Gas migration in water saturated clays by coupled hydraulic-mechanical model

A. Pazdniakou and M. Dymitrowska

IRSN/PRP-DGE/SRTG/LETIS 92262 Fontenay-aux-Roses cedex – France

Keywords : multiphase flow, fluid-solid interaction, smoothed particle hydrodynamics.

1 Introduction

The principal objective of this study is to improve the representation of gas migration in highly water saturated clays. The gas produced by anaerobic corrosion of iron composing many structures of radioactive wastes deep disposal may lead to important increase of pressure. Various gas transport mechanisms can be active, separately or simultaneously. These include the transport of dissolved gases by advection and diffusion, the flow of small gas bubbles inside the water phase, the dilatation of existing and creation of new pathways due to pressure build-up (Figure 1). In this study we try to get a better understanding of the last mechanism at the microscopic scale by means of numerical simulation.

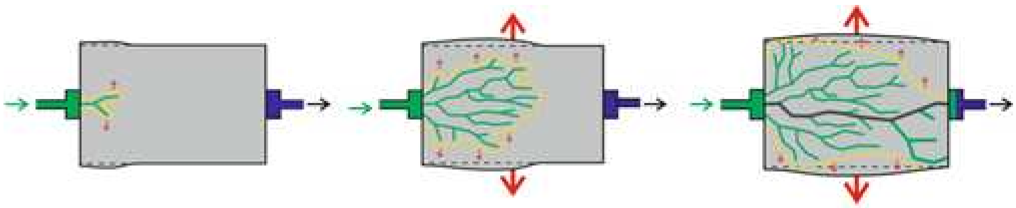

Figure 1: Creation of new pathways inside a clay sample caused by pressure build-up [1].

2 Model description

Fluid flow inside a porous medium can be described by different equations depending mainly on physical phenomena taken into account and the scale chosen for the flow description. At macroscopic scale, the Darcy equation and its modifications are widely used; at microscopic scale, up to several nanometers confinement, fluid flow can be described by the Navier-Stokes equations; when the confinement is limited to few nanometers, fluid flow can be described by the molecular dynamics and stochastic methods which take into account molecular interactions. In our case, the pore size ranges from several nanometers to few microns, which allows to employ the Navier-Stokes equations with a good accuracy. The multiphase flow is described in terms of continuum force model which introduces surface tension effects in terms of a volumetric surface tension force. This force is normal to the fluid-fluid interface and proportional to its local curvature. The solid-fluid contact angle is described in a similar way.

Clay material is usually composed of a mixture of various minerals. At the macroscopic scale, this mixture can be considered as a continuum medium with homogeneous mechanical properties, but this is no longer true at the microscopic scale where the clayey matrix and mineral inclusions of various sizes can be clearly distinguished. Due to their mechanical properties, the mineral inclusions can be considered as incompressible rigid bodies, while the clayey matrix exhibits elastic and plastic response to the fluid pressure.

3 Numerical model

Both the fluid and solid phases are simulated by means of Smoothed Particle Hydrodynamics (SPH) [2], which is a Lagrangian mesh free method. Nowadays, this method is widely applied in various engineering and scientific areas. For our purposes, it is important that the method can be successfully applied to simulate fluid hydrodynamics, elastic, plastic and rigid bodies as well as coupled solid-fluid systems behaviour. All these simulations can be performed within the same conceptual framework, which may decrease significantly the amount of work to be done. Another considerable advantage is that the method is meshless, which simplifies significantly simulation of multiphase systems with moving interfaces, and also allows to obtain the description of some physical processes (such as fracture propagation) which is not influenced by the mesh presence. Also the method may take profit of CUDA technology for massively parallel computations on GPU. Results obtained for simplified geometries and for micro-tomography images of the real clay samples will be presented and discussed.

References

[1] R. Cuss, J. Harrington, R. Giot and C Auvray. Experimental observations of mechanical dilatation at the onset of gas flow in Callovo-Oxfordian claystone, *Clays in Natural and Engineered Barriers for Radioactive Waste Confinement*, 400, 507-519 (2014).
[2] J. J. Monaghan, Smoothed Particle Hydrodynamics, *Rep. Prog. Phys.*, 68, 1703-1759 (2005).