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PhD POSITION IN GEOMECHANICS

Numerical study of erosion and dissolution mechanisms in rock fractures: Application to geothermal engineering

Our Ref.: Ineris-228231-2824631

BACKGROUND AND MOTIVATIONS OF THE THESIS

Understanding the thermo-hydro-mechanical behaviour of fault zones or naturally fractured reservoirs is essential for both fundamental and applied geosciences, in particular for assessing the safety of underground storage facilities and structures, such as those linked to deep geothermal energy. In the case of deep geