2023 Annual Meeting of the Imperial College Consortium on Pore-Scale Modelling and Imaging

12th January 2023

Martin Blunt and Branko Bijeljic

Department of Earth Science and Engineering
Imperial College London

Personnel and projects

- Martin Blunt, Professor of Flow in Porous Media – overall supervision and theories of multiphase flow in porous media
- Branko Bijeljic, Principal Research Fellow – multiphase flow and reactive transport
- Sajjad Foroughi, Post-doctoral researcher – pore-scale modelling
- Sati Asli Gundogar, Post-doctoral researcher – pore-scale modelling and analysis
- Linqi Zhu, Visiting Post-doctoral researcher – machine learning in flow in porous media
- Abdullah Alhosani, 3rd year PhD student – imaging of near-miscible three-phase flow
- Luke Giudici, 3rd year PhD student – pore-scale modelling and the effect of wettability
- Sepideh Goodarzi, 2nd year PhD student – analysis of hysteresis
- Hussein Alzahrani, 2nd year PhD student – surfactant flooding
- Abdulaziz Alsaleh, 2nd year PhD student – simulation of polymer flooding
- Ademola Adebimpe, 1st year PhD student – pore-scale modelling of intermittency
- Jack Ma, 1st year PhD student – application of machine learning to pore-scale modelling
- Waleed Dokhon, 1st Year PhD student – hydrogen storage
- Ahmed Alzaabi, , 1st Year PhD student – carbon dioxide and hydrogen storage
- Min Li, Visiting PhD student – modelling flow in gas diffusion layers
- Mingliang Qu, 1st year PhD student Zhejiang University, China – multiphysics modelling
- Qingyang (Lewis) Lin, Professor, Zhejiang University, China – multiphase flow

Public domain publication

Open access papers and repository of data and codes (where applicable).
Talks, images and data available at:

https://www.imperial.ac.uk/earth-science/research/research-groups/pore-scale-modelling/

See also the Digital Rocks Portal, BGS etc.

Agenda: 23rd Pore-Scale Imaging and Modelling Meeting

9:00am Welcome coffee

9:30am Martin Blunt – Welcome and introduction to time-scales for equilibrium in gas storage

10:00am Sepi Goodarzi – Trapping, Ostwald ripening and hysteresis in hydrogen storage

10:30am Mingliang Qu – Pore-scale modelling of heat and mass transfer in porous materials (online)

11:00 – 11:20am – Coffee break

11:20am Guanglei Zhang – Multiphase flow, pore-scale imaging and analysis in complex reservoir samples (online)

12:00 noon Hussein Alzahrani – Pore-scale imaging and analysis of surfactant flooding

12:30pm - Lunch

1:30pm Branko Bijeljic – Introduction to the afternoon

1:45pm Sajjad Foroughi – Application of multi-scale network models to predict multiphase flow in samples with micro-porosity

2:30pm Luke Giudici – The generalized network model for multiphase flow: calibration and comparison with direct numerical simulation

3:00pm Ademola Adebimpe – A thermodynamically-based pore network model of intermittency

3:30pm Min Li – Modelling and analysis of multiphase flow in gas diffusion layers

4:00pm Discussion and close

6:30pm Dinner – Polish Club Exhibition Road

Flow in Porous Media as a Scientific Discipline

Move away from application-specific siloes to view flow in porous media as a discipline in its own right.

Explore how to use similar methods to study a wide range of applications: agriculture, water resources, subsurface storage (CO_2, H_2, heat) and manufactured media, from coffee filters to fuel cells and babies' nappies.

Inspired by the mission of InterPore, https://www.interpore.org/

New directions

Advances in Geo-Energy Research

Vol. 7, No. 2, p. 111-131, 2023

Invited review

Review of underground hydrogen storage: Concepts and challenges

Hamed Hematpur[1], Reza Abdollahi[2], Shahin Rostami[3], Manouchehr Haghighi[2], Martin J. Blunt[4]*

PHYSICAL REVIEW E **106**, 045103 (2022)

Ostwald ripening and gravitational equilibrium: Implications for long-term subsurface gas storage

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(Received 8 August 2022; accepted 22 September 2022; published 10 October 2022)

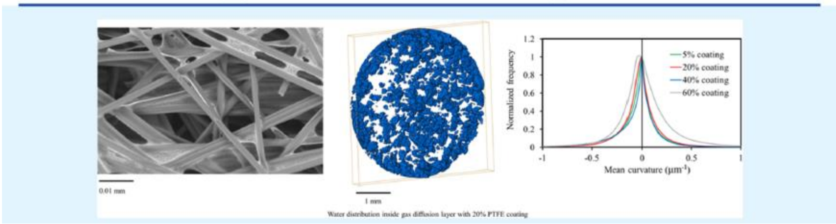
ACS APPLIED ENERGY MATERIALS

www.acsaem.org Article

Minimal Surfaces in Porous Materials: X-Ray Image-Based Measurement of the Contact Angle and Curvature in Gas Diffusion Layers to Design Optimal Performance of Fuel Cells

