Spurin, C., Bultreys, T., Rücker, M., Garfi, G., Schlepütz, C., Novak, V., Berg, S., Blunt, M. and Krevor, S. (2021). The development of intermittent multiphase fluid flow pathways through a porous rock. *Advances in Water Resources*, 150, p.103868. <https://doi.org/10.1016/j.advwatres.2021.103868>>.

One of the important transport modes for natural gas production and CO2 storage is intermittent fluid flow, which has not been fully understood why it occurs at surface conditions. Recently, Spurin et al., (2021) have found intermittency is more likely to occur in poorly connected pore spaces. They also investigated the intermittency implications of relative permeability as an upscaled flow property. They observed increasing capillary pressure increases the relative permeability in a non-linear fashion. If the capillary pressure has a close value to the non-wetting phase entry pressure, intermittency pathways can be observed in the intermediate-sized pores.

M. J. Blunt, *Multiphase flow in permeable media: A pore-scale perspective*. Cambridge University Press, 2017

Understanding the behaviour of three phase flow is one of the important feature to design the reservoir models, as it can explain the oil, gas and water behaviours in geological system

At present, relative permeability – the saturation-dependent factor by which flow conductance is reduced in multiphase flow – can either be measured experimentally or predicted empirically.

A. H. Alizadeh and M. Piri, "Three-phase flow in porous media: A review of experimental studies on relative permeability," *Reviews of Geophysics,* vol. 52, no. 3, pp. 468-521, 2014/09/01 2014, doi: 10.1002/2013RG000433.

our empirical models are currently incapable of predicting three-phase relative permeability to within an acceptable accuracy in many circumstances. Amongst the various experimental methods, the steady-state method is considered the most reliable since it directly uses the multiphase Darcy law in the measurement procedure.

1. Gao, Y., Lin, Q., Bijeljic, B., & Blunt, M. J. (2017). X-ray microtomography of intermittency in multiphase flow at steady state using a differential imaging method. Water Resources Research, 53, 10, pp.274–10,292. https:// doi.org/10.1002/2017WR021736

Gao and et al. (2017) investigated the impacts of flowrate on the pore-scale distribution of fluids during coinjection. They examined a arrange of fractional flow at the lower capillary number, Ca, (3\*10-7) to measure steady state relative permeability. The results showed although the convectional theory is consist for the lower Ca, the intermittent phase appeared significantly in fraction of the pore space when water and oil both present at the higher capillary number. Moreover, the method that they used to measure the relative permeability took less time.

doi: 10.1103/PhysRevE.103.013110: Gao et al. [18] observed intermittent pore occupancy during simultaneous injection of decane and brine in a Bentheimer sandstone for a capillary number, Ca = 7.5 × 10−6, while fixed pathway flow was seen for a lower capillary number, Ca = 3.0 × 10−7

1. Scanziani, A., Alhosani, A., Lin, Q., Spurin, C., Garfi, G., Blunt, M. J., & Bijeljic, B. (2020). In situ characterization of three-phase flow in mixed-wet porous media using synchrotron imaging. Water Resources Research, 56, e2020WR027873. https://doi.org/ 10.1029/2020WR027873

Scanziani and et al. (2020) investigated a mixed wet carbonate rock sample for the dynamics of immiscible gas injection. The results showed the most to least wetting phase in order of oil, water and gas. They also found gas can appear intermediate wet phase in some of the displacement, the gas is not completely nonwetting to water.

1. Gao, Y., Lin, Q., Bijeljic, B. and Blunt, M. (2020). Pore-scale dynamics and the multiphase Darcy law. *Physical Review Fluids*, 5(1), pp.013801-12. <http://doi/10.1103/PhysRevFluids.5.013801>

Gao and et al. (2020) studied the behaviour of injected oil and water through a sandstone at steady state condition to determine flow regimes. They found a linear relationship between flowrate and pressure gradient in the fixes pathway, which were consist with the multiphase Darcy law. The results indicated another regime, known as intermittent flow. They observed a non-linear relationship, a power law, between flow rate and pressure gradient, which is rapidly changes in fluid configuration of the pore space.

Yihuai doi. org/10.1029/2020GL090477 (Gao et al. (2020) quantified the threshold capillary number for the onset of intermittency Cai as ∼10−5 and found a = 0.6 from experiments of steady-state flow on water-wet Bentheimer sandstone for fw = 0.5; however, there were only eight data points)

In this recent work [22], when the capillary number was increased from 2.1 × 10−7 to 4.2 × 10−5, we observed fluid displacements with complex interface dynamics in three flow regimes: regime 1 for Ca < 10−6 was capillary dominated, regime 2 beyond Ca∗ ≈ 10−6 was characterized by the onset of dynamics, while regime 3 for Ca > Cai ≈ 10−5 was defined as the intermittent flow regime with a nonlinear relationship between flow rate and pressure gradient.

In our previous work [22] we observed two types of fluctuation: the first, called type 1, was when we saw a distinct change in the phase occupying a voxel from one scan to the next, as shown in Fig. 3. This represented a change in fluid configuration that occurred over a timescale of 1 min or more. The second behaviour, called type 2, was when the fluctuations were rapid enough to occur within 1 min, shown in Fig. 2.

1. Zhang, Y., Bijeljic, B., Gao, Y., Lin, Q., & Blunt, M. J. (2021). Quantification of nonlinear multiphase flow in porous media. Geophysical Research Letters, 48, e2020GL090477. https://doi. org/10.1029/2020GL090477

Zhang et al. (2021) proposed that the exponent in the power law in the transition from linear to nonlinear flow is a function of fractional flow. For flowrate equals to 0.2, the value of a = 0.74 ± 0.02 showed the lowest degree of intermittency and the strong deviation from linear occurred in flowrate of 0.6 with the lowest exponent a = 0.44 ± 0.02.

1. Gao Y, Raeini AQ, Blunt MJ, Bijeljic B. (2021). Dynamic fluid configurations in steady-state two-phase flow in Bentheimer sandstone. Phys Rev E. Jan;103, pp. 013110-14. doi: 10.1103/PhysRevE.103.013110. PMID: 33601546.
2. Gao Y, Raeini AQ, Blunt MJ, Bijeljic B. (2019). Pore occupancy, relative permeability and flow intermittency measurements using X-ray micro-tomography in a complex carbonate, Advances in Water Resources, 129, Pages 56-69,ISSN 0309-1708, <https://doi.org/10.1016/j.advwatres.2019.04.007>.

Gao et al. [19] confirmed intermittency in Estaillades limestone at Ca = 7.3 × 10−6 and observed that the intermittency is principally seen in the smaller and intermediate-sized pores and throats.

1. Catherine Spurin, Tom Bultreys, Branko Bijeljic, Martin J. Blunt, and Samuel Krevor. (2019). Intermittent fluid connectivity during two-phase flow in a heterogeneous carbonate rock Phys. Rev. E **100**, 043103

### Mechanisms controlling fluid breakup and reconnection during two-phase flow in porous media. Catherine Spurin, Tom Bultreys, Branko Bijeljic, Martin J. Blunt, and Samuel Krevor, Phys. Rev. E 100, 043115 – Published 29 October 2019