Making alkaline electrolyzers flexible

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Flexibility of alkaline electrolyzers

- A disadvantage of current alkaline electrolyzers is lower flexibility than PEM electrolyzers*
- Flex in current alkaline electrolyzers is now about 10%/min, where full ramp up/down within 30s is desired
- Why would one electrochemical technology fundamentally be more inflexible than another?
- The inflexibility is possibly related to the traditional lack of need for flex due to the use of hydropower.

*eg. in IRENA report 2018

Flexibility limitations in water electrolysis

1. Rectifier

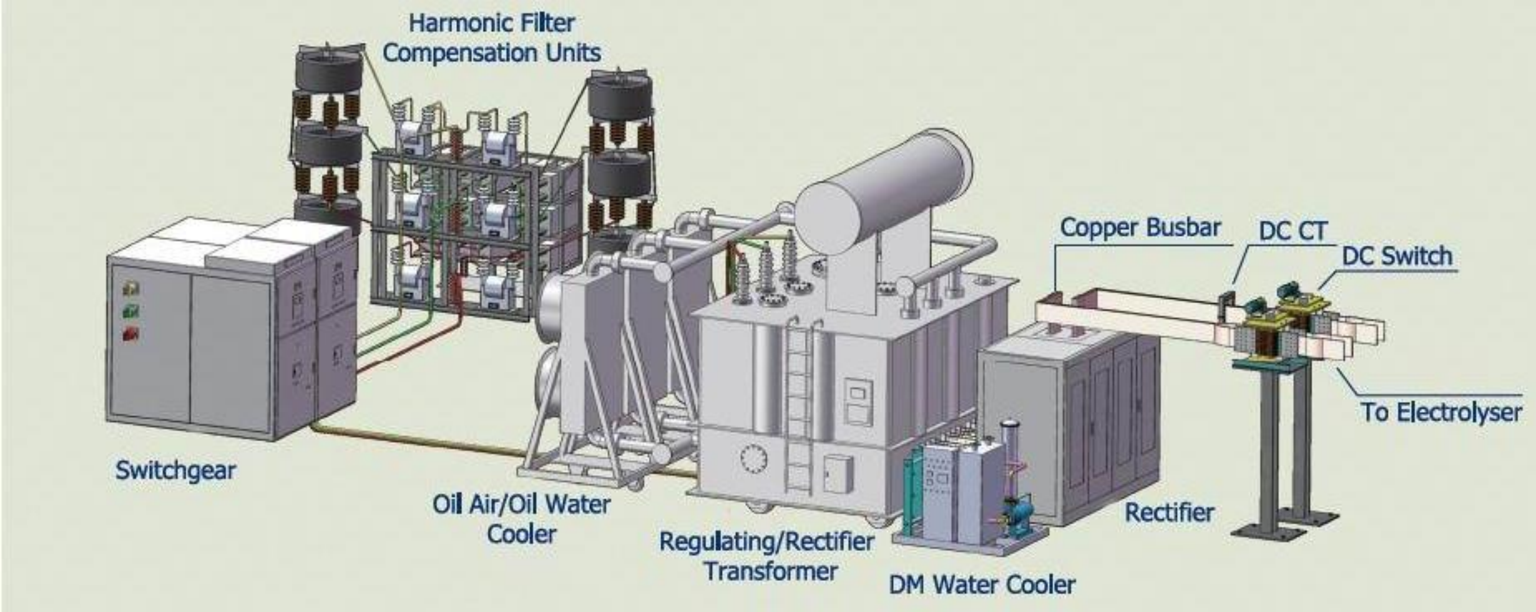
2. Gas purity

3. Heat management

4. Gas-liquid flow

Rectifiers

- Rectifiers convert alternating current (AC) available from the grid into direct current (DC) needed for the electrolyzer
- Rectification is not perfect and typically results in so-called harmonics, which result in energy losses. When the electrolyzer is operated at lower loads the negative effect of harmonics increases.
- Solutions are available to reduce harmonics and operate the electrolyzer flexibly, such as the use of buck rectifier converters. Yet, some of these solutions can be costly.
- The challenges associated with power conversion are often overlooked by chemical engineers!



