Poromechanical modeling investigations of adsorption effects in a double porosity media.

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1. Introduction.

This research study aims at characterizing the influence of an adsorbed phase on the instantaneous deformations in microporous media (width pores < 2nm). Activated or natural carbons, tight rocks, clay, cementitious materials and numerous biomaterials such as bones are among these materials. In recent years, a major attention has been paid on these microporous materials because the surface-to-volume ratio (i.e., the specific pore surface) increases with decreasing characteristic pore size. These materials can trap an important quantity of fluid molecules as an adsorbed phase. This is important for applications in petroleum and oil recovery, gas storage, separation. For these microporous materials, a deviation from standard poromechanics, which was introduced by Biot [1] 75 years ago, is expected. In very small pores, the molecules of fluid are confined. Interaction between molecules is modified. This effect, denoted as molecular packing, includes fluid-fluid and fluid-solid interactions and has significant consequences at the macroscale, such as instantaneous swelling. In-situ adsorption-induced coal swelling has been identified as the principal factor leading to a rapid decrease in CO_2 injectivity during coal bed methane production enhanced by CO_2 injection. Generally, natural and synthesised porous media are composed of a double porosity: the microporosity where the fluid is trapped as an adsorbed phase and a meso or a macro porosity required to ensure the transport of fluids to and from the smaller pores. If adsorption in nanopores induces instantaneous deformations at a higher scale, the matrix swelling may close the transport porosity, reducing the global permeability of the porous system or annihilating the functionality of synthesised materials.

2. Methods.

The point of view of poromechanic is a mean to understand this problematic. When a porous media is immersed in the gas, Coussy [6] [7] predicts the shrinkage of the media. The classical poromechanic have to extend to take account the adsorption phenomenon. A new poromechanical framework allowing adsorption induced strain predictions by taking into account the incremental variations of porosity upon swelling for pure microporous, isotropic and homogeneous materials saturated by a single fluid in reversible and isothermal conditions was developped [2]. In this study, the model is then extended for double porous media presenting both a microporosity where the fluid is trapped as an adsorbed phase and a transport macroporosity. The porosities are defined by the classification of l' *Internationnal Union of Pure and Applied Chemistry* (IUPAC) [5].

In the litterature, differents autors was measured the coal swelling due to the adsorption phenomenon ([3], [4]). In this study, a new experimental procedure is built for simultaneous measurement of both adsorption and swelling quantities by respectively a manometric technique and a full-field digital image correlation technique. The experimental rig allows additional measurements such as initial porous volume, skeleton density and modulus of compressibility and thermal expansion coefficient.

3. Results.

The experimental procedure is applied to test the reliability of the proposed model for a commercial active carbon saturated with pure methane (30 C, 0-120 bars) and pure carbon dioxide (45 C, 0-50 bars).

The material has the particularity to present both a high microporosity (30%) and a high macroporosity (40%) and a good agreement is obtained in term of adsorption induced swelling quantities (figure 1). Once the model validated, it is used to quantify the decrease of transport macroporosity induced by microporous matrix swelling.

The last part is dedicated to the study of a natural carbon extracted from a mine with enhanced coal bed methane recovery potentialities. The material has the particularity to present three different porosities: a microporosity where the gas is trapped (0.5%), a transport macroporosity (4%) and a natural cleat network (11 %) also participating in the global transport. The obtaining of full-field displacement maps provides insight of the cleat network influence and helps to isolate homogeneous zones where the poromechanical model may be applied and compared to the experimental results. Here again, a good agreement is obtained in term of adsorption-induced swelling quantities.

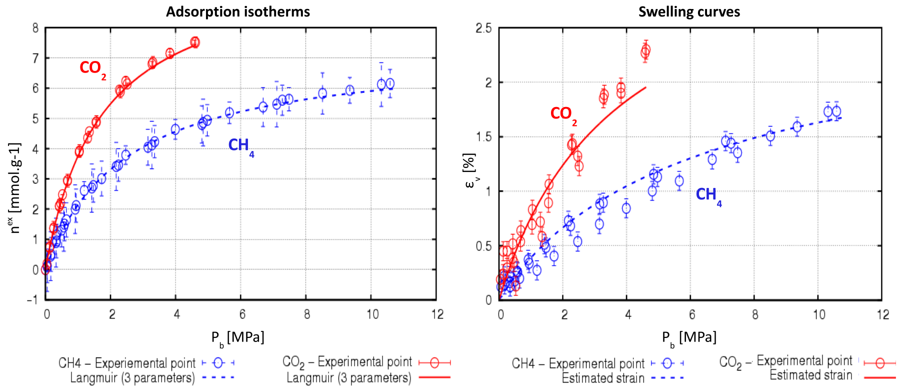

Figure 1: Adsorption isotherms and swelling curves. Thanks to the adsorption isotherms measured experimentally (CH_4 and CO_2), the deformations predicted by the model extended correspond to the deformations measured by the experimental set-up.

4. Conclusions.

In this work, a poromechanical model extended to the double porosity is presented which determines the swelling of an isotropic and homogeneous materials thanks to the adsorption isotherm. The model validation was made by the application of the novel apparatus developed in this study. The adsorbed quantities and the induced swelling were measured both on the active carbon and on the natural carbon which were saturated with pure CO_2 and pure CH_4. A good agreement is observed between the swelling predicted by our model and the swelling measured by the experimental setup for the two porous media.

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