Liquid and Gas Flow in Electrochemical Systems

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Introduction & Motivation

Electrochemical systems are widely used for being efficient and environmental friendly, but….

System: Electrochemical cell with gas evolving electrodes

Energy consumption

Analyze factors by experiments and modeling:

•Gas and liquid flow fields
•Bubble-liquid interactions

Increase efficiency

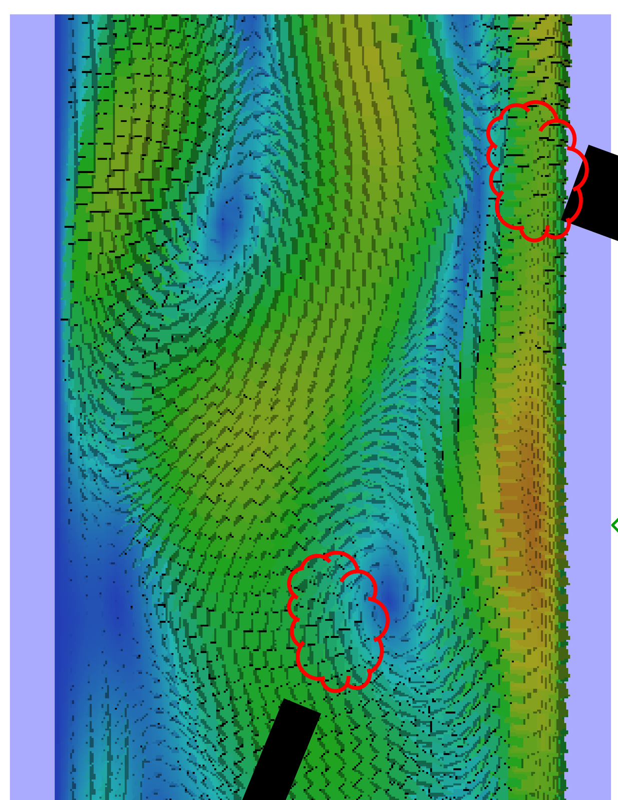
Focus on:
•Bubble departure from the surface
•Mass transfer
•Bubble coalesce

Multiscale Modeling

Reactor scale

1-D models → Simple, informative, capable of capturing averaged efficiency parameters

• Detailed flow field prediction → Navier-Stokes equations (PDE) [3]
•Toolkit: CFD



PDE's → Requires BC's to solve

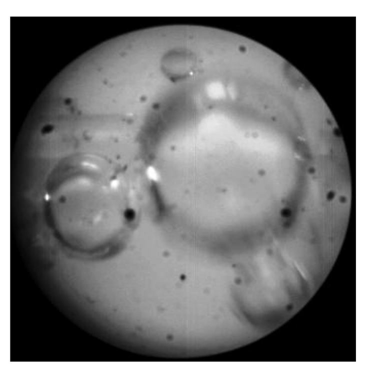
Electron balance:
Faraday's law →
Mass of gas injected

Particle scale

Can we use **sub-models** to better represent the physical phenomena near the electrode?

The flow is driven by bubbles generated on the electrode → Bubble size

Initial bubble size

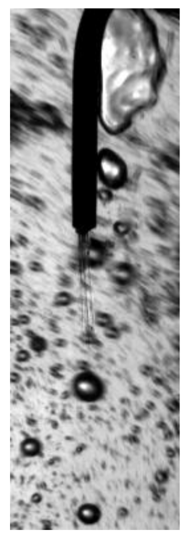


Bubble size distribution:
Bubble coalescence

Experimental System & Techniques

Electrochemical system with gas evolving electrode

Optical Probe



• Phase hold-up
• Bubble size

High speed camera

• Phase hold-up
• Bubble size
• Qualitative description

Micro Pressure Transducers

• Pressure fluctuations

System:
Anode: RuO_2/TiO_2 dimensional stable anode (DSA®)
Cathode: Titanium

Suitable for
• Chlorate production $NaCl\,(s) + 3\,H_2O\,(l) \rightleftharpoons NaClO_3 + H_2\,(g)$
• Water splitting $2H_2O \longrightarrow 2H_2 + O_2$

Planned Experiments

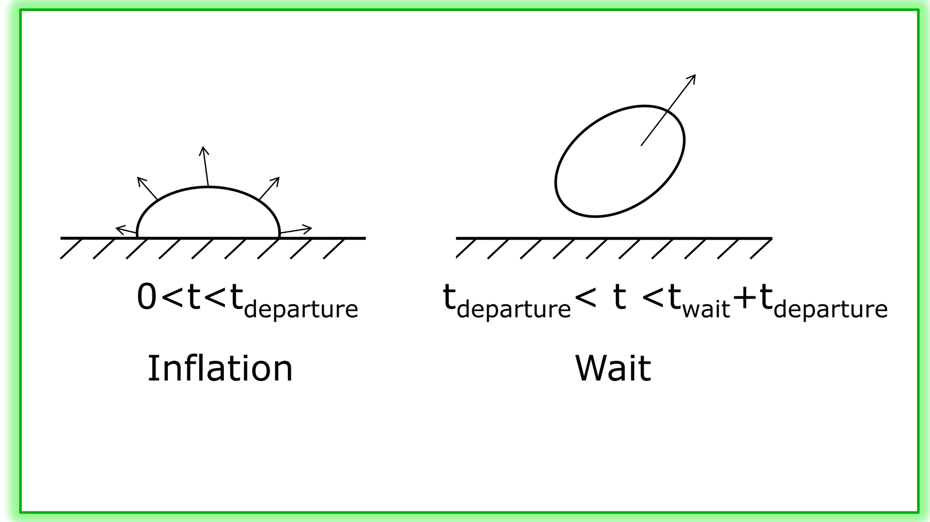
Aim: Systematically investigate the effect of different bubble sizes on the flow characteristic. This will be done in three phases:

