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Volumetric response of coal to CO_2 at pressures up to 100 MPa

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Adsorption-induced swelling of the coal matrix has been identified as the principal factor controlling the reduction in injectivity of CO_2 during Enhanced Coalbed Methane production (ECBM). To determine the magnitude of coal swelling, and its dependence on the amount of CO_2 adsorbed, numerous laboratory studies have been performed at constant temperature and CO_2 pressures up to 20 MPa. Although thermodynamic models predict that the volumetric response of the coal matrix with increasing CO_2 pressure is a combined effect of adsorption-induced swelling and elastic compression, these effects have not been separated in experiments and the influence of compression on the observed net volumetric expansion of the coal matrix is often neglected.

Here, we report the results of dilatometry experiments conducted on unconfined, cylindrical coal matrix samples (4.00 mm in diameter and 4.00 mm long) of high volatile bituminous coal (Brzeszcze, Poland) and anthracite (Ibbenbüren, Germany). Our aim was to measure the net volumetric effect of CO_2 on coal and to separate this into adsorption-induced swelling and elastic compression, which should exceed the swelling effect at the highest pressures used.

The experiments were performed using a specially developed, high pressure dilatometer that incorporates eddy current sensors to measure one-dimensional sample expansion or contraction with a resolution of around 50 nm, after correction for stiffness effects in the set-up. In each experiment, the samples were equilibrated with CO_2 at a constant temperature (40 °C), and CO_2 pressures up to 100 MPa controlled by an ISCO 65D syringe pump. Volumetric strains were determined as a function of CO_2 pressure from the strains determined parallel and perpendicular to the layering in our coal samples. The bulk modulus of our samples was independently determined to calculate the elastic compression at high pressure.

Our results show that both types of coal exhibited a net expansion in response to interaction with CO_2 at pressures below $\sim$30 MPa, where a peak volume was measured. Above CO_2 pressures of $\sim$30 MPa, the samples showed significant relative contraction, which was more pronounced in the high volatile bituminous coal. We attribute the contraction effect to elastic compression of the coal matrix being dominant at high pressure, where the difference in behaviour between our samples is a reflection of their different elastic stiffness. Using the net volumetric response and the bulk modulus as determined for these samples, we calculated the true swelling for each sample. Together with independent measurements of absolute CO_2-uptake, this yields a true swelling-adsorption relationship.
The data and analysis presented demonstrate that a separation of volumetric effects into adsorption-induced swelling and elastic compression is crucial to understand the true volumetric effect and thermodynamics of CO_2 adsorption by coal. Similar arguments may apply to understanding the volumetric behaviour of shale caprocks exposed to CO_2.

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