Reassessing Electrothermal Simulation Techniques to Develop Realistic Models

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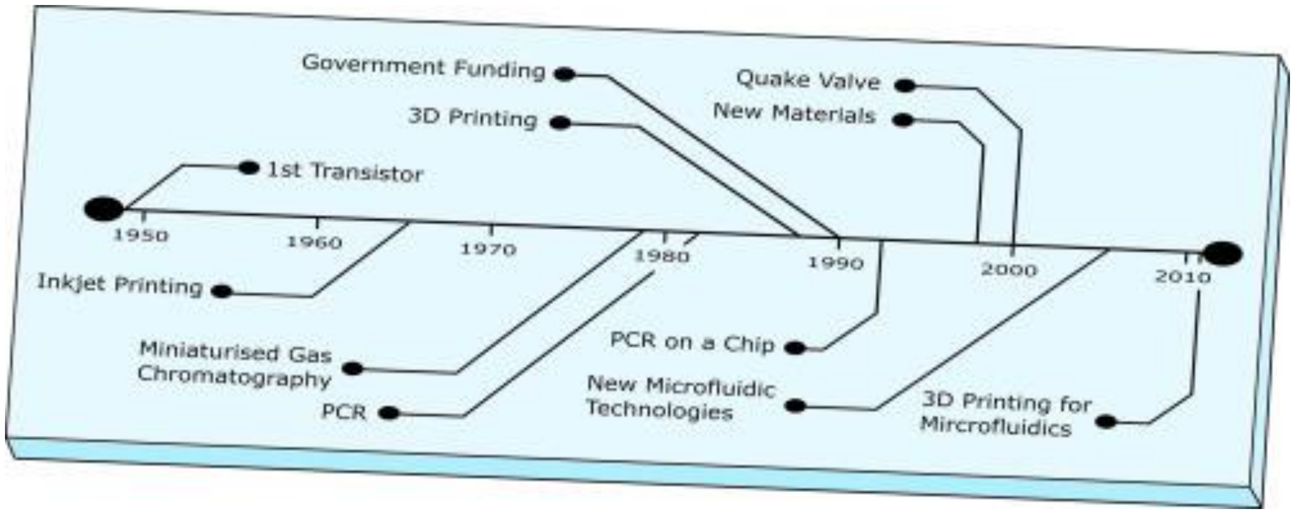
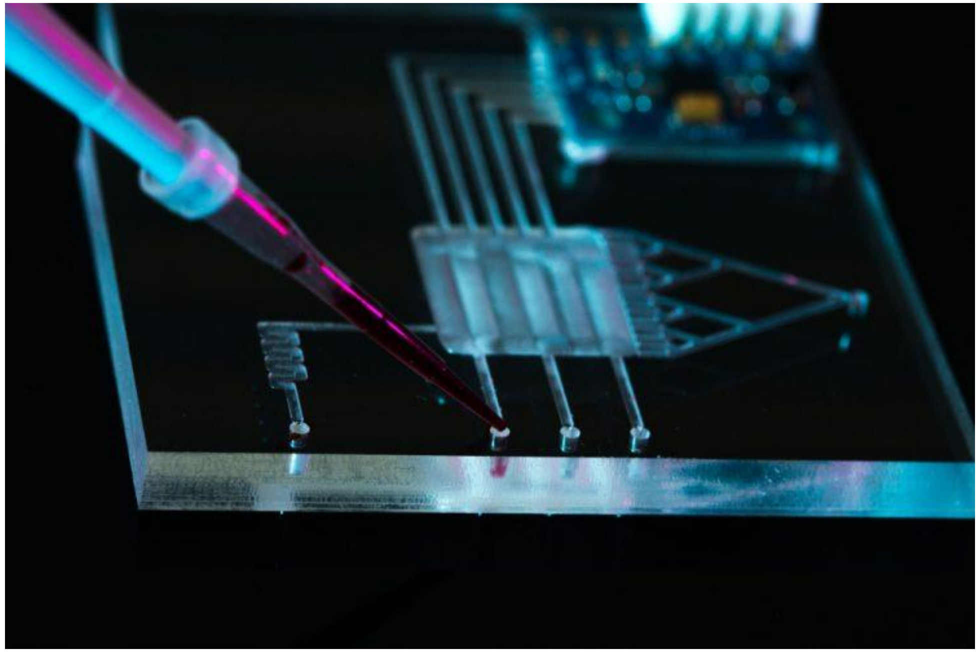
Microfluidics

