HAL open science

Coupling of adsorption and strain in coal

Laurent Brochard, Matthieu Vandamme, Roland Pellenq, Fen-Chong Teddy

To cite this version:

Laurent Brochard, Matthieu Vandamme, Roland Pellenq, Fen-Chong Teddy. Coupling of adsorption and strain in coal. ALERT-geomaterials - Workshop 2011 (21st edition), Oct 2011, Aussois, France. . hal-03995472

HAL Id: hal-03995472

https://hal.science/hal-03995472

Submitted on 18 Feb 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Distributed under a Creative Commons Attribution 4.0 International License

No.2-3: Coupling of adsorption and strain in coal

Laurent BROCHARD*, Matthieu VANDAMME*, Roland PELLENQ+, Teddy FEN-CHONG*

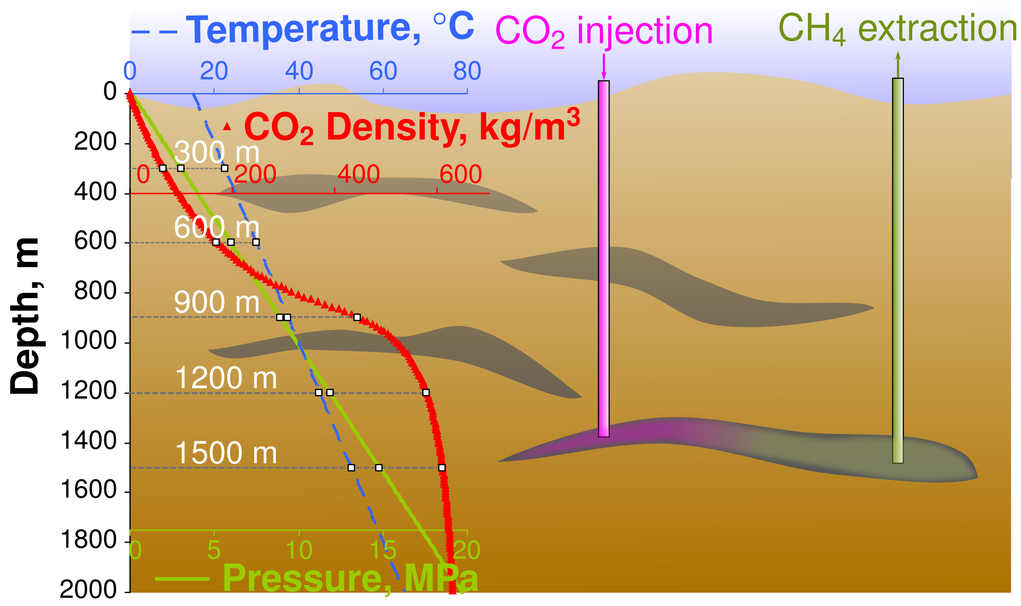
*Université Paris-Est, Laboratoire Navier (UMR CNRS 8205), Ecole des Ponts ParisTech
+CINaM (UPR 3118), Université de Marseille & Civ. and Env. Eng., MIT

