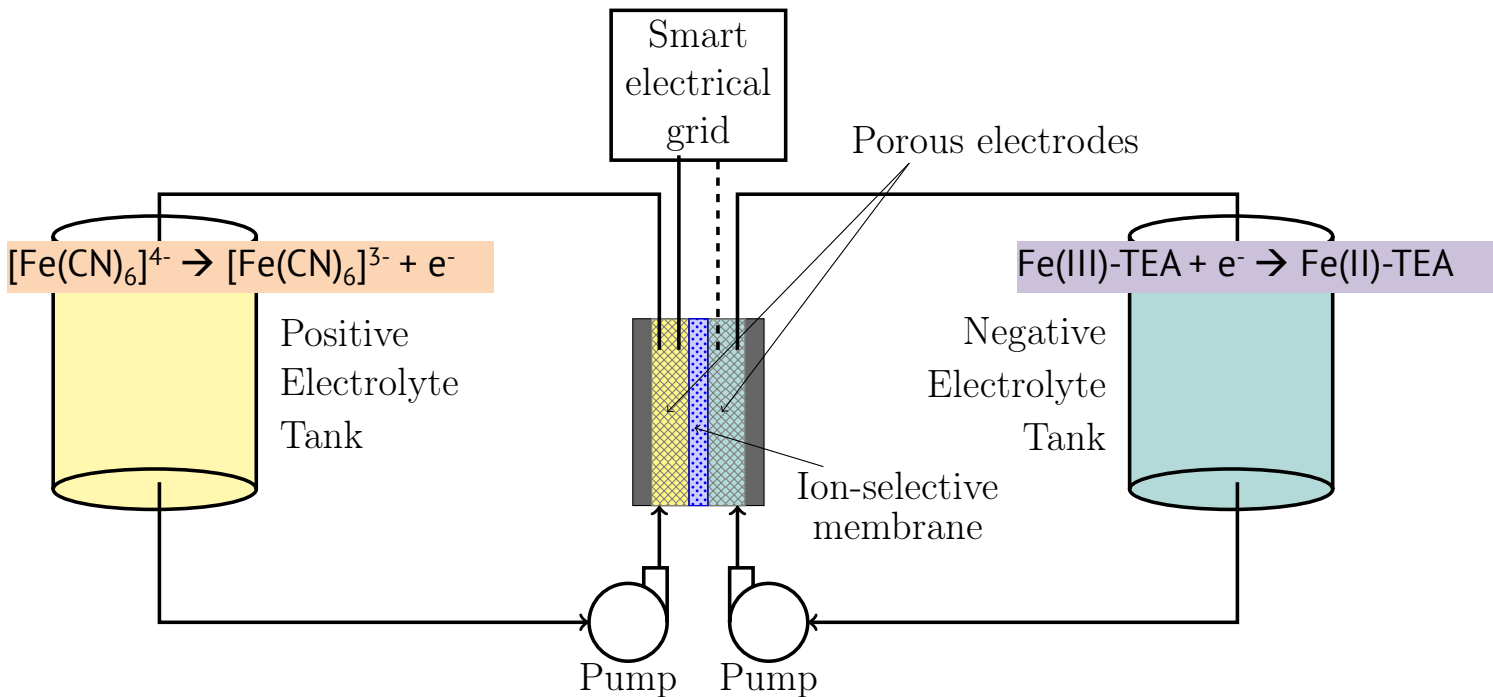
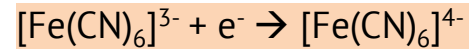
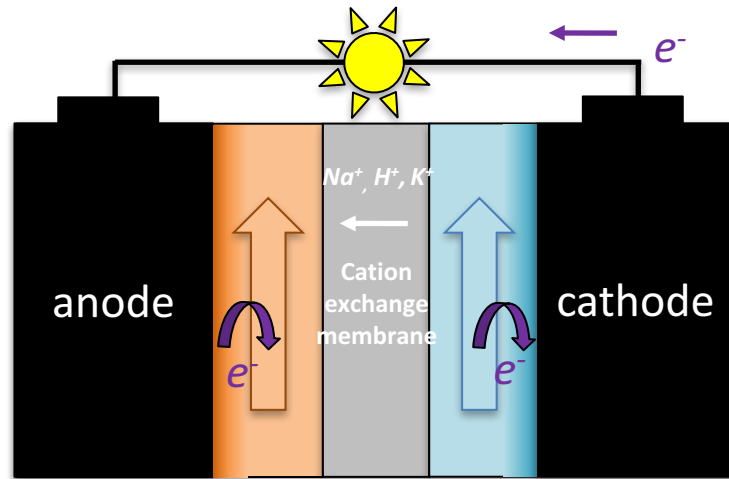


Embroidered electrodes for the fundamental understanding of redox flow cells (EmbelRed)



