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Residual trapping of supercritical CO_2 in oil-wet sandstone

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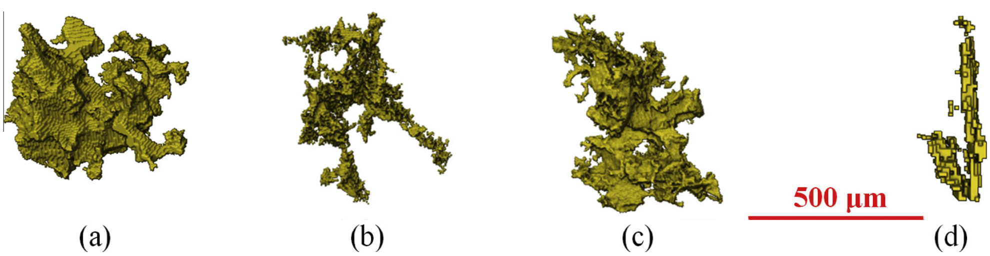
GRAPHICAL ABSTRACT



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ABSTRACT

Residual trapping, a key CO_2 geo-storage mechanism during the first decades of a sequestration project, immobilizes micrometre sized CO_2 bubbles in the pore network of the rock. This mechanism has been proven to work in clean sandstones and carbonates; however, this mechanism has not been proven for the economically most important storage sites into which CO_2 will be initially injected at industrial scale, namely oil reservoirs. The key difference is that oil reservoirs are typically oil-wet or intermediate-wet, and it is clear that associated pore-scale capillary forces are different. And this difference in capillary forces clearly reduces the capillary trapping capacity (residual trapping) as we demonstrate here. For an oil-wet rock (water contact angle $\theta = 130°$) residual CO_2 saturation $S_{CO2,r}$ (≈8%) was approximately halved when compared to a strongly water-wet rock ($\theta = 0°$; $S_{CO2,r} \approx 15\%$). Consequently, residual trapping is less efficient in oil-wet reservoirs.

1. Introduction

Carbon geo-sequestration has been identified as a feasible technology to mitigate global warming [1–3]. Technically, CO_2 is captured from large emitters (e.g. coal-fired power plants), and injected deep underground into geological formations for storage. However, although CO_2 is in a dense supercritical state at reservoir conditions (below 800 m depth), it migrates upwards as it has a lower density than the resident formation brine. One key mechanism, which prevents the CO_2 from leaking back to the surface is residual trapping, where the CO_2 plume is split into many micrometre sized bubbles which are immobilized by capillary forces in the pore network of the rock [4–8]. Pore-scale residual trapping has been proven to work in clean sandstone [7] and carbonate [9,10]. However, this mechanism has not been proven for oil-wet rock, despite its key importance as initial industrial scale CO_2 storage projects are very likely to occur in oil reservoirs [11]; and these oil reservoirs are typically oil-wet [12]. The significance of oil reservoirs for carbon storage is high, as sequestration can be directly combined with CO_2 driven enhanced oil recovery [13–15]; furthermore, depleted oil reservoirs already have required infrastructure in place [16], and they are typically well characterised in terms of seismic surveys, which significantly aids (reservoir scale) CO_2 flow monitoring [17].

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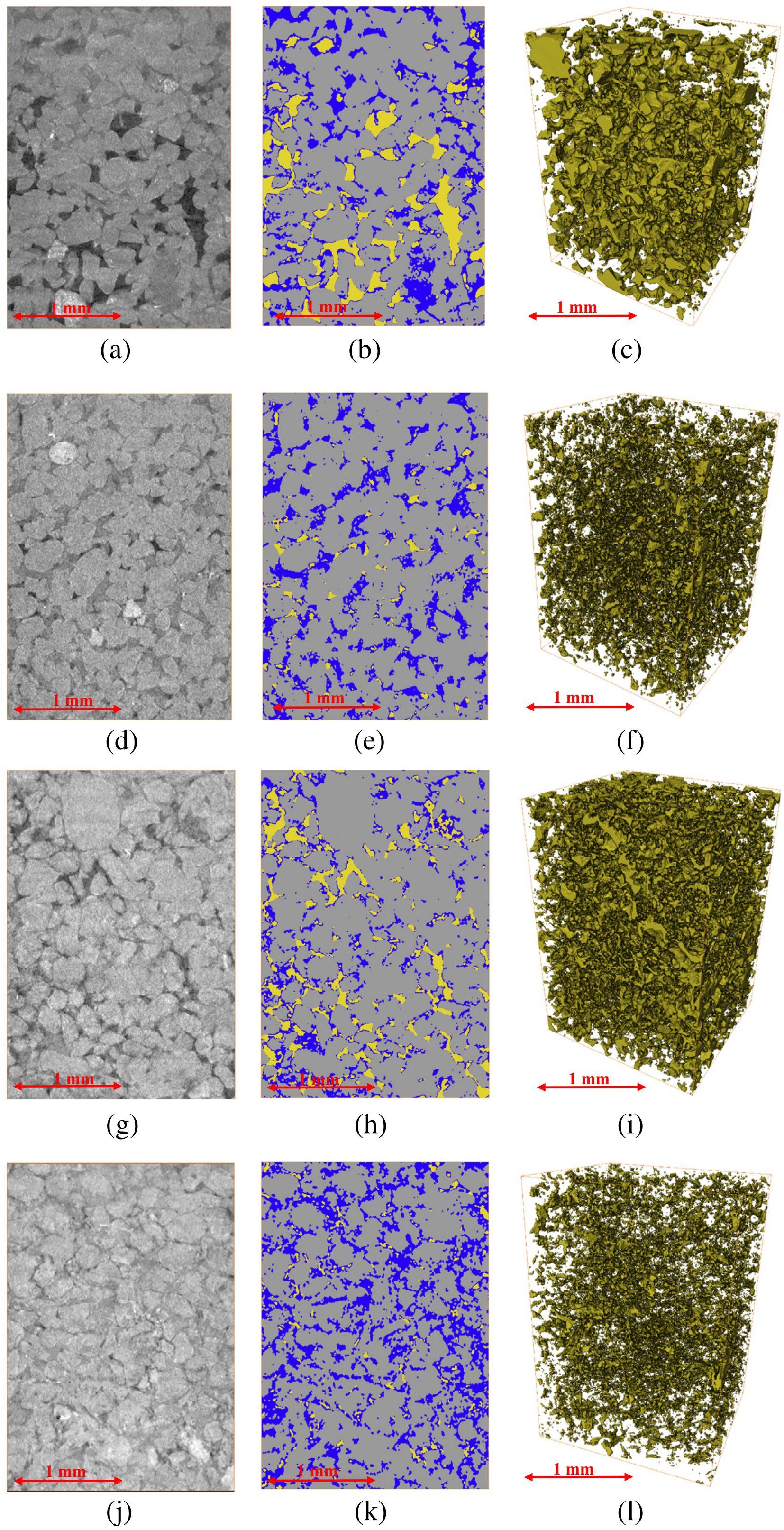

Fig. 1. μCT image of Bentheimer sandstone at 10 MPa pore pressure and 318 K: (a) water-wet initial CO_2 saturation, raw image; (b) water-wet initial CO_2 saturation, segmented image; (c) CO_2 clusters in 3D for the water-wet initial CO_2 saturation, a volume of 3 mm^3 is shown; (d) water-wet residual CO_2 saturation, raw image; (e) water-wet residual CO_2 saturation, segmented image; (f) CO_2 clusters in 3D for the water-wet residual CO_2 saturation, a volume of 3mm^3 is shown; (g) oil-wet initial CO_2 saturation, raw image; (h) oil-wet initial CO_2 saturation, segmented image; (i) CO_2 clusters in 3D for the oil-wet initial CO_2 saturation, a volume of 3 mm^3 is shown; (j) oil-wet residual CO_2 saturation, raw image; (k) oil-wet residual CO_2 saturation, segmented image; (l) CO_2 clusters in 3D for the oil-wet residual CO_2 saturation, a volume of 3mm^3 is shown. CO_2 is black/dark grey, brine is grey and sandstone is light grey; in the segmented images CO_2 is yellow, brine is blue and rock is grey. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)