



Original Paper

Compressibility and Permeability Behavior of Deep Coal Seam Based on 3D Evolution of Open Tensile Fractures: Insights for Early Production Stage

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This paper focuses on the early stage of methane extraction from deep coalbed methane (CBM) reservoirs, where open fractures and cleats are under minimal stress. At this stage, methane desorbs from the coal matrix into open fractures and cleats due to dewatering and pore pressure decrease, and the compaction and permeability behavior of coal significantly influences methane gas flow. As production advances, the stress caused growth and propagation of fractures significantly alter coal compressibility and fluid flow dynamics accordingly. Conventional compressibility models treat the rock's pore-fracture network as a single entity, neglecting distinct contributions from micropores, macropores, and fractures to coal compressibility. To address this gap, this research analyzed pore-fracture volumes, compressive stresses, porosity, and permeability, introducing pore-type-based compressibility models and pore-fracture-network-based permeability models of coal seams under progressive loading. Using digital rock technology, scanning electron microscopy, deep learning on computed tomography (CT) scans, nuclear magnetic resonance, and numerical simulations of fluid flow, this study explored the dynamic evolution of pore space under increasing stress. The developed convolutional neural network, based on the U-Net model, achieved acceptable accuracy in segmenting CT images, with an Intersection over Union (IoU) exceeding 95%. Meanwhile, the pore evolution analysis and permeability simulations were validated using corresponding data and techniques. In the context of deep CBM exploitation, the comprehensive approach of this study enhanced our understanding of the interplay between pore space evolution, compressibility, and permeability behavior, and contributes to improved characterization of the evolution regime of open fractures using cutting-edge techniques. This approach not only enables the development of reliable predictive models but also provides insights into efficient methane extraction at the early production stage and supplies baseline data for coal's geomechanical behavior in further stages.

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