COMSOL CONFERENCE
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On Modeling and Simulation of Electroosmotic Micropump for Biomedical Applications

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Outline

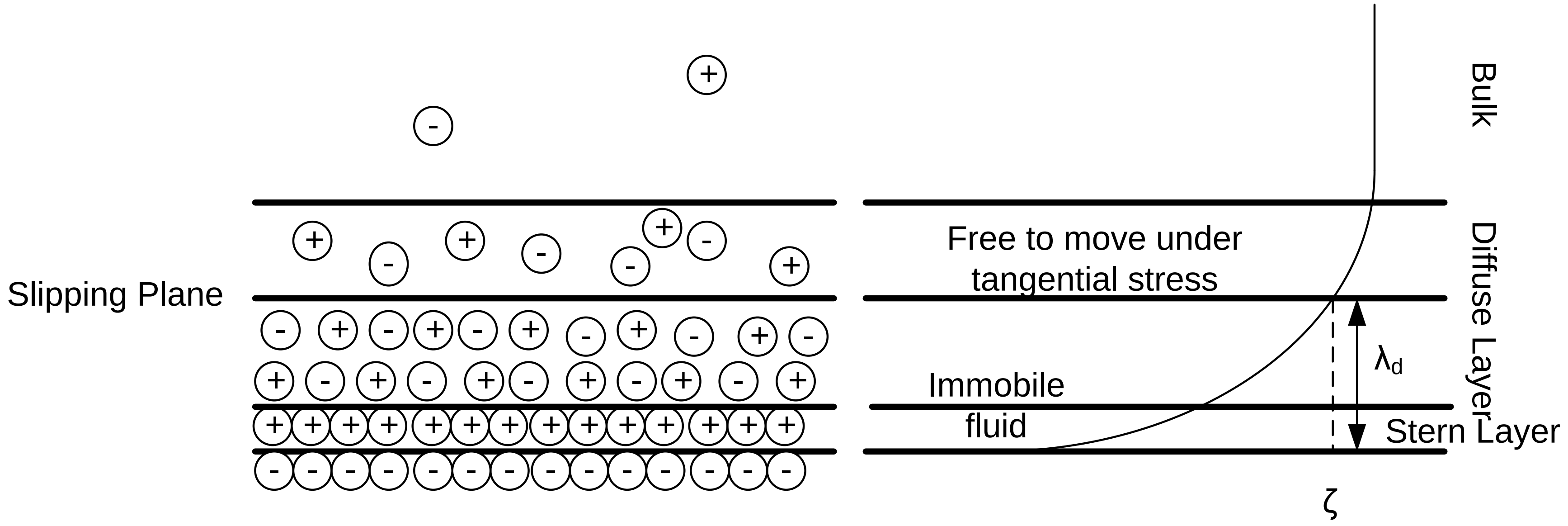
- Micro-Total Analysis Systems
- Electroosmotic Micropump
- Non-Newtonian Fluids
- Governing Equations
- COMSOL Modeling
- Simulated Model
- Verification
- Results
- Conclusion

Micro Total Analysis Systems (µTAS)

- Usage : Medical Diagnostics, Drug Delivery, DNA Analysis, Toxicity Monitoring
- Lab on a Chip and usage of microfluidics
- Require
  - Small volume of fluids
  - Parallel processing (multiple of samples at once)
  - Low Power consumption
- Micropumps for control fluid flow inside the channels
- Fluid channels height or depth of 1µm-500µm

