

23rd Anniversary of the Imperial College Consortium on Pore-Scale Modelling and Imaging

Yearly progress report

3rd January 2023

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and Ademola Adebimpe**

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.

Two of our post-docs left to take up academic positions: Dr Yihuai Zhang is now a lecturer at the University of Glasgow, while Guanglei Zhang has a permanent academic position in China under the exceptional talents programme. We have recently welcomed a new post-doc to our group Dr Asli Gundogar, who will be working on pore-scale modelling, as well as four new PhD students Hussein Alzahari, Ademola Adebimpe, Jack Ma and Waleed Dokhon, and a new post-doctoral visitor, Linqi Zhu.

As mentioned last year, we have shifted the focus of our teaching and research away from applications principally associated with improved hydrocarbon recovery, towards activities related to the energy transition and porous materials more generally. At this consortium meeting you will hear talks on hydrogen storage, the analysis and modelling of multiphase flow in gas diffusion layers, as well as heat and mass transport with applications to catalytic reactors and heat exchangers. We are also rekindling our interest in applying machine learning to flow in porous media. In addition, we will describe our latest research on multi-scale imaging, experiments, analysis and modelling, the proper incorporation of curvature in pore-network models, and extensions our models to accommodate intermittent flow. We will also outline our plans to develop flow in porous and particulate media as a coherent discipline in its own right with integrated teaching, training and research across departments at Imperial College.

Our new MSc course GEMS (Geo-energy with Machine Learning and data Science) <https://www.imperial.ac.uk/earth-science/prosp-students/pg-courses/geo-energy-machine-learning/> is going well, training the next generation of subsurface geoscientists and engineers, who will have excellent computational skills applied to data science and machine learning. We also thank Total Energies for sponsoring a full scholarship on the programme.

As mentioned last year, we no longer prepare a separate written report. As a matter of routine practice, we now make all our publications – and associated data – open access. Rather therefore 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 2022.

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 – 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

Min Li, Visiting PhD student – modelling flow in gas diffusion layers

Also a collaboration with Zhejiang University in China:

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

Mingliang Qu, 2nd 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/>

Project publications in 2022 with web links

Journal publications

1. L Ladipo, M J Blunt and P R King, "Crossflow effects on low salinity displacement in stratified heterogeneity," *Journal of Petroleum Science and Engineering*, **208**, 109565 (2022).
<https://doi.org/10.1016/j.petrol.2021.109565>
2. K Singh, T Bultreys, A Q. Raeini, M Shams and M J Blunt, "New type of pore-snap-off and displacement correlations in imbibition," *Journal of Colloid and Interface Science*, **609**, 384–392 (2022).
<https://doi.org/10.1016/j.jcis.2021.11.109>
3. Y Zhang, Q Lin, A Q Raeini, Y Onaka, H Iwama, K Takabayashi, M J Blunt and B Bijeljic, "Pore-scale imaging of asphaltene deposition with permeability reduction and wettability alteration," *Fuel*, **315**, 123202 (2022).
<https://doi.org/10.1016/j.fuel.2022.123202>
4. M Ramezanzpour, M Siavashi, A Q Raeini and M J Blunt, "Pore-scale simulation of nanoparticle transport and deposition in a microchannel using a Lagrangian approach," *Journal of Molecular Liquids*, **355**, 118948 (2022).
<https://doi.org/10.1016/j.molliq.2022.118948>
5. A M Selem, N Agenet, M J Blunt and B Bijeljic, "Pore-scale processes in tertiary low salinity waterflooding in a carbonate rock: Micro-dispersions, water film growth, and wettability change," *Journal of Colloid and Interface Science*, **628**, 486–498 (2022).
<https://doi.org/10.1016/j.jcis.2022.06.063>
6. E Ranaee, R Khattar, F Inzoli, M J Blunt and A Guadagnini, "Assessment and uncertainty quantification of onshore geological CO₂ storage capacity in China," *International Journal of Greenhouse Gas Control*, **121**, 103804 (2022).
<https://doi.org/10.1016/j.ijggc.2022.103804>
7. G Imani, L Zhang, M J Blunt, S Foroughi, M Ntibahanana, H Sun and J Yao, "Three-dimensional simulation of droplet dynamics in a fractionally-wet constricted channel," *Advances in Water Resources*, **170**, 104341 (2022).
<https://doi.org/10.1016/j.advwatres.2022.104341>
8. S Foroughi, B Bijeljic and M J Blunt, "A Closed-Form Equation for Capillary Pressure in Porous Media for All Wettabilities," *Transport in Porous Media*, **145**, 683–696 (2022).
<https://doi.org/10.1007/s11242-022-01868-3>
9. M J Blunt, "Ostwald ripening and gravitational equilibrium: Implications for long-term subsurface gas storage," *Physical Review E*, **106**, 045103 (2022).
<https://link.aps.org/doi/10.1103/PhysRevE.106.045103>
10. F Amrouche, D Xu, M Short, S Iglauer, J Vinogradov and M J Blunt, "Experimental study of electrical heating to enhance oil production from oil-wet carbonate reservoirs," *Fuel*, **324(A)**, 124559 (2022).
<https://doi.org/10.1016/j.fuel.2022.124559>
11. 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*, (2022).
<https://doi.org/10.1007/s11242-022-01836-x>