One of the fastest growing fields of study in modern medicine



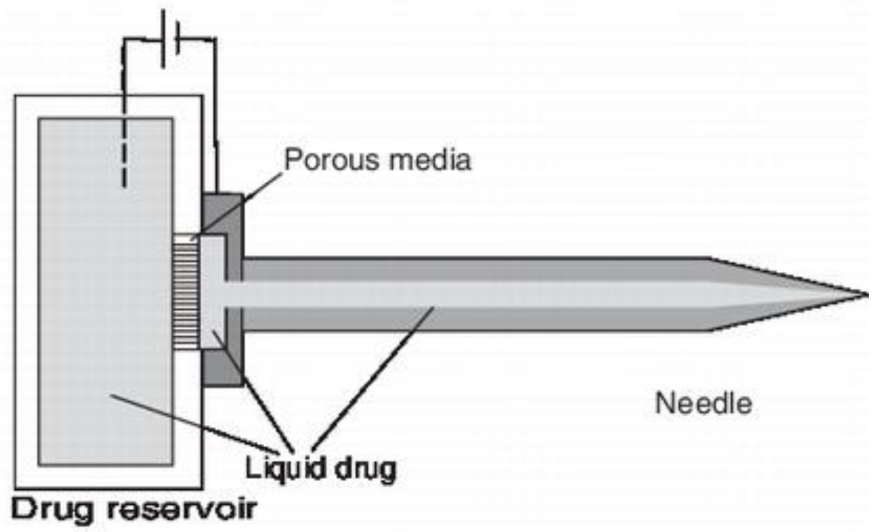
Convery et al. *Micro and Nano Engineering* (2019)



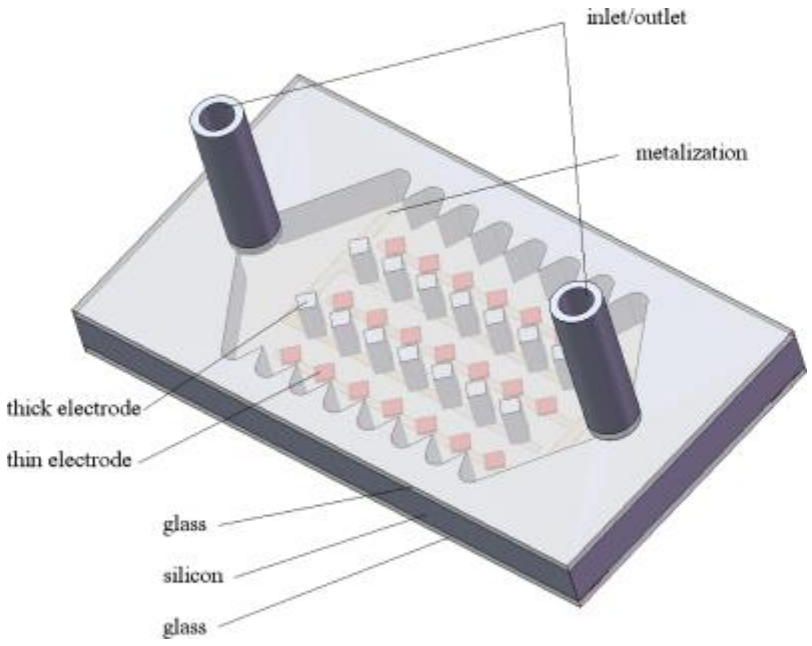
https://www.europeanpharmaceuticalreview.com/news/72373/lab-on-a-chip-bacterial-cells/

Electrokinetic Pumping

Application of electric field to a fluid to cause bulk fluid flow or particulate flow



Chen et al. *Expert Opin. Drug Deliv.* (2007)



Iliescu et al. *Biomicrofluidics* (2009)

Alternating Current Electrothermal Flow

Electric Field

↓ Joule Heating

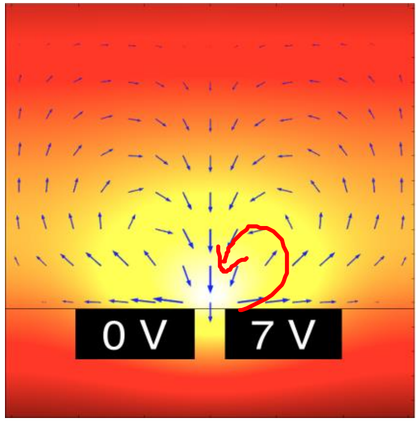
Temperature Gradient

↓ Changes in ε, σ, e, etc.

