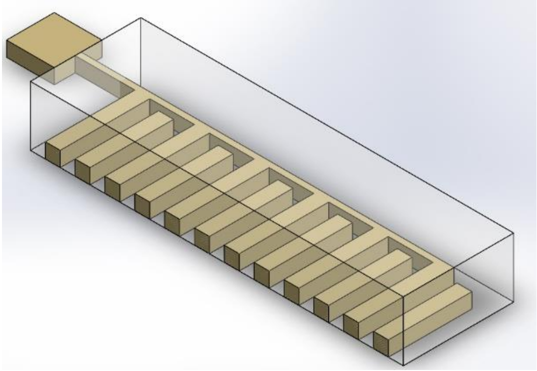
- Utilizing the influence of the electric field on electric charges in a dielectric fluid.
- High E => Injection of electrons
- Transfer of momentum

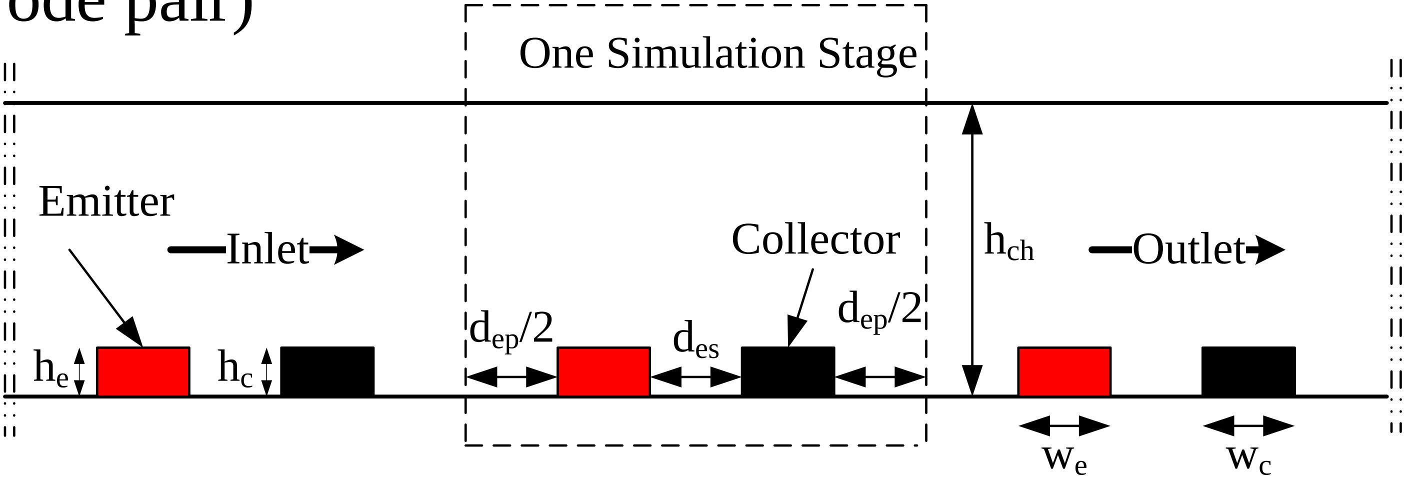
  (Ion Drag) => fluid flow
- Low σ => Small I (Low P)



Factors influencing EHD Pumping

- Working Fluid
  - High permittivity, low viscosity
- Geometric design of the electrodes
  (Height, width, shape)
- Spacing (interelectrode, electrode pair)
- Study parameters
- Symmetry
- Planar vs Saw tooth





Governing Equations

Electric body force (Force density)

$$\boxed{\mathrm{F}_e = \rho_e \mathrm{E}} - \frac{1}{2}\mathrm{E}^2 \nabla\varepsilon + \frac{1}{2}\nabla\left[\mathrm{E}^2 \rho \left(\frac{\partial \varepsilon}{\partial \rho}\right)_T\right]$$

Electrophoretic Force (Coulomb Force)

Dielectrophoretic Force

Electrostrictive Force

Gauss’s Law

$$\nabla . \vec{\mathrm{E}} = \frac{\rho_e}{\varepsilon} \qquad \mathrm{E} = -\nabla V$$