12. G Imani, L Zhang, M J Blunt, C Xu, Y Guo, H Sun and J Yao, "Quantitative determination of the threshold pressure for a discontinuous phase to pass through a constriction using microscale simulation," *International Journal of Multiphase Flow*, **153**, (2022).
<https://doi.org/10.1016/j.ijmultiphaseflow.2022.104107>
13. C Spurin, M Rücker, M Moura, T Bultreys, G Garfi, S Berg, M J Blunt and S Krevor, "Red Noise in Steady-State Multiphase Flow in Porous Media," *Water Resources Research*, **58**, e2022WR031947 (2022).
<https://doi.org/10.1029/2022WR031947>
14. A Q Raeini, L M Giudici, M J Blunt and B Bijeljic, "Generalized network modelling of two-phase flow in a water-wet and mixed-wet reservoir sandstone: Uncertainty and validation with experimental data," *Advances in Water Resources*, **164**, 104194, (2022).
<https://doi.org/10.1016/j.advwatres.2022.104194>
15. M-L Qu, S-Y Lu, Q Lin, S Foroughi, Z-T Yu and M J Blunt, "Characterization of Water Transport in Porous Building Materials Based on an Analytical Spontaneous Imbibition Model," *Transport in Porous Media*, **143**, 417–432 (2022).
<https://doi.org/10.1007/s11242-022-01776-6>
16. M J Shojaei, B Bijeljic, Y Zhang and M J Blunt, "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," *ACS Applied Energy Materials*, **5**(4), 4613-4621 (2022).
<https://doi.org/10.1021/acsaem.2c00023>
17. Y Zhang, B Bijeljic and M J Blunt, "Nonlinear multiphase flow in hydrophobic porous media," *Journal of Fluid Mechanics*, **934**, R3 (2022).
<https://doi.org/10.1017/jfm.2021.1148>
19. S Mukherjee, R T Johns, S Foroughi and M J Blunt, "Fluid – Fluid Interfacial Area and Its Impact on Relative Permeability - A Pore Network Modeling Study," *SPE Journal*, **27**, 1-11 (2022).
<https://doi.org/10.2118/209445-PA>
18. 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>

Conference proceedings

20. A Selem, N Agenet, M Blunt and B Bijeljic, "Observations of water-in-oil micro-dispersions as a displacement mechanism in secondary and tertiary low salinity waterflooding," *Proceedings of the Fourth EAGE WIPIC Workshop*, March 2022.
<https://doi.org/10.3997/2214-4609.20224123>

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Martin Blunt and Branko Bijeljic, January 2023