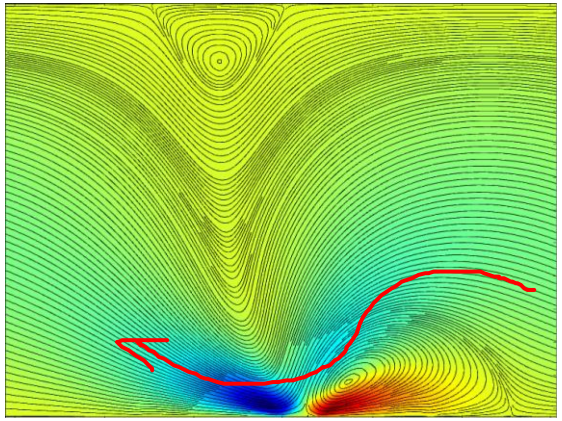
Fluid Quantity Gradients

↓ Navier-Stokes Equation

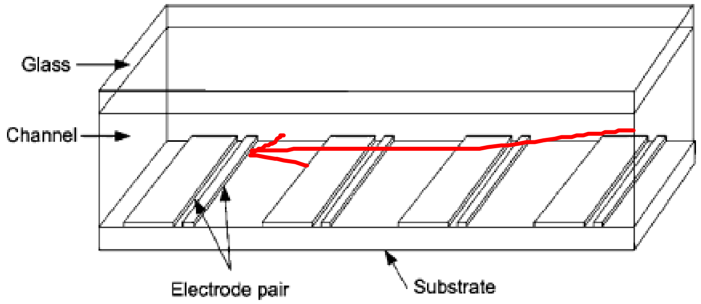
Fluid Flow



Symmetrical Electrodes



Asymmetrical Electrodes

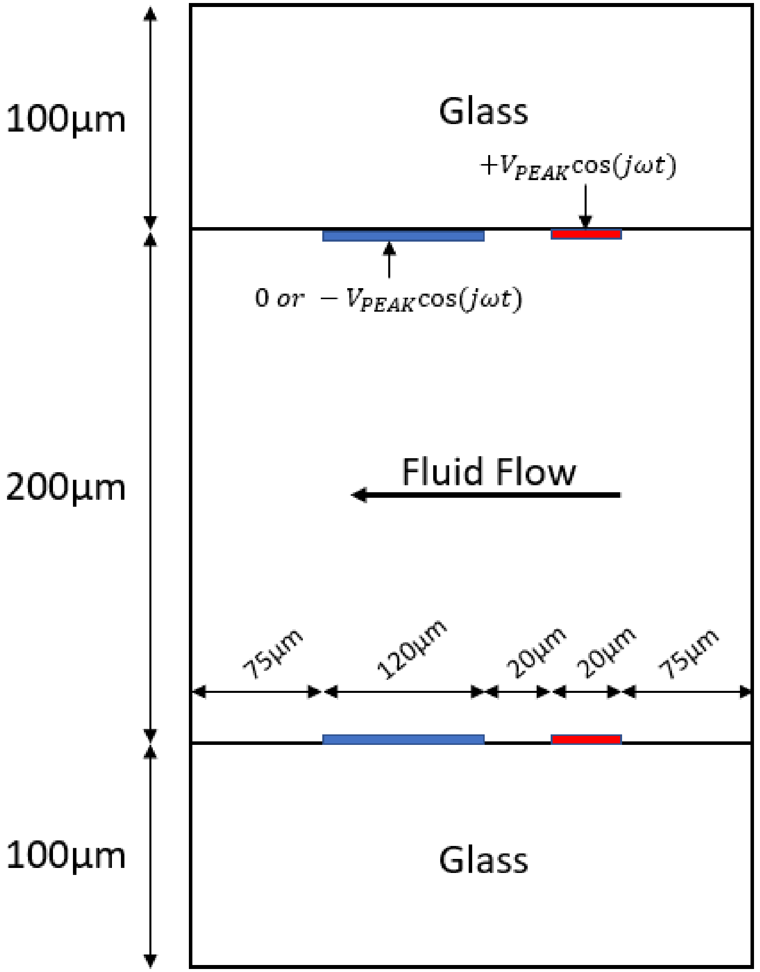


Zhang et al. *Microfluid Nanofluid* (2011)

