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Experiment and model of multi-scale dynamic diffusivity and permeability for gas(CH4/He)) flow in micro-nano pores in series connection of coal

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Abstract: Coal is a porous medium that contains multi-scale pores with a pore aperture from millimeter level to nanometer level. The pore aperture differential can reach one million orders of magnitude, which causes the multi-scale characteristics in space and time for coal permeability and significantly influences gas drainage. However, the current experiment and theory of steady-state permeability cannot reflect the multi-scale characteristics. A cylindrical coal sample with a height of 100 mm and diameter of 50 mm is used to conduct the unsteady diffusion-seepage experiment with and without stress loading using methane and helium. Meantime, the steady method is adopted to conduct the experiment with the same stress loading for comparison. The experimental results show that, the apparent diffusion coefficient of a cylindrical coal sample attenuates with time. This apparent diffusion coefficient shows two different multi-scale characteristics in time, one is the smooth dynamic attenuation and the other is the dynamic attenuation in a two-stage step. A dynamic model for the apparent diffusion coefficient is proposed, and it can accurately describe the complete unsteady flow process of gas in a cylindrical coal sample. The geometrical and mathematical models of the multi-scale pores in series are proposed. Then, the multi-scale structure of pore in series is validated by the mercury injection experiment. After that, the multi-scale permeability model is mathematically proved. Based on Knudsen number, the continuous flow, slip flow, transition flow and molecule free flow are identified and introduced with the multi-scale pore aperture to build a multi-scale permeability model that reflects the effect of the effective stress and gas flow regime. The mechanism of the multi-scale seepage is that the pore aperture and the number of pores in series connection determine multi-scale permeability. The multi-scale effect is far larger than the effect of the effective stress. The gas outflow firstly starts from the outside fractures, and then the inside small pores and finally the nano pores. With time goes on, the gradual increase in the number of pores in series connection leads to the gradual reduce in the equivalent pore aperture, which causes the equivalent pore aperture to get close to the minimum pore aperture. Therefore, the equivalent permeability quickly decreases with time, which is a reflection of the multi-scale pore space in coal. In coal, gas flows through the multi-scale pores with different flow regimes, and the coal permeability decreases by a million orders of magnitude from millidarcy level to nanodarcy level. The new experimental observation and modelling of the multi-scale permeability are different from the previous experiments and theory of seepage and diffusion, which provides an experimental solution for the research of the multi-scale seepage. The diffusion coefficient and permeability are apparently unified, and the distinguishment in micro-level and combination in macro-level of the multi-scale permeability are realized. The research results are significant for the dynamic measurement and theory description of the ultra-low permeability of coal, the explanation of the fast reduction in coalbed methane production and the assessment on gas drainage.

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References

Time Block Preference

Time Block B (14:00-17:00 CET)

Participation

Online

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