Charge Conservation

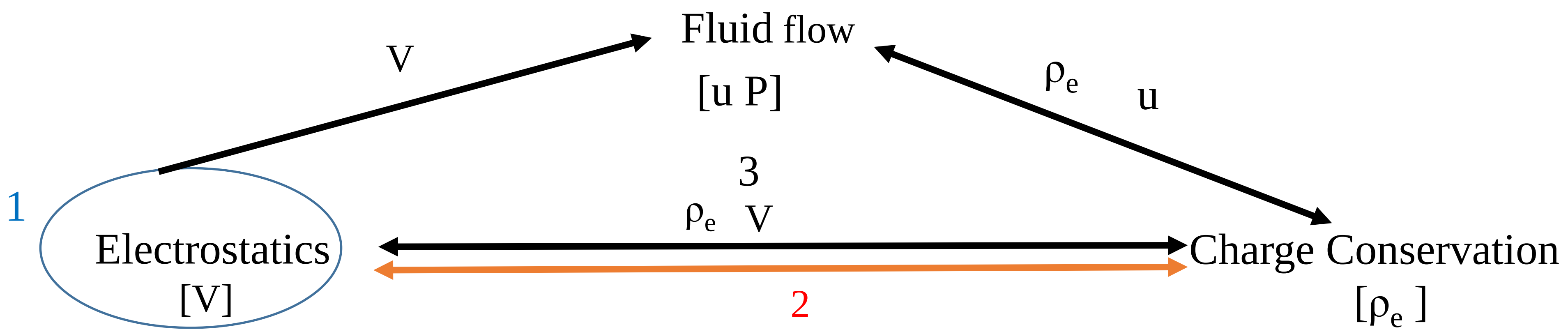
$$\frac{\partial \rho_e}{\partial t} + \nabla . \mathrm{J} = 0 \qquad \mathrm{J} = \mu_e \rho_e \mathrm{E} + \mathrm{D}\nabla\rho_e + \rho_e u + \sigma \mathrm{E}$$

Continuity and Navier Stokes (laminar, steady and incompressible flow)

$$\nabla . u = 0$$

$$\rho\left[\frac{\partial u}{\partial t} + (u.\nabla)u\right] = -\nabla p - \mu\nabla^2 u + \mathrm{F}_e$$

COMSOL Modeling



Fluid flow

[u P]

V

ρ_e u

1

Electrostatics

[V]

3

ρ_e V

Charge Conservation

[ρ_e]

2

Charge Conservation (Transport of diluted species)

$$\nabla.(-D_i.\nabla\, c_i - z_i \mu_{e,i}\, F c_i \nabla V) + u.\nabla c_i = R_i \qquad (\rho_e = c\, Na\, E_0)$$