 http://www.jocite.com/en/ctt/1/76.htm

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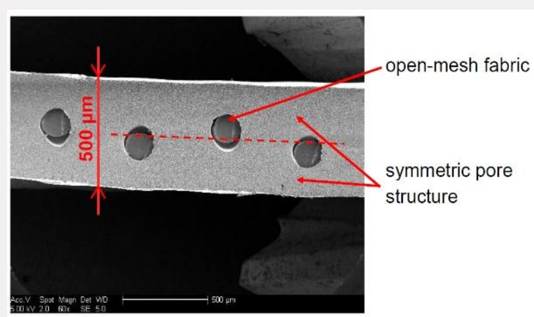
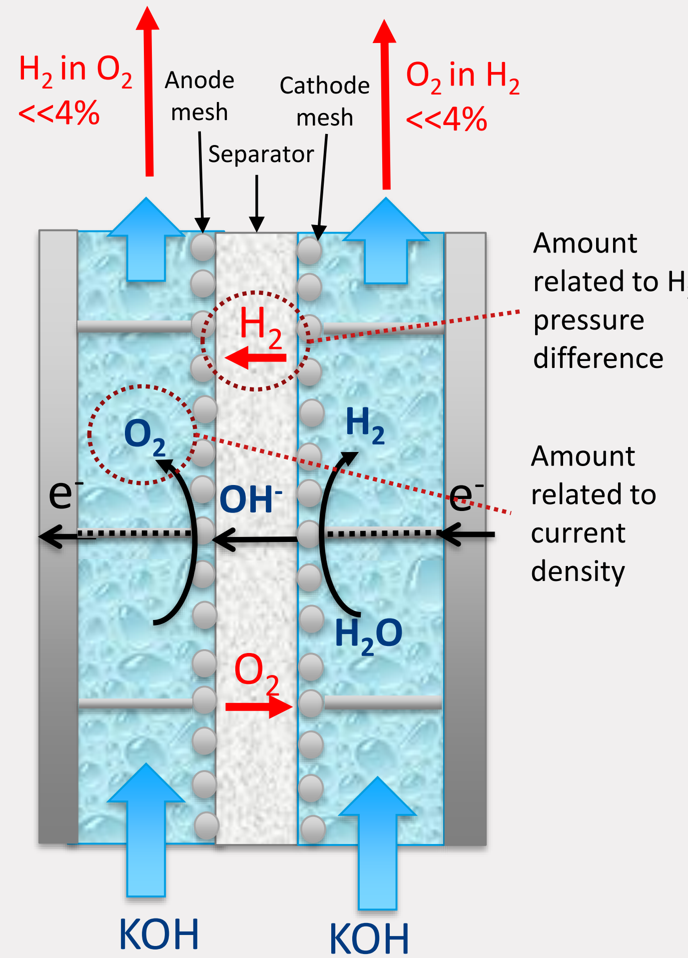
Gas purity

- Flexible operation means that there is significant operation time at low current densities, which results in lower gas purities
- This was a real issue for old separators, but significant progress has been made with polysulfone-ZrO_2 membranes that are able to reduce H_2 in O_2 to below 1% at low load*

	Gas purity
Current density	↑
Membrane thickness	↓
Operating pressure	↓
Temperature	↓