ACET Simulations

Typical setup consists of three physics models:

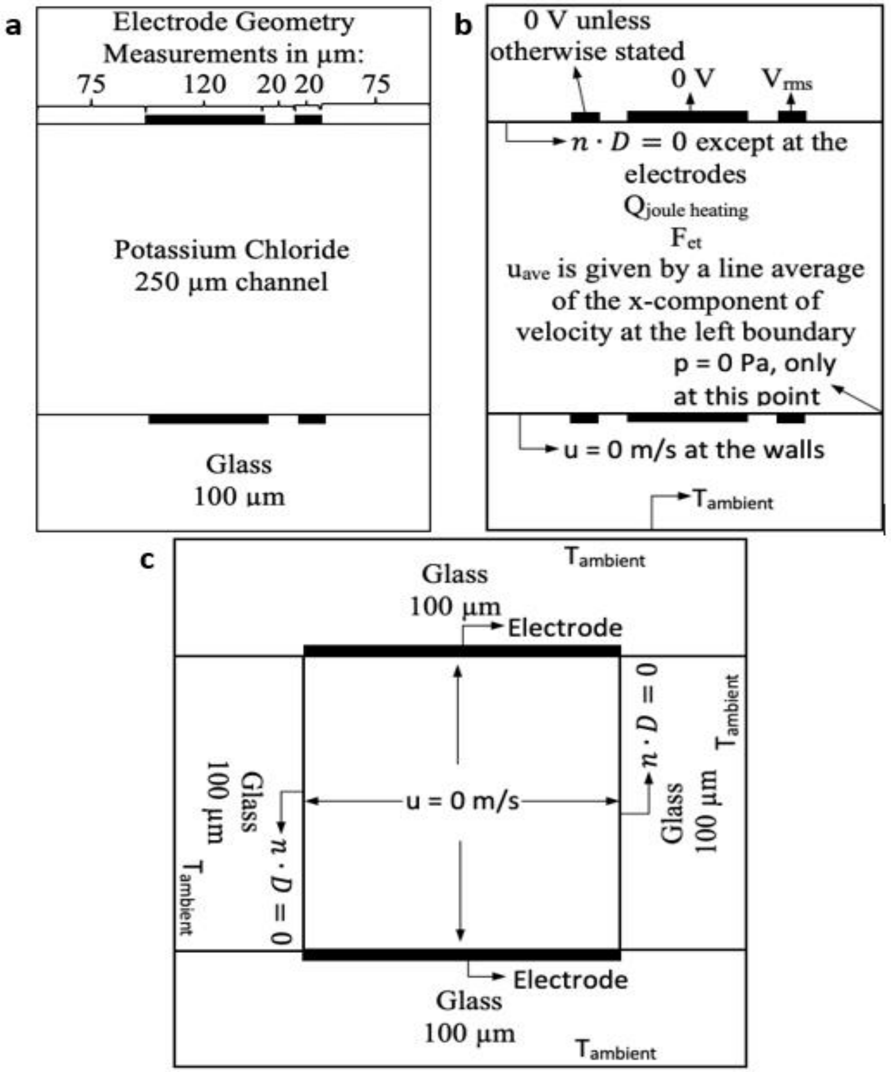
- Laminar Flow:
  - Microfluidics by nature have extremely laminar flow
  - Body force derived by literature
  - Zero inlet pressure, no slip conditions
- Heat Transfer in Solids/Fluids
  - External room temperature
  - Heat transfer through the channel walls
- Electrostatics/Electric Currents
  - Electric conduction limited to the fluid
  - DC equivalencies of AC signals are made



Two Dimensional Simulations

Several assumptions have been made to simulate ACET systems

- Infinite channel width
- Planar electrodes
- Heating limited to Joule effects
- Inert electrodes
- Effects from literature including:
  - Zero impact from convection
  - Temperature independent viscosity



Lijnse et al. *SN Applied Sciences* (2020)

Channel Heating

COMSOL Electromagnetic Heating (EMH)

