# PS Modelling Wettability Alteration in Microporous Carbonate Rocks*

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## Abstract

Representing the wettability of a porous medium in a model is crucial for modelling multi-phase flow processes. The wetting behaviour of a system from pore to pore is difficult to assess since no accurate measurement technique is available. In fact, the commonly used classification system for mixed-wettability states (mixed-wet large, mixed-wet small, fractionally-wet) is presumably unable to mimic complex wettability configurations, especially found in microporous carbonates as a result of their heterogeneous multi-scale pore space. Indeed, the presence of microporosity (pores that are <10μm in diameter) adds complexity to the task since its wetting characteristics have been largely unknown. Nevertheless, recent experimental results suggested the existence of a unifying pattern of wettability on micrite particles that may simplify the modelling of wettability in carbonate rocks. In this work, we modelled a physically-based wettability alteration mechanism based on the tightly correlated concepts of disjoining pressure and thin-films collapse. We incorporated the model into an existing state-of-the-art two-phase flow network model, and were able to qualitatively reproduce the pore-scale wettability trends observed from high resolution imaging. By analysing the pore occupancies, relative permeability and capillary pressure curves, and the residual oil saturations, we demonstrated that in the particular case where micropores provide the connectivity to the network, the wettability state of the micropores is essential as it proved to control the recovery.

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## INTRODUCTION

- Understanding the wettability of a porous medium is essential for oil recovery optimisation.
- The common classification system for mixed-wettability states (Figure 5), either distributed according to pore size (Mixed-Wet Large and Mixed-Wet Small) or randomly (Fractionally-Wet) is probably insufficient to describe complex wettability configurations.
- Particularly, carbonates with micro-porosity (<10µm in diameter) display a highly unpredictable distribution of wettability due to the heterogeneity of their multi-scale pore space.
- Nonetheless, recent experimental results [1] suggest the existence of a unifying pattern of wettability in microporous carbonates.

## OBJECTIVES

- Model a physically-based scenario of wettability alteration.
- Reproduce qualitatively a pattern reported in the literature for wettability distributions in carbonates.
- Produce Capillary Pressure ($P_c$), Relative Permeability ($K_r$) and Residual Oil Saturation ($S_{or}$) curves.

## METHODOLOGY

- We model a physically-based wettability alteration mechanism based on the concepts of disjoining pressure and thin-films collapse, dependent on pore size, shape and prevailing capillary pressure [2].
- We incorporate the model into an existing state-of-the-art Two-Phase Flow Network Model [3].
- The simulations are carried out on the integrated two-scale network shown in Figure 1. The methodology of the multi-scale construction from a microporous carbonate dataset are presented in [4].

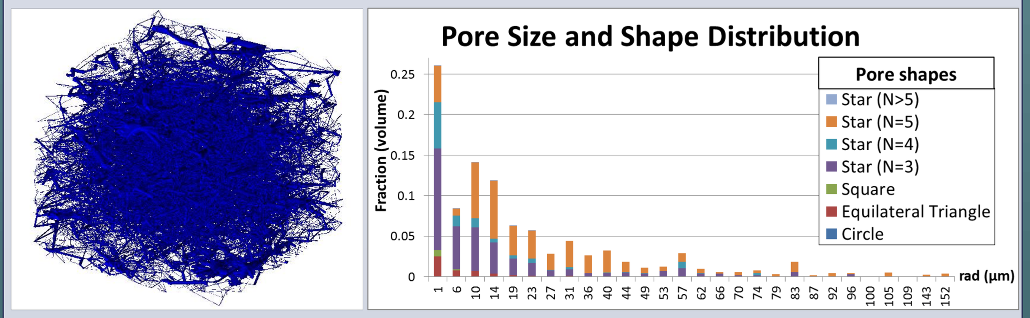


Figure 1: Carbonate Network (a) 3D representation and (b) pore size and shape distribution

## PRIMARY DRAINAGE

First, Primary Drainage (PD) is modelled, assuming a weakly water-wet rock (30° contact angle). The process may continue until the Irreducible Water Saturation is reached (Figure 2(a)), where no further pore-scale displacements are possible under capillary control, or stopped at a fixed $S_{wi}$ (Figure 2(b)).

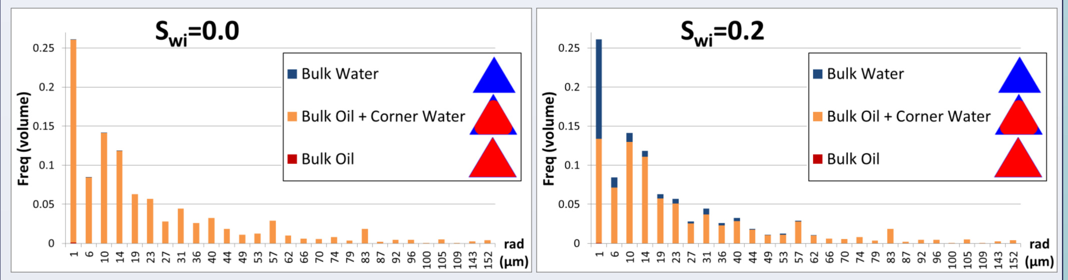


Figure 2: Pore occupancy at the end of PD at (a) $S_{wi}$=0 and (b) $S_{wi}$=0.2 shown on the pore size distribution

## AGEING – WETTABILITY ALTERATION

As an alternative to the common wettability distributions, a physically-based scenario was developed, referred to as Altered-Wet. The mechanism is illustrated in Figure 3, where thin water films coating the pore walls control wettability. Indeed, where the thin films collapse, the pore surfaces are rendered oil-wet.

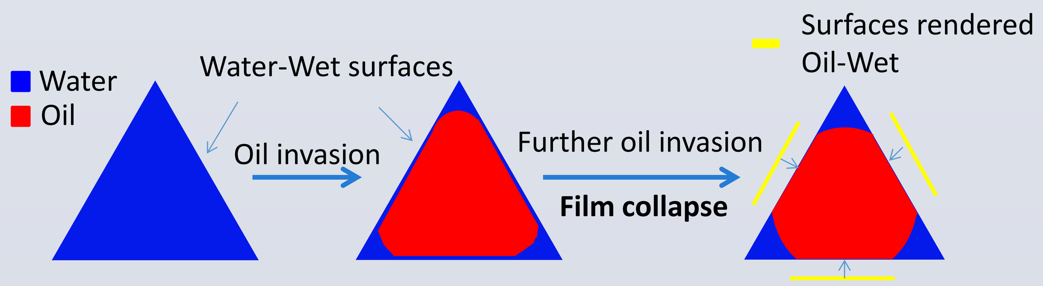


Figure 3: Illustration of the Altered-Wet mechanism in a triangular pore cross-section

Pore size and shape (resulting in wall curvature) mainly control the stability of the thin films, hence the wettability. As illustrated in Figure 4(a), by strictly using concave star shapes: the more curved the pore surface (in absolute value), the more oil-wet it is likely to be. Therefore, the model qualitatively reproduces the unifying pattern shown by high-resolution imaging Figure 4(b).

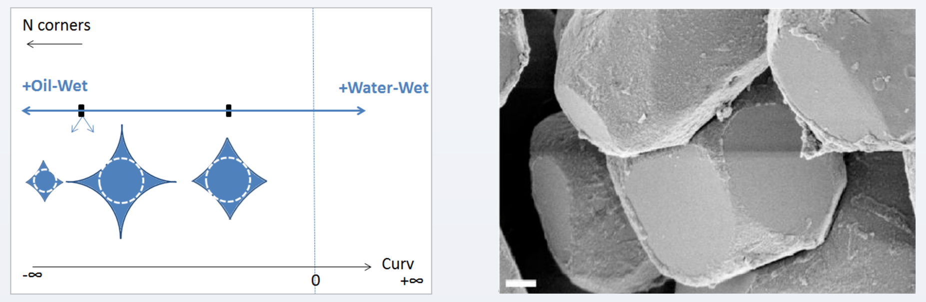


Figure 4: (a) Likelihood of pore wettability depending on curvature and number of corners and (b) FESEM imaging of the oil deposits (i.e. the footprint of the wettability alteration) [1]

The Altered-Wet model resulted in a wettability distribution distinct from the mixed-wet and fractionally-wet distributions (Figure 5), and exhibits a more complex configuration determined by both pore size and shape.

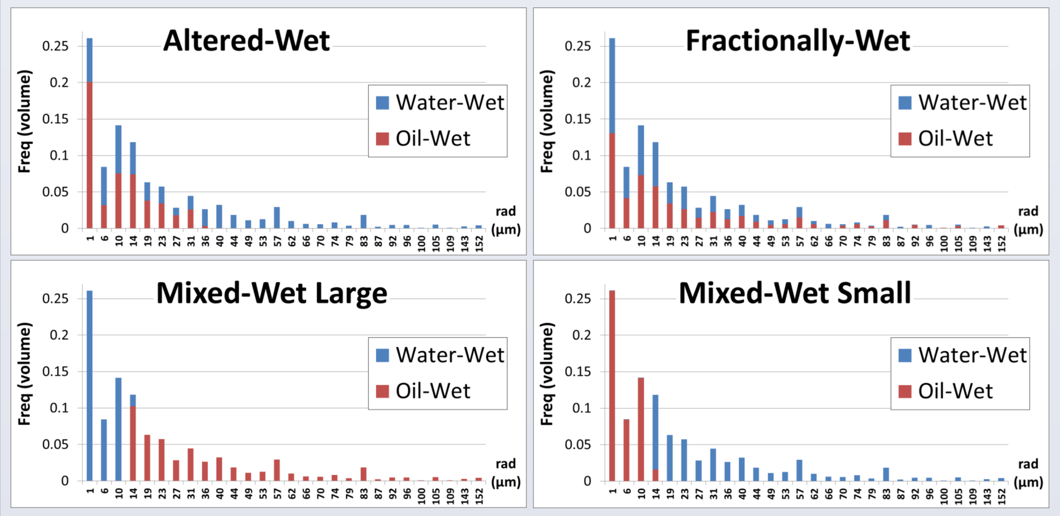


Figure 5: Different wettability distributions shown on the pore size distribution at $f_{oil\text{-}wet}$=0.5

## WATER-FLOOD

The water-flood process is modelled to reach an $S_{or}$ value below which no further oil mobilization can take place by capillary forces. During the process, oil layers may form in oil-wet pores [5] (Figure 6), which play an important role in oil flow. Indeed, they prevent oil from being trapped.

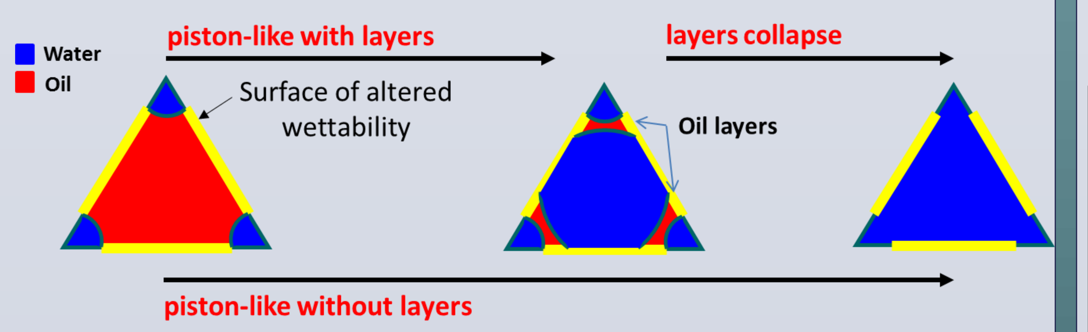


Figure 6: Displacements involving oil layers formation and collapse in a triangular pore cross-section

The pore occupancy is shown at the end of the water-flood for the different wettability distributions at a fixed oil-wet fraction (Figure 7).

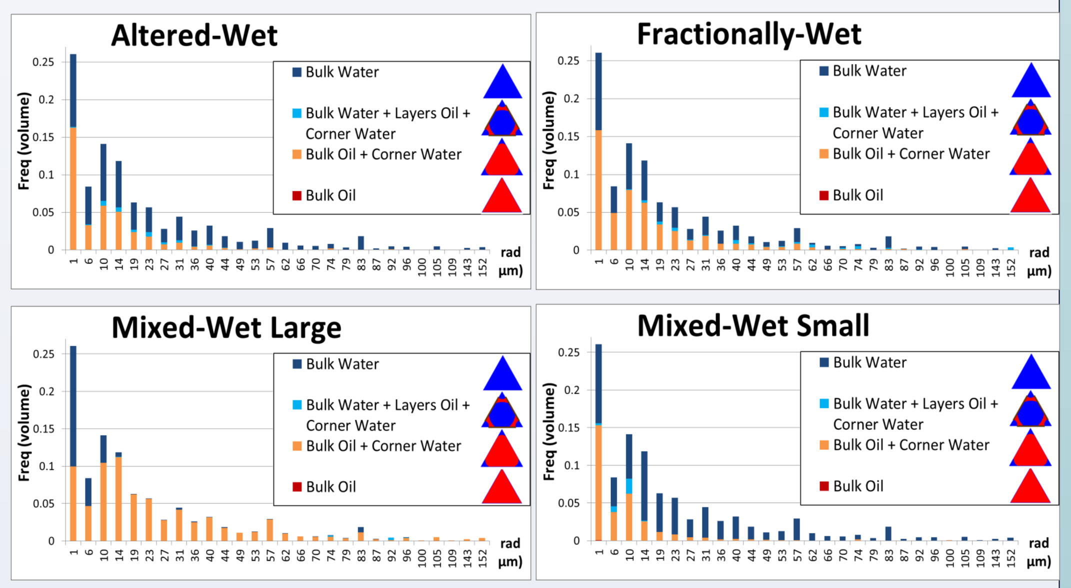


Figure 7: Pore occupancy at the end of the water-flood for the different wettability distributions ($f_{oil\text{-}wet}$=0.5) shown on the pore size distribution

Since the micropores provide the overall connectivity for the disconnected macroporous space in the considered microporous carbonate dataset, two interesting limiting cases emerge:

- Mixed-Wet Large: The micro-pores are water-wet, therefore these pores are first filled with water, thereby trapping oil in the macro-pores. Consequently, the recovery is poor compared to the other scenarios.
- Mixed-Wet Small: The micro-pores are oil-wet, therefore they are left to be filled at the end of the process, with the formation of some oil-layers (light-blue in Figure 7), leading to the best recovery amongst the different scenarios.

The recoveries for the Altered-Wet and Fractionally-Wet scenarios lie between these two extreme cases.

The resulting $P_c$ and $K_r$ and $S_{or}$ curves for the different wettability distributions (Figure 8) show that the wettability configuration greatly affects the petrophysical properties for this particular dataset.

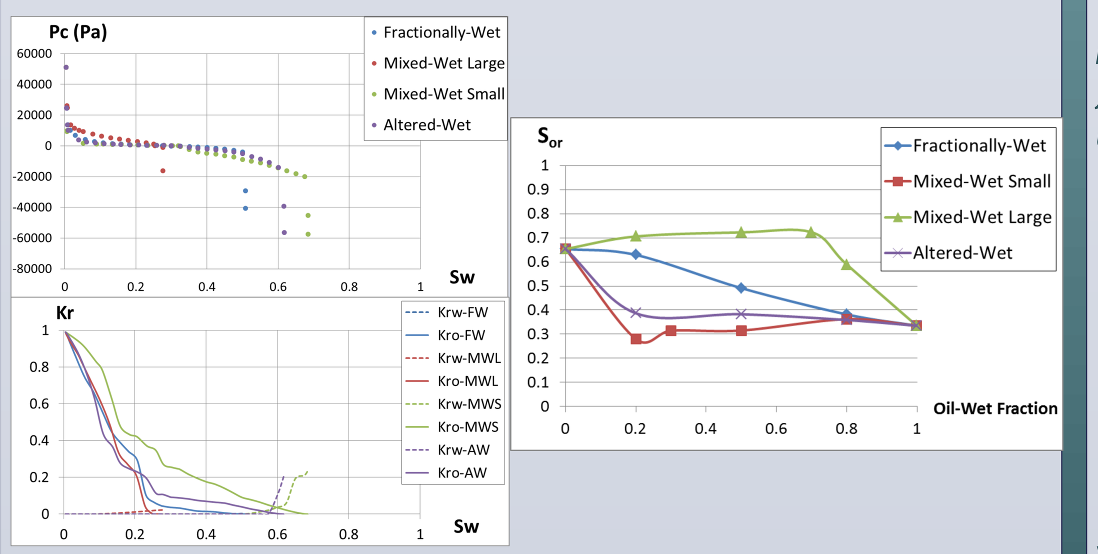


Figure 8: (a) $P_c$ and $K_r$ curves ($f_{oil\text{-}wet}$=0.5) and (b) $S_{or}$ for different wettability fractions and distributions

## CONCLUSIONS

- We implemented a physically-based wettability alteration scenario in a state-of-the-art two-phase flow network model.
- The model qualitatively reproduced a unifying pattern of wettability observed in microporous carbonates by high-resolution imaging, where the more curved faces become preferentially oil-wet.
- We showed that under the circumstances where micropores provide the connectivity to the network, the wettability state of the micropores is vital as it controls the recovery.

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