Zirfon



*Ìnformation provided by Agfa at ICE2019

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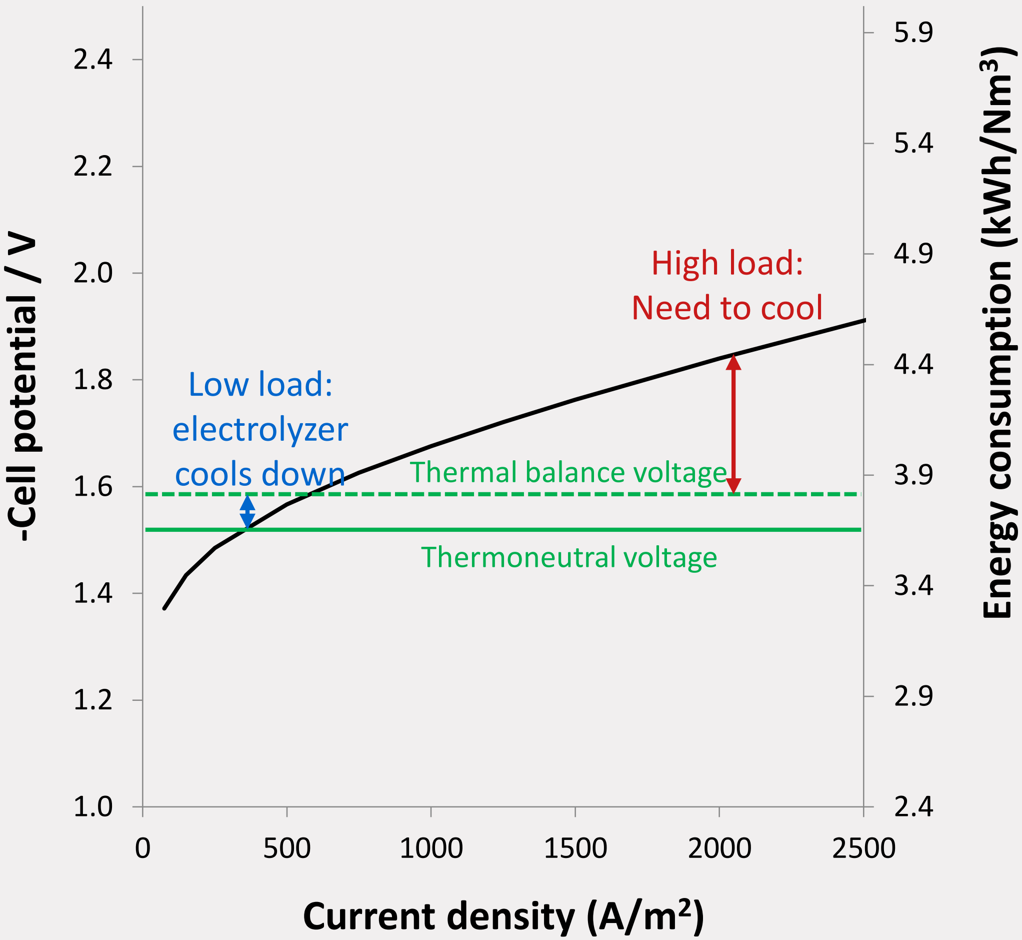
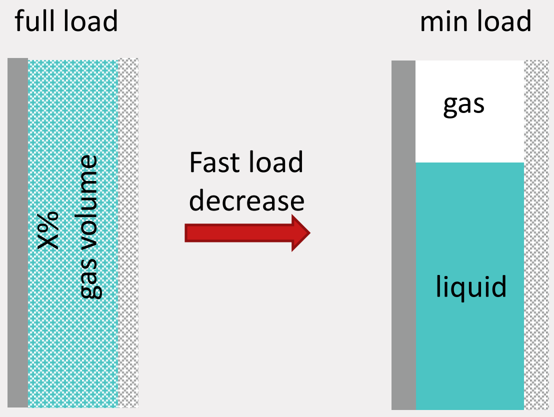
Heat management

- The heat generation of an electrolyzer depends on its operating load
- An electrolyzer that has cooled down cannot quickly ramp up (would lead to voltage peaks)
- Electrolyzers can be made more flexible by keeping the temperature constant at all time by adjusting the inlet temperature (eg. through steam heating)

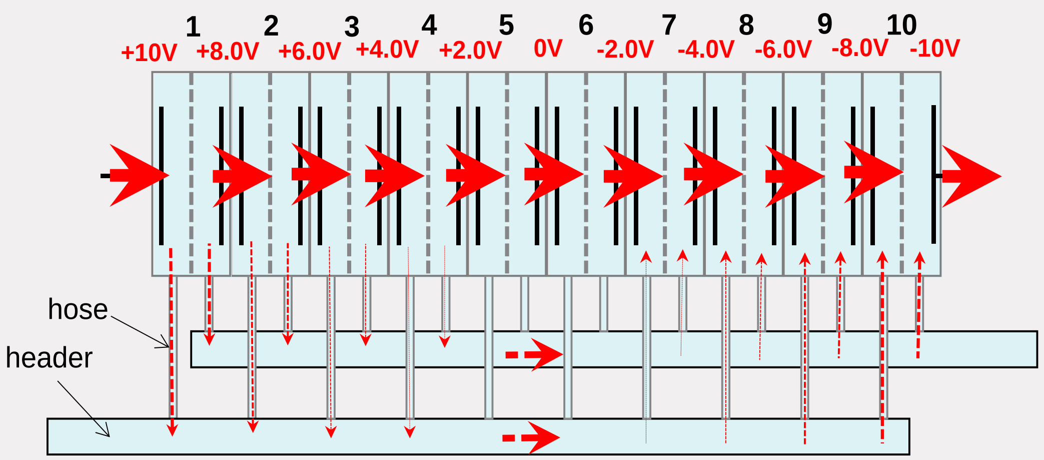


Gas-liquid flow

- Changes in load lead to rapid increase or decrease in the generated gas volume, which can lead to pressure fluctuations or undesired gas-liquid separation in the electrolyzer
- These issues are enhanced by the small inlets and outlets, needed to minimize stray currents
- Our current understanding of gas-liquid flow and coalescence in electrolyzers is rather poor and there is a need for better understanding