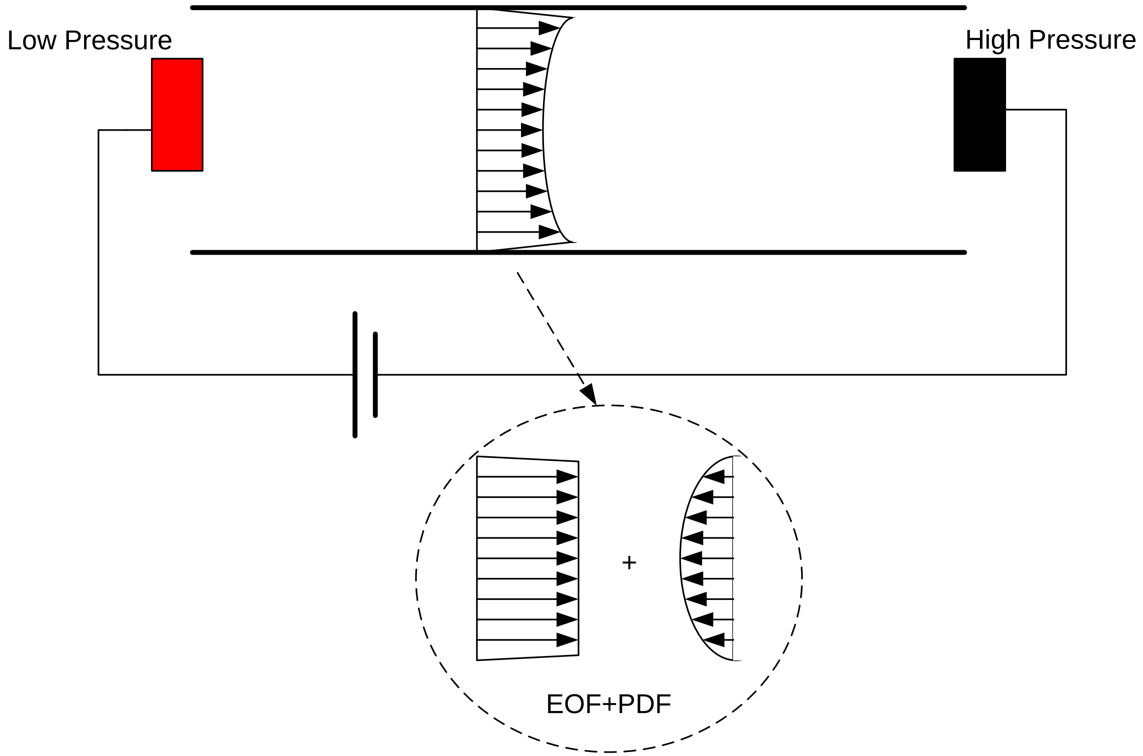
Electroosmotic Micropump

- A non-mechanical micropump (no moving parts)
- The Fluid motion is induced by an applied electric potential across the channel.
- Electric Double Layer (EDL)



Electroosmotic Micropump

- Electroosmotic Flow and Pressure Driven Flow



Non-Newtonian Fluid

- It is a fluid where its viscosity is not constant with applied sheer stress.
- Shear thinning
  - Viscosity decreases with high shear strain
- Newtonian
  - Viscosity is constant with shear strain
- Shear Thickening
  - Viscosity increases with high shear strain

Blood is considered a shear thinning non-Newtonian fluid.

Governing Equations

Navier-Stokes Equations

$$\rho(\boldsymbol{u}.\nabla)\boldsymbol{u} = -\nabla \boldsymbol{P} + \mu\nabla^2\boldsymbol{u} + \boldsymbol{F}$$

Reynolds number <1 => creeping flow and inertial terms could be neglected.

ρ_e= 0 at the bulk => F=0

$$0= -\nabla \boldsymbol{P} + \mu\nabla^2\boldsymbol{u}$$

Electroosmotic Slip Velocity

$$u = \mu_{eo}E = \frac{\varepsilon_o\ \varepsilon_r\zeta}{\mu}$$

Continuity Equation

$$\nabla.\boldsymbol{u}=0$$

Carreau model for non-Newtonian fluid

$$\mu = \mu_\infty + (\mu_o - \mu_\infty)[1 - (\lambda\dot{\gamma})^2]^{\frac{n-1}{2}}$$