Model has been verified against documented experimental results

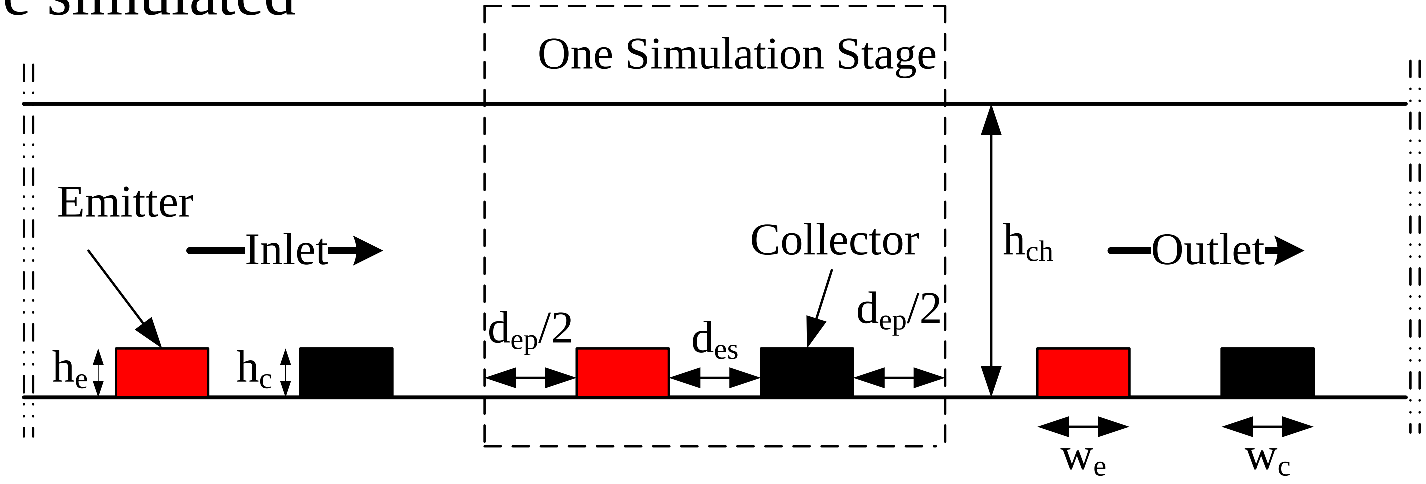
Simulated Designs

Three main ratios composed of six parameters were varied:

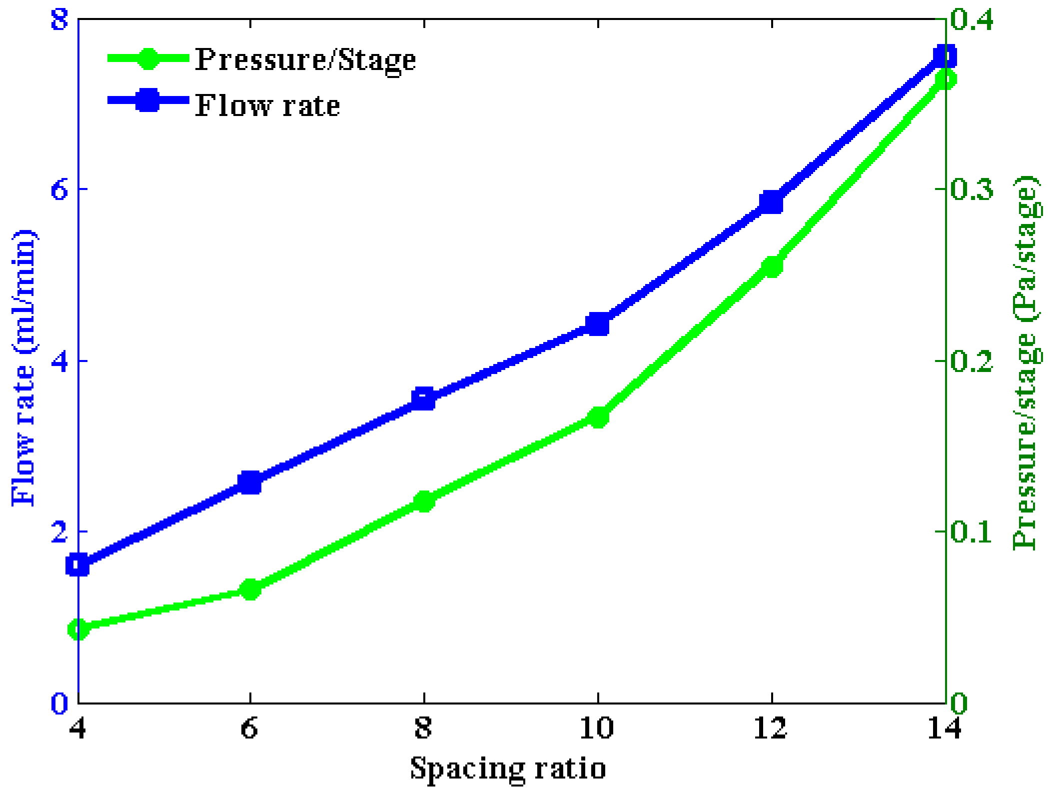
$$d_s = \frac{d_{ep}}{d_{es}} \qquad w_r = \frac{w_c}{w_e} \qquad h_r = \frac{h_c}{h_e}$$