- Determined to have no impact on channel flow under certain conditions

Joule heating

- Dielectric heating from oxide layer

Electrode cooling

- Electrodes act as a heatsink

Convective cooling

- Localized energy losses

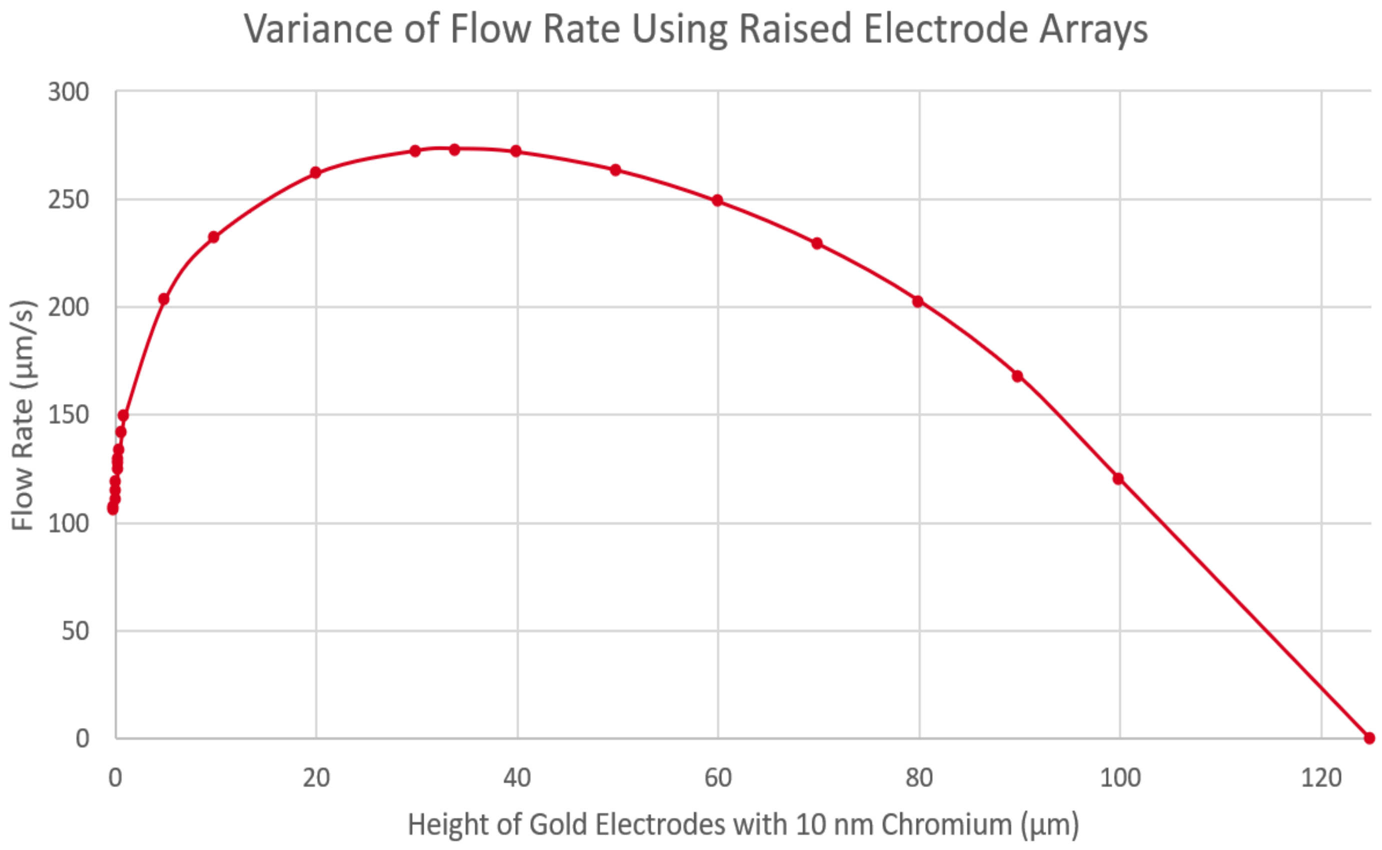
Heating from external sources

- Impacts from microscope illumination, fluctuations in ambient temperature, etc.