Mohammad Javad Shojaei,* Branko Bijeljic, Yihuai Zhang, and Martin J. Blunt

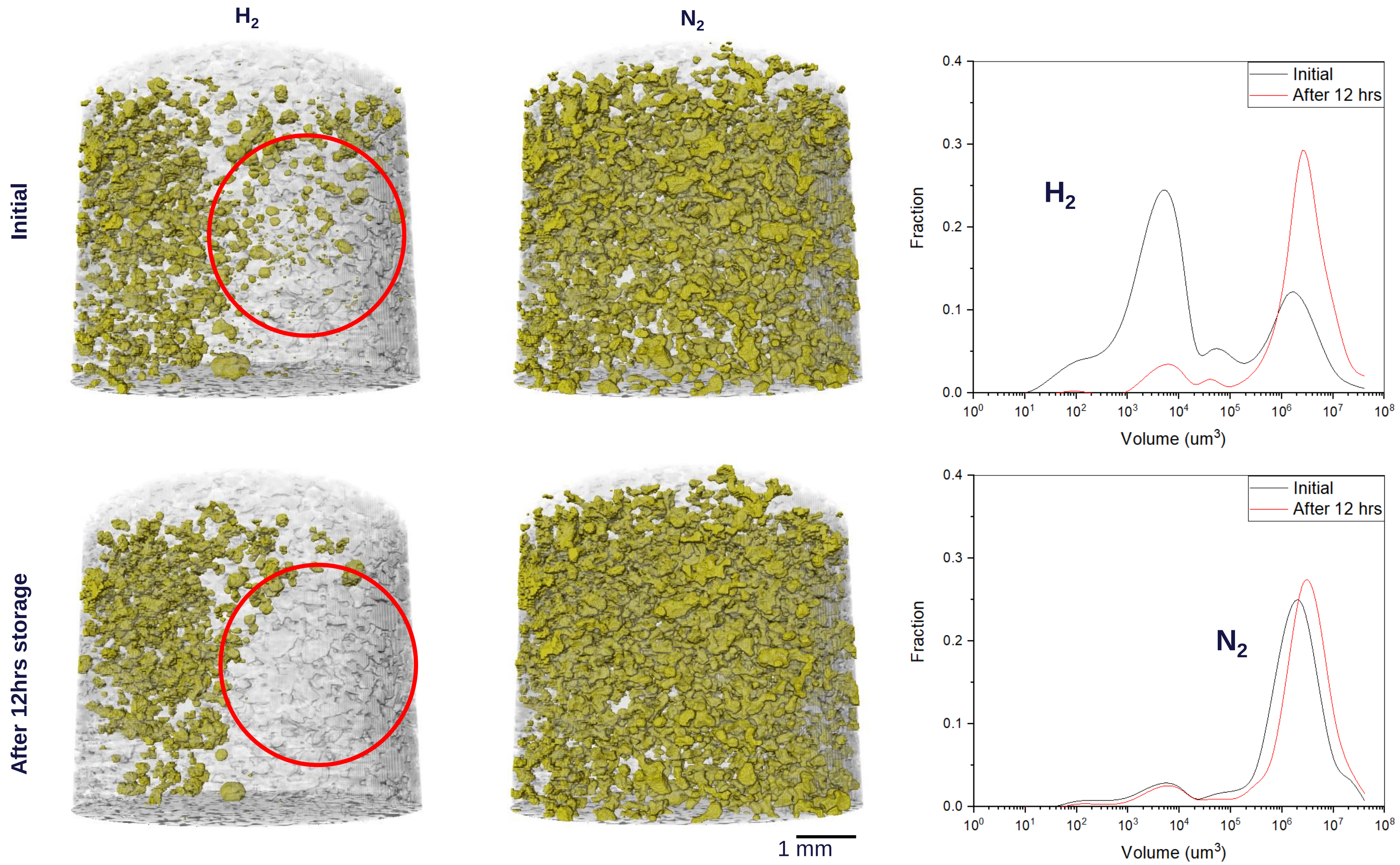
Cite This: https://doi.org/10.1021/acsaem.2c00023