ABSTRACT

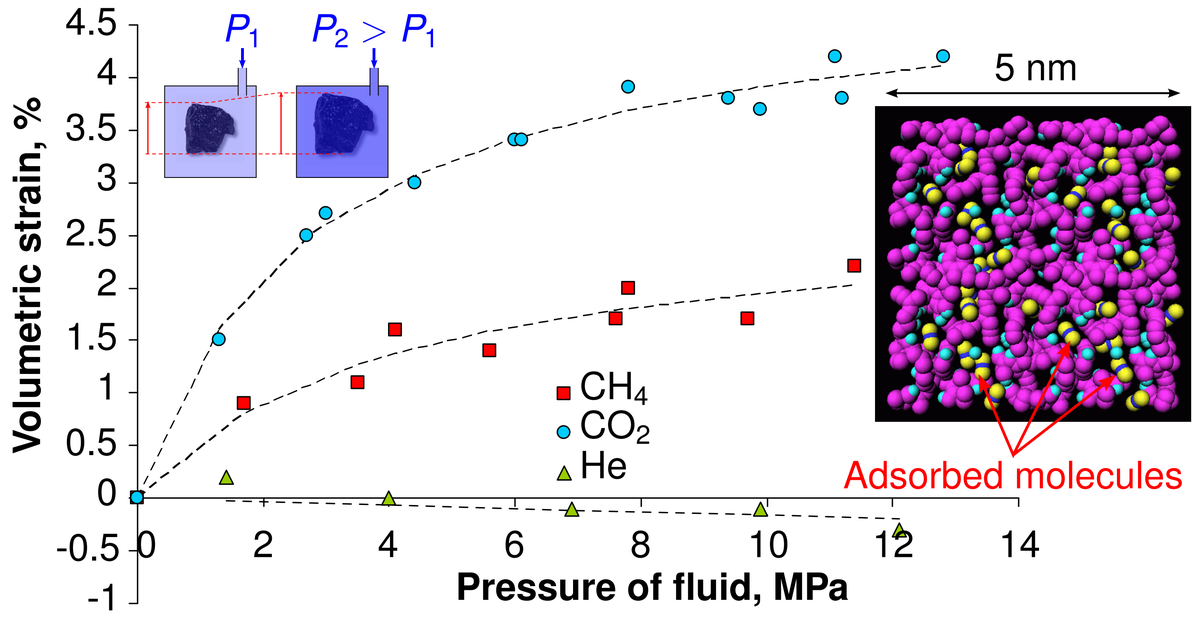
The swelling of coal induced by an adsorption of CO_2 impedes a large scale deployment of carbon storage projects in coal fields. How adsorption can lead to a strain of a porous material is theoretically explained by poromechanical equations extended to microporous media. The adsorption-induced stress depends on the amount adsorbed per unit undeformed volume, in particular how this amount varies with strain. In this work we study the coupling between adsorption and strain in coal in two different ways: by molecular simulation of adsorption in a realistic molecular model of the coal matrix and by analyzing results of immersion experiments in which both the adsorbed amount and the swelling of the sample are measured. For positive strains, the adsorption depends linearly on the strain and the derivative of the adsorbed amount with respect to the strain is almost proportional to the adsorbed amount at zero strain. However, carbon dioxide exhibits a peculiarity for temperatures and pressures close to the critical temperature and pressure, which can be explained by the molecular aggregation which occurs in such conditions. These adsorption behaviors combined with the poromechanical equations enable us to estimate the differential swelling of coal for coalbeds at various depths.

CONTEXT - CARBON SEQUESTRATION AND SWELLING OF COAL

In order to mitigate climate change, carbon dioxide from anthropic emission can be stored in coal seams. These reservoirs are deposits of natural gas, which is therefore recovered during the injection process.



Injection pilots have encountered an important loss of injectivity, due to the differential swelling: CO_2 adsorption in coal induces a larger swelling of coal than CH_4 adsorption.



(swelling curves adapted from Ottiger et al. (2008))

POROMECHANICS EXTENDED TO ADSORPTION IN MICROPORES

Constitutive equations valid for microporous media (Brochard et al., 2011 - submitted):

General constitutive equations

$$\begin{cases} \sigma = K\epsilon - \frac{\partial}{\partial \epsilon}\left[\int_0^P n\overline{V}_{bulk}dP\right]_{P,e_{ij}} \\ n = n(\epsilon, P) \\ s_{ij} = 2Ge_{ij} \end{cases}$$

- σ and s_{ij} are the volumetric and deviatoric stresses;
- ϵ and e_{ij} are the volumetric and deviatoric strains;
- P is the bulk pressure of the fluid;
- K and G are the elastic moduli of the sample in the absence of any fluid;
- $n(\epsilon, P)$ is the adsorbed amount per unit undeformed volume;
- $\overline{V}_{bulk}$ is the molar volume of the bulk fluid

Requires to know how the adsorbed amount n depends on both the pressure P and the strain ϵ.