The seventh parameter was the h_{ch}

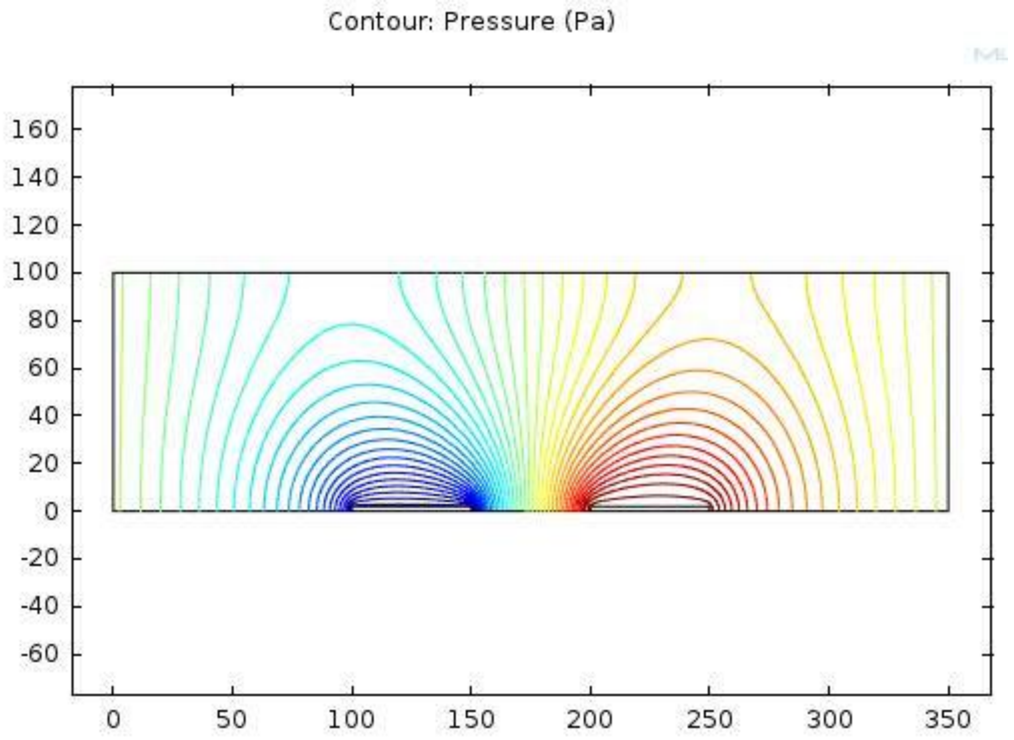
Total of 25 designs were simulated



Results: d_s

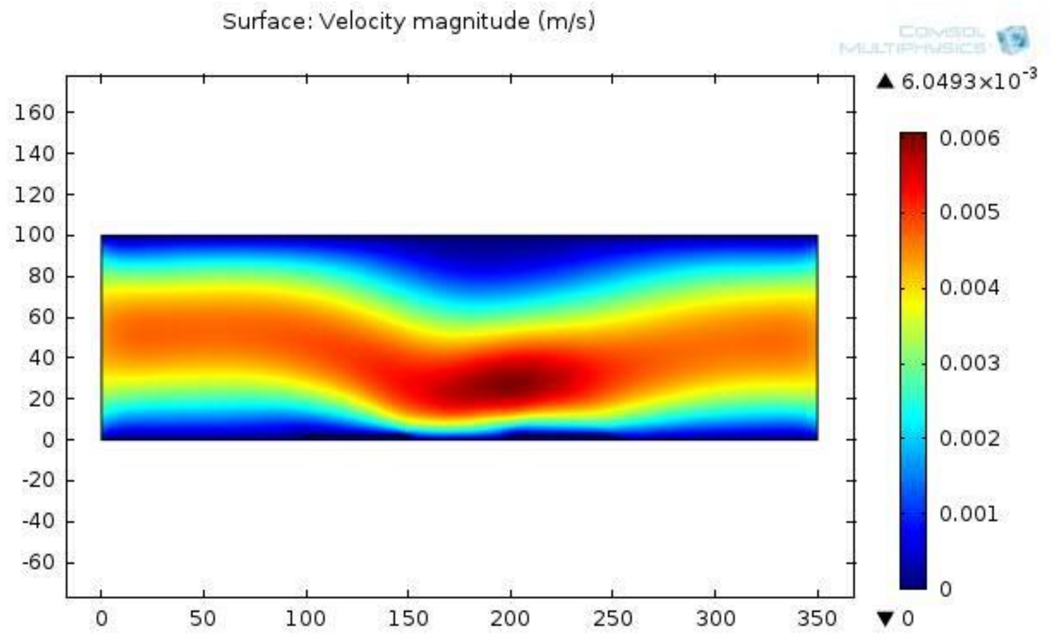


