Contribution ID: **831**

Type: **Poster Presentation**

Gas mass transfer in deep coal cleats: coupling multiple flow mechanisms and poromechanics with creep

Thursday, 16 May 2024 15:05 (1h 15m)

Deep coal rocks normally have higher gas content compared with shallow to medium-depth coal formations, showing great exploitation potential. However, they generally have complex pore structure and exhibits poor gas transport capacity under high overburden stress. The utilization of massive hydraulic fracturing can effectively release the productivity of deep coal reservoir. Nevertheless, the high overburden stress enhances the rock elasticity. Thus, during fracturing fluid flowback and the later long gas production periods, coal permeability loss due to matrix creep deformation in addition to the effective-stress-induced permeability reduction. Accurate characterization of deep coal rock permeability is an indispensable step toward precise simulation of gas transport and accurate assessment of productivity.

Coal permeability is mainly offered by the cleat system. To fully consider the impact of multiple gas transport mechanisms and creep on coal permeability evolution, this research presents a unified apparent permeability model based on the poromechanical theory and flow regime correction. Multiple flow mechanisms, including viscous flow, Knudsen diffusion, desorption, and real-gas effects are coupled in the single-fracture/cleat flux equation with dynamic viscosity. The fractal theory is employed for permeability upscaling. Specifically, the dynamic fracture/cleat aperture incorporates the impacts of desorption-induced internal swelling, full-stage/two-stage creep-induced compression and fracture/cleat aperture shrinkage depending on the actual stress state.

The proposed permeability model's results show good agreement with experimental data and can explain the time-dependent permeability evolution during the full-stage creep process. A new permeability surface concept is established to better illustrate permeability evolution by including the time dimension. During gas extraction, initially, permeability mainly influenced by the decelerated creep with the permeability drop gradually slows down. Then, rock creep deformation enters the steady stage, leading to a slight permeability change. The third-stage permeability evolution is caused by the accelerated creep that only appears when the effective stress is excessed the yield stress. To clarify the competitive effects of multiple gas transport and rock deformation mechanisms on deep coal cleat permeability, a novel controlling mechanism diagram was proposed with three realms for the creep-dominated region, gas-pressure-dominated region, and the desorption-dominated region, respectively. The contributions of different gas transport mechanisms on permeability evolution during different pressure and time scales were further analyzed. Due to the analytical feature, this model can be easily inserted into fully-coupled numerical simulator to predict deep coal rock gas production.

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Session Classification: Poster

Track Classification: (MS03) Flow, transport and mechanics in fractured porous media