

# Coupling of adsorption and strain in coal

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The recovery of methane from coal beds is enhanced by the injection of carbon dioxide. This technique called enhanced coal bed methane recovery enables in addition to store carbon dioxide underground for hundreds of years, thus contributing to climate change mitigation efforts. One of the main issues encountered by the experimental injection pilots is the loss of permeability of the reservoir during injection. This loss is due to the differential swelling of coal induced by the preferential adsorption of carbon dioxide in coal over methane.

How adsorption leads to a strain of the adsorbent can be explained theoretically with poromechanical equations extended to adsorption in micropores [1]. The adsorption-induced stress depends on the amount of adsorbed fluid, in particular how this amount varies with the strain of the porous medium. Most of adsorption models disregard the dependency between adsorption and strain and, to the best of our knowledge, the effect of strain on adsorption has never been measured experimentally for coal. In this work, we study the coupling between adsorption and strain in coal in two different ways: by simulating adsorption of methane in a realistic molecular model of the organic matrix of coal, and by analysing the results of immersion experiments of coal sample, in which both the amount adsorbed and the swelling of the sample are measured.

Molecular simulations show that the amount  $n$  of adsorbed methane per unit undeformed volume depends almost linearly on the strain  $\varepsilon$  for positive strains. Moreover, the quantity  $C = (\partial n / \partial \varepsilon / P) / n(\varepsilon=0)$ , which we call the coupling coefficient, is almost independent of the pressure:  $C = 6.30 \pm 15\%$ . With the second approach, based on the analysis of the results of immersion experiments of Ottiger et al. [2], we also obtain a coupling coefficient almost independent of the pressure. The value of the coupling coefficient depends on the bulk modulus of the sample, which was not available in the data of Ottiger et al.. For a bulk modulus of 2.65 GPa the coupling coefficient we derived was the least pressure-dependent:  $C = 6.05 \pm 7\%$ . This value is consistent with the value derived from the molecular simulation and a bulk modulus of 2.65 GPa is in the range of values usually observed for coal.

We analyse as well the results of experiments of carbon dioxide adsorption in coal. For subcritical pressures ( $< 8$  MPa), the coupling coefficient for carbon dioxide is almost independent of the pressure and its value  $C = 6.40 \pm 7\%$  is close to the value obtained for methane. By contrast, for higher pressures the coupling coefficient became pressure dependent and reaches a maximum value  $C = 10.53$  for a fluid pressure of 10.76 MPa. Molecular aggregation of carbon dioxide molecules, which occurs in these conditions, could explain this peculiarity. As a first attempt to model the adsorption-induced strain of coal we assume that the coupling coefficient for carbon dioxide is independent of the pressure and equal to the average value over the range of pressures considered:  $C = 7.60 \pm 20\%$ . This rough modelling captures satisfactorily the swelling of coal samples immersed fluids.

The poromechanical constitutive equations combined with adsorption isotherms estimated by molecular simulation enable to estimate the poromechanical behaviour of coal in any geological conditions. The differential swelling of coal is estimated for injection sites at various depths.

## REFERENCES

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