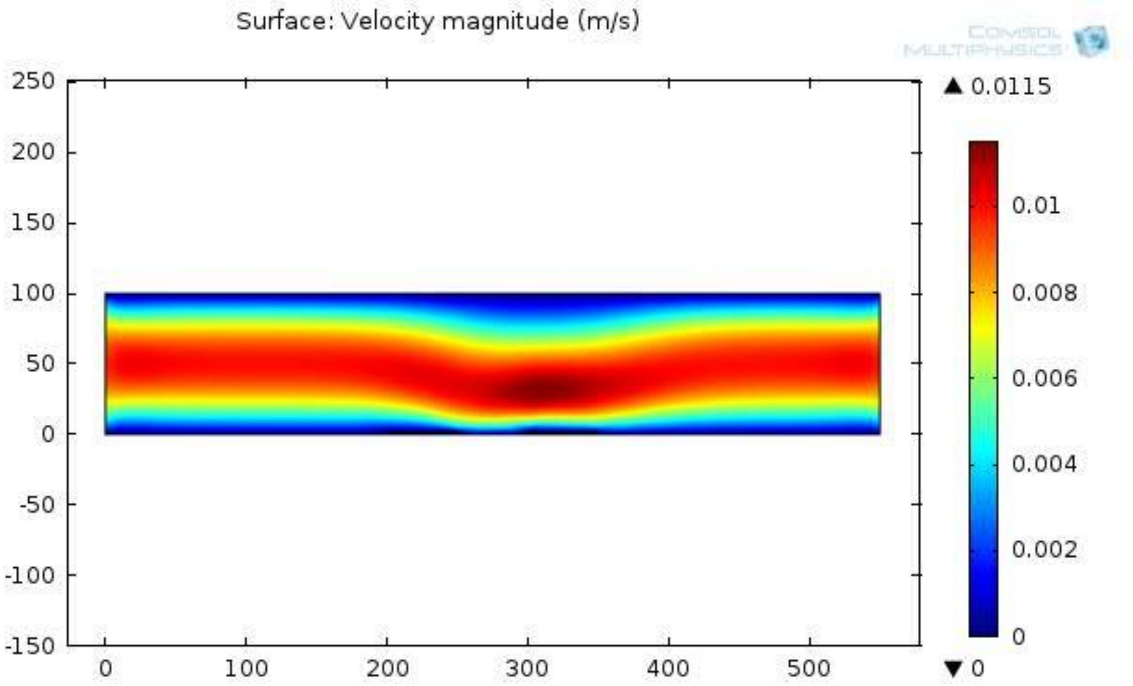
Pressure/Stage
Flow rate
Flow rate (ml/min)
Pressure/stage (Pa/stage)
Spacing ratio
0
2
4
6
8
0
0.1
0.2
0.3
0.4
4
6
8
10
12
14



