Three-phase is ubiquitous in many energy-related physical processes such as oil recovery, carbon dioxide geo-sequestration, fuel cells optimisation and contaminant removal (Blunt, 2017). In a world which is continuously requiring more energy due to population increase, and at the same time less emissions of greenhouse gases due to the efforts in mitigating climate change, the combination of gas driven enhanced oil recovery (EOR) with CO_2 storage (CCS) is certainly one of the technologies the world has to adopt for its sustainable development (IEA, 2017).

X-ray micro-CT tomography has recently allowed for major improvements in the understanding of two-phase flow (Blunt et al., 2013; Bultreys et al., 2016; Singh et al., 2019). In our studies we apply the techniques developed for two phases to systems where three phases – water, oil and gas, involved in EOR and CCS – are present, also developing new methods required by the peculiarities of three-phase flow. We were able to image the flow of the three phases during and after their injection in porous rocks, for different rocks and wettability.

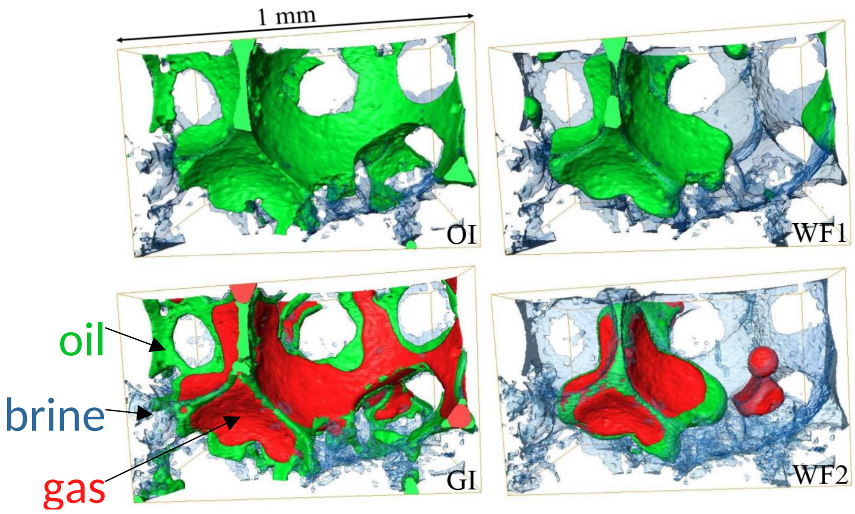

Figure 1: Three-dimensional visualisation of the arrangement of three immiscible phases - brine, oil and gas - in the pore space of a carbonate rock at high pressure and temperature. The four images are obtained at the end of oil injection (OI), first waterflooding (WF1), gas injection (GI) and second waterflooding (WF2).

The first experiment consisted of oil injection in a water-wet Ketton sample completely saturated with brine, followed by brine, gas and brine injection. The sample was imaged after each injection step using a laboratory micro computed tomography (μ-CT) scanner. With this experiment, we were able to image the three phases at the end of each injection step and visualise the arrangement of the three phases in the pore space, as shown in figure 1. The wettability has a strong effect on how the three phases occupy the pores and we quantified with pore occupancy analysis that, in water-wet samples, brine occupies the smallest pores, oil the middle and gas the centre of the biggest pores (Scanziani et al., 2018).
The second experiment was similar to the first one, but it was performed at Diamond synchrotron facility, where the higher energy of X-rays allowed dynamic imaging during the injections. We were able to dynamically image the formation of oil layers during gas injection and the lowering in their thickness over time. We also obtained images of the dynamics of double capillary trapping: the mechanism causing the trapping of gas in the centre of the pores during the second waterflooding. We studied this mechanism using four Minkowski functions – volume, connectivity, interfacial area and curvature of interfaces – which can be used to completely characterise multiphase flow (Armstrong et al., 2018).

The third experiment was performed at conditions which better replicate the subsurface at oil reservoirs, as the reservoir carbonate sample, the brine and the crude oil were provided from a producing oil field in the Middle East. This sample was also aged, causing a change of the wettability towards oil-wet conditions, which is believed to be found in carbonate reservoirs. We observed how a change in wettability (measured by *in situ* contact angle (AlRatrout et al., 2017; Scanziani et al., 2017)) affects the wettability order, pore occupancy, recovery and trapping (figure 2).

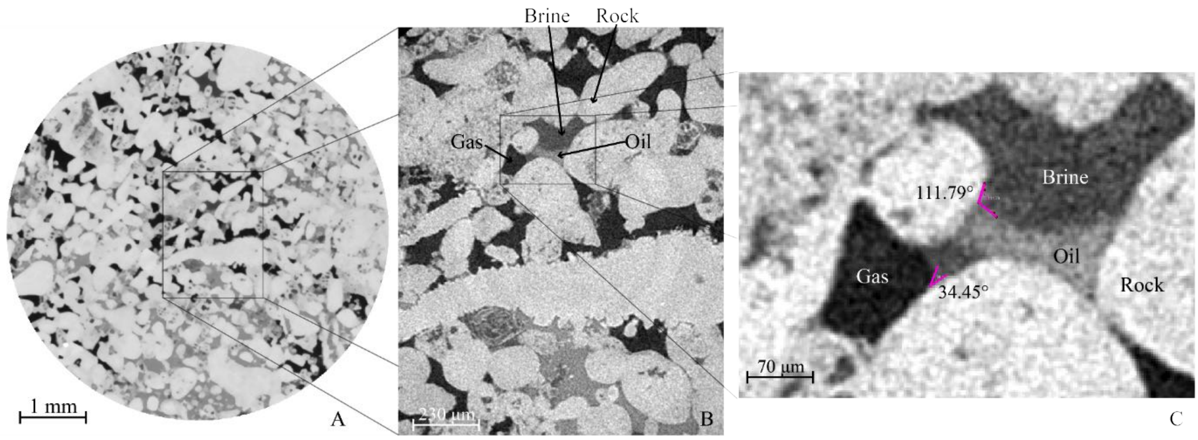

Figure 2: two dimensional slice of grey scale three dimensional images of the pore space obtained with micro-CT. We show how the change in wettability (quantified by contact angles) affects the arrangement of the fluids in the pore space.

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