Hertha Firnberg Project www.uibk.ac.at/textilchemie/embelred



$$E^{\circ'}_a = +0.240 \text{ mV} \quad (\text{vs. Ag/AgCl 3M KCl})$$

$$E^{\circ'}_c = -1.061 \text{ mV} \quad (\text{vs. Ag/AgCl 3M KCl})$$

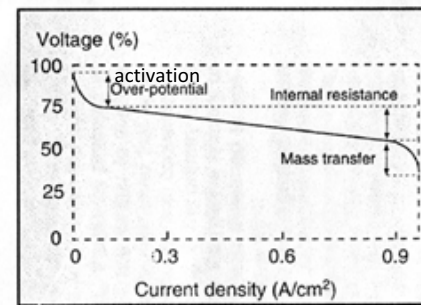
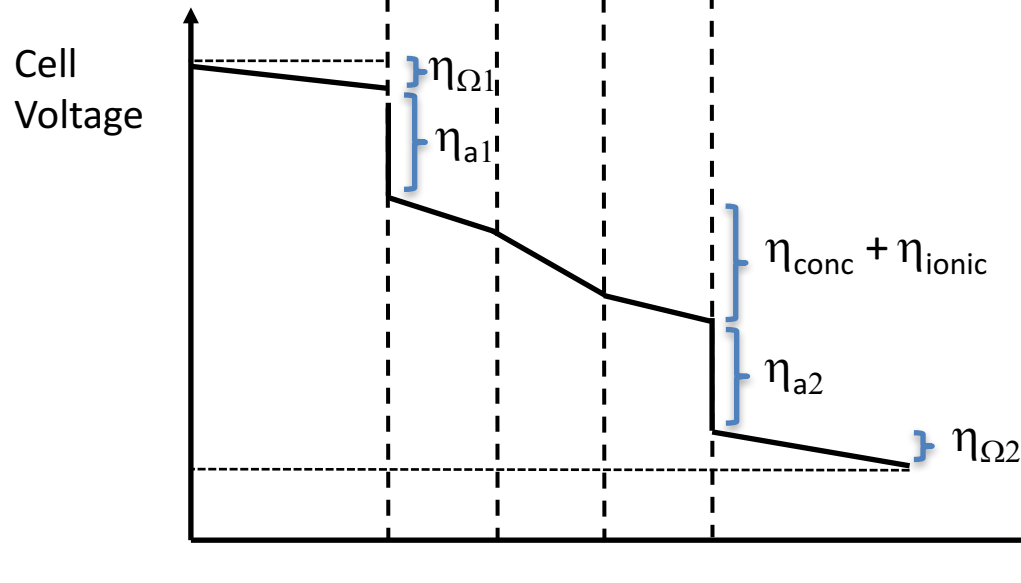
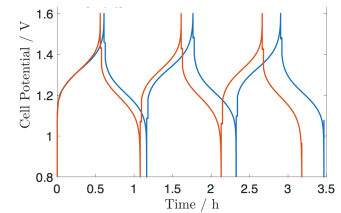


Figure 3. Voltage and current density output.

$$E^{\circ'}_{\text{cell}} = E^{\circ'}_a - E^{\circ'}_c = 1.30 \text{ V} \quad (\text{vs. Ag/AgCl 3M KCl})$$



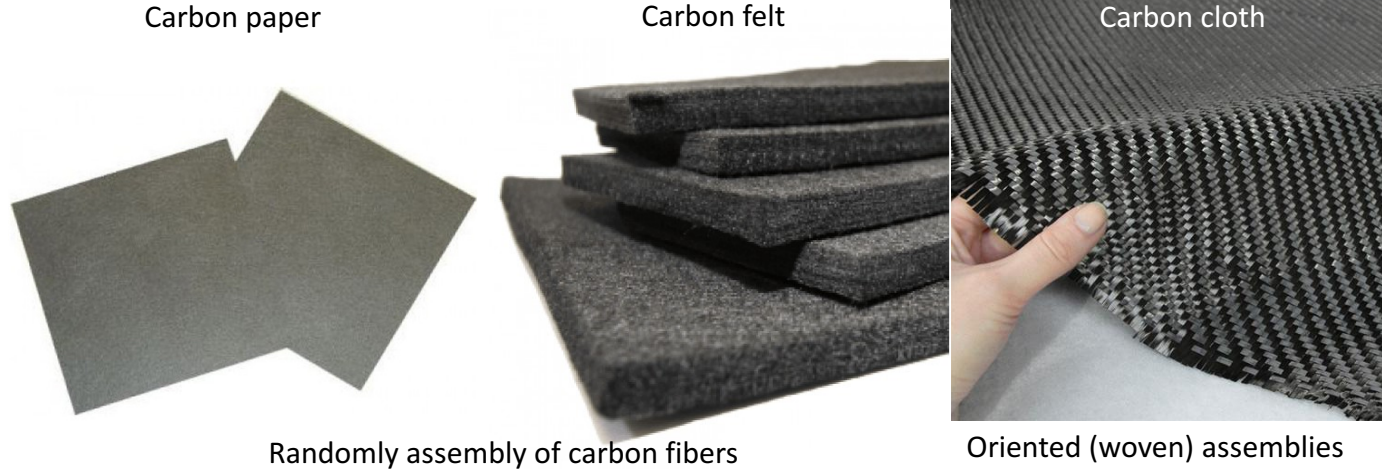
Losses contributions:

- **Ohmic and ionic potential drops (η_{Ω} , η_{ionic}):** conductivity limitations
- **Activation overvoltage (η_a):** charge transfer through the electrode/electrolyte interface
- **Concentration overvoltage (η_{conc}):** controlled by mass transport processes: diffusion, convection, migration

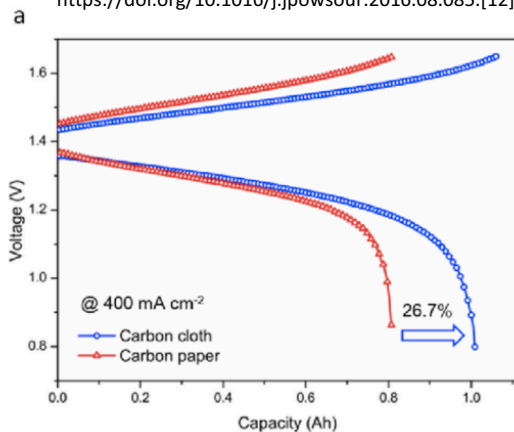
The role of electrode orientation to enhance mass transport in redox flow batteries

Electrochemistry Communications 111 (2020) 106650

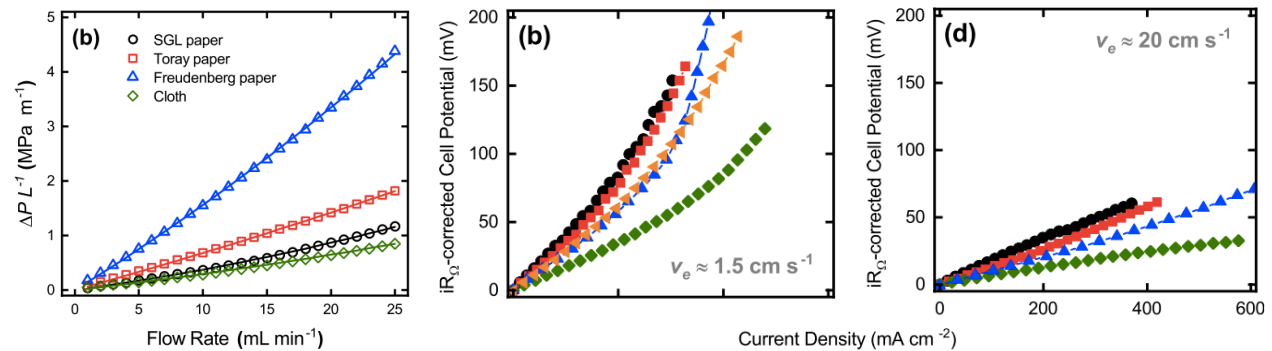
Introduction



X.L. Zhou, T.S. Zhao, Y.K. Zeng, L. An, L. Wei, J. Power Sources 329 (2016) 247–254,
<https://doi.org/10.1016/j.jpowsour.2016.08.085>. [12]



A. Forner-Cuenca, E.E. Penn, A.M. Oliveira, F.R. Brushett, J. Electrochem. Soc. 166 (2019) A2230–A2241,
<https://doi.org/10.1149/2.0611910jes>.