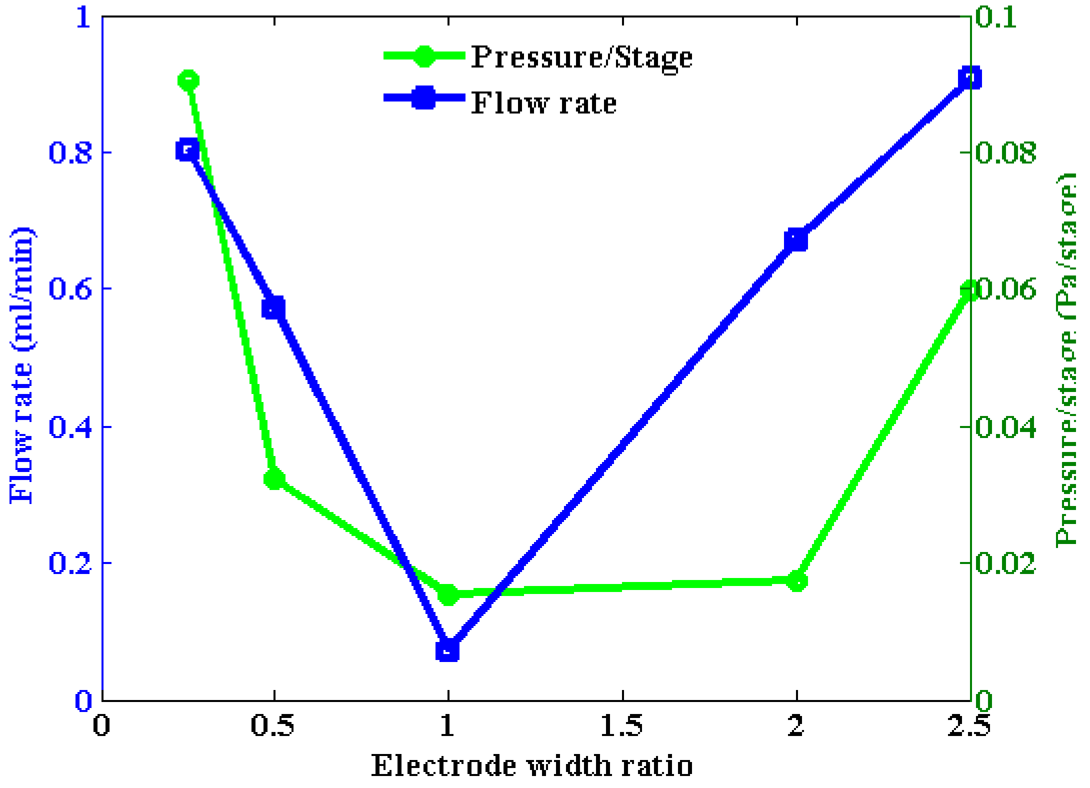
Contour: Pressure (Pa)
160
140
120
100
80
60
40
20
0
-20
-40
-60
0
50
100
150
200
250
300
350