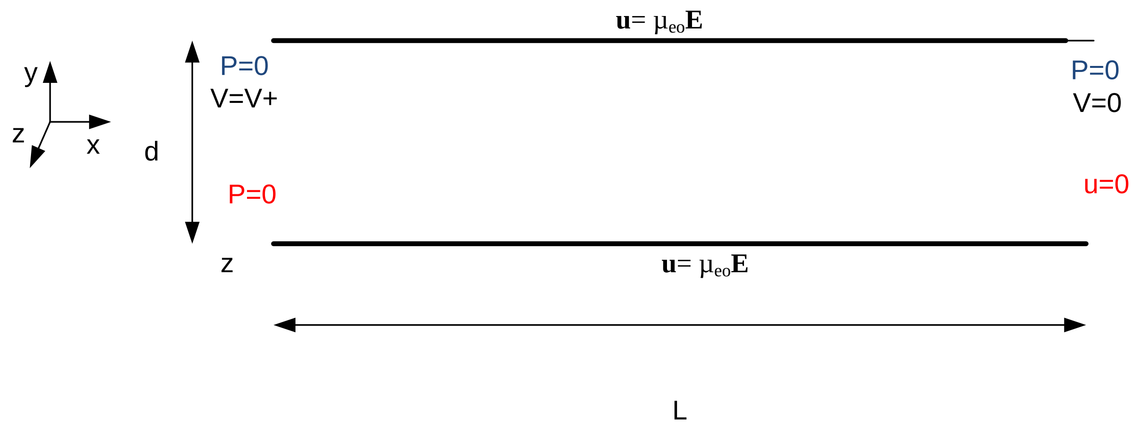
Gauss Law

$$\boldsymbol{E} = -\nabla V$$

$$\nabla.\boldsymbol{D} = \rho_e \qquad \boldsymbol{D} = \varepsilon_o\ \varepsilon_r\boldsymbol{E}$$

COMSOL Modeling

- Coupled Physics used are:
  - Creeping Flow
  - Electrostatics
- Boundary Conditions:
  - Creeping Fluid Flow
    - Maximum Velocity (free flow boundary condition)
    - Maximum Pressure
    - Electroosmotic wall velocity
  - Electrostatics

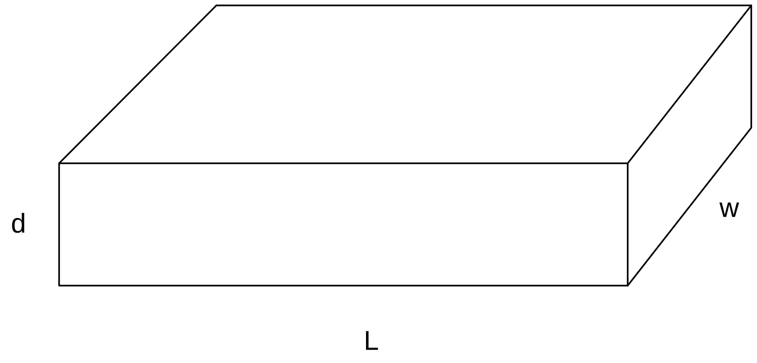


Simulated Model

- For a Planar Electroosmotic Micropump
  - High voltage is required for an applicable pressure and volume flow rate.

$$\Delta P = \frac{-12\varepsilon_0\,\varepsilon_r\zeta\,\Delta V}{d^2}$$

$$\Delta Q = u_{wall}\,A = \frac{-\varepsilon_0\,\varepsilon_r\zeta\,\Delta V}{\mu L}wd$$



- To maximize the pressure with the same voltage (minimize d)

However to maintain the same Q (L has to be reduced)

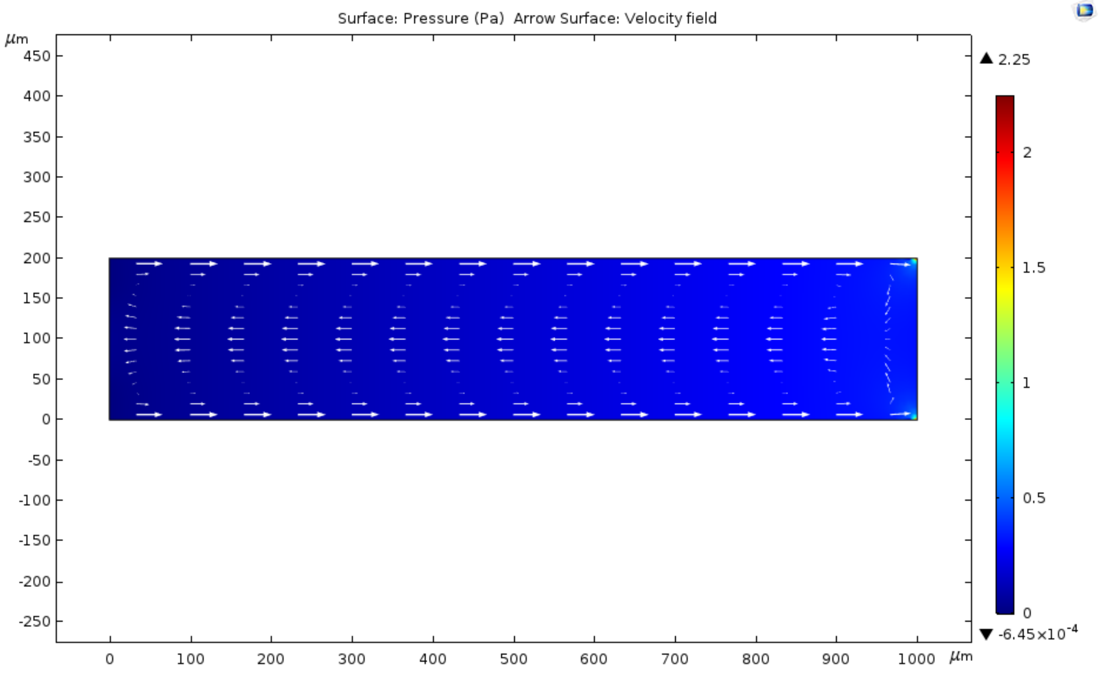
- The velocity of different combination of the d and L will be examined