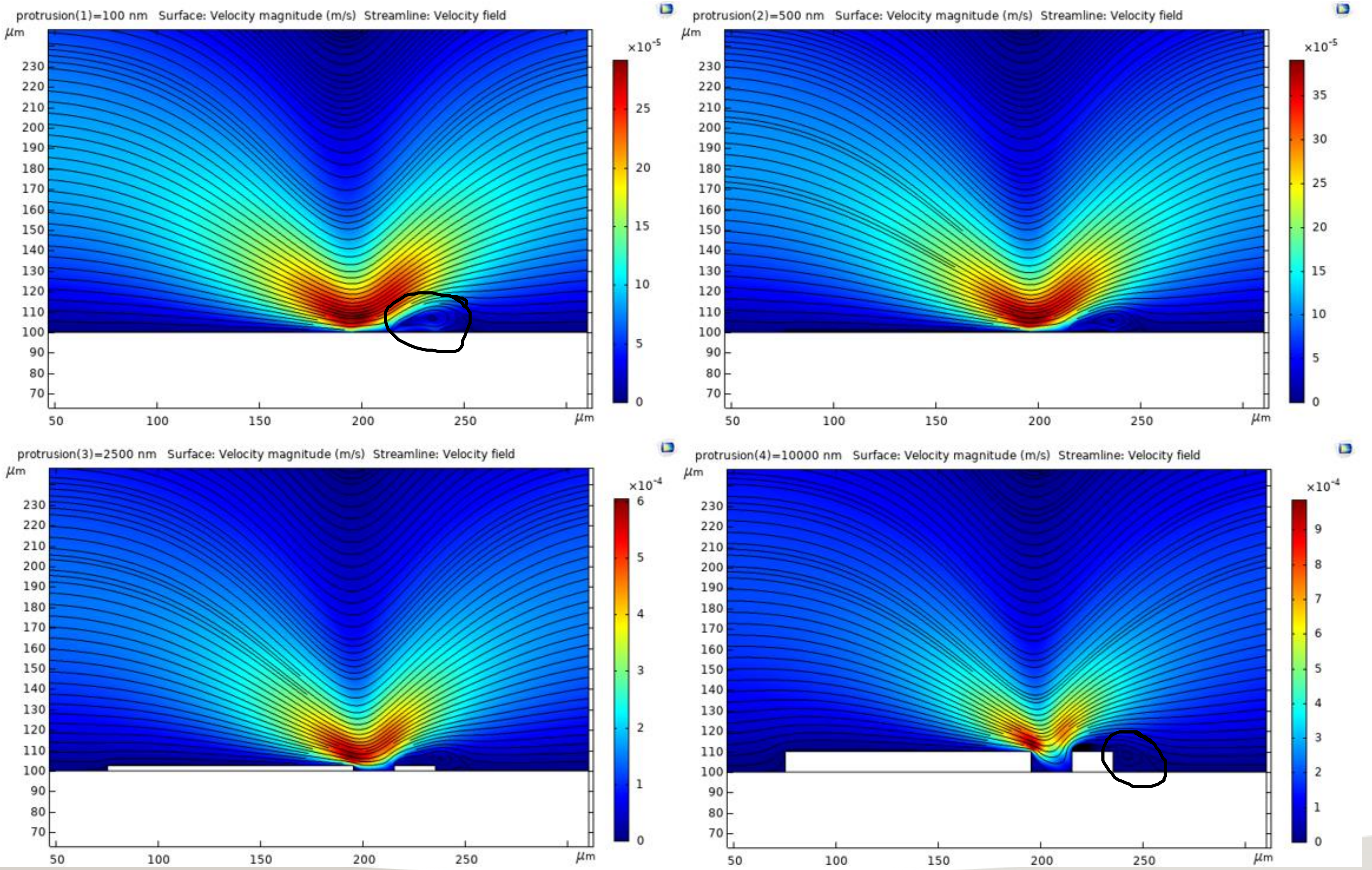
Change	Output Flow Rate (um/s)	Introduced Variance
EMH Module Stationary Study	9.42E-05	0.00%
Heat convection from velocity field	9.15E-05	-2.85%
Electrodes fixed at 293.15 K	5.42E-05	-42.47%
Temperature dependent viscosity	1.08E-04	14.4%

Electrode Protrusion and Coatings

- Typical electrodes protrude ~100s of nanometers into the channel
- Simulation boundaries within realistic range
- Increase in flow rate until 35 micron
- Likely due to increased electric field presence and modified vortex location

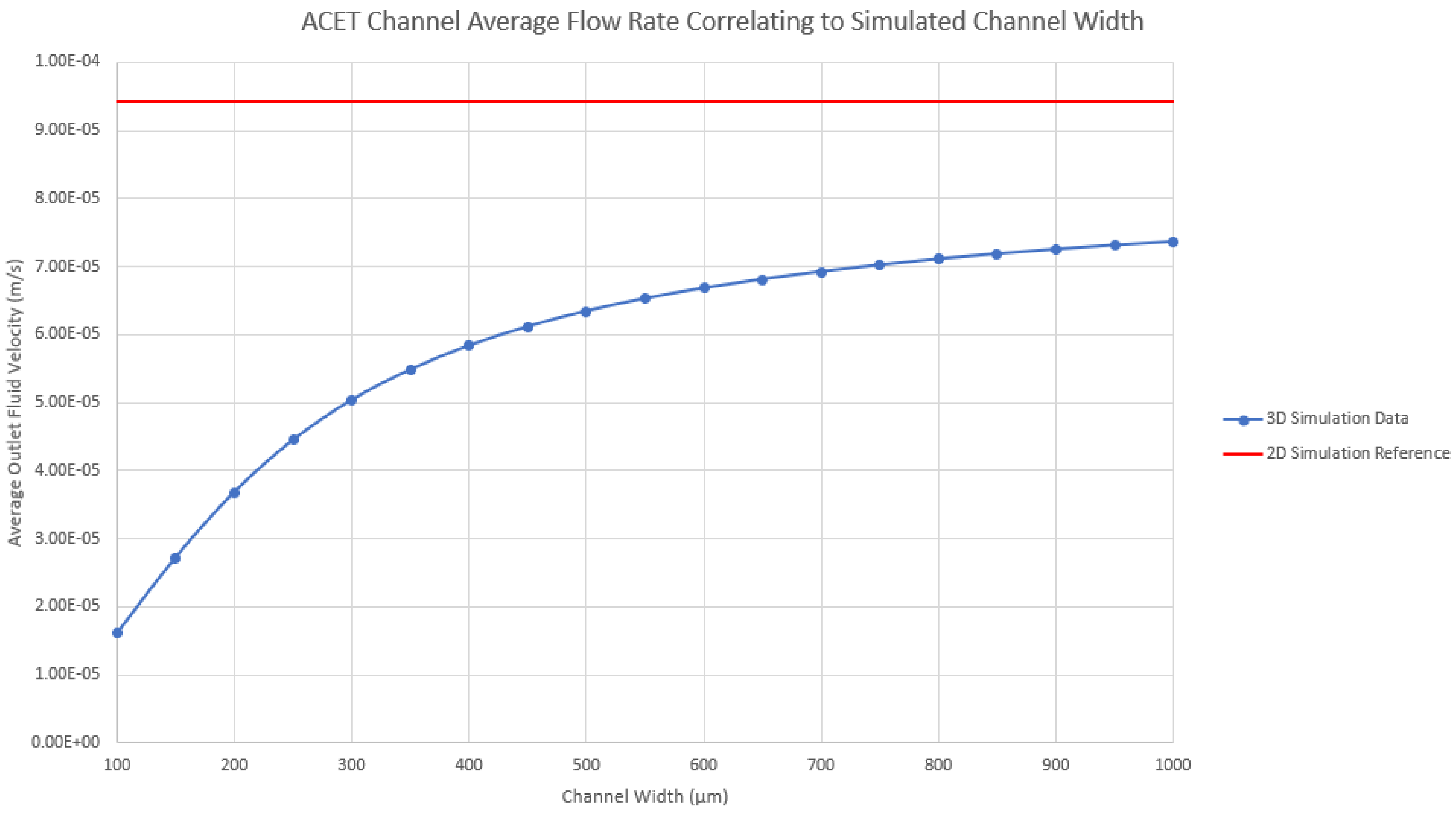


Electrode Protrusion and Coatings



Three Dimensional Modelling

- Key factor impacting fluid flow
- Most computationally intensive adjustment
- Implications from data are that the series will converge, but not until width is in excess of several centimeters



Conclusions

- Three dimensional models are most physically relevant
- Minor changes increase accuracy
- Computational resources, while improved are still limited
- Several overall improvements to ACET design outcomes

Change	Output Flow Rate (um/s)	Introduced Variance
Protrusion of electrodes into the channel (120nm)	1.03E-04	9.36%
Heat convection from velocity field	9.15E-05	-2.85%
Temperature dependent viscosity	1.08E-04	14.4%
Three-Dimensional Channel Model (5:1 Width:Length)	7.36E-05	-21.8%

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