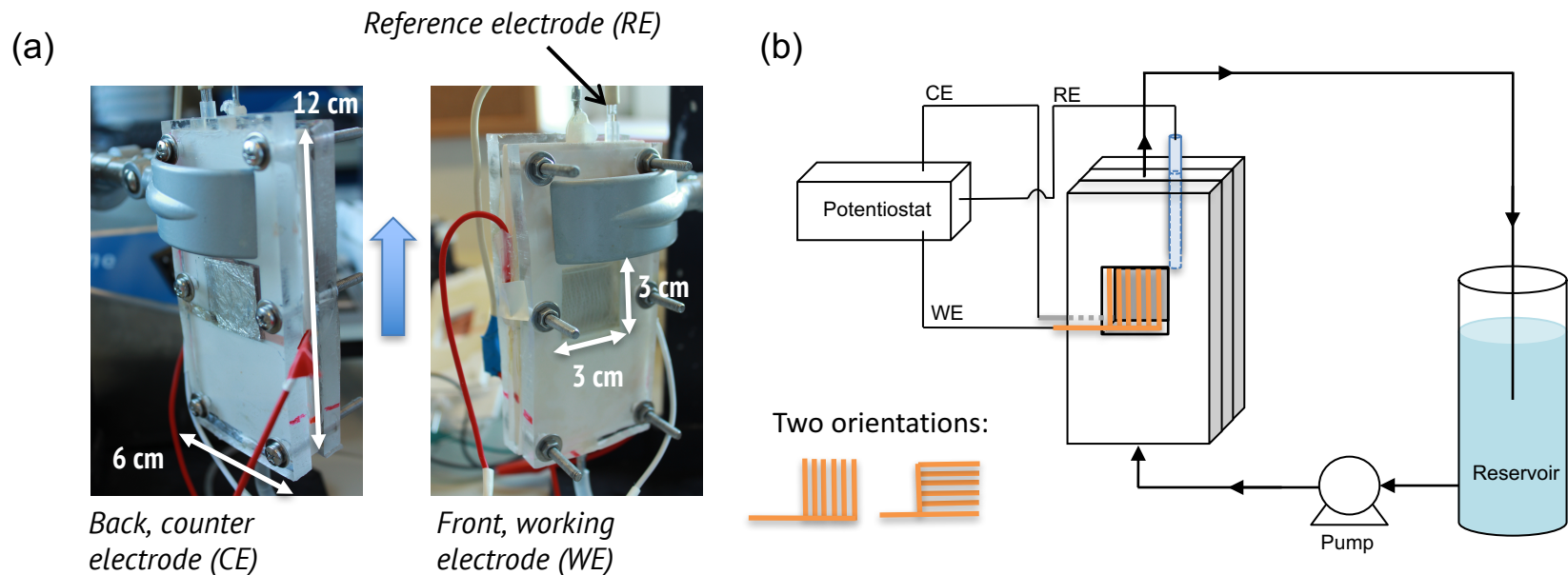


Research hypothesis:

- Does the fiber orientation influence the mass transfer in redox flow batteries?