Current profile in electrolyzer:



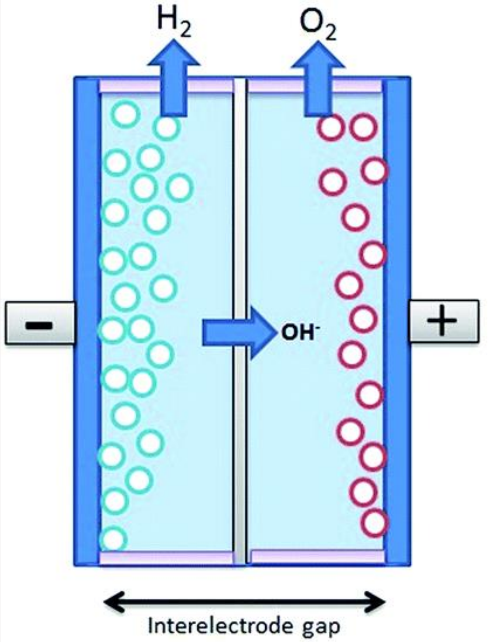
Gas-liquid flow

- **Introduction bubble phenomena**
- **Computational Fluid Dynamics (CFD) Model**
- **Results**
  - Validation using experimental data from literature
  - Transient simulations (flexibility!) for 2 industrial geometries
    - a) NEL electrolyzer (porous plate electrodes)
    - b) Zero-gap configuration
- **Conclusions**

Introduction bubble phenomena

Rising Bubbles

- concentrate near electrode
- cause local turbulence → efficient mixing
- form a curtain of increasing thickness
- act as moving electrical insulators → increase ohmic drop



The performance of an electrolyzer is closely linked to the hydrodynamic characteristics of the gas-liquid flow.

CFD Model

One half cell (sketch shows NEL geom.)

2D Eulerian + k-ε Model

Operation conditions: 2 *bar,* 80^{o}*C*

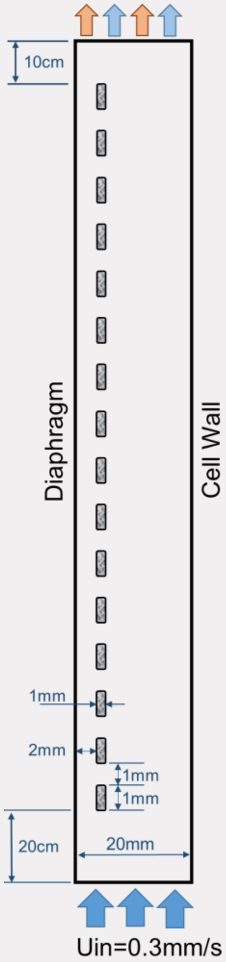
Electrolyte is 30% KOH aqueous solution

Gas phase is a mixture of hydrogen and water vapor

Bubble size: 100 *μm*

Current densities: 750 *A/m*^{2} *(later 2000 A/m*^{2}*)*

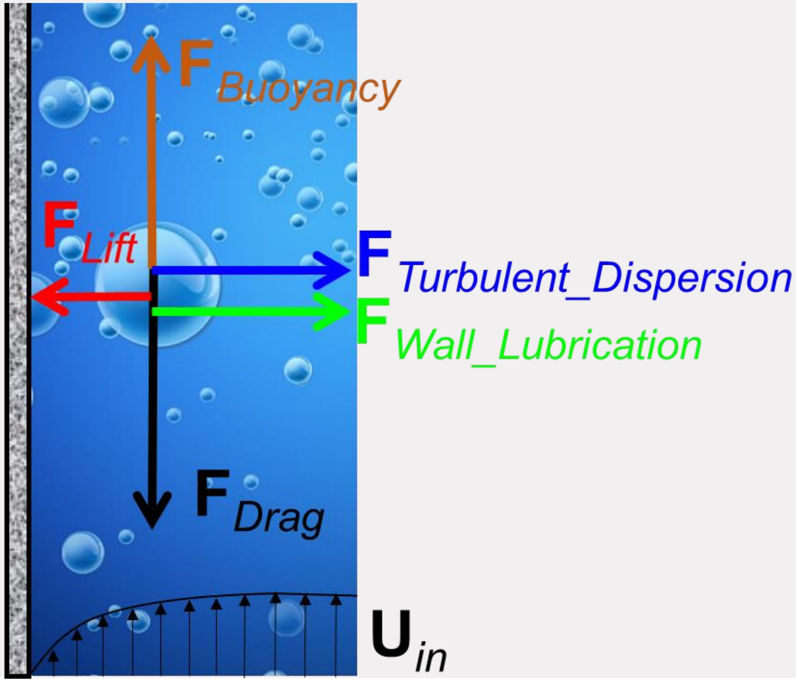
Bubble generation at electrode: *gas inlet* boundary condition



Challenges:

- Predicting the thickness of the hydrogen bubbles curtain,
- Estimating gas volume fraction in a cell.

