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# ENHANCED POROMECHANICS FOR THE MODELING OF SWELLING IN MICROPOROUS MATERIALS: COUPLED EFFECTS, SIZE EFFECTS AND UPSCALING ISSUES

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The purpose of this work is to achieve a better understanding of the coupling between adsorption and swelling in microporous materials. This is typically of utmost importance in the enhancement of non-conventional reservoirs or in the valorization of CO2 geological storage. Indeed, in situ adsorption-induced coal swelling has been identified as the principal factor leading to a rapid decrease of CO2 injectivity during enhanced coal-bed methane production by CO2 injection. The coal swelling may close the cleat system and reduce the global permeability. We consider here the case of fully saturated porous solids with pores down to the nanometer size (less than 2nm). Hardened cement paste, tight rocks, activated carbon or coal are among those materials. First, experiments performed on activated carbon fully saturated with CH4 and CO2 at 30C and up to 120 and 50 bars respectively are recalled. Damage and permament strains are observed upon swelling due to adsorption.

Most continuum approaches to swelling upon adsorption of gas rely on a coupling between the adsorption isotherms and the mechanical deformation. An enhanced poromechanical framework has been proposed to express the swelling increment as a function of the increment of bulk pressure with constant porosity [1]. This framework is extended to take into account the evolution of porosity upon swelling [2]. Moreover, the interaction between swelling and the adsorption isotherms is examined by proposing a correction to the Gibbs formalism by taking into account the pore volume variation upon swelling.

The uspcaling techniques which were implemented did not, however, account for the fact that the skeleton is microporous. Interactions between pore walls were assumed to be negligible but for microporous materials this is not true. Typical measurements of BET surfaces for activated carbons are in the range of hundreds (and sometimes thousand) of meters per gram, with an average pore size below 2 nm. Surface effects may no longer be neglected. Furhermore, existing data on coal exhibit a drastic decrease of the stiffness of the porous material compared to the stiffness of the bulk material (above 50 percent sometimes) with a rather low porosity (in the range of 10 percent). This cannot be explained with classical homogenisation schemes.

There are in the literature several proposals in which upscaling (homogenisation) techniques account for these surface effects. Surface forces are introduced and additional elastic interfaces are placed on the pore surfaces. This addition results into a stiffening of the porous material and size effect, i.e. a variation of the mechanical parameters (for instance the bulk modulus) with the void size at constant porosity. We examine here two other possibilities:

- In the first proposal, Van der Walls (solid-solid) interaction forces are introduced. This can be performed quite easily by considering that the pores have stiffness which is a function of their size. A positive stiffness corresponds to the attractive part and produces a stiffening of the porous material. A negative stiffness corresponds to repulsive forces and induces a weakening of the material. The influence of attractive forces is observed for pore sizes in the nanometer range and can be neglected above 10 nm. The stiffening may reach 5 to10 percent. The influence of the repulsive forces is restricted to pores of the subnanometric size. Although repulsive forces are the only ones which yield a weakening that is consistent with experiments, they act between two surfaces that are so close to each other that the defintion of a pore itself in this case may be questionable.

- In the second proposal, we consider that near the surface of a pore there is a weak boundary layer which results from a reorganisation of the interaction forces between atoms due to the presence of a free surface. A three-phase homogenisation scheme is implemented. Because the thickness of this weak boundary layer is assumed to be constant, size effect is observed and it depends on the ratio of this boundary layer to the spacing of the pores. In this case, a weakening of the porous material upon a decrease of the pore size is observed and seems to be consistent with experimal observations at least qualitatively.

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