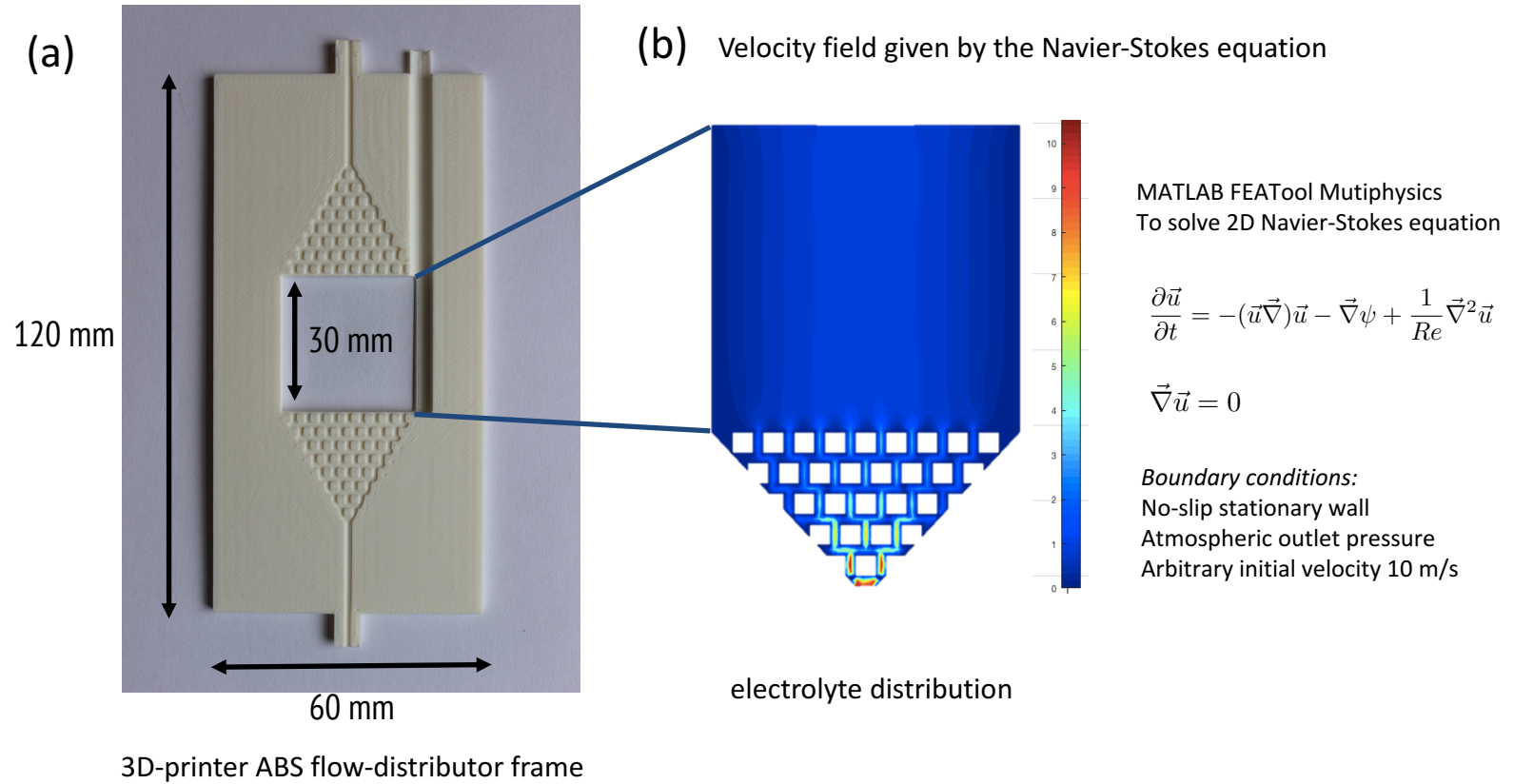
Experimental

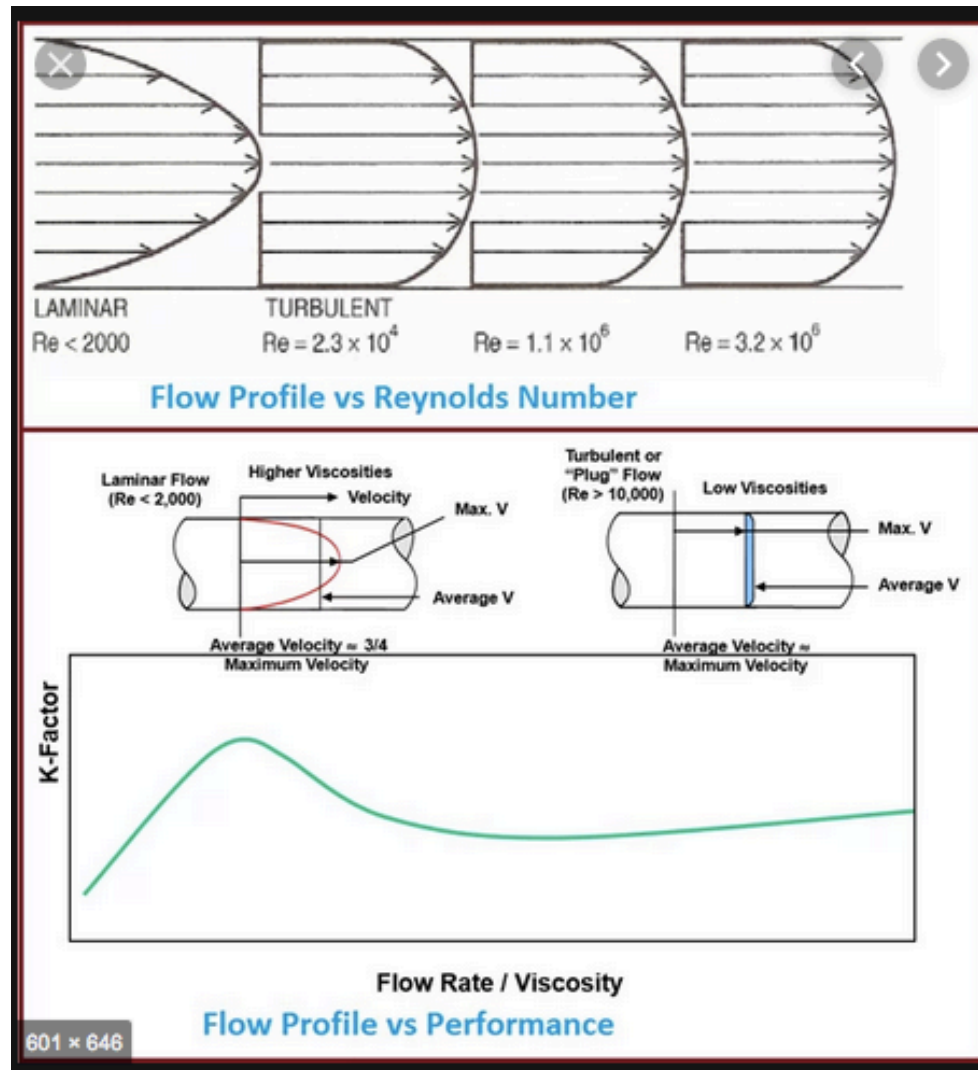
- Control over other electrode parameters: uniform electrolyte velocity, well-defined electrodes, electroactive surface area, flow-by configuration.