Forces acting on bubbles:



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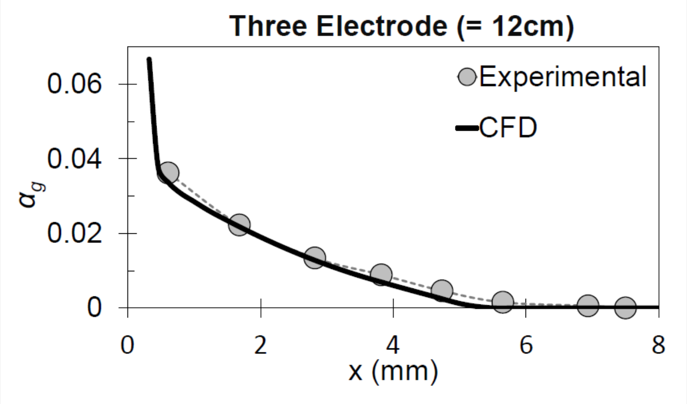
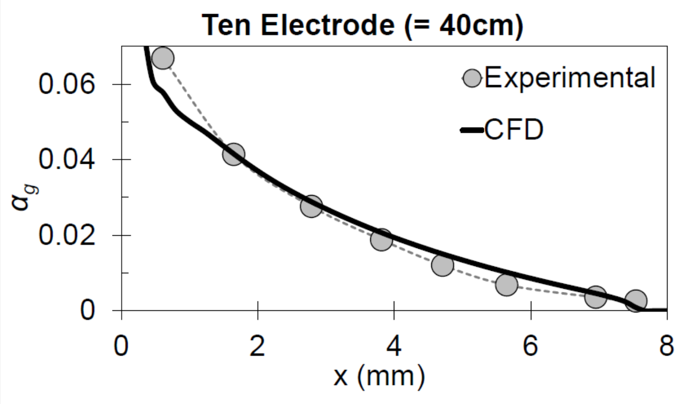
Results - Validation

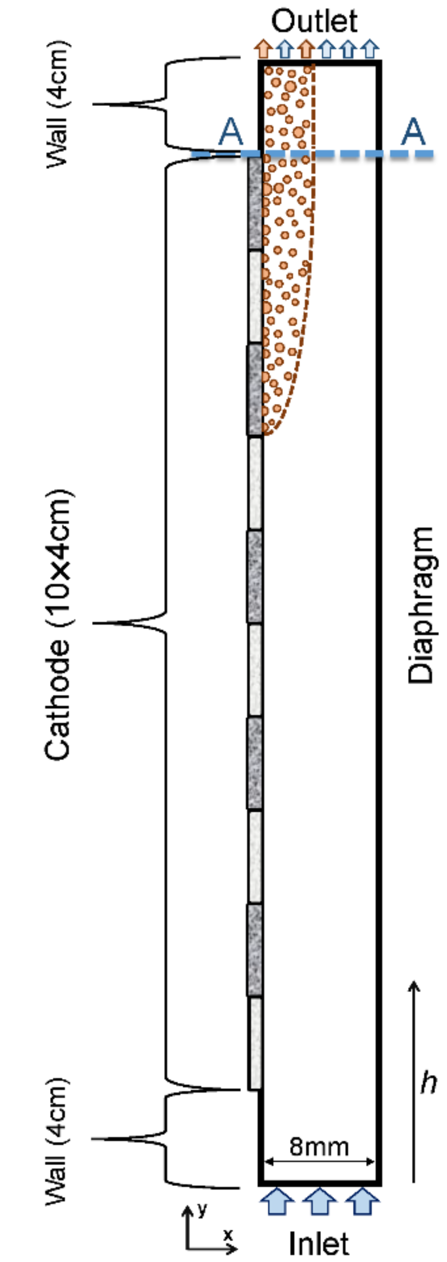
H. Riegel et. al., J. Applied Electrochemistry (1998)