New directions

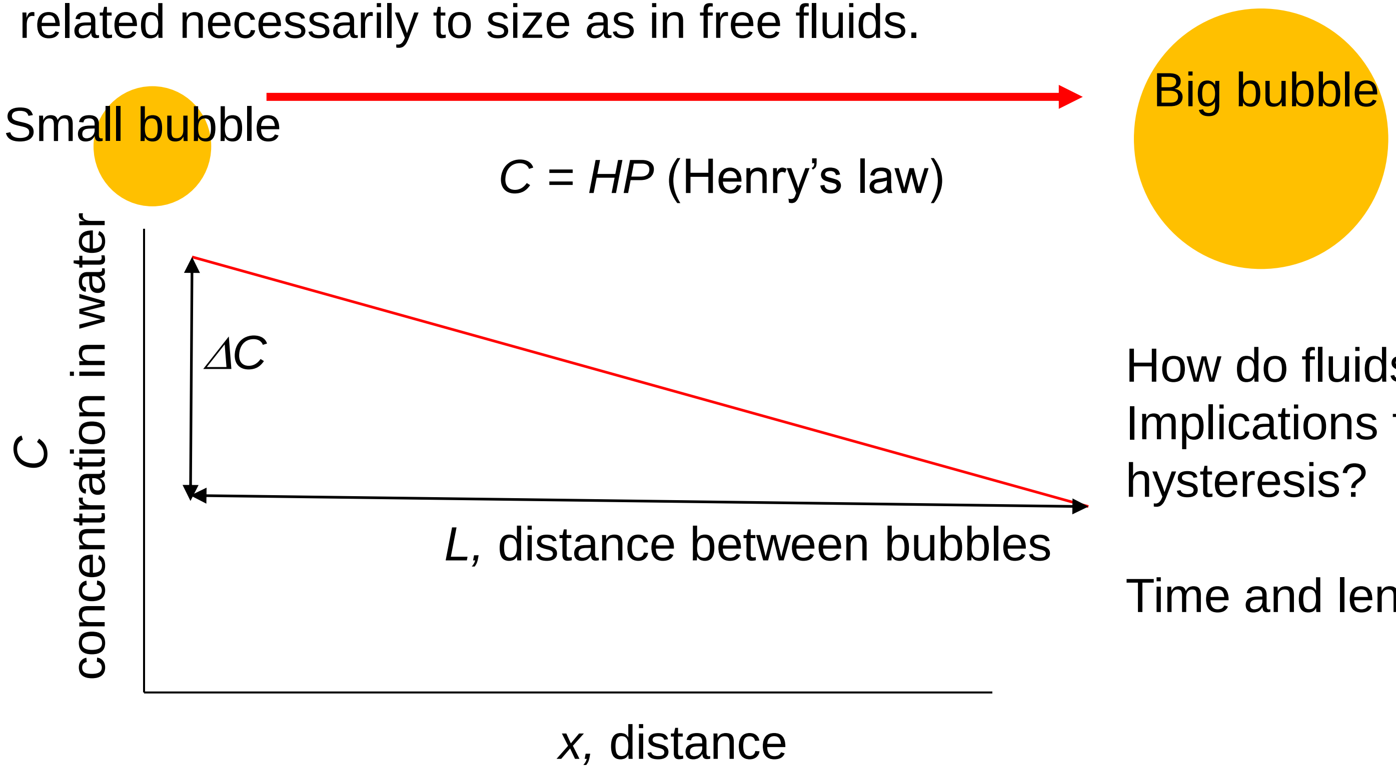
- Consideration of fibrous (high porosity) porous media with application to gas diffusion layers in fuel cells (Min Li)
- Heat and mass transfer, plus reaction, with application to heat exchangers and packed bed reactors (Mingliang Qu)
- Subsurface hydrogen storage, pore-scale rearrangement of phases and hysteresis (this talk and Sepi Goodarzi; Waleed Dokhon)
- Thermodynamic modelling and analysis of multiphase flow in porous media (Ademola Adebimpe)
- Multi-scale modelling and incorporation of three-dimensional curvature (Sajjad Foroughi and Luke Giudici; Asli Gundogar)
- Continuation of work on imaging and analysis of complex displacement processes (Guanglei Zhang and Hussein Alzahrani; Abdulla Alhosani)
- Applications of machine learning in multiphase flow (Linqi Zhu and Jack Ma)

Ostwald ripening in hydrogen storage after water invasion



Ostwald ripening - theory

Diffusive flux of dissolved gas from smaller (higher pressure) bubbles to larger ones. In a porous medium we assume the bubble pressures are fixed – not related necessarily to size as in free fluids.



How do fluids rearrange?
Implications for trapping and hysteresis?

Time and length scales?