Experimental

- Uniform electrolyte velocity across the electrode surface:



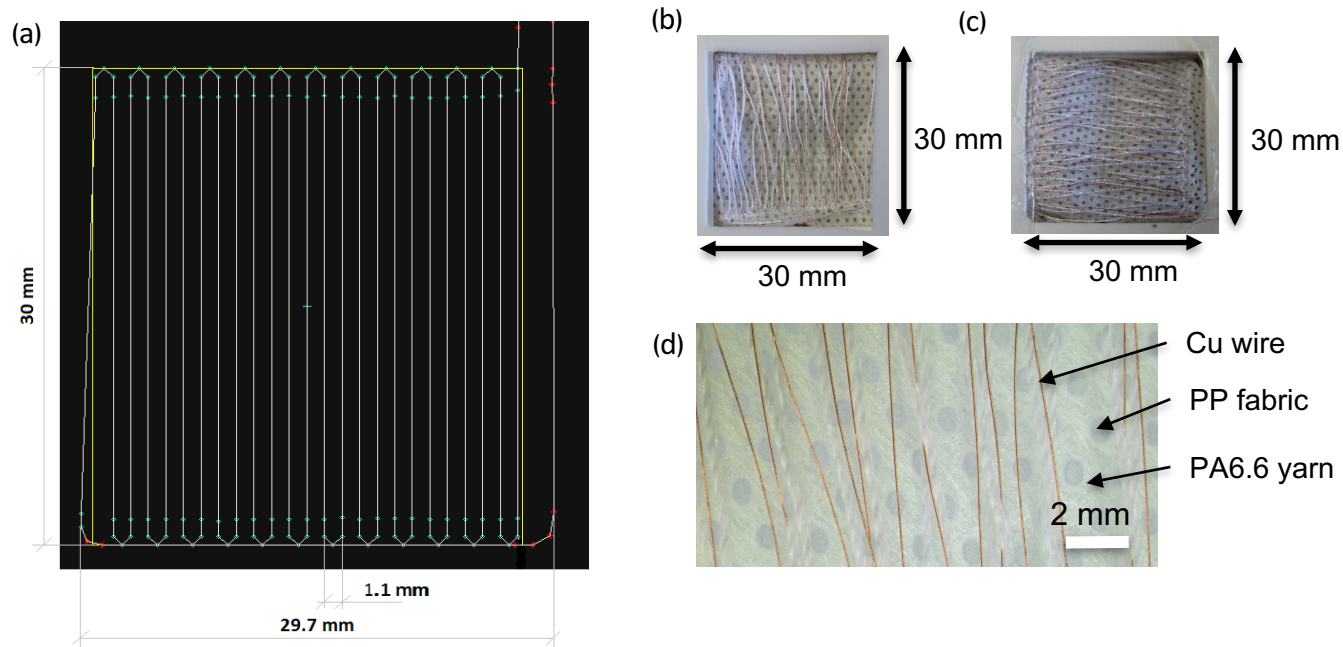


Experimental

- Well-defined electrodes, electroactive surface area:

Two orientations:

- Perpendicular to the flow direction
- Parallel to the flow direction



Results

- The current is proportional to the reaction rate (Faraday's law).

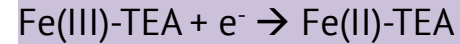
$$\frac{dm}{dt} = \epsilon \frac{M}{nF} I = r$$

(ϵ current efficiency, $[M] = \text{g/mol}$,
 $[dm/dt] = \text{g/s}$, 96485 C/mol , $[I] = \text{A}$, n
 electrons transferred)

$$\frac{\text{g}}{\text{s}} = \frac{\text{g/mol}}{\text{C/mol}} \text{ C/s}$$

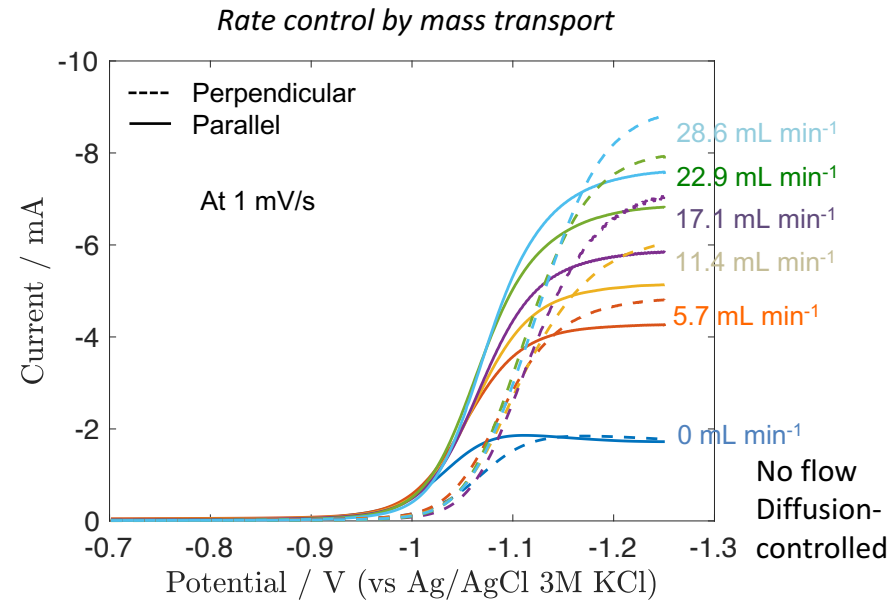
- Limiting current (I_L):** is the maximum current, which results if the concentration of the reactant at the electrode surface is zero.

