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Dynamics of two-phase flow in coal using X-ray micro-computed tomography imaging and positron emission tomography

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The fluid dynamics of gas-brine flow within porous media play a crucial role in the recovery of hydrocarbon gas and the sequestration of CO2. Coal seams are targeted as a reservoir rock because of their strong adsorption properties. However, permeability is an issue as they consist of matrix and fracture components, present a complex flow channel system for competing fluids and gases. During production, the initial dewatering process reduces pressure and induces CH4 desorption from the matrix into fractures, accompanying brine flow towards production wells. CO2 injection further displaces CH4 and stores CO2 in the matrix due to competitive adsorption with CH4. Moreover, Coal seams are dynamic during gas depletion and successive injection as the matrix shrinks and then swells, altering the structure of the flow channels. This introduces additional complexity to the transportation behaviour of the fluids. This study introduces an innovative approach to investigate the dynamics of gas-water two-phase flow within fractured coal cores. The methodology involves an integration of unsteady-state two-phase fluid flow experiments, dynamic positron emission tomography (PET) imaging, and high-resolution X-ray micro-computed tomography (micro-CT) imaging. Under reservoir pressure conditions, micro-CT imaging is employed to capture the fracture structure of the coal sample. A gas-injection-based unsteady-state flooding test is subsequently conducted on a water-saturated sample at the same pressures, with PET scanning used for dynamic imaging of the displacement process. This flooding experiment is designed to emulate gas-water transport behaviour in a coal seam during production, facilitating real-time data collection of gas injection volume, inlet-outlet differential pressure variations, and water production. The obtained data is utilized to predict the relative permeability curves of the sample. Following the flooding experiment, a multi-scale image analysis is performed by aligning low-resolution PET images at different time steps with the high-resolution micro-CT image. it superimposes the flow path onto the fracture structure of the sample, allowing for the determination of water saturation and characterization of flow behaviour. This analysis leverages the unique advantages of PET's dynamic imaging capabilities and micro-CT's high image resolution to enhance the visualization of fluid transportation behaviour within the media. Overall, this approach offers significant potential for sensitivity analysis on relative permeability of a porous media, including not only coal, but also reservoir rocks like sandstone and shale. It can consider factors such as stress, temperature, and wettability, enabling a quantitative comparison of relative permeability and offering visual insights into fluid flow behaviour as conditions change. This contributes to precise predictions of relative permeability, aiding in the identification of optimal scenarios for both hydrocarbon exploitation and carbon sequestration.

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