25th Anniversary of the Imperial College Consortium on Pore-Scale Modelling and Imaging

Yearly progress report

2nd January 2025

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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.

Our activities have continued to grow this year – indeed we now have over 20 researchers in the group. We now have a large integrated effort on hydrogen storage, from the pore to the field scales, as well as a continued emphasis on machine learning. We also continue to work in our traditional areas of carbon dioxide storage, while pursuing new ideas related to the design of manufactured porous materials. Our overall theme is to study flow in porous media with application to the energy transition.

The highlight of 2024 for me was my election as a Fellow of the Royal Society. This is a huge honour that reflects on the hard work, imagination and dedication of the many wonderful PhD students, post-docs and other colleagues I have had the good fortune to work with over the years.

Linqi Zhu who left in 2023 is now back at Imperial as a post-doc supervised by Gege Wen who is a new lecturer in the department. His research leverages the large datasets we have to construct machine learning models to predict and interpret multiphase flow, and particularly to make best use of our time-resolved synchrotron images. He works closely with Menglu Kang, who is a new visitor from China. In return, two of our visitors – Yang Gao and Gang Luo – have now left, and Shanlin Ye is due to return to China early this year. Faisal Aljaberi has visited us from Khalifa University in the UAE working on improved methods to calculate curvature and contact angle from pore-scale images and to use the results for improved wettability characterization in our network modelling codes.

We have welcomed several new PhD students: Oranan Ariyarit who will study carbon dioxide storage in oil fields with application to projects in her native Thailand; Mohammed Bello who will work on reactive transport; Sasha Karabasova who is studying rate-dependent effects in flow in porous media through direct numerical simulation; and Yuxi Liang, who has transferred from Civil Engineering and is developing a pore-scale model of salt precipitation in carbon dioxide storage.

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 2024. As a start maybe read an article published in the inaugural issue of the new *InterPore Journal* that presents a perspective on research needs in porous media for the energy transition: this lays out a vision for our work over the coming years.

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

Linqi Zhu, Post-doctoral researcher – machine learning and time-resolved images

Sepideh Goodarzi, 4th year PhD student – analysis of hysteresis in hydrogen storage

Hussein Alzahrani, 4th year PhD student – surfactant flooding

Abdulaziz Alsaleh, 3rd year PhD student – simulation of polymer flooding

Ademola Adebimpe, 3rd year PhD student – pore-scale modelling of intermittency and Ostwald ripening

Jack Ma, 3rd year PhD student – application of machine learning to pore-scale modelling

Waleed Dokhon, 2nd year PhD student – experimental studies of hydrogen storage

Ahmed Alzaabi, 2nd year PhD student – comparison of nitrogen, carbon dioxide and hydrogen storage

Anfal Al Zarafi, 2nd year PhD student – carbon dioxide storage in reservoir carbonates

Olatunbosun Adedipe, 2nd year PhD student – reactive transport and cement dissolution

Ibrahim Alobaidan, 2nd year PhD student – modelling and design of hydrogen storage

Qianqian Ma, 2nd year PhD student – experimental studies of reactive transport

Yuxi Liang, 2nd year PhD student – pore-scale modelling of salt precipitation

Sasha Karabasova, 1st year PhD student – pore-scale modelling of rate effects

Mohammed Bello, 1st year PhD student – reactive transport

Oranan Ariyarit, 1st year PhD student – carbon dioxide storage in depleted oilfields

Shanlin Ye, Visiting PhD student – supervoxel segmentation

Menglu Kang, Visiting PhD student – denoising pore-scale images using machine learning

Faisal Aljaberi, Visiting PhD student – improved characterization of wettability

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 2024 with web links

Journal publications

1. J Siavashi, M Mahdaviara, M J Shojaei, M Sharifi and M J Blunt, "Segmentation of two-phase flow X-ray tomography images to determine contact angle using deep autoencoders," Energy, **288**, 129698 https://doi.org/10.1016/j.energy.2023.129698 (2024).

2. S Foroughi , B Bijeljic, Ying Gao, and M J Blunt, "Incorporation of Sub-Resolution Porosity Into Two-Phase Flow Models With a Multiscale Pore Network for Complex Microporous Rocks," Water Resources Research, **60**, e2023WR036393. https://doi.org/10.1029/2023WR036393 (2024).