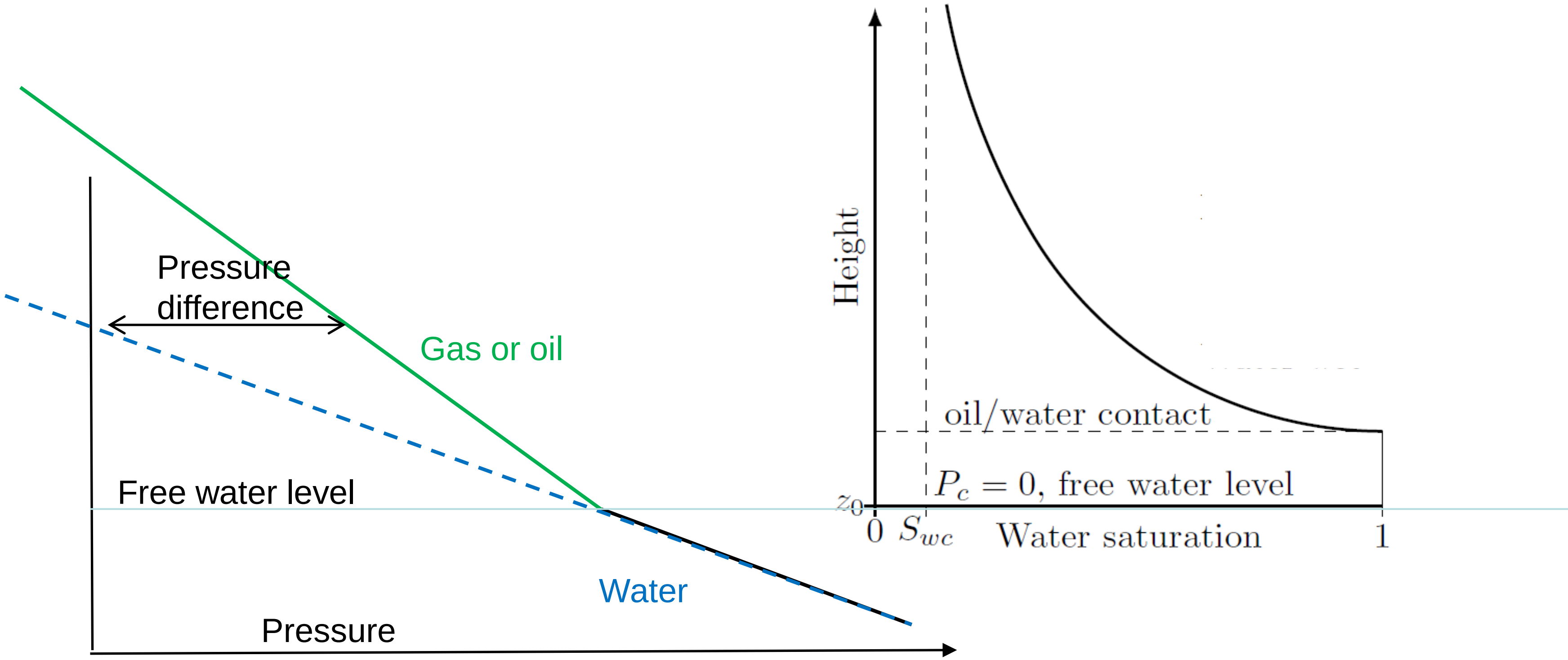
$$\Delta C = H \Delta P \sim H P_c \sim H\sigma/r \text{ (Young-Laplace)}$$

$$Flux\text{ , } F = AD\,\Delta C / L \quad \text{(Fick's law); } A \text{ is typical pore area.}$$