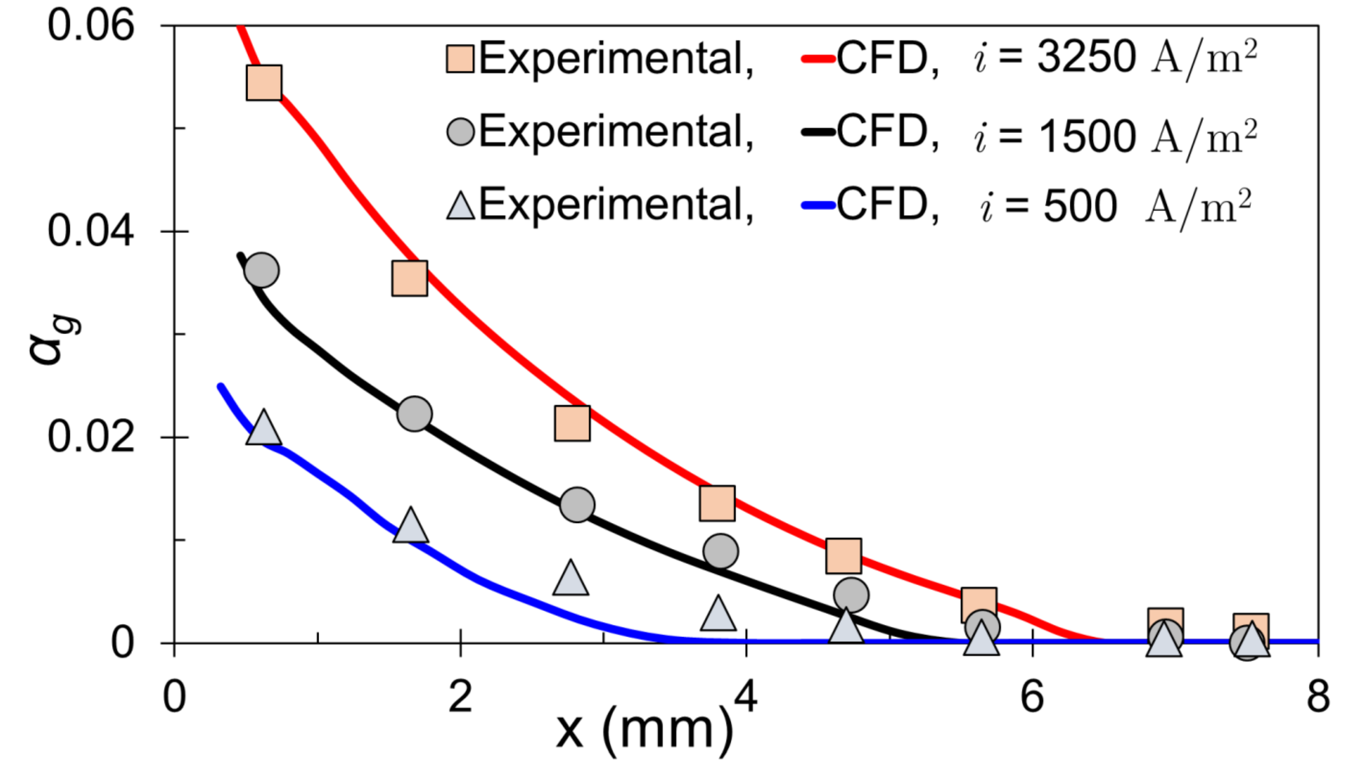
Inlet velocity: 0.69 m/s

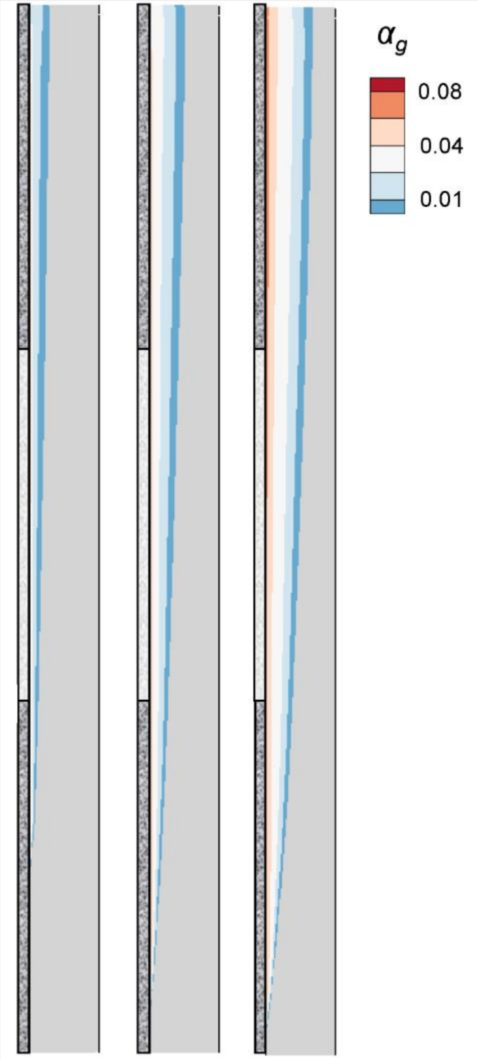
Current density: 500, 1500 and 3250 A/m2








