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Permeability of coal to CH_4 under fixed volume boundary conditions: the effect of stress-strain-sorption behaviour

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Permeability evolution in coal reservoirs during CO_2-Enhanced Coalbed Methane (ECBM) production is strongly influenced by swelling/shrinkage effects related to sorption and desorption of CO_2 and CH_4, respectively. Numerous permeability models, coupling the swelling response of coal to gas sorption, have been developed to predict in-situ coal seam permeability evolution during (E)CBM. However, experimental studies, aimed at testing such models, have mainly focused on the permeability changes occurring under constant lateral stress conditions, which are inconsistent with the in-situ boundary condition of (near) zero lateral strain. We performed CH_4 permeability measurements, using the steady-state method, on a cylindrical sample of high volatile bituminous coal (25mm in diameter), under (near) fixed volume versus fixed stress conditions. The sample possessed a clearly visible cleat system. To isolate the effect of sorption on permeability evolution, helium (non-sorbing gas) was used as a control fluid. The bulk sample permeability to helium, under stress control conditions, changed from $4.07\times10^{-17}$to $7.5\times10^{-18}m^2$, when the effective stress increased from 19.1 to 35.2MPa. Sorption of CH_4 at a constant pressure of 10MPa, under fixed volume boundary conditions, resulted in a confining pressure increase from a poroelastically supported value of 29.3MPa to a near-equilibrium value of 38.6MPa over 171 hours. This is caused by the combined effect of the sorption-induced swelling and the self-compression of the sample. The concentration of CH_4 adsorbed by the sample was 0.113 mmol/g_{coal}. During the adsorption process, the permeability to CH_4 also decreased from 2.38×10^{-17} to $4.91\times10^{-18}m^2$, proving a strong influence of stress-strain-sorption behavior ($c.f.$ Hol et al., 2012) on fracture permeability evolution. The CH_4 permeability subsequently measured under stress controlled conditions varied from 1.37×10^{-17} to $4.33\times10^{-18}m^2$, for same change in confining pressure, i.e. 28.9 to 39MPa. This difference between fixed volume and fixed stress boundary conditions likely reflects difference in the degree of equilibration. The difference in sample permeability measured with helium versus CH_4 suggests an additional effect of sorption on transport paths, independently of the poro-elastic effects. The permeability change with respect to the effective stress for both CH_4 and He are well fitted by the permeability model developed by Walsh (1981), which considers the effect of contact asperity deformation on effective fracture aperture and hence permeability. Physically, the model parameters reflect the apparent specific stiffness of the fracture. Using appropriate parameter values, the Walsh model therefore offers a promising basis for predicting permeability evolution from in-situ stress evolution. To predict the effective stress development with time in situ, i.e. under fixed volume boundary conditions, a simple model, coupling 1D diffusion model, 2D constitutive model for stress-strain-sorption behaviour, and the relation for joint closure with the normal effective stress, is presently being developed.