Modeling fluid flow and effective permeability of fractured porous media by singular integral equations method

Abstract

Fluid flow through fractured porous geological formations is an important process for many areas of the geosciences such as groundwater hydrology, petroleum engineering, underground storage (CO2 or nuclear wastes) and geothermal energy. This thesis aims to develop a method for numerical modelling of fluid flow through fractured porous media and for determination of their effective permeability by taking advantage of recent results based on formulation of the problem by Singular Integral Equations. In parallel, it was also an occasion to continue on the theoretical developement and to obtain new reseults in this area.

The governing equations for flow in such materials are reviewed first and mass conservation at the fracture intersections is expressed explicitly. Using the theory of potential, the general potential solutions are proposed in the form of a singular integral equation that describes the steady-state flow in and around several fractures embedded in an infinite porous matrix under a far-field pressure condition. These solutions represent the pressure field in the whole body as functions of the infiltration in the fractures, which fully take into account the fracture interaction and intersections. Closed-form solutions for the fundamental problem of fluid flow around a single fracture are derived, which are considered as the benchmark problems to validate the numerical solutions. In particular, the solution obtained for the case of an elliptical disc-shaped crack obeying to the Poiseuille's law has been compared to that obtained for ellipsoidal inclusions with Darcy's law.

The numerical programs have been developed based on the singular integral equations method to resolve the general potential equations. These allow modeling the fluid flow through a porous medium containing a great number of fractures. Besides, this formulation of the problem also allows obtaining a semi-analytical infiltration solution over a single fracture depending on the matrice permeability, the fracture conductivity and the fracture geometry. This result is the important key to upscalling the effective permeability of a fractured porous medium by using different homogeneisation schemes. The results obtained by the selfconsistent scheme have been in particular established, which exhibits the percolation threshold for the fracture network.

The multi-region approach can be used to extend the general potential solution written for the infinite domain to that for a finite domain. A closed-form solution for flow in and around a single partially saturated fracture, surrounded by an infinite matrix subjected to a far-field condition, is also derived combining the solutions for a superconductive fracture and for an imprevious fracture. This solution is then employed to estimate the effective permeability of unsaturated fractured porous media.

The effective permeability model is applied to study the hydromechanical behaviour of a fault zone constituted by a clay core surrounded by fractured zones in the context of CO2 geological storage. The pressure injection induces an overpressure in the reservoir that may affect the permeability of the fractured zones leading to complexe coupled hydromechanical phenomena. The simulation results allow evaluating the risk of leakage of the reservoir brine to higher aquifers as well as the risk of fault reactivation.

Keywords: fractured porous media, effective permeability, singular integral equation, fracture intersection, unsaturated fracture, CO2 geological storage, fault reactivation.