0.06
0.04
0.02
0
α_g
0
2
4
6
8
x (mm)
Experimental, CFD, i = 3250 A/m²
Experimental, CFD, i = 1500 A/m²
Experimental, CFD, i = 500 A/m²

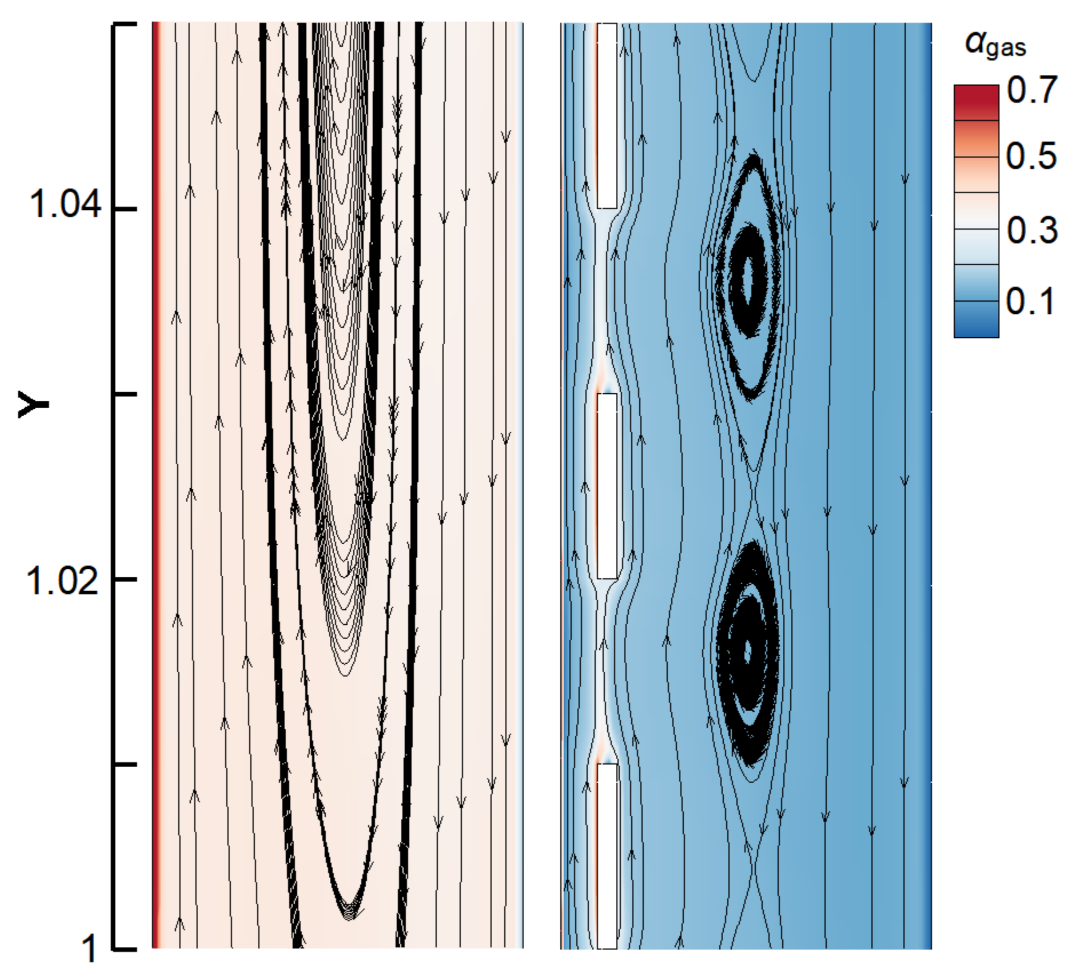

α_g
0.08
0.04
0.01

Results
zero gap (left) versus porous plate (=NEL) (right)