3. A I Adebimpe, S Foroughi, B Bijeljic, and M J Blunt, "Percolation without trapping: How Ostwald ripening during two-phase displacement in porous media alters capillary pressure and relative permeability," Physical Review E, **110**, 035105 https://doi.org/10.1103/PhysRevE.110.035105 (2024).

4. S Goodarzi, Y Zhang, S Foroughi, B Bijeljic, and Martin J. Blunt, "Trapping, hysteresis and Ostwald ripening in hydrogen storage: A pore-scale imaging study," International Journal of Hydrogen Energy, **56**, 1139-1151. https://doi.org/10.1016/j.ijhydene.2023.12.029 (2024).

5. Y Da Wang, L M Kearney, M J Blunt, C Sun, K Tang, P Mostaghimi and R T Armstrong, "*In situ* characterization of heterogeneous surface wetting in porous materials," Advances in Colloid and Interface Science, **326**, 103122. https://doi.org/10.1016/j.cis.2024.103122 (2024).

6. M J Blunt, A Bazylak, M Brook, A Muggeridge, and F M Orr, "Research Needs in Porous Media for the Energy Transition," InterPore Journal, **1**(1), ipj260424–2. https://doi.org/10.69631/ipj.v1i1nr14 (2024).

7. M-L Qu, Ji Yang, S Foroughi, Y Zhang, Z-T Yu, M J Blunt, and Q Lin, "Pore-to-meter scale modeling of heat and mass transport applied to thermal energy storage: How local thermal and velocity fluctuations affect average thermal dispersivity," Energy, **296**, 131147. https://doi.org/10.1016/j.energy.2024.131147 (2024).

8. L Zhu, B Bijeljic, and M J Blunt, "Generation of pore-space images using improved pyramid Wasserstein generative adversarial networks," Advances in Water Resources, **190**, 104748. https://doi.org/10.1016/j.advwatres.2024.104748 (2024).

9. S Ye, X Song, M J Blunt, and B Bijeljic, "Domain adaptation neural network based prediction of real-time drill bit tooth wear," Geoenergy Science and Engineering, **240**, 213041. https://doi.org/10.1016/j.geoen.2024.213041 (2024).

10. A Izadpanahi, M J Blunt, N Kumar, M Ali, C C G Tassinari, M A Sampaio, "A review of carbon storage in saline aquifers: Mechanisms, prerequisites, and key considerations," Fuel, 369, 131744. https://doi.org/10.1016/j.fuel.2024.131744 (2024).

11. M Ramezanpour, M Siavashi, H Khoshtarash, and M J Blunt, "Transport and deposition of nanoparticles in porous media at the pore scale using an Eulerian-Lagrangian method," Journal of the Taiwan Institute of Chemical Engineers, **161**, 105536. https://doi.org/10.1016/j.jtice.2024.105536 (2024).

12. F Amrouche, M J Blunt, S Iglauer, F Aiouache, and M Short, "A novel hybrid enhanced oil recovery technique to enhance oil production from oil-wet carbonate reservoirs by combining electrical heating with nanofluid flooding," Materials Today Sustainability, **27**, 100915. https://doi.org/10.1016/j.mtsust.2024.100915 (2024).

13. Y Gao, S Foroughi, Z Ma, S Yuan, L Xiao, B Bijeljic, and M J Blunt, “Gradient Information Enhanced Image Segmentation and Automatic In Situ Contact Angle Measurement Applied to Images of Multiphase Flow in Porous Media,” Water Resources Research, **60**(9), e2023WR036869. https://doi.org/10.1029/2023WR036869 (2024).

14. W Dokhon, S Goodarzi, H M Alzahrani, M J Blunt, and B Bijeljic, “Pressure decline and gas expansion in underground hydrogen storage: A pore-scale percolation study,” International Journal of Hydrogen Energy, **86**, 261-274. https://doi.org/10.1016/j.ijhydene.2024.08.139 (2024).

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Martin Blunt and Branko Bijeljic, January 2025