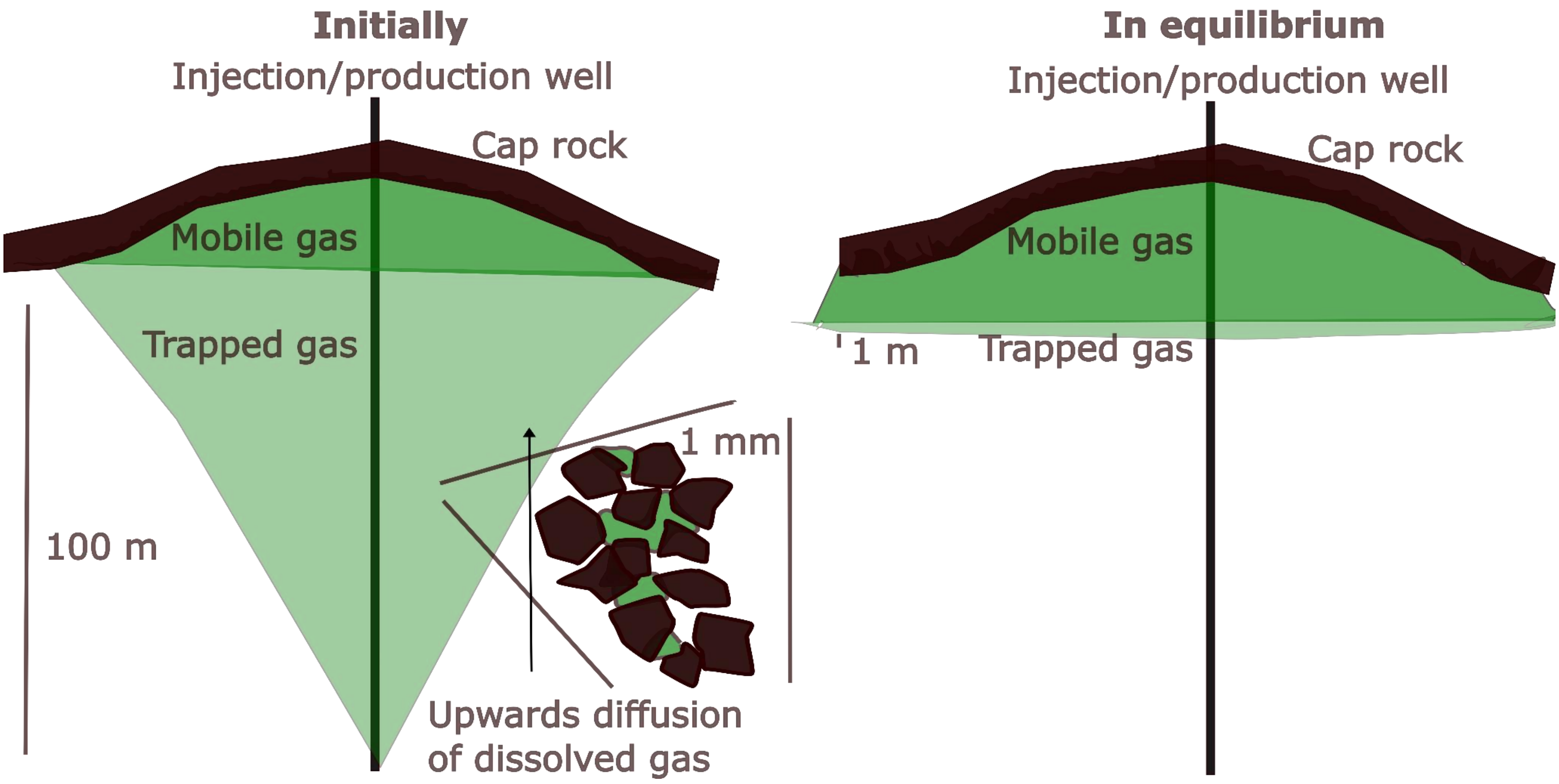
Capillary-Gravity Equilibrium

$$P_c(S_w) = \Delta\rho g z.$$

Traditional capillary-gravity equilibrium. Dissolved gas is not in equilibrium, as gas pressure decreases with height. Equilibrium achieved by a constant upwards flux of dissolved material balanced by a downwards flow of gas in its own phase. Energy provided thermally.



