24th Anniversary of the Imperial College Consortium on Pore-Scale Modelling and Imaging

Yearly progress report

2nd January 2024

Martin Blunt, Branko Bijeljic, Qingyang Lin, Sajjad Foroughi, Sepideh Goodarzi, Waleed Dokhon, Ahmed Alzaabi, Hussein Alzahrani, Olatunbosun Adedipe, Ademola Adebimpe, Mingliang Qu, Jack Ma, Shanlin Ye, Yang Gao and Gang Luo

Executive Summary

This is the annual report of the Imperial College Consortium on Pore-Scale Modelling and Imaging. At our project meeting we will highlight the progress we have made over the last year as well as presenting plans for the future.

This last year has seen significant growth and renewal of our group as we continue to develop new research topics in hydrogen storage, machine learning and reactive transport. Abdullah Alhosani has now graduated: he won the John Archer Award for the best PhD student in the department with a truly extraordinary record of 12 journal publications on three-phase flow and displacement dynamics. He is now working for ADNOC in a prominent role working on sustainability. While Dr. Sultan Al-Jaber was in the limelight at the recent COP28 conference in the UAE, Abdullah was working hard behind the scenes. Luke Guidici also graduated and is now applying his coding skills working for an online bank. He made major advances in our understanding of the role of three-dimensional curvature in multiphase flow in the context of pore-scale modelling.

We now have a full team in the laboratory with the arrival of two new post-doctoral researchers, Rukuan Chai and Anin Patmonoaji. We have also welcomed new PhD students Ahmed Alzaabi, Waleed Dokhon, Olatunbosun Adedipe, Anfal Al Zarafi, Ibrahim Alobaidan, and Qianqian Ma While two of our visitors, Min Li and Linqi Zhu, left this year, we have welcomed new researchers who are making great progress on the application of machine learning to problems in imaging, flow in porous media and drilling: Yang Gao, Gang Luo and Shanlin Ye.

Our research is now almost entirely focussed on topics related to flow in porous media and the energy transition: carbon dioxide and energy storage, thermal energy storage and recovery, reactive transport, as well as the design and analysis of manufactured porous materials. Another new interest is using the large amount of data we have acquired from our pore-scale imaging experiments to provide training data for machine learning methods to generate fake pore-space images, and to assist in image segmentation and analysis.

We no longer prepare a separate written report. As a matter of routine practice, we now make all our publications – with associated codes and data – open access. Rather than collate some papers, I will simply provide the DOI links to all our recent work: in this way you can read whatever interests you from the considerable body of material that we have published in 2023.

Of course, we have many more results and ideas to present; these will be discussed at the meeting itself.

The current researchers in the group are:

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 – generalized pore-scale modelling and analysis

Rukuan Chai, Post-doctoral researcher – imaging and analysis of carbon dioxide storage

Anin Patmonoaji, Post-doctoral researcher – experimental measurements of displacement

Sepideh Goodarzi, 3rd year PhD student – analysis of hysteresis

Hussein Alzahrani, 3rd year PhD student – surfactant flooding

Abdulaziz Alsaleh, 2nd year PhD student – simulation of polymer flooding

Ademola Adebimpe, 2nd year PhD student – pore-scale modelling of intermittency and Ostwald ripening

Jack Ma, 2nd year PhD student – application of machine learning to pore-scale modelling

Waleed Dokhon, 1st year PhD student – experimental studies of hydrogen storage

Ahmed Alzaabi, 1st year PhD student – comparison of nitrogen, carbon dioxide and hydrogen storage

Anfal Al Zarafi, 1st year PhD student – carbon dioxide storage in reservoir carbonates

Olatunbosun Adedipe, 1st year PhD student, reactive transport and cement dissolution

Ibrahim Alobaidan, 1st year PhD student, modelling and design of hydrogen storage

Qianqian Ma, 1st year PhD student, experimental studies of reactive transport

Yang Gao, Visiting PhD student, machine-learning based image segmentation

Gang Luo, Visiting PhD student, machine-learning applies to NMR measurements

Shanlin Ye, Visiting PhD student, AI-driven management of drilling

Also a collaboration with Zheijang University in China:

Qingyang (Lewis) Lin, Professor, Zhejiang University, China – multiphase flow

Mingliang Qu, 3rd year PhD student Zhejiang University, China – multiphysics modelling

All our publications, theses, reports and presentations are available on our website:
https://www.imperial.ac.uk/earth-science/research/research-groups/pore-scale-modelling/

We also have a Github site where we have placed all our codes:
https://github.com/ImperialCollegeLondon/porescale

Project publications in 2023 with web links

Journal publications

1. G Zhang, S Foroughi, A Q Raeini, M J Blunt and B Bijeljic, "The impact of bimodal pore size distribution and wettability on relative permeability and capillary pressure in a microporous limestone with uncertainty quantification," Advances in Water Resources **171**, 104352 (2023)
   https://doi.org/10.1016/j.advwatres.2022.104352