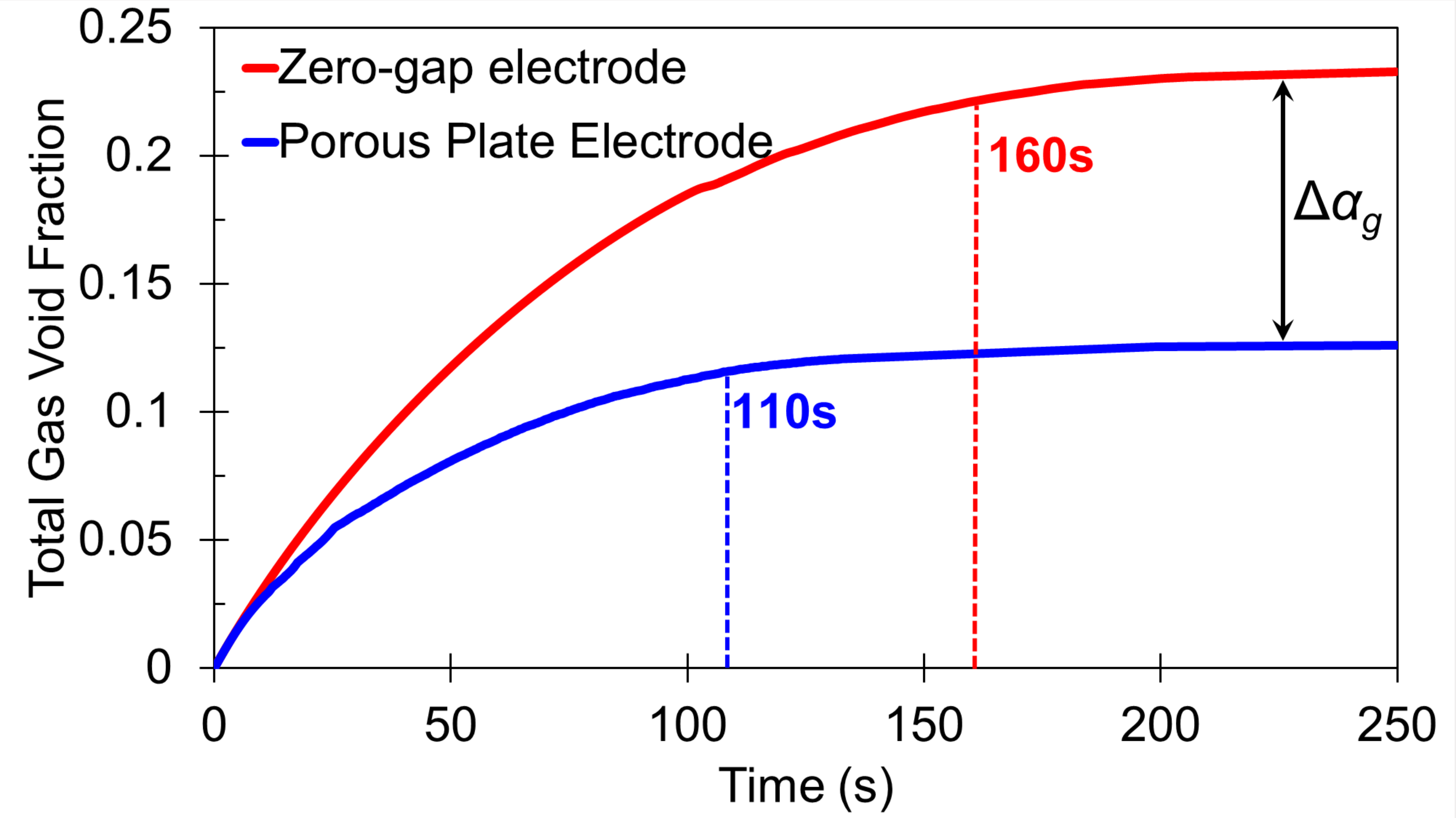
Current density = 750 A/m2

Streamlines: Liquid phase

Colors: Gas void fraction



Transient results (important for flexible operation!)
- current jumps from 0 to 750 A/m2 at time=0



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Conclusions

- There seems to be no reason why alkaline electrolysis cannot be made more flexible, but it requires careful considerations of all flexibility limitations in the design.

- CFD was used to assess the effect of different geometries on flexibility performance (dynamic gas-liquid flow behavior):

    - Empirical parameters in CFD model were tuned using experimental data.
    - Porous plate electrode was predicted to be more suitable for flexible operation than zero-gap: electrode location / geometry matters!
    - General validity of models is still a problem: more comparisons with experimental data are needed.