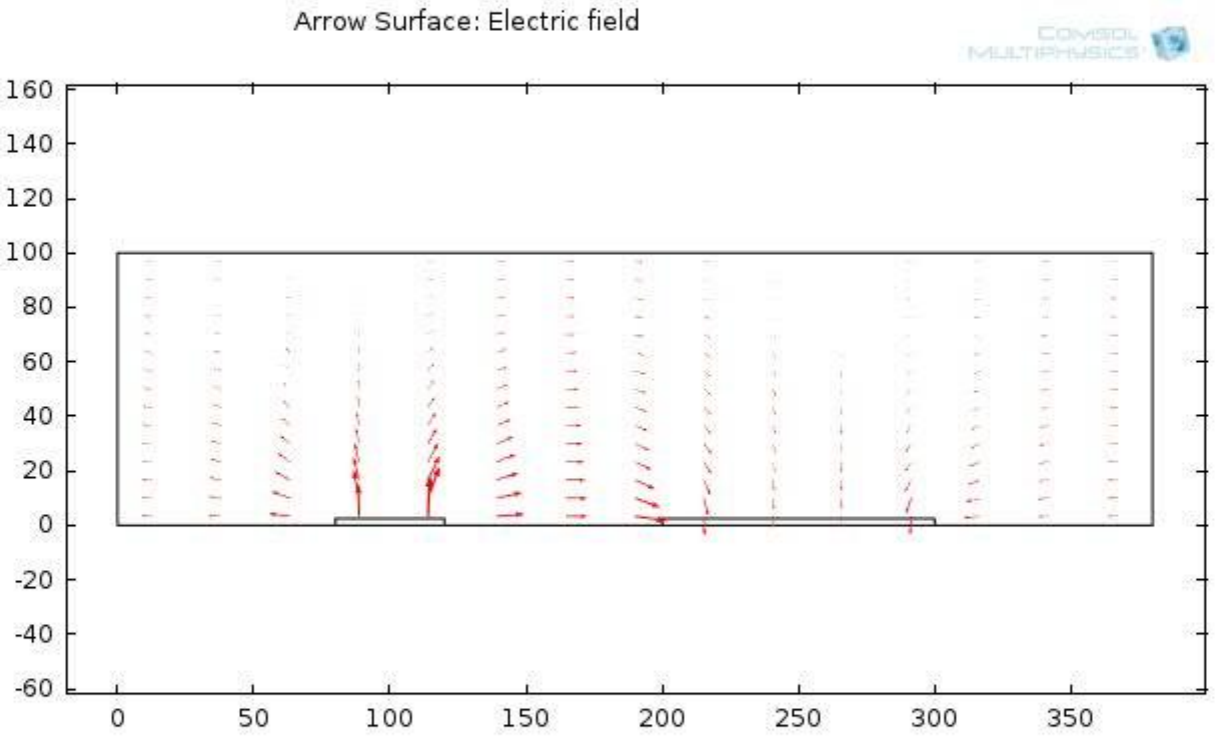
Results: d_s


Surface: Velocity magnitude (m/s)
COMSOL MULTIPHYSICS
▲ 6.0493×10⁻³
▼ 0
160
140
120
100
80
60
40
20
0
-20
-40
-60
0
50
100
150
200
250
300
350
0.006
0.005
0.004
0.003
0.002
0.001
0

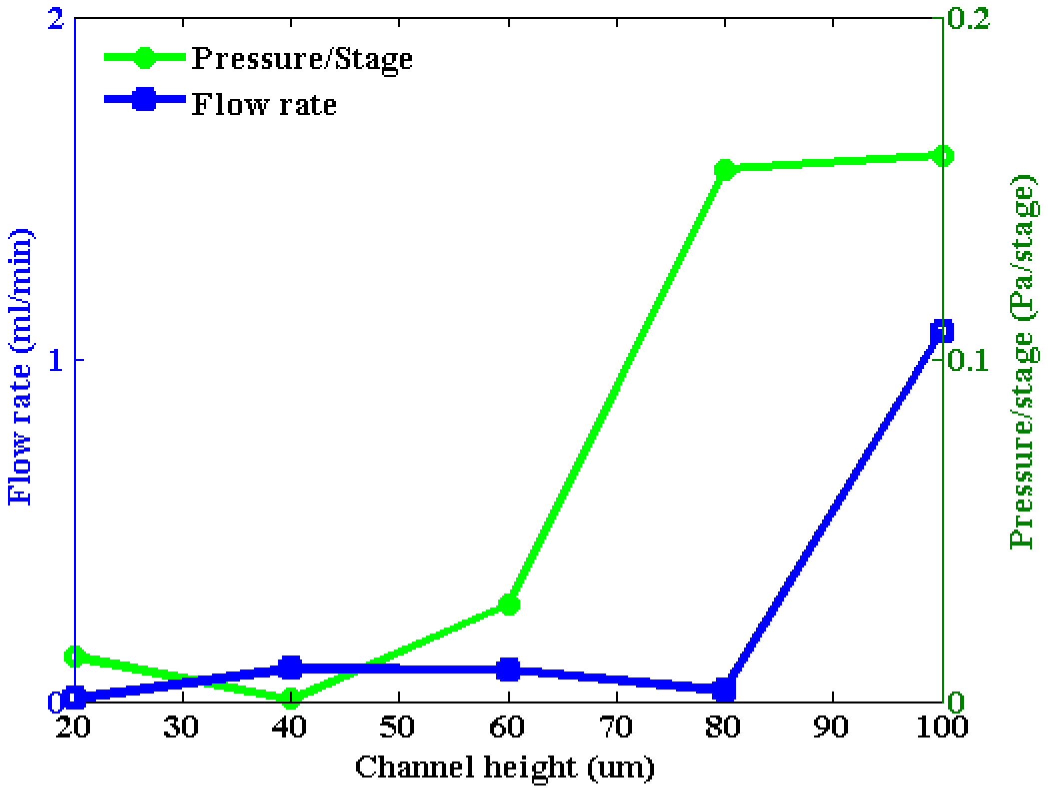

Surface: Velocity magnitude (m/s)
COMSOL MULTIPHYSICS
▲ 0.0115
▼ 0
250
200
150
100
50
0
-50
-100
-150
0
100
200
300
400
500
0.01
0.008
0.006
0.004
0.002
0