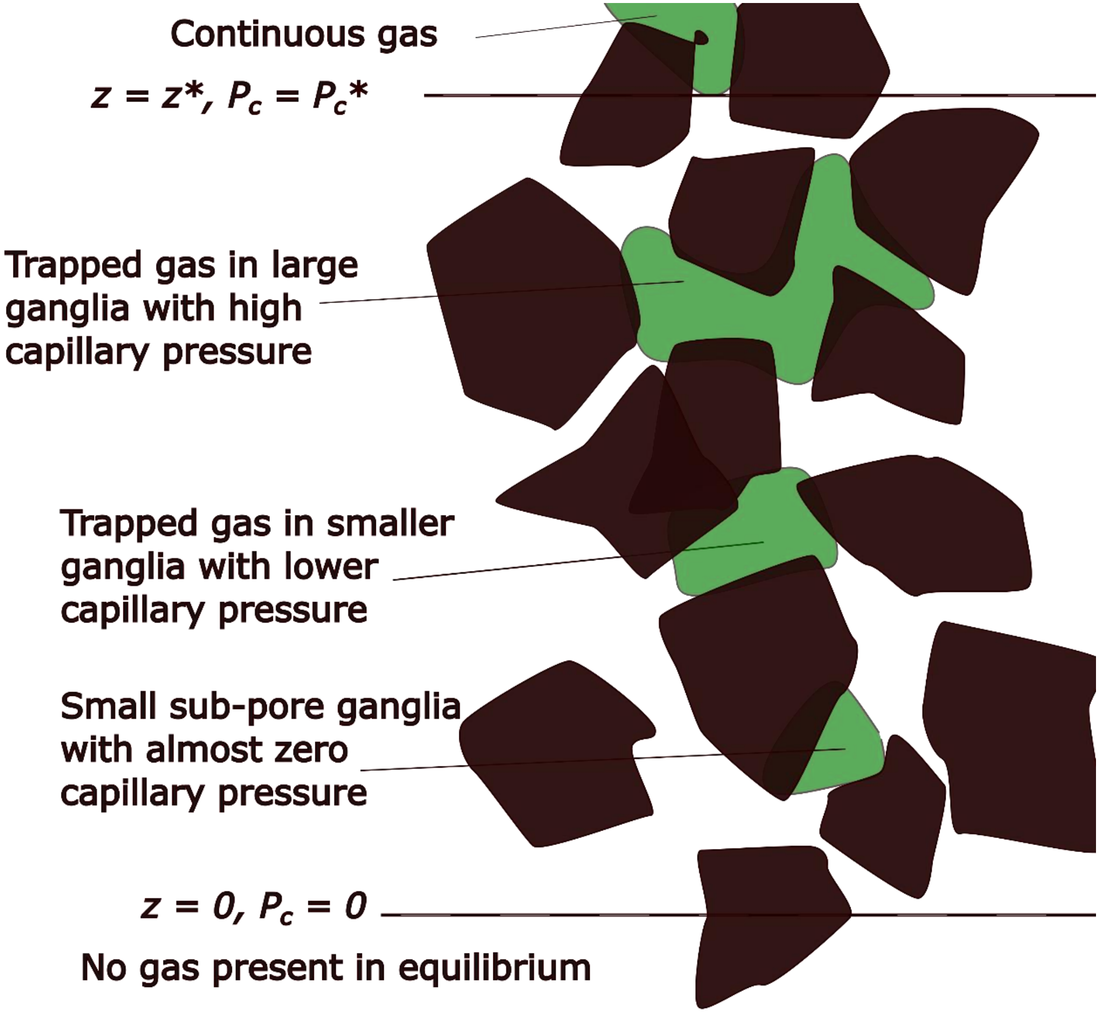
Ostwald Ripening



Ostwald Ripening

$$z^* = \frac{P_c^*}{\rho_w g + P^*(V_g \rho_w - m_g)g/RT}$$

Account for water pressure changes with depth, and density of the aqueous phase containing dissolved gas.