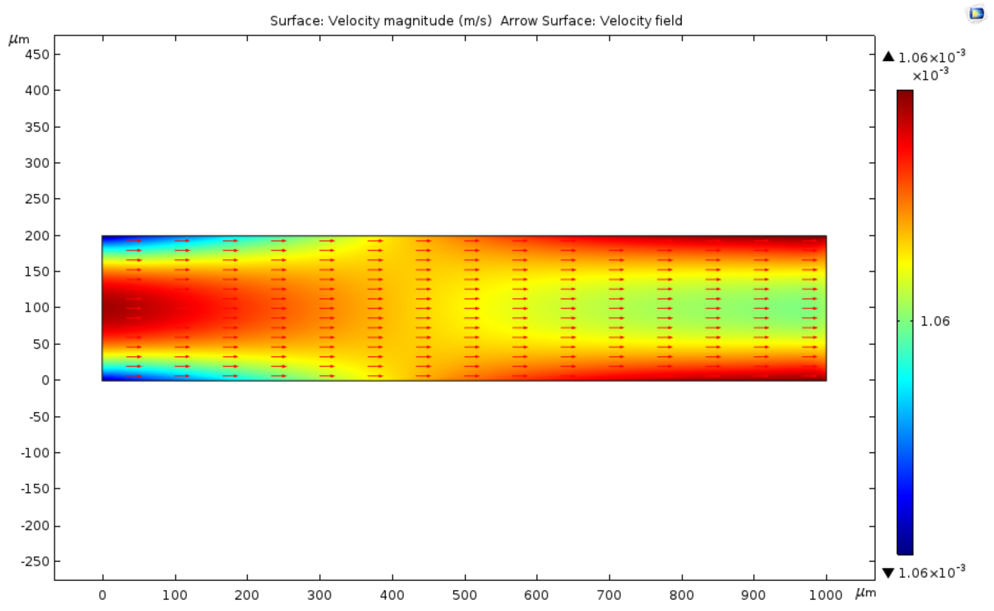
Verification

- Analytical Verification:

A Planar Electroosmotic Micropump using water as the working fluid.

L=1000 μm d = 200 μm with an applied 30 V





Data

- Variations in d and L were as follows:

d(um)	160	80	40	20	10	5
L(um)	3200	1600	800	400	200	100

- A constant applied voltage of 20 V
- Blood Carreau Law values are:

Parameter	Value
μ_∞	0.056 Pa.s
μ_o	0.00345 Pa.s
λ	3.313 s
n	0.3568

Parameter	Value
ρ	998 Kg/m^3
ε_r	78.5
ζ	-50 mV

Results

- Variations in d and L were as follows:

d(um)	160	80	40	20	10	5
L(um)	3200	1600	800	400	200	100
Velocity (um/s)	3.88E-6	7.76E-6	15.5E-6	31E-6	62.1E-6	124E-6

Conclusions

- The Assumption of using the electroosmotic velocity as a boundary condition was appropriate.
- For the same voltage, the velocity can be increased by decreasing the length of the channel
- Pressure can also be increased with the same voltage by decreasing the depth of the channel