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Study on pore-fracture morphology and mineral-induced acid-heat-flow-solid simulation of coal under supercritical CO2

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Introduction
Carbon capture and storage (CCS) in geological reservoirs has emerged as a rapidly effective option for mitigating the accumulation of greenhouse gases [1,2]. However, the flow and reactions of supercritical CO2 (SCCO2) within coal seams entail a complex process, encompassing minerals dissolution and precipitation, adsorption behaviour, microstructural changes and mechanical weakening effects [3]. These factors hold a crucial role in ensuring the secure and long-term geological storage of CO2 in deep reservoirs. However, existing models mainly focus on temperature, flow and mechanics, leaving a significant gap in the multi-physics field considering the effect of SCCO2 acidification on coal structure in deep reservoir. On this basis, a comprehensive acid-thermal-flow-solid model was developed and established to account for mineral dissolution processes. This model was employed to study the influence of coal pore-fracture morphology and mineral distribution on the assessment of SCCO2 geological sequestration in deep reservoirs, thereby addressing the limitations inherent in existing models concerning the characteristics of CO2 storage in deep reservoir.
Methodology
A geometric model representing a circular reservoir was constructed. Within this model, the wellbore radius was defined as 0.1 m, while the radius of the matrix region was established at 1 m. The mesh distribution employed throughout the simulation is depicted in Fig. 1. Natural fracture distributions were incorporated in the model, with the permeability of these natural fractures typically being 1,000 times that of the matrix permeability.
Results and Discussion
A reduction in porosity was observed radiating from the wellbore towards the boundaries under interactions with SCCO2, with this distribution being influenced by fractures. An increase in the initial porosity of the coal samples corresponded to a more significant alteration in porosity after exposure to SCCO2, as depicted in Fig. 2. Following SCCO2 interaction, reservoir porosity increments resulting from adsorption expansion, dissolution, and total porosity were observed to decrease with an increase in initial porosity. The reservoir's total porosity was found to be 1.24 to 1.56 times that of its initial state after SCCO2 treatment. The increase in total reservoir permeability was found to intensify over time; nevertheless, as the reservoir's initial porosity increased, this enhancement was decreases gradually. For coal samples with initial porosities of 0.05, 0.06, 0.07, 0.08, 0.09, and 0.1, the corresponding permeability increments were determined as 23.57, 15.11, 10.45, 7.80, 6.11, and 4.98, respectively. This indicates that the lower the initial porosity of the reservoir, the more pronounced the alteration of its flow characteristics by SCCO2.

Fig. 1. Geometric model and simulation results. a) The grid distribution of the reservoir's geometric model. b) The porosity distribution of reservoirs with different initial porosities after exposure to SCCO2. c) The variation in porosity of reservoirs with different initial porosities after exposure to SCCO2. d) The variation in permeability of reservoirs with different initial porosities after exposure to SCCO2.

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