Dependent on the supply of the reactants at the electrode surface,
 dependent on the **electrolyte velocity**



$$E^{\circ'} \approx -1.061 \text{ mV (vs. Ag/AgCl 3M KCl)}$$

Potentiodynamic polarization curves:



Results

- **Mass transfer coefficient: (movement of mass)**
rate of mass transfer per unit area per unit
concentration difference

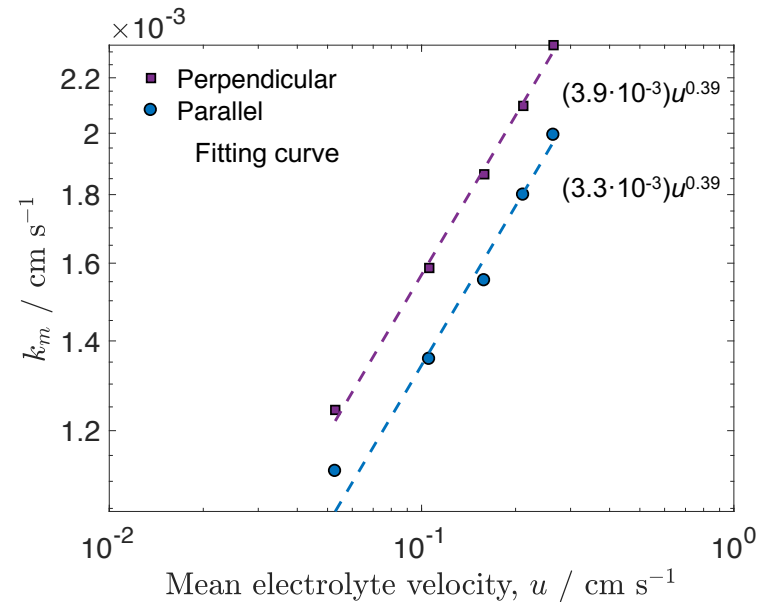
$$k_m = \frac{I}{nF(C_B - C^*)A} = \frac{I_L}{nFC_B A}$$

Empirical equation: $k_m = au^b$

Mass transport process is determined by the variables:

velocity u ,
viscosity ν ,
diffusion coefficient D ,
mass transfer coefficient k
characteristic length L for the geometry flow model

Pi-theorem: principle that you can write every equation into a non-dimensional product.



$$\pi = \left(\frac{kL}{D} \right)^\beta \left(\frac{uL}{\nu} \right)^\eta \left(\frac{\nu}{D} \right)^{-\gamma-\beta}$$

Sherwood number (Sh)	Reynolds number (Re)	Schmidt number (Sc)
Convective	Inertia /	Kinematic
mass transfer /	friction	viscosity/diffusivity
diffusion mass		
transport		

$$Sh = aSc^b Re^c$$

$$Sh = 13.9 Re^{0.39}$$

$$Sh = 11.8 Re^{0.39}$$

(18% greater mass transport
perpendicular electrodes)

Results

Convection-diffusion equation:

Molar mass flux diffusional convective mass transport

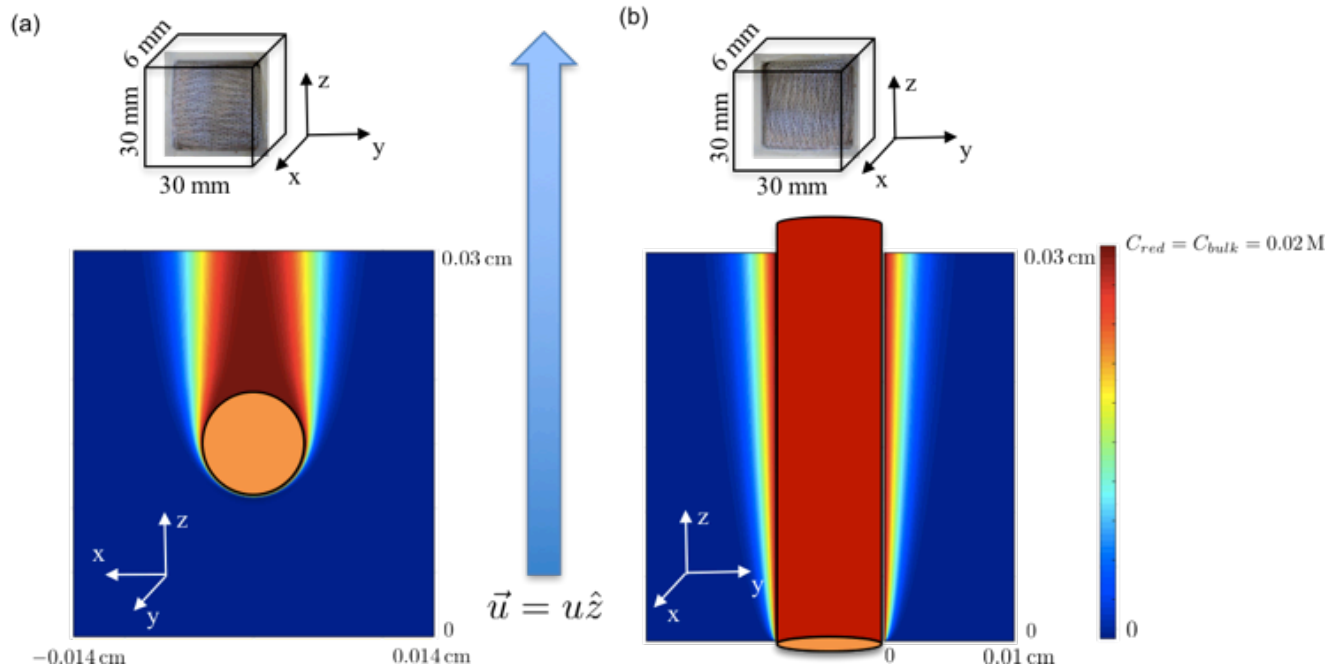
$$\vec{N}_j = -D_j \vec{\nabla} C_j + \vec{u} C_j$$