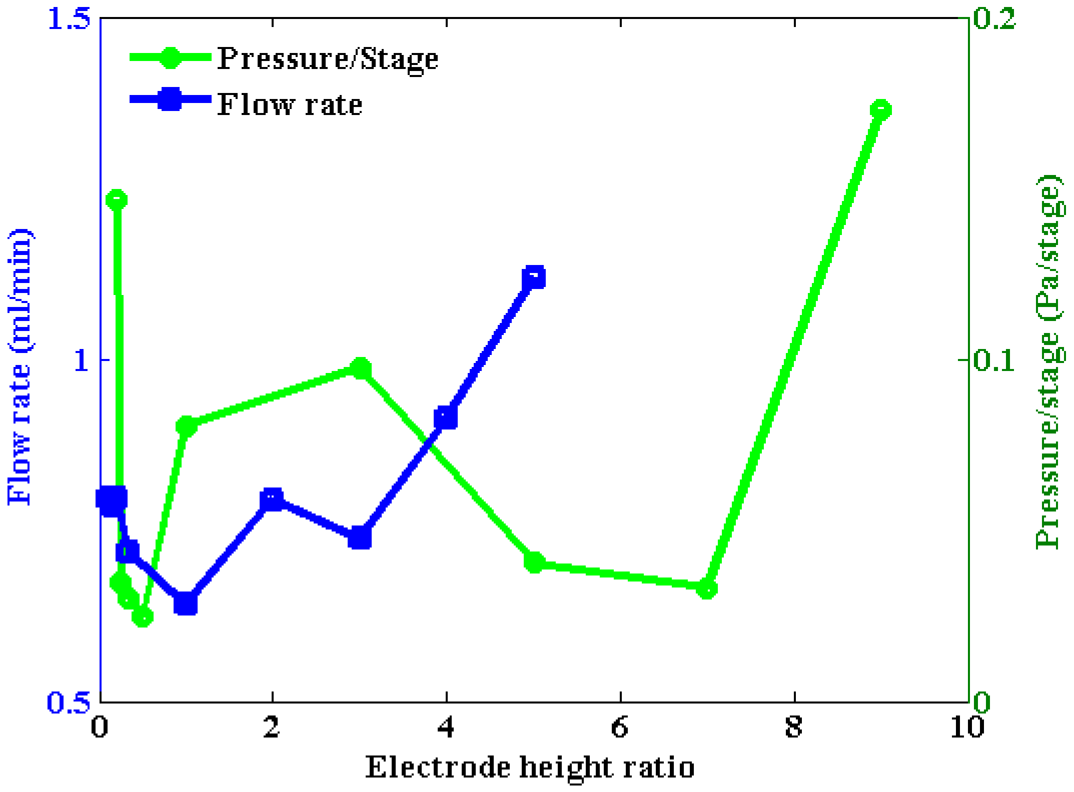
Results: w_r


Pressure/Stage
Flow rate
Flow rate (ml/min)
Pressure/stage (Pa/stage)
Electrode width ratio
0
0.2
0.4
0.6
0.8
1
0
0.02
0.04
0.06
0.08
0.1
0
0.5
1
1.5
2
2.5


Arrow Surface: Electric field
COMSOL MULTIPHYSICS
160
140
120
100
80
60
40
20
0
-20
-40
-60
0
50
100
150
200
250
300
350

Results: h_{ch} & h_r





Conclusion

An optimal design would make use of the following:

- Asymmetry in electrode height and width
- d_s in the range of 3-4
- h_{ch} should be increased (beware charge density vs height)

Thank You