PhD project

Modeling of the behavior of a fractured porous medium submitted to gas pressurization

In the context of the Cigéo project, the excavation of underground galleries in the Callovo-Oxfordian claystone induces a network of fractures around the excavated zone. This fracturing exhibits a typical profile of propagation in mixed I/II mode, which originates from the instantaneous discharge of the claystone after excavation. The topology and spatial extent of the induced network of fractures has been widely studied by ANDRA[1] around the excavations of the Laboratoire Souterrain de Meuse/Haute-Marne (LSMHM). Over long time, this network of fractures is expected to experience additional loadings by gas (mostly H_2) originating from the corrosion of metals used in the envelop of nuclear waste packages and from water radiolysis. The accumulation of these gases induces a pressurization that can affect the fractured zone. ANDRA has been investigating the risks associated with gas pressurization since 2003. In particular, gas-fracturing tests have been performed in a vertical well drilled from the surface and in wells drilled from the LSMHM.

The goal of this PhD project is to set up a numerical simulation tool able to model and simulate the mechanical response of a fractured porous medium submitted to gas pressurization while taking into account the peculiar thermo-hydro-mechanical (THM) couplings of claystone. The project is organized in three parts: 1- set up of the numerical tool, 2- numerical study under THM loadings with gas pressurization, and 3- confrontation experience-simulation.

Set up of the numerical simulation

We propose to set up the numerical simulation based on Disroc[2]. Discroc is a finite element code dedicated in particular to the simulation of the fractured media. Cracking is accounted for by cohesive zone models, which are well adapted to the modeling of brittle and quasi-brittle media. These models avoid the main issues of Griffith models: they do not exhibit stress singularities at crack tips, and they can model both crack initiation and crack propagation. Disroc has already been used for the study of fracturing in several PhD and research projects in various labs including Navier lab. In particular, the propagation of fracture under THM couplings raises specific questions that have been addressed in the PhD thesis of Z. Ouraga[3] dedicated to the natural fracturing of sedimentary formations (oil and gas reservoirs), and of T. D. Vo[4] dedicated to the desiccation cracking of soils. A more recent research work[5] investigated the propagation of fractures under the effect of a fluid injection (Figure 1).

The study of fracturing due to gas pressurization requires extending these works, dedicated to the case of a single incompressible fluid, to the case of a multi-phase fluid (liquid + gas) in an unsaturated medium. Moreover, the fluid flows are potentially highly sensitive to the many THM couplings they induce (fluid pressurization) or sustain (thermal gradients). Theses couplings are an important research topic at Navier lab, and recent advances make it possible to take into account quantitatively the effects of adsorption associated with bound water thanks to rigorous thermodynamics formulations of the poro-mechanics under adsorption[6,7]. The numerical modeling proposed in this work will aim at integrating these new formulations. The implementation of these new poro-mechanical formulations in Disroc is rather simple (analytical formulation with the same structure as usual poro-mechanics).

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[1] Armand et al. (2014) Rock Mech. Rock Eng., 47, 21-41. doi:10.1007/s00603-012-0339-6.
[2] Ouraga (2017) Modélisation de la fracturation naturelle des sédiments: impacts sur la modélisation de bassin. PhD thesis ENPC.
[3] Disroc (2016) A Finite Element code for modelling coupled THMC phenomena in porous fractured media. Fracsima, www.fracsima.com
[4] Vo (2017) Modélisation Numérique et Analytique de la Fissuration de séchage des Sols Argileux. PhD thesis ENPC.
[5] Jung et al. (2019) Fracture Closure Mechanisms during Flowback from Hydraulic Fracture Networks, in preparation.
[6] Brochard et al. (2012) Journal of the Mechanics and Physics of Solids, 60(4), 606–622. http://doi.org/10.1016/j.jmps.2012.01.001
[7] Brochard et al. (2019) Thermo-poro-mechanics extended to adsorption effects and application to the anomalous thermal pressurization of interstitial water in undrained clays, submitted (JMPS)