Test the limits of the experimental apparatus
•Externally inject bubble the system trough distributor at the bottom (Controlled conditions)
•Test the limits of the pressure fluctuation method for different flow regimes
•Outline the pressure signature for different flow regimes
•Use the camera to qualitatively map the flow field
•Use camera pressure transducer duo to calibrate the pressure traducers

Analyze the system under controlled conditions
•Create artificial gas evolving wall by injecting gas a porous membrane
•Use the camera to qualitatively map the flow field
•Map pressure signal with respect to bubble size

Analyze system with gas evolving electrode
•Run the electrochemical system under different operating conditions
•Use the camera to qualitatively map the flow field
•Use the map on step 2 to characterize the flow the electro chemical system with gas evolving electrode

Modeling
Bubble Growth on the Surface



Cyclic generation and departure of bubbles

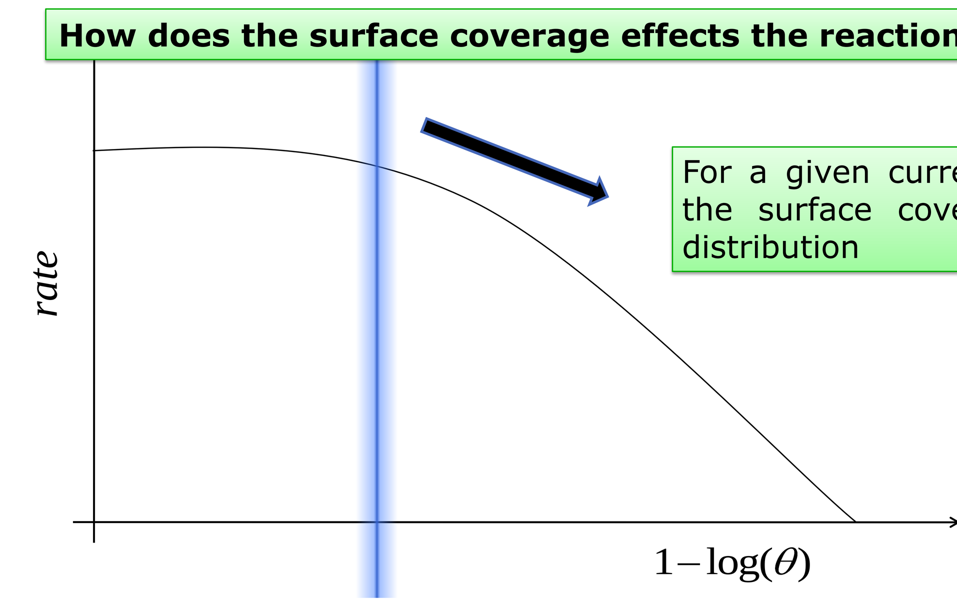
The inflation of bubble introduces additional resistance → Lower reaction rate

Inflation Period	Wait Period
• Transfer of reactants to the wall • Reaction on the wall • Transfer of products to the nucleation site • Change bubble volume (Inflation)	• Departure of bubble • Convective transfer of species to the wall
?	?
• What is the size of the bubble on the departure? • What is the rate of inflation?	• How long is the wait time for a given current density?

Island model[4] will be used to calculate the rate of bubble infilation hence the temporal change in bubble coverage

An time estimate realtionship will be introduced (similar to nucleate pool boling)[5]

How does the surface coverage effects the reaction?



For a given current density the surface coverage is a distribution

$$\theta(t) = \frac{A_{Bubble}}{A_{Total}}$$

Summary

This work focuses on elucidating flow pattern formation in narrow channels. In general, bubbles generated on an electrode surface lift the liquid. The lifting of the liquid has been shown to create circulation cells, affecting mass transfer, conductivity and energy consumption. The experimental results will provide a mapping of flow patterns as a function of bubble size. This map can later be used to enhance and control gas evolving from electrode surfaces in narrow channels. An improved knowledge of gas behavior on the electrode surface scale will ensure that the mass transfer effects are taken into account, with respect to reaction kinetics, on bench scale systems. These mass transfer interactions strongly depend on the size of the bubbles, which are heavily dependent on the departure size of bubbles and the rate of coalescence/break-up within the system. The proposed work aims to provide fundamental tools to accurately predict the size of bubbles.

References

1. For different aspects of the work, please refer to Annual CREL report (Page 54) or contact me directly at morali@wustl.edu
2. http://electrochem.cwru.edu/encycl/art-b01-brine.htm
3. On going work with Alessio Alexiadis. A. Alexiadis, M. P. Dudukovic, P. Ramachandran, A. Cornell, J. Wanngård and A. Bokkers "Liquid –gas flow patterns in a narrow electro-chemical channel" submitted to Chemical Engineering Science
4. D. Kuan, H. Davis, and R. Aris, "Effectiveness of catalytic archipelagos--I Regular arrays of regular islands," *Chemical Engineering Science*, vol. 38, no. 5, pp. 719-732, 1983.
5. C. Y. Han and P. Griffith, "The mechanism of heat transfer in nucleate pool boiling--Part I: Bubble initiation, growth and departure," *International Journal of Heat and Mass Transfer*, vol. 8, no. 6, pp. 887-904, Jun. 1965.