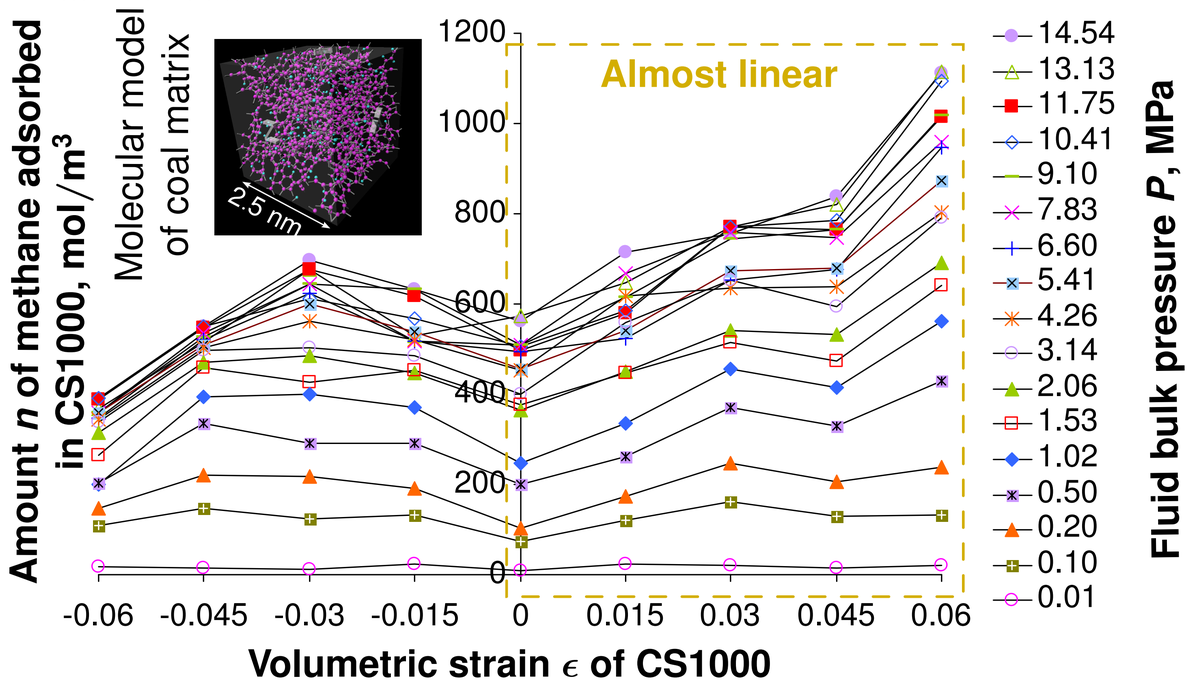
How adsorption of CO_2 and CH_4 in coal depend on the strain ?

CONCLUSIONS

- Adsorption in coal depends linearly on strain for positive strains;
- The ratio $(\partial n/\partial \epsilon|_P)/\,n(\epsilon = 0)$ is pressure-independent except for carbon dioxide adsorption at temperatures and pressures near the critical point;
- The differential swelling is independent of the injection site depth.

