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The Impact of Microscale Surface Roughness on Fluid Displacement Mechanisms and Residual Saturations in Porous Media

Monday, 31 May 2021 09:40 (15 minutes)

Understanding the factors and mechanisms behind the trapping and immobilisation of residual saturations of carbon dioxide (CO2) and oil phases in the pore spaces of reservoir rocks during immiscible fluid displacement is vital for geological CO2 storage and enhanced oil recovery (EOR) (1). The extent of trapping that occurs determines the success and efficiency of such subsurface operations. Whilst the objective of CO2 storage operations is to maximise residual trapping of CO2, in EOR operations the objective is to supress and minimise trapping of the oil phase (2). Fluid displacement processes and residual trapping are strongly influenced by the topological roughness of the porous rock (3). Currently, there is very limited data on the effects of surface roughness on fluid displacement processes (4). Accordingly, in this study we aim to quantify the effects of microscale surface roughness on pore-scale fluid displacement processes.
To investigate the impact of surface roughness on pore-scale fluid displacement, immiscible displacement of air by water was conducted in a transparent glass micromodel at a flowrate of 8.33μL/min. The experiment was repeated three times to ensure reliability of results. The micromodel was fabricated using an ultrafast picosecond laser(5) and its pore network structure was comprised of cylindrical pillars 400 μm in diameter arranged in a rhombohedral type of packing. Due to the inherent nature of the laser fabrication process, the walls and surfaces of the laser machined porous structure were rough textured. The average hillock height to pore depth ratio (Ω) for this micromodel was determined to be 5μm/50μm (10%) and the average measured surface roughness (Sa) of the micromodel was 1.2μm. To isolate the effects of surface roughness on immiscible two-phase fluid displacement, a Direct Numerical Simulation (DNS) of the water-air fluid displacement process was performed for the same porous structure assuming completely smooth surfaces in OpenFoam using the Volume of Fluid (VOF) method.
Comparing the experiments with the numerical simulation, our results demonstrate that microscale surface roughness has a strong and significant influence on pore-scale fluid displacement mechanisms and its contribution should not be ignored. We show that at a hillock height to pore depth ratio (Ω) of 10%, surface roughness can increase residual saturations in such a porous structure by up to 49% from 4% in the numerical simulation to 53% in the micromodel with rough surfaces. This implies that surface roughness can promote the isolation and trapping of clusters of CO2 in CO2 storage operations, thereby increasing efficiency of the process. In EOR operations, the effects of surface roughness are detrimental as the sweep efficiency of displacement process is significantly reduced.

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Time Block Preference

Time Block B (14:00-17:00 CET)

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Primary author: NHUNDURU, Rumbidzai (Heriot-Watt University)

Co-authors: Dr JAHANBAKHSH, Amir (Heriot-Watt University); Dr WLODARCZYK, Krystian (Heriot-Watt University); Dr SHAHROKHI, Omid (Heriot-Watt University); Dr GARCIA, Susana (Heriot-Watt University); Prof. MAROTO-VALER, Mercedes (Heriot-Watt University)

Presenter: NHUNDURU, Rumbidzai (Heriot-Watt University)

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