Time-scales for equilibrium

$$t = \frac{l^2 r \phi S_{gr} \rho_g}{2DH\sigma m_g}.$$

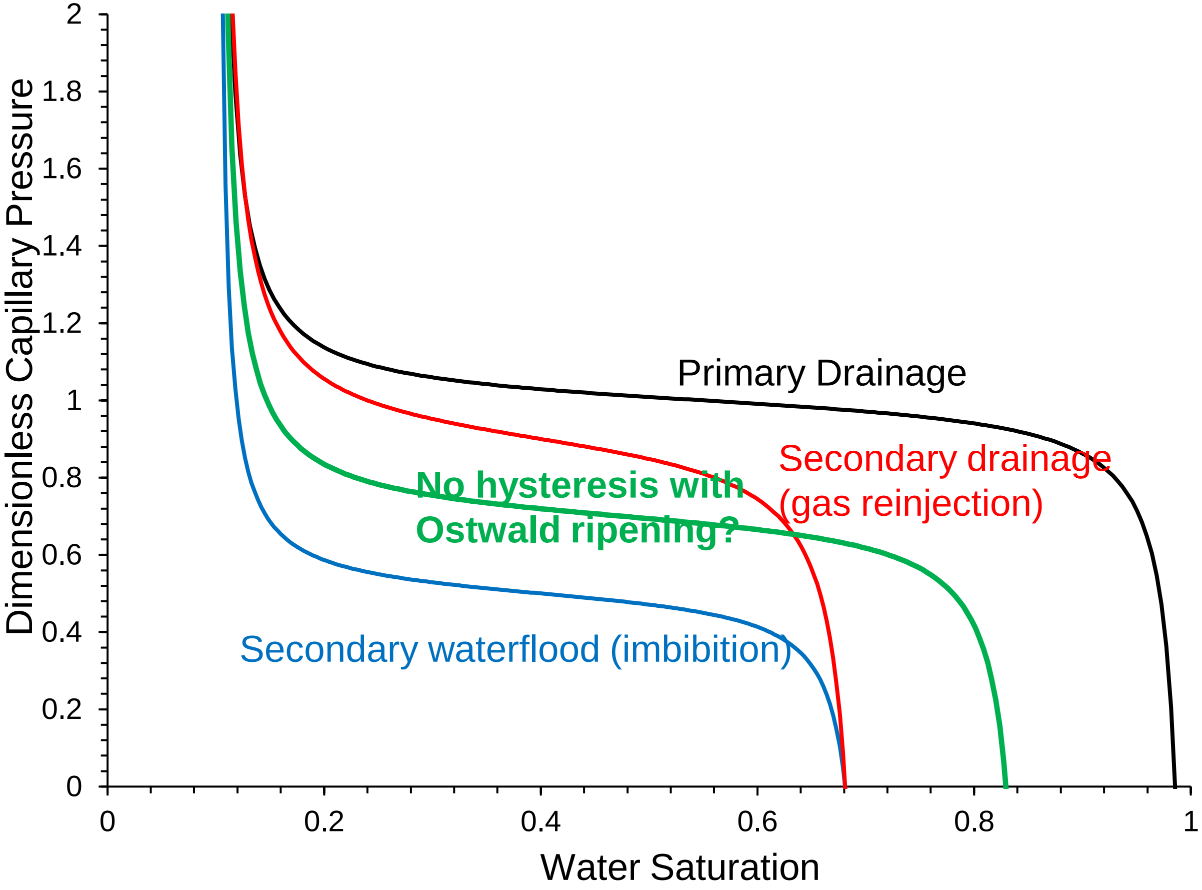
Property/Gas	CO_2	H_2	CH_4	N_2
Density ρ_g [kg.m^{-3}]	400	7.1	68	112
Interfacial tension with brine σ [Pa.s]	0.0349	0.07	0.057	0.0635
Molecular mass m_g [kg.mol^{-1}]	0.044	0.002	0.016	0.028
Partial molar volume V_g [m^3.mol^{-1}]	3.5×10^{-5}	2.5×10^{-5}	2.5×10^{-5}	4×10^{-5}
Diffusion coefficient D [m^2.s^{-1}]	7.2×10^{-10}	1.8×10^{-9}	6.4×10^{-10}	7.0×10^{-10}
Henry's constant H [mol.m^{-3}.Pa^{-1}]	1.8×10^{-4}	6.9×10^{-6}	9.2×10^{-6}	4.7×10^{-6}
Transition zone height z^* [m]	0.29	0.52	0.44	0.50
Timescale for pore-scale equilibrium t [s]	1.5×10^6	3×10^6	9×10^6	1.4×10^7
Timescale for field equilibrium t [s]	4×10^{13}	2×10^{14}	4×10^{14}	7×10^{14}

Implications

- At the field-scale (100s m) the timescales for equilibrium are millions of years: other processes, such as dissolution and reaction are faster.
- At the pore-to-core scale, the timescales are hours to months, which is relevant for storage operations. For hydrogen with seasonal storage maybe only one injection/withdrawal cycle per year.
- Core-scale properties – capillary pressure and relative permeability – may be affected. What will these functions be? Reduction in hysteresis.
- Subject of current and future work (Sepi and new student Waleed Dokhon).

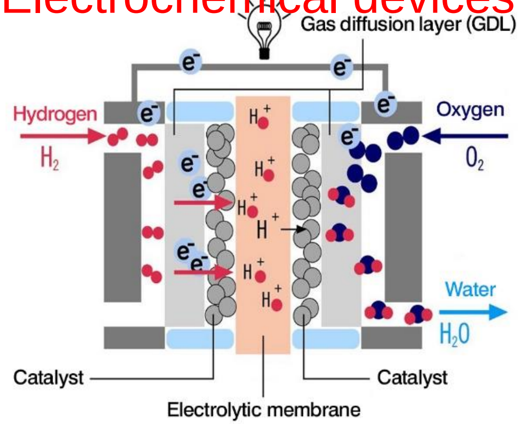
Working hypothesis

- Reduced/no hysteresis. Goof for hydrogen storage but may reduce the amount of capillary trapping for carbon dioxide.



Does it matter?