STRAIN-ADSORPTION COUPLING

First approach: Molecular simulation of adsorption in the organic matrix of coal

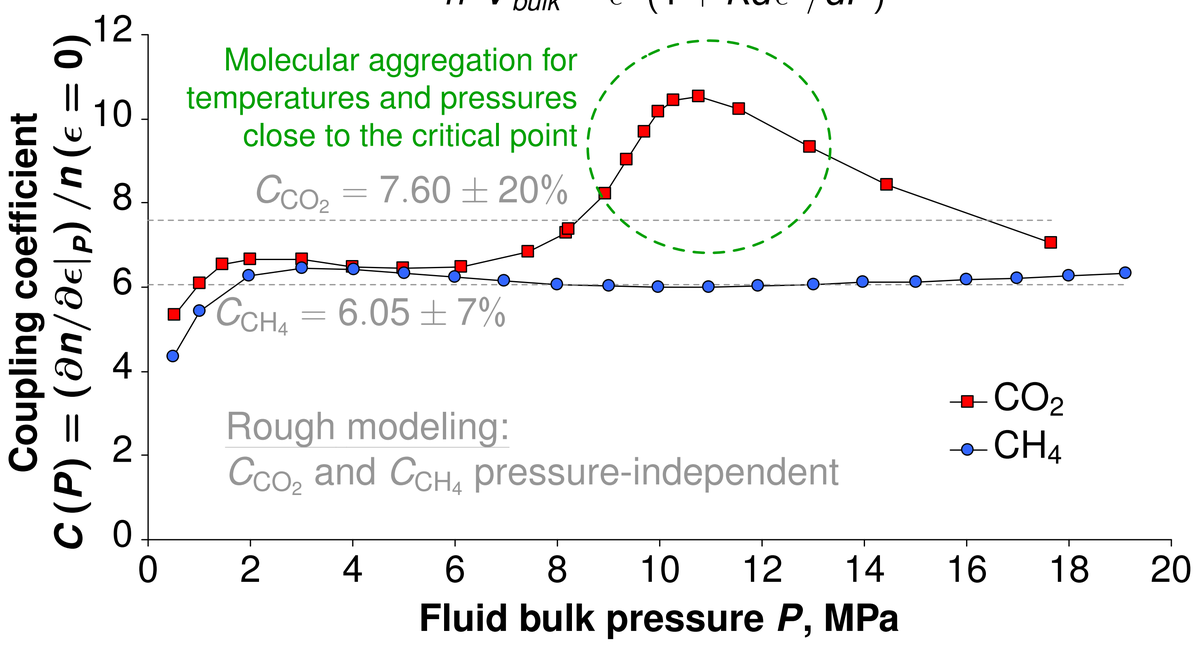


The slope $\partial n/\partial \epsilon$ of the linear portion is proportional to the amount adsorbed at zero strain: $C(P) = \frac{\partial n}{\partial \epsilon}\Big|_P / \,n(\epsilon = 0) = 6.30 \pm 15\%$

Second approach: Analysis of results of immersion experiments

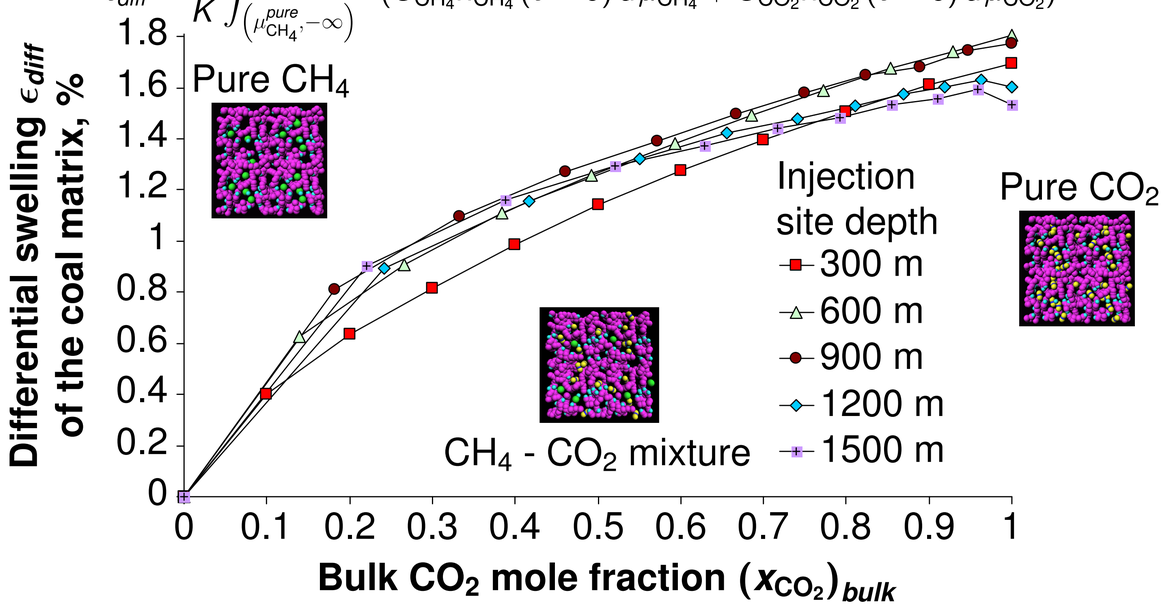
In unjacketed conditions, the strain $\epsilon^u(P)$, the adsorbed amount $n^u(P)$, and the coupling coefficient $C(P)$ are related according to:

$$C(P) = \frac{1 + Kd\epsilon^u/dP}{n^u\overline{V}_{bulk} - \epsilon^u(1 + Kd\epsilon^u/dP)}$$



(Analysis of the experimental results of Ottiger et al. (2008))

APPLICATION TO CARBON STORAGE

Differential swelling during the injection process in coalbeds:

$$\epsilon_{diff} = \frac{1}{K}\int_{\left(\mu^{pure}_{CH_4}, -\infty\right)}^{\left(\mu_{CH_4}, \mu_{CO_2}\right)} \left(C_{CH_4}n_{CH_4}(\epsilon = 0)\,d\mu_{CH_4} + C_{CO_2}n_{CO_2}(\epsilon = 0)\,d\mu_{CO_2}\right)$$