$$[\text{mol s}^{-1} \text{ cm}^{-2}] = [\text{cm}^2 \text{ s}^{-1}] [\text{mol cm}^{-3} \text{ cm}^{-1}] + [\text{cm s}^{-1}] [\text{mol cm}^{-3}]$$

(flux = rate per unit area)

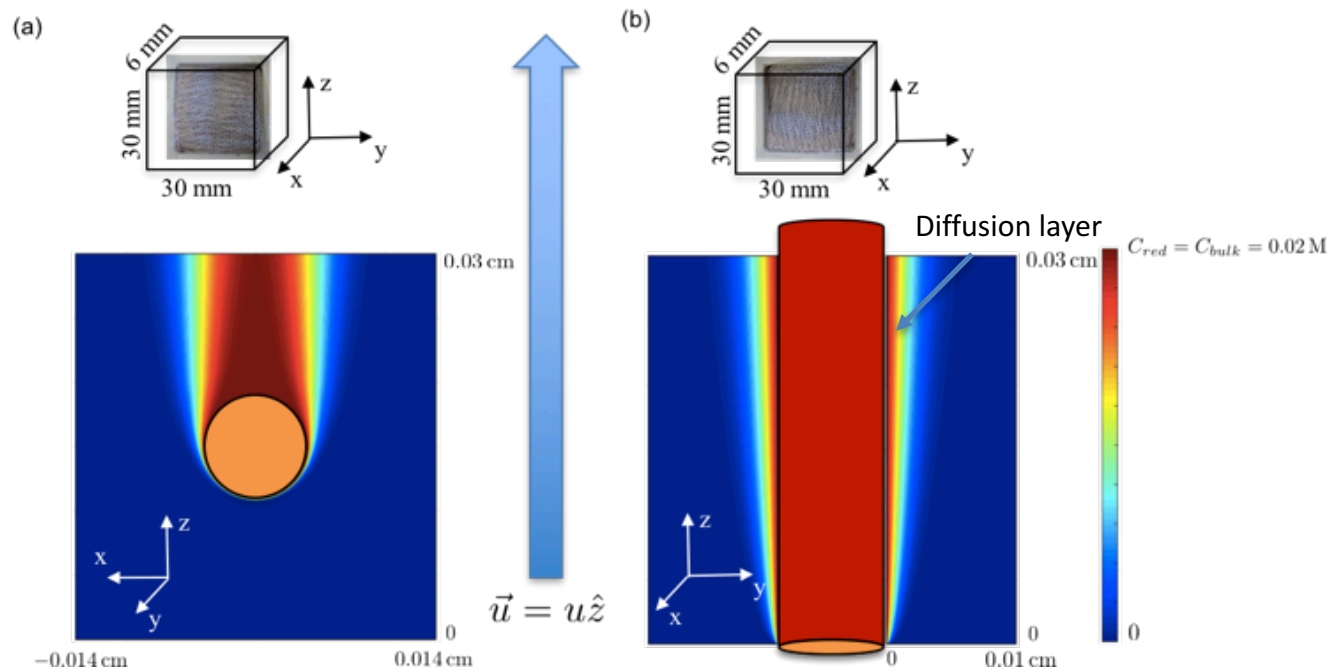
$$\frac{\partial C_j}{\partial t} = -\vec{\nabla} \cdot \vec{N}_j$$

$$\frac{\partial C_j}{\partial t} = D \nabla^2 C_j - \vec{u} \cdot \nabla C_j = 0$$



Discussion

- Smaller distance between wires? (electrodes of high-packing density)
- Electrolyte permeability?
- Electrolyte filling (driven by capillarity)
- Flow-through systems? (electric field parallel to the electrolyte flow)



Thank you for your attention!