Electrochemical devices



Carbon and Hydrogen Storage

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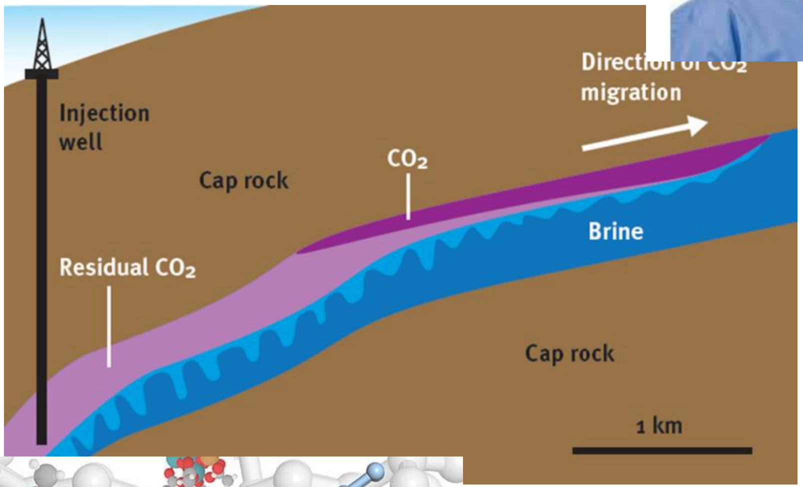
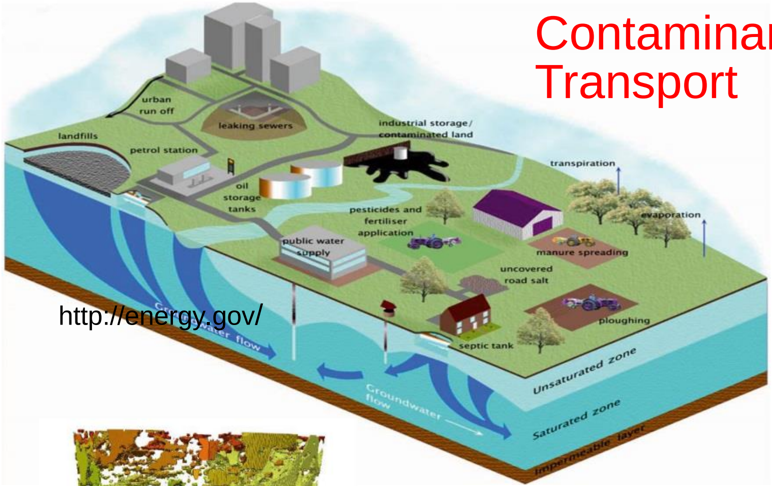
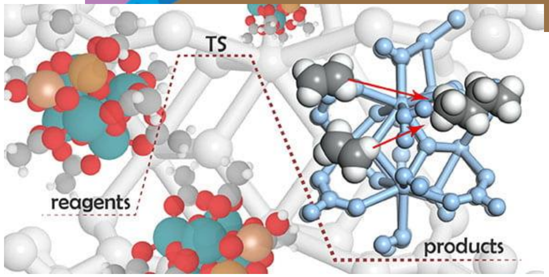


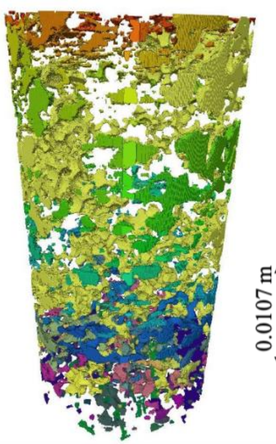
Contaminant Transport

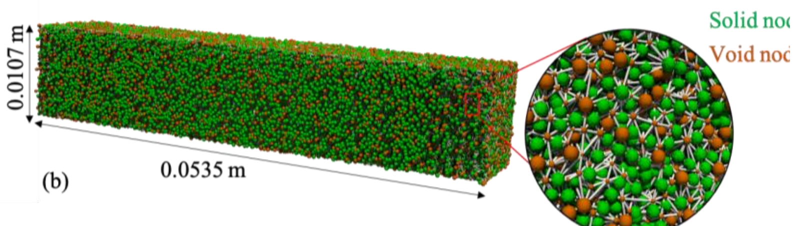


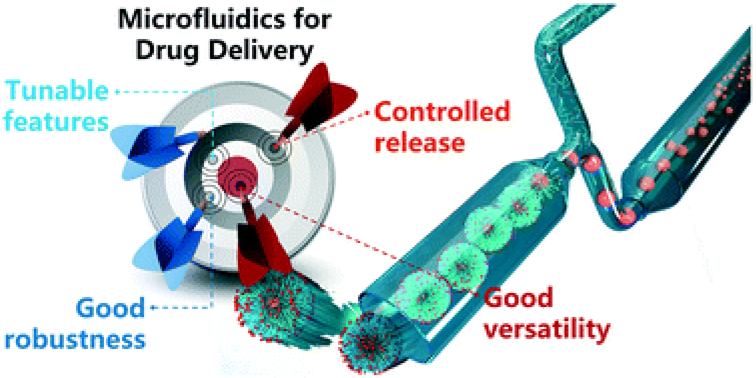
http://energy.gov/



Heat and Mass Transport







Many thanks

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