

Porous Flow of Energy and CO₂ Transformation and Storage in Deep Formations: An Overview

Rui Song ^{1,2,*}  and Jianjun Liu ^{1,2} ¹ State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan 430071, China; jliu@whrsm.ac.cn² University of Chinese Academy of Sciences, Beijing 100049, China

* Correspondence: rsong@whrsm.ac.cn

The transformation and storage of energy and carbon dioxide in deep reservoirs include underground coal gasification, the underground storage of oil and gas, the underground storage of hydrogen, underground compressed air energy storage, the geological utilization and storage of carbon dioxide, etc., which are related to the realization of low-carbon development, green development, and sustainable development. Fluid mechanics in porous media with a consideration for multiphysics coupling processes is one of the key disciplines supporting the above-mentioned large-scale projects. In order to strengthen the deep integration of seepage mechanics theory and engineering, as well as promote the development of emerging interdisciplinary subjects, we launched a call for papers with the support of relevant academic journals. A total of ten papers related to energy or CO₂ transformation and storage in deep formations were accepted and published in this Special Issue.

As a promising way to enhance oil recovery and carbon sequestration, the multiphase flow mechanism of CO₂–formation water has attracted some scholarly interest. Li et al. [1] studied the CO₂ miscible flooding process in a two-dimensional double-layered heterogeneous visualization model and found that the gas absorption capacity of the reservoir, the gravitational differentiation, and the miscible mass transfer were key factors affecting the migration of the oil–gas interface and distribution of the miscible zone. Song et al. [2] also investigated the CO₂–oil two-phase flow in pore-scale two-dimensional models using the phase field method and analyzed the effects of the capillary number, viscosity ratio, wettability, density, gravity, interfacial tension, and absolute permeability on the two-phase fluid flow characteristics. Qu et al. [3] determined the variations in rock microstructure, minerals, and crude oil properties (e.g., components, viscosity) in the CO₂ Huff-n-Puff in a low-permeability reservoir, and Tang et al. [4] tested the CO₂–brine relative permeability in the sandstone of Ordos basin. As can be seen, the pore-scale fluid transport mechanism was emphasized by many scholars. However, most studies on this topic focused on the immiscible flow of CO₂ liquids, neglecting the miscible gas-flooding mechanism which contributed significantly to enhancing oil recovery. The mathematical and numerical modeling of complex interactions between CO₂–liquids–grains remain substantial challenges for scholars, e.g., a dynamic miscible gas-flooding mechanism with a reaction between CO₂ with grains, etc.

Scientific efforts have also been devoted to the development of low-carbon energy, e.g., natural gas hydrate and coalbed methane. Song et al. [5] studied the hydrate decomposition process in porous sediments by means of numerical modeling using computational fluids dynamics (CFD) codes, including fluid heat and mass transfer, multiphase flow mechanics, and reaction kinetics with phase change. The effects of the gas saturation, outlet pressure, temperature, absolute permeability, and geo-stress on the decomposition of natural gas hydrate were studied. Wang et al. [6] determined the mineral composition and parametric characteristics of the microstructure of coal in the Ordos basin, as well as its relationship



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with the adsorption capacity. However, the porous flow mechanism considering phase change with a reaction in the complex and disordered microstructure of rock remained difficult to track using experiments or numerical modeling [7], which requires further scientific efforts in the future.

The mechanical response of rock during fluid flows in the pores was also emphasized by scholars focusing on underground energy and CO₂ transformation and storage. Zheng et al. [8] tested the mechanical properties and failure characteristics of layered rock using uniaxial compression tests. Song et al. [9] proposed a scheme for calculating the critical differential pressure of sand production coupled with laboratory tests and inversed analysis with well logging data and numerical simulations, which were validated using the engineering benchmark data. The effects of moisture contents and the cycling times of gas injection and withdrawal on the critical differential pressure were predicted. Tan et al. [10] studied the mechanical (deformation, damage, or failure) and acoustic responses under cyclic loading–unloading processes in the high-rate injection and production of underground gas storage. They found that mixed tensile–shear cracks are continuously generated in low-permeability sandstone during the cyclic loading process, and the shear cracks are more obviously developed. Wang et al. [11] studied the effects of grain size and layer thickness on the physical and mechanical properties of 3D-printed rock analogs, which provided references for preparing samples with more controllable properties and printing schemes for laboratory tests. Although plenty of scientific efforts were devoted to the manufacturing of rock or rock-like samples, the parallel tests on the samples with the same pore structure and mineral grains as the natural rock samples were still challenging [12], which requires a deep understanding in cementation and diagenesis processes.

The papers published in this Special Issue cover some important aspects of energy and CO₂ transformation and storage in deep formations. We believe that the presented studies will contribute to the development of theoretical, experimental, and numerical modeling methods, as well as providing guidance for engineering applications in this area.

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