2. H Khoshtarash, M Siavashi, M Ramezanpour and M J.Blunt, "Pore-scale analysis of two-phase nanofluid flow and heat transfer in open-cell metal foams considering Brownian motion," Applied Thermal Engineering, **221,** 119847 (2023).
   https://doi.org/10.1016/j.applthermaleng.2022.119847

3. H Hematpur, R Abdollahi, S Rostami, M Haghighi and M J Blunt, "Review of underground hydrogen storage: Concepts and Challenges," Advances in Geo-Energy Research, **7**, 111-131 (2023).
   https://doi.org/10.46690/ager.2023.02.05

4. Y Zhang, B Bijeljic, B, Y Gao, S Goodarzi, S Foroughi and M J Blunt, "Pore-scale observations of hydrogen trapping and migration in porous rock: Demonstrating the effect of Ostwald ripening," Geophysical Research Letters, **50**, e2022GL102383 (2023).
   https://doi.org/10.1029/2022GL102383

5. A Alhosani, A Selem, S Foroughi, B Bijeljic and M J Bunt, "Steady-state three-phase flow in a mixed-wet porous medium: A pore-scale X-ray microtomography study," Advances in Water Resources, **172**, 104382 (2023).
   https://doi.org/10.1016/j.advwatres.2023.104382

6. M Mahdaviara, M J Shojaei, J Siavashi, M Sharifi and M J Blunt, "Deep learning for multiphase segmentation of X-ray images of gas diffusion layers," Fuel, **345**, 128180 (2023).
   https://doi.org/10.1016/j.fuel.2023.128180

7. L M Giudici, A Q Raeini, M J Blunt and B Bijeljic, "Representation of Fully Three-Dimensional Interfacial Curvature in Pore-Network Models," Water Resources Research, **59**, e2022WR033983 (2023).
   https://doi.org/10.1029/2022WR033983

8. L M Giudici, A Q Raeini, T Akai, M J Blunt and B Bijeljic, "Pore-scale modeling of two-phase flow: A comparison of the generalized network model to direct numerical simulation," Physical Review E**, 107,** 035107 (2023).
   https://doi.org/10.1103/PhysRevE.107.035107

9. F Amrouche, M J Blunt, S Iglauer, M Short, T Crosbie, E Cordero and D Xu, "Using magnesium oxide nanoparticles in a magnetic field to enhance oil production from oil-wet carbonate reservoirs," Materials Today Chemistry, **27**, 101342 (2023).
   https://doi.org/10.1016/j.mtchem.2022.101342

10. M-L Qu, M J Blunt, X Fan, S Foroughi, Z-T Yu, and Q Lin, "Pore-to-mesoscale network modeling of heat transfer and fluid flow in packed beds with application to process design," AIChE J, e18213 (2023).
    https://doi.org/10.1002/aic.18213

11. G Zhang, S Foroughi, B Bijeljic and M J Blunt, "A Method to Correct Steady-State Relative Permeability Measurements for Inhomogeneous Saturation Profiles in One-Dimensional Flow," Transport in Porous Media, **149**, 837–852 (2023).
    https://doi.org/10.1007/s11242-023-01988-4

12.   R Oliveira, M J Blunt and B Bijeljic, **"**Impact of Physical Heterogeneity and Transport Conditions on Effective Reaction Rates in Dissolution," Transport in Porous Media, **146**, 113-138 (2023).
https://doi.org/10.1007/s11242-022-01836-x

13.   R Moghadasi, S Goodarzi, Y Zhang, B Bijeljic, M J Blunt and A Niemi, "Pore-scale characterization of residual gas remobilization in CO_2 geological storage," Advances in Water Resources, **179**, 104499 (2023).
https://doi.org/10.1016/j.advwatres.2023.104499

14.   R Moghadasi, S Foroughi, F Basirat, S R McDougall, A Tatomir, B Bijeljic, M J Blunt and A Niemi, "Pore-Scale Determination of Residual Gas Remobilization and Critical Saturation in Geological CO_2 Storage: A Pore-Network Modeling Approach," Water Resources Research, **59**, e2022WR033686 (2023).
https://doi.org/10.1029/2022WR033686

15.   G Zhang, M Regaieg, M J Blunt and B Bijeljic," Primary drainage and waterflood capillary pressures and fluid displacement in a mixed-wet microporous reservoir carbonate," Journal of Hydrology, **625**, 130022 (2023).
https://doi.org/10.1016/j.jhydrol.2023.130022

16.   A M Selem, N Agenet, S Foroughi, M J Blunt and B Bijeljic, "Pore-Scale Imaging of Emulsification of Oil during Tertiary and Secondary Low Salinity Waterflooding in a Reservoir Carbonate," Energy & Fuels, **37**, 21, 16368–16377 (2023).
https://doi.org/10.1021/acs.energyfuels.3c02317

17.   M Li, Sajjad Foroughi, J Zhao, B Bijeljic and M J Blunt, "Image-based pore-scale modelling of the effect of wettability on breakthrough capillary pressure in gas diffusion layers," Journal of Power Sources, **584**, 233539 (2023).
https://doi.org/10/1016/j.powsour.2023.233539

Martin Blunt and Branko Bijeljic, January 2024