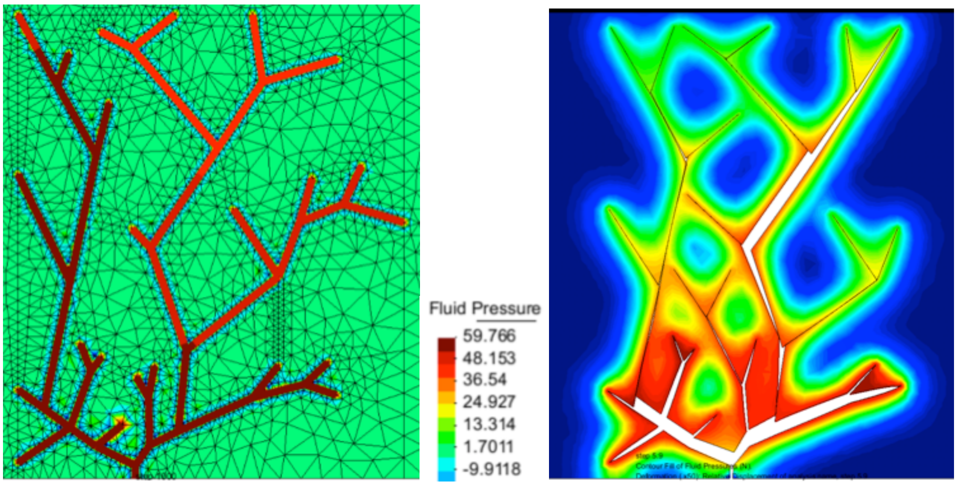

Figure 1: Explicit modeling of the fractures induced by the injection of a pressurized fluid in a porous medium[8]

Numerical study under THM loadings with gas pressurization

The parameters of the numerical tool will be calibrated so as to reproduce the behavior of the Callovo-Oxfordian claystone. In this respect, various experimental results available in the literature or obtained in other ANDRA projects will be considered. The behaviors of the non-adsorbed fluids (gas, free water) will be accounted for with usual models (ideal gas, incompressible, or empirical equation of states if these two limit cases prove inappropriate in the range of temperatures-pressures of interest). The behavior of the bound water will be obtained by crossing experimental data of the THM couplings and molecular simulation data available in the literature[9].

The numerical tool will then be applied to various simple cases in order to evaluate the main factors influencing the gas breakthrough. Special attention will be dedicated to the role of THM couplings specific to claystone (notably: swelling/shrinkage and thermal pressurization).

Confrontation experience-simulation

In order to evaluate the numerical model, a confrontation with experiment is necessary. In agreement with ANDRA, the numerical model will be used to simulate the gas-fracturing tests performed at LSMHM or other lab tests performed for ANDRA during this PhD. The 3D aspects will be accounted for with the future version of Disroc that shall be released during this PhD.

Practical details and applications

The applicants must hold a Master of Science or equivalent in the field of mechanics and physics of (geo)-materials, with a strong taste for numerical approaches. Interested applicants are invited to send a CV, a motivation letter and their transcripts to L. Brochard (laurent.brochard@enpc.fr) or A. Pouya (amade.pouya@enpc.fr) by **27 March 2019**.

Localization: Navier lab (https://www.navier-lab.fr) located at Ecole des Ponts ParisTech (6-8 avenue Blaise Pascal, 77455 Champs-sur-Marne, France)
Advisors: Laurent Brochard and Amade Pouya (directeur de thèse)
Duration: 3 years, starting in Fall 2019
Funding: application for funding will be submitted in the framework of the call for grants of the Agence nationale pour gestion des déchets radioactifs. Following the eligibility rules of ANDRA, applicants must be **26 years old or less on October 1st 2019 and be citizen of the European Union**.

[8] Jung, (2018) Master thesis ENPC.
[9] Honorio et al. (2017) Langmuir, 33(44), 12766–12776. http://doi.org/10.1021/acs.langmuir.7b03198