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Pore Scale Investigations of Forced Imbibition/Drainage in Porous Media Studied by in situ X-Ray Microtomography

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The forced imbibition or drainage of an aqueous phase into an initially oil filled bead matrix is studied. The advancement of the water front is imaged in real-time using ultrafast x-ray tomography. The 3d time series are analysed in terms of oil saturation, front area and morphology of the pore-throat filling behaviour. The displacement behaviour hardly depends on gravitational effects and details of the pore space, as was explicitly tested. For flow rate of the invading phase or viscosity of the defending phase below a certain threshold the dependence of both viscosity and velocity can be also neglected. For typical front velocities of about 3 µm/s, as e.g. relevant for oil recover, the multiphase flow is dominated by capillarity and the wettability of the porous matrix with the invading phase is the key parameter to understand the displacement behaviour. We could identify a wetting and a non-wetting regime for small and low contact angles of the invading phase with a transition region of about &theta &sim 30° separating both regimes. Within each regime the displacement behaviour is fairly insensitive to the exact contact angle.
A compact front develops for early times for a wettable invading phase whereas a branched front develops for a non-wettable invading phase. The two regimes and the developing front shapes can be explained by local instabilities as introduced by Cieplack and Robbins [1]. In particular the absence or the appearance of 'Burst-Instabilities' where the local instability occurs when the pressure in a throat exceeds the required filling pressure can be used to distinguish the transition between both wetting regimes. For the non-wetting system where the local front progression occurs mainly by 'Burst-Instabilities' an interconnected and very extended network of invading and defending phase develops at later times. The interconnected network of the defending phase is slowly drained by gutter flow leading to an increased residual saturation which is reached only after a substantial flush of the invading phase.

[1] M. Cieplak, M. O. Robbins, Phys. Rev. Lett. 60, 2042 (1988) & Phys. Rev. B 41, 11508 (1990)

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