

EO: 15nm pnc-Si, 1mM NaCl

Jirachai Getpreecharsawas

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Overview

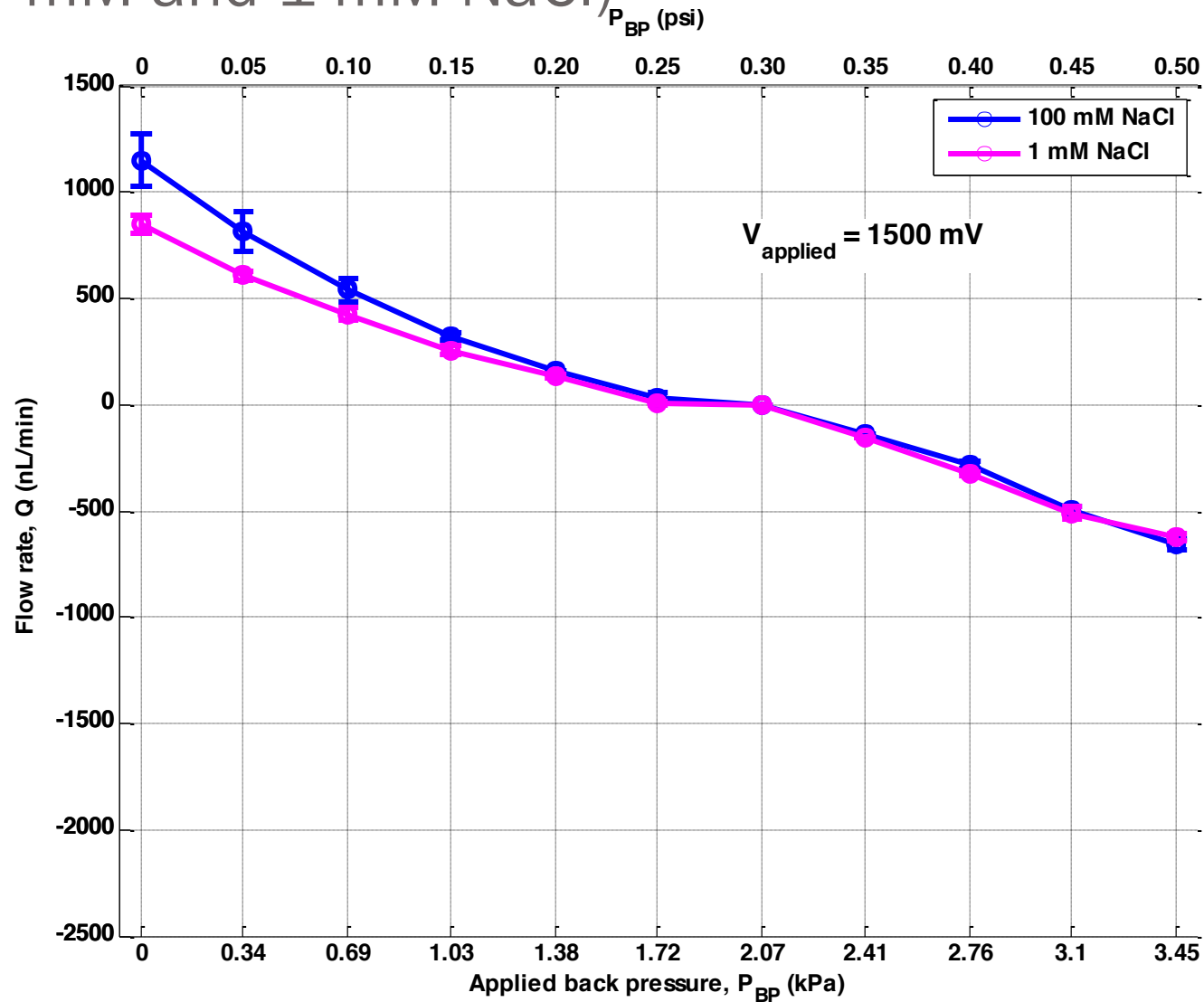
Previously

- Pnc-Si membrane thickness:
15 nm and 30 nm
- Electrolyte concentration:
100 mM NaCl
- Applied voltage:
1500 mV (max)

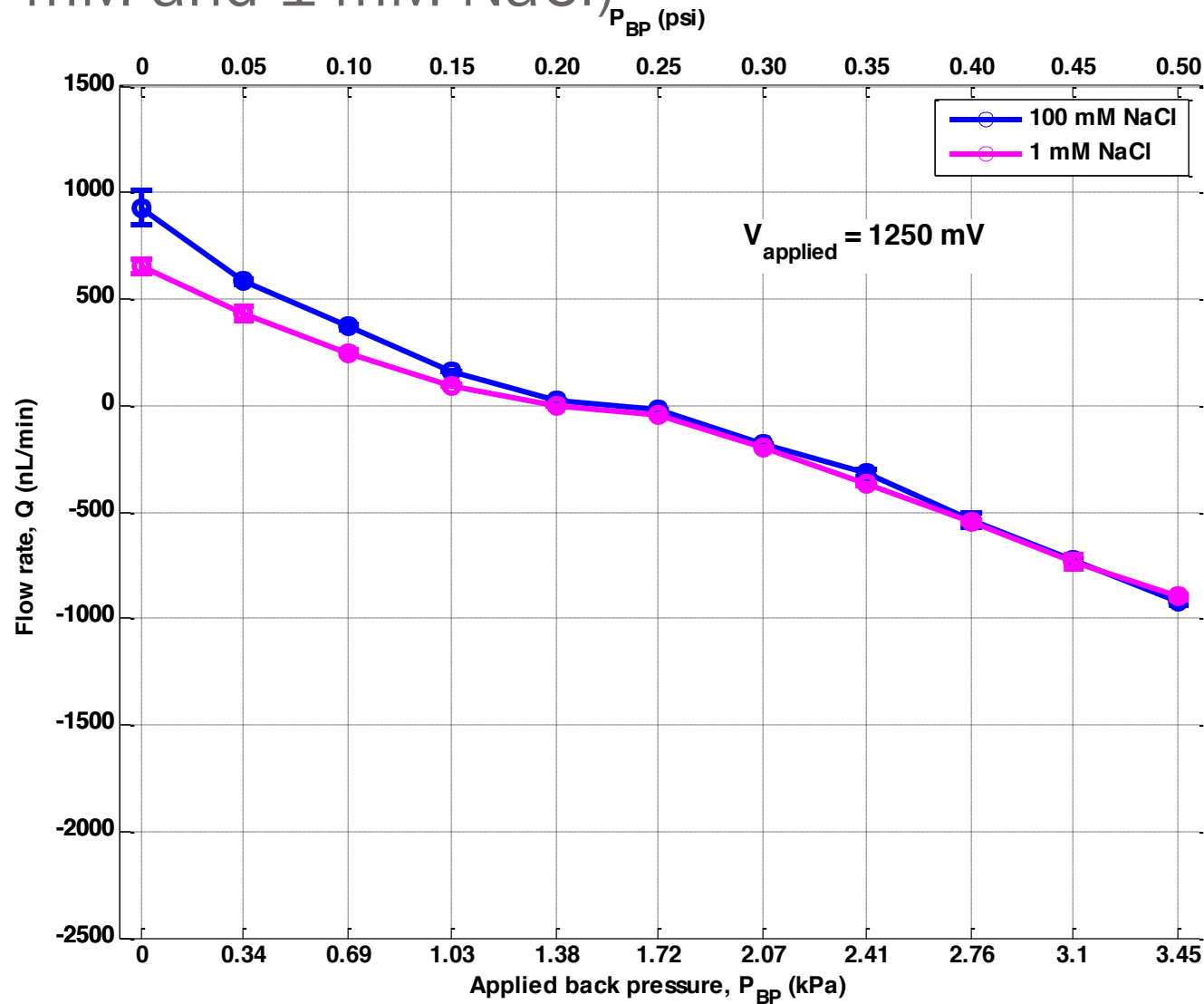
Update

- Pnc-Si membrane thickness:
15 nm
- Electrolyte concentration:
1 mM NaCl
- Applied voltage:
1500 mV (max)

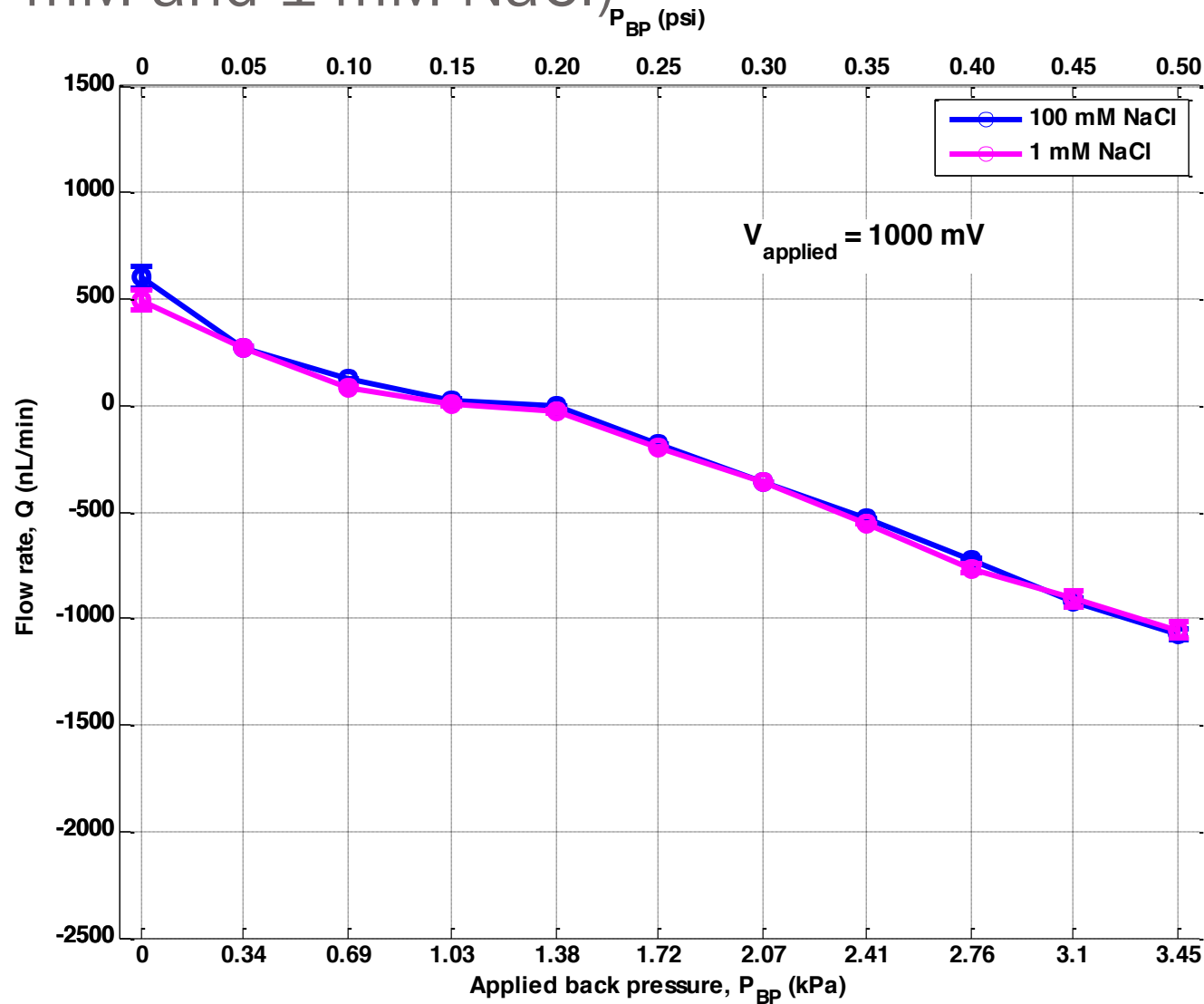
Experiment Results for 15nm-thick pnc-Si membrane (100 mM and 1 mM NaCl)



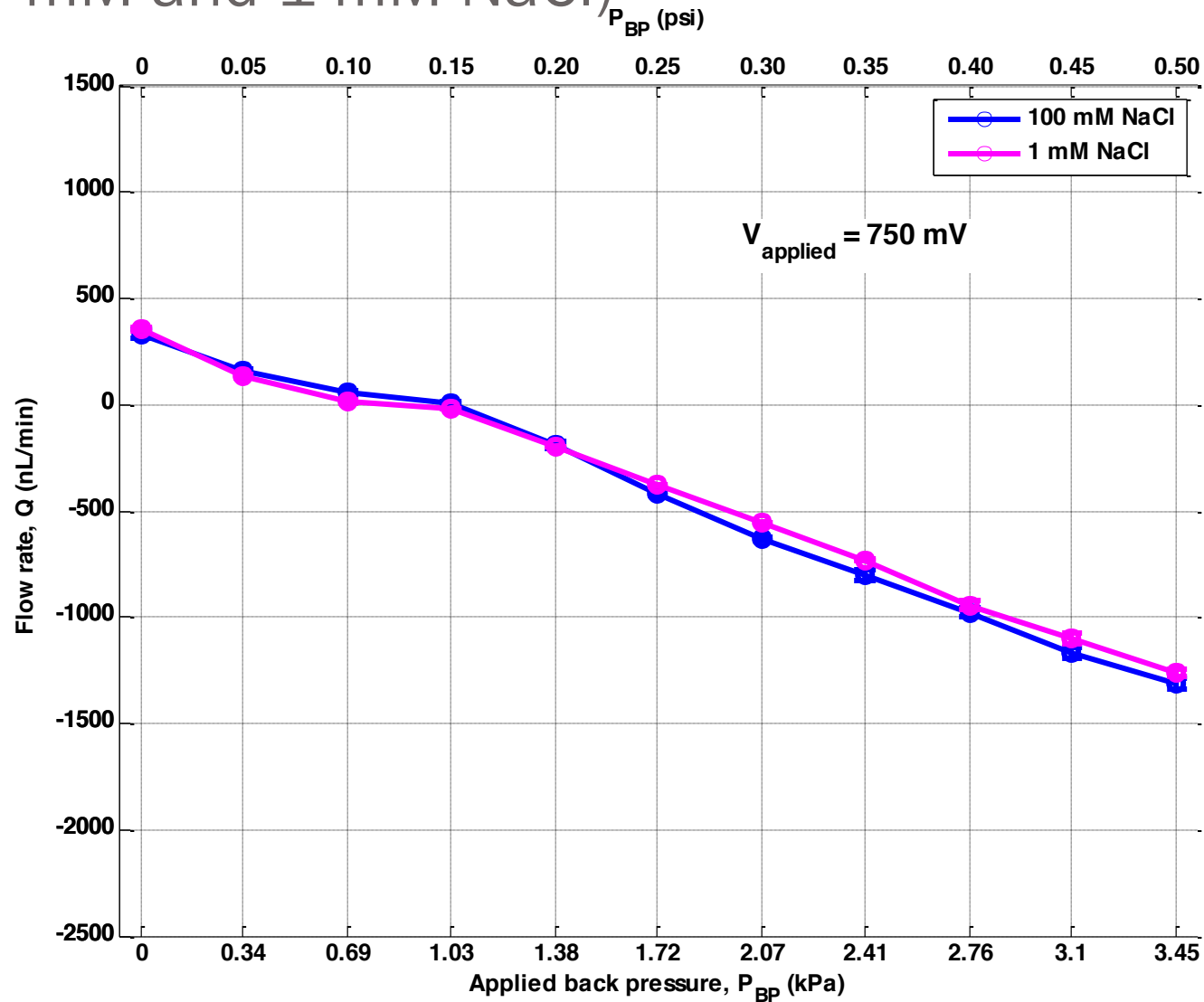
Experiment Results for 15nm-thick pnc-Si membrane (100 mM and 1 mM NaCl)



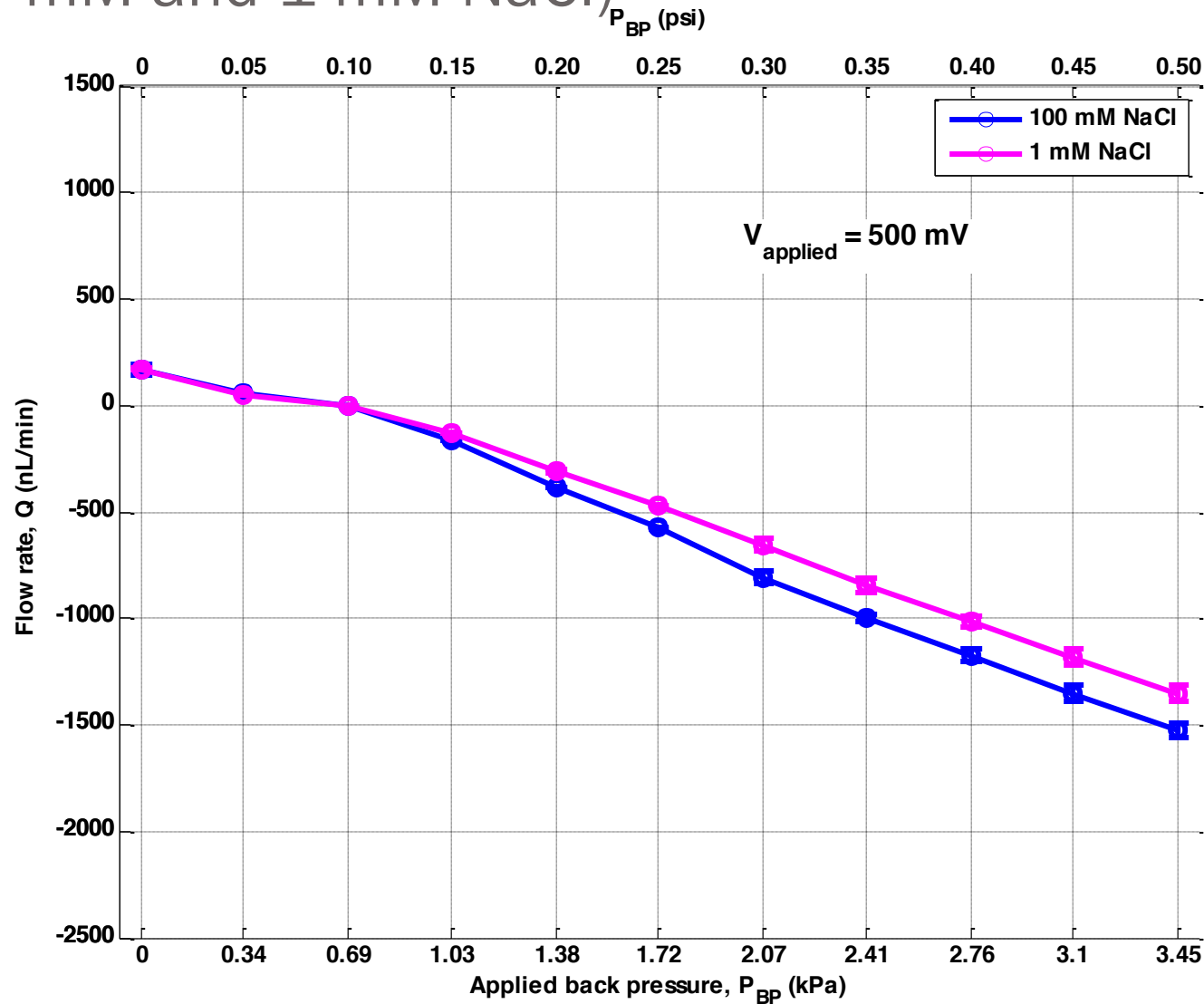
Experiment Results for 15nm-thick pnc-Si membrane (100 mM and 1 mM NaCl)



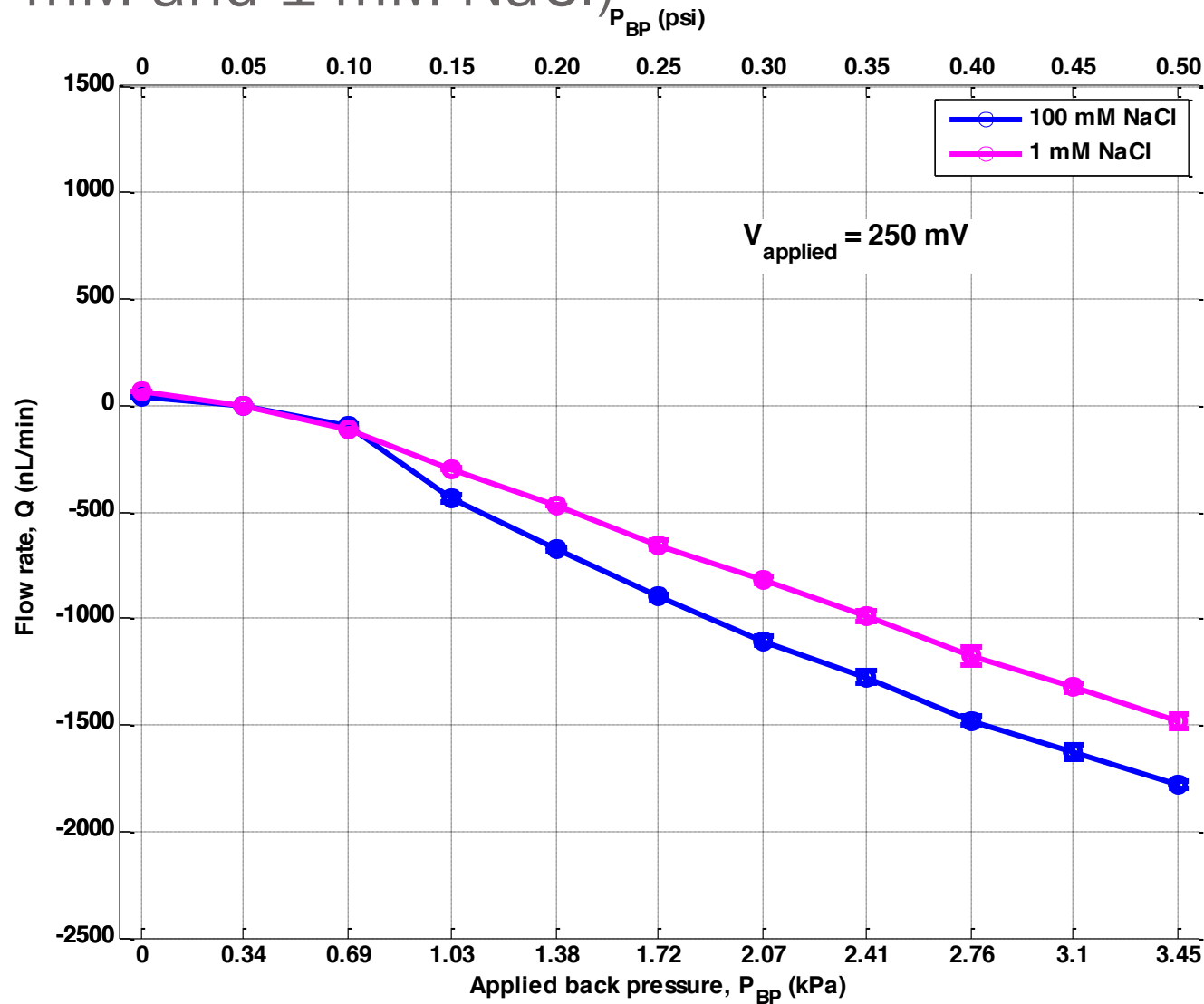
Experiment Results for 15nm-thick pnc-Si membrane (100 mM and 1 mM NaCl)



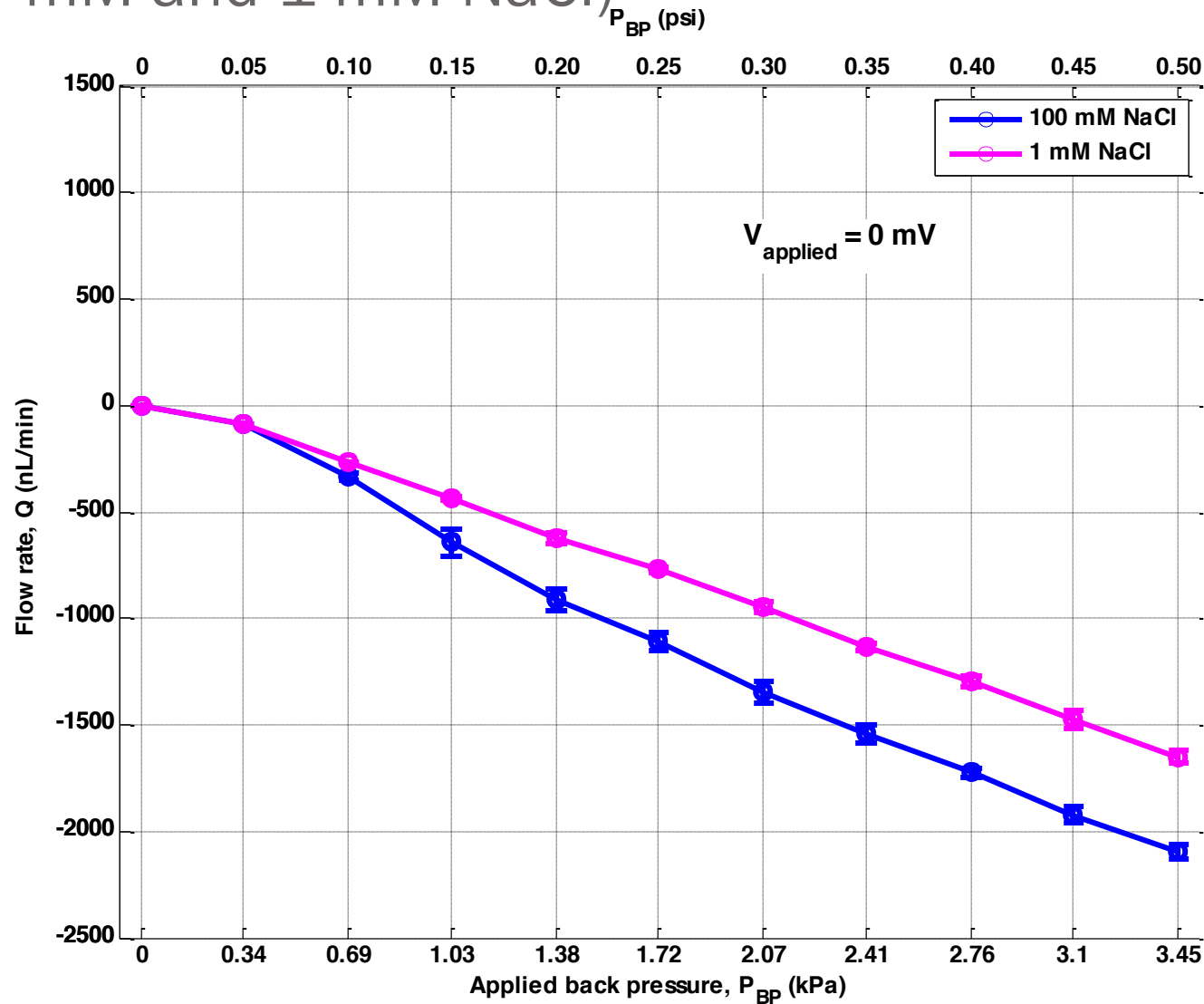
Experiment Results for 15nm-thick pnc-Si membrane (100 mM and 1 mM NaCl)



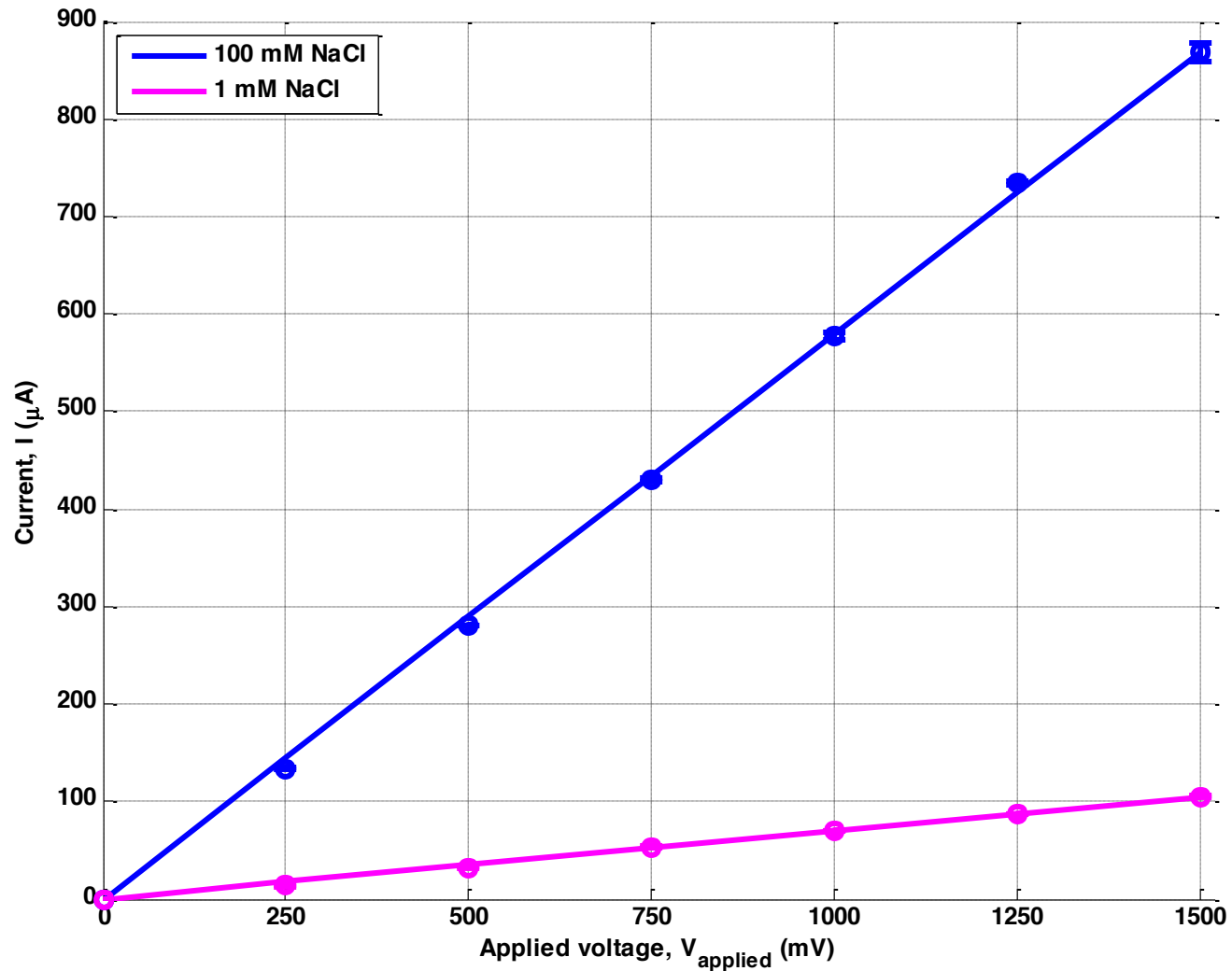
Experiment Results for 15nm-thick pnc-Si membrane (100 mM and 1 mM NaCl)



Experiment Results for 15nm-thick pnc-Si membrane (100 mM and 1 mM NaCl)



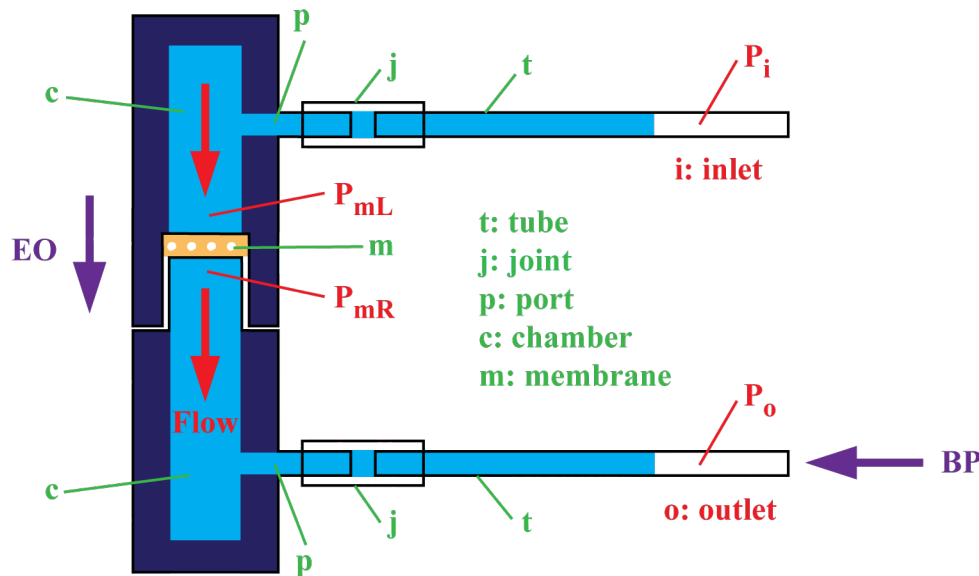
Experiment Results for 15nm-thick pnc-Si membrane (100 mM and 1 mM NaCl)



Modeling: Impact of Meniscus

- Extended Bernoulli Equation (Conservation of Energy)

$$\frac{P_i}{\rho} + \beta \frac{\bar{v}_i^2}{2} + gZ_i + h_p = \frac{P_o}{\rho} + \beta \frac{\bar{v}_o^2}{2} + gZ_o + h_{L,\text{minor}} + h_{L,\text{major}}$$



$Q_\Sigma > 0$: Flow in the same direction as EO

$$\Delta P = P_{mR} - P_{mL} = P_{BP} + \rho(h_{L,\text{minor}} + h_{L,\text{major}})$$

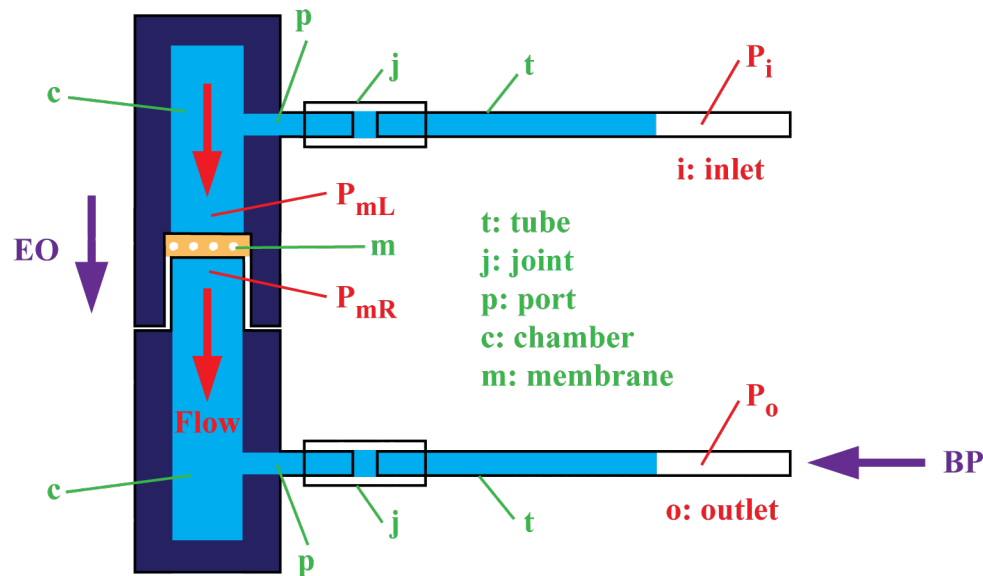
$Q_\Sigma < 0$: Flow in the same direction as BP

$$\Delta P = P_{mR} - P_{mL} = P_{BP} - \rho(h_{L,\text{minor}} + h_{L,\text{major}})$$

Modeling: Impact of Meniscus

- Minor head loss (due to flow across regions of different cross-sectional areas)

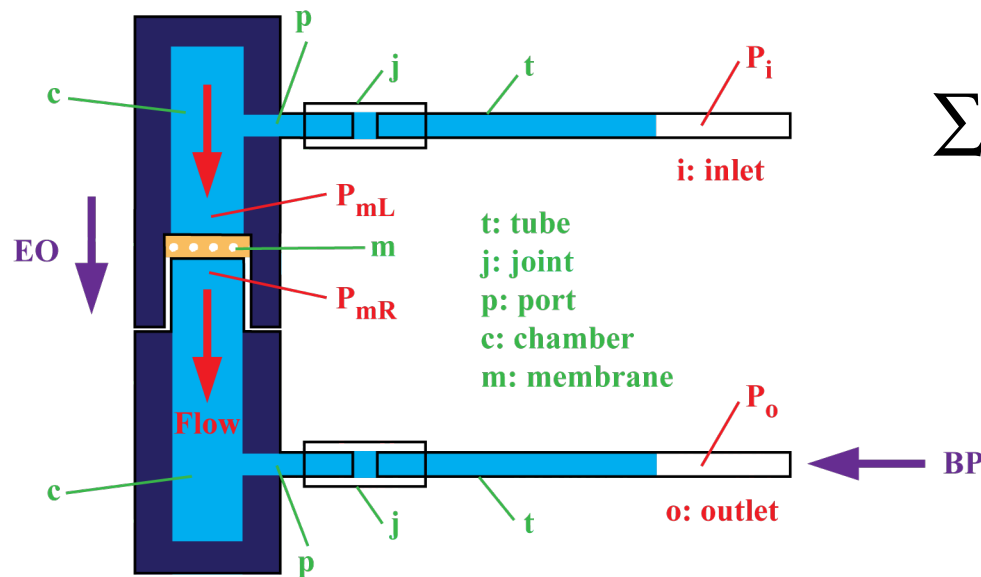
$$h_{L,\text{minor}} = \frac{1}{2} \left(\left[\sum k \right]_t + \left[\sum k \right]_p \frac{D_t^4}{D_p^4} + \left[\sum k \right]_m \frac{\pi^2 D_t^4}{16 \phi^2 A_m^2} \right) \bar{v}_t^2$$



Modeling: Impact of Meniscus

- Major head loss (due to fluidic resistance and pressure drop across the moving interface or menisci)

$$h_{L,\text{major}} = \sum h_{L,\text{res}} + \sum h_{L,\text{int}}$$



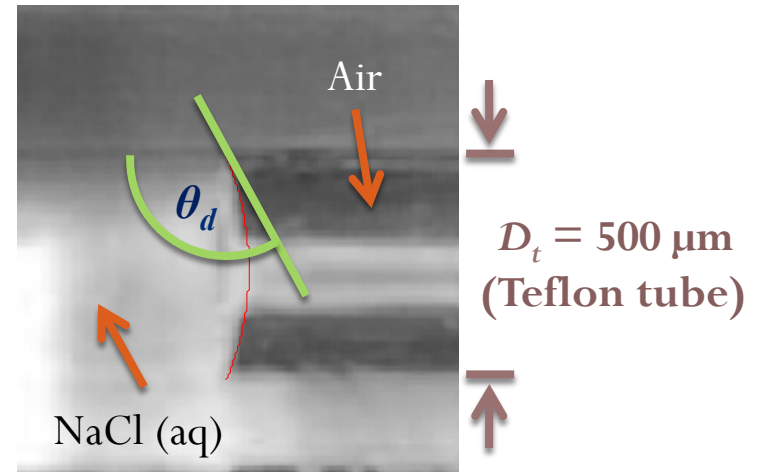
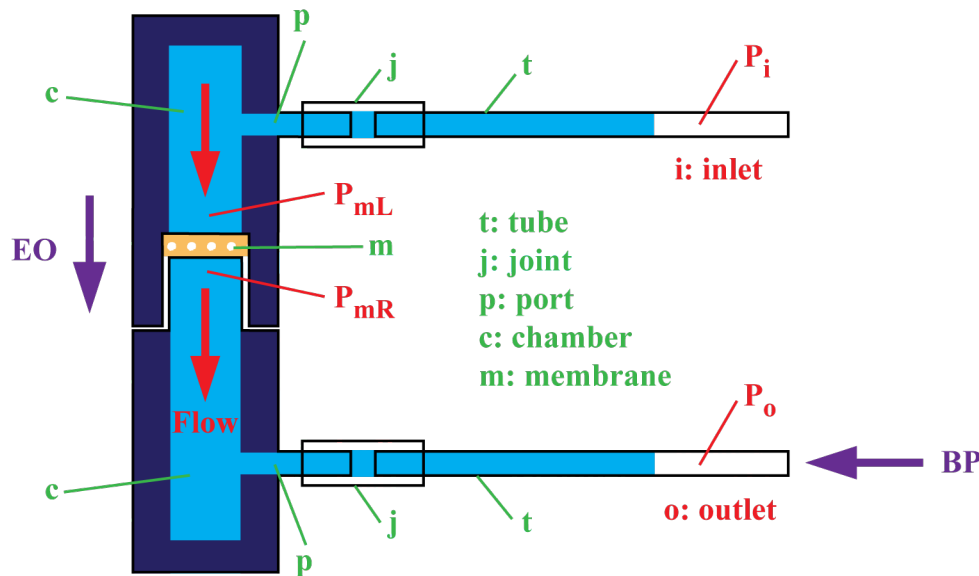
$$\sum h_{L,\text{res}} = \frac{32\mu D_t^2}{\rho} \left(\frac{L_t}{D_t^4} + \frac{L_c}{D_c^4} \right) \bar{v}_t$$

Modeling: Impact of Meniscus

- Major head loss due to the pressure drop across the moving menisci with surface tension γ

Young-Laplace equation[†]:

$$P_{gas,inter} - P_{liquid,inter} = \frac{4\gamma}{D_t} \cos \theta_{eq}$$



[†] M. Hilpert, "Effects of dynamic contact angle on liquid infiltration into horizontal capillary tubes: (Semi)-analytical solutions," *Journal of Colloid and Interface Science*, vol. 337, Apr. 2009, pp. 131–137.

Modeling: Impact of Meniscus

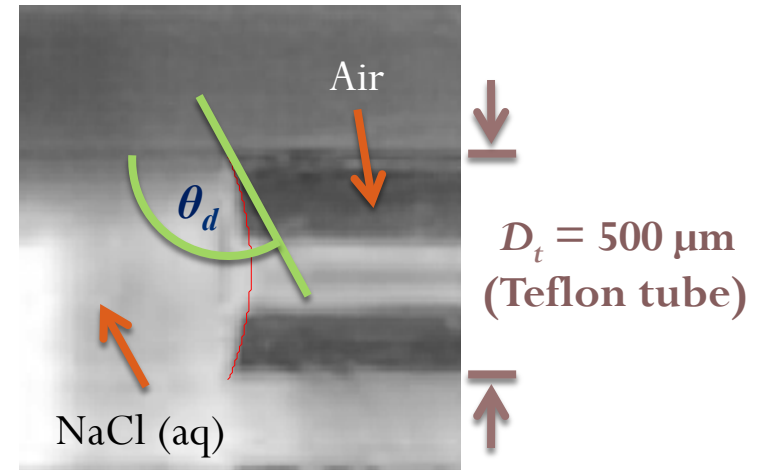
- Major head loss due to the pressure drop across the moving menisci with surface tension, γ

Young-Laplace equation:

$$P_{gas,inter} - P_{liquid,inter} = \frac{4\gamma}{D_t} \cos \theta_{eq}$$

- The equilibrium contact angle, θ_{eq} , can be obtained from the dynamic contact angle, θ_d , as [‡]

$$\cos \theta_{eq} = \frac{\cos \theta_d + 2\sqrt{Ca}}{1 - 2\sqrt{Ca}} ; \quad Ca = \frac{\mu}{\gamma} \bar{v}_t$$



[‡] P.V. Remoortere and P. Joos, "The kinetics of wetting: The motion of a three phase contactline in a capillary," *Journal of Colloid and Interface Science*, vol. 141, no. 2, Feb. 1991, pp. 348–359.

Modeling: Impact of Meniscus

- Head loss due the pressure drop across the **receding** meniscus

$$h_{L,int-rec} = \frac{4\gamma}{\rho D_t} \left(\frac{\cos \theta_{d,rec} + 2\sqrt{\frac{\mu}{\gamma} \bar{v}_t}}{1 - 2\sqrt{\frac{\mu}{\gamma} \bar{v}_t}} \right)$$

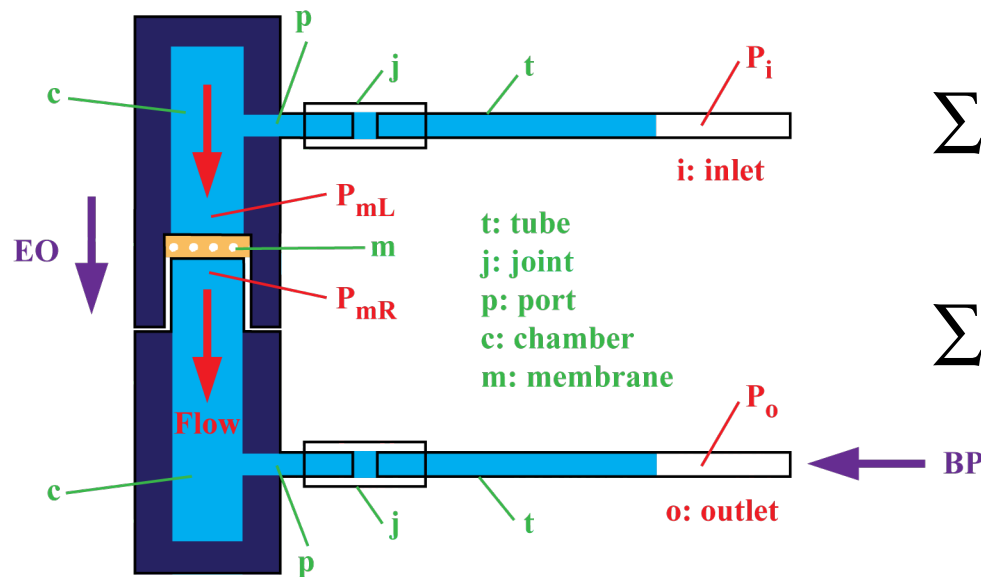
- Head loss due the pressure drop across the **advancing** meniscus

$$h_{L,int-adv} = -\frac{4\gamma}{\rho D_t} \left(\frac{\cos \theta_{d,adv} + 2\sqrt{\frac{\mu}{\gamma} \bar{v}_t}}{1 - 2\sqrt{\frac{\mu}{\gamma} \bar{v}_t}} \right)$$

Modeling: Impact of Meniscus

- Major head loss (due to fluidic resistance and pressure drop across the moving interface or menisci)

$$h_{L,\text{major}} = \sum h_{L,\text{res}} + \sum h_{L,\text{int}}$$



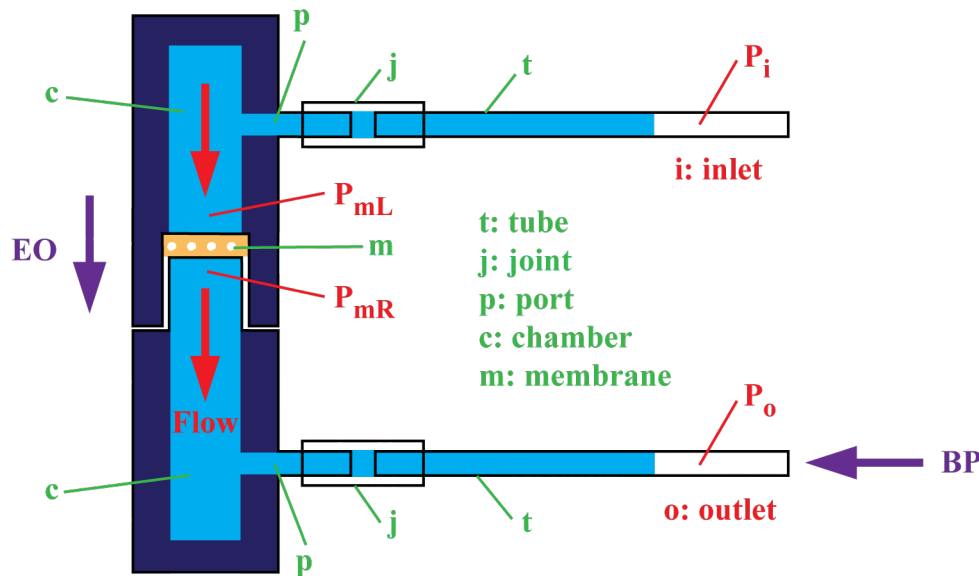
$$\sum h_{L,\text{res}} = \frac{32\mu D_t^2}{\rho} \left(\frac{L_t}{D_t^4} + \frac{L_c}{D_c^4} \right) \bar{v}_t$$

$$\sum h_{L,\text{int}} = \frac{4\gamma}{\rho D_t} (\cos \theta_{d,\text{rec}} - \cos \theta_{d,\text{adv}}) \frac{1}{1 - 2\sqrt{\frac{\mu}{\gamma} \bar{v}_t}}$$

Modeling: Impact of Meniscus

- For flow with very low Re (< 1 in our case)

$$h_{L,minor} \approx 0 \quad \text{and} \quad h_{L,major} \approx \frac{4\gamma}{\rho D_t} (\cos \theta_{d,rec} - \cos \theta_{d,adv})$$



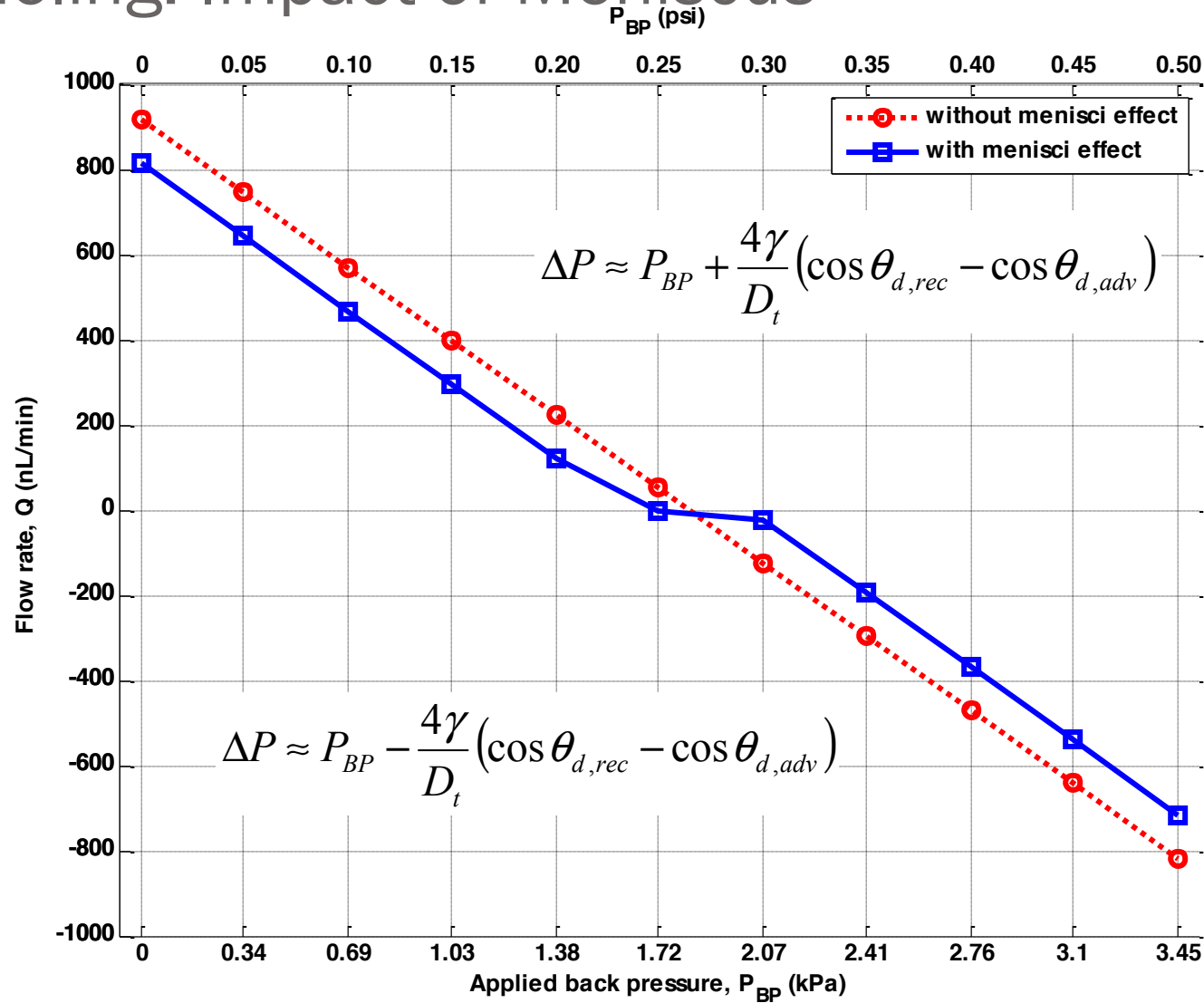
$Q_\Sigma > 0$: Flow in the same direction as EO

$$\Delta P = P_{mR} - P_{mL} \approx P_{BP} + \frac{4\gamma}{D_t} (\cos \theta_{d,rec} - \cos \theta_{d,adv})$$

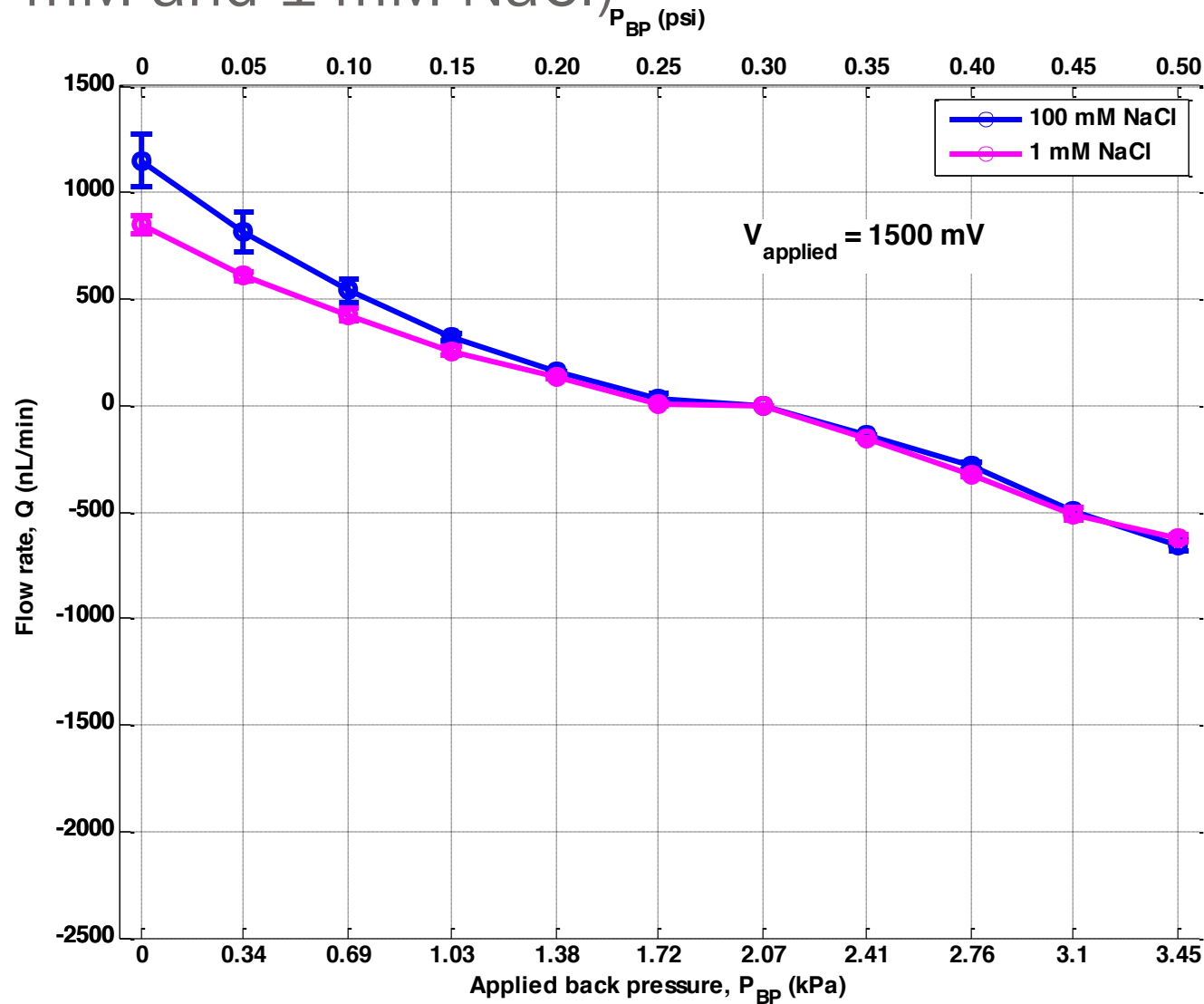
$Q_\Sigma < 0$: Flow in the same direction as BP

$$\Delta P = P_{mR} - P_{mL} \approx P_{BP} - \frac{4\gamma}{D_t} (\cos \theta_{d,rec} - \cos \theta_{d,adv})$$

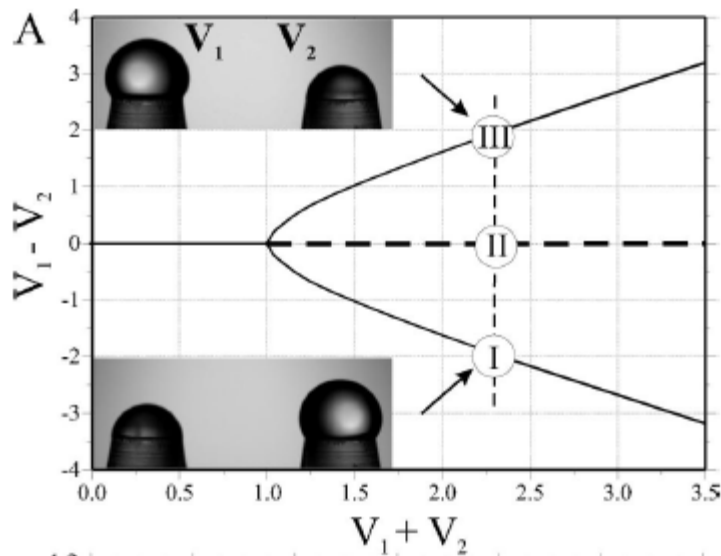
Modeling: Impact of Meniscus



Experiment Results for 15nm-thick pnc-Si membrane (100 mM and 1 mM NaCl)



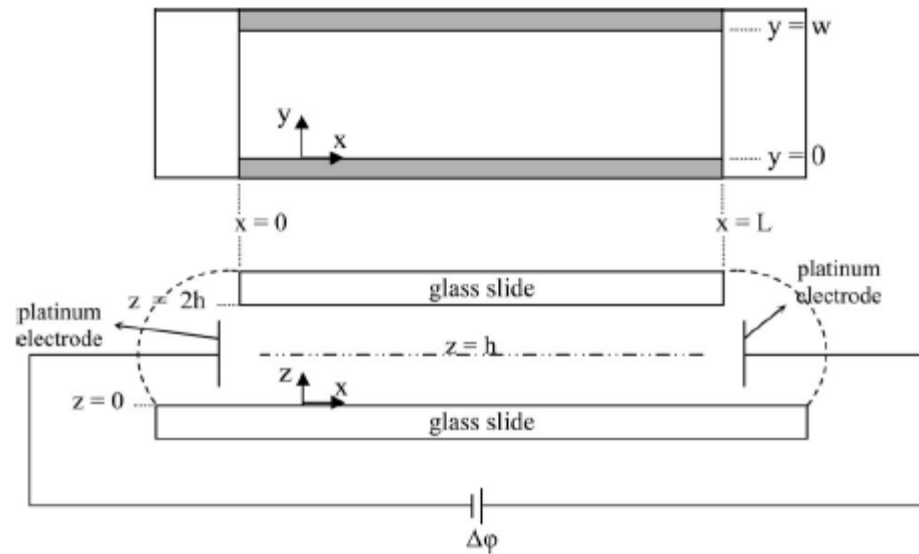
Impact of Meniscus



volumes V_1 and V_2 . Each droplet is pinned on a circular contact line and has an internal pressure p_i proportional to its curvature, according to the Young–Laplace law. If the droplets are smaller than about a millimeter (capillary length scale), gravity has a negligible influence, and droplet shapes are spherical caps, to good approximation.

Determination of the zeta potential of porous substrates by droplet deflection. I. The influence of ionic strength and pH value of an aqueous electrolyte in contact with a borosilicate surface

Impact of Meniscus



The changes of liquid volume lead to changes of the liquid boundary curvatures on both sides. This curvature difference gives rise to a Laplace pressure gradient that balances with the gradient of electrical and viscous stresses at a steady state. The

Using electrocapillarity to measure the zeta potential of a planar hydrophobic surface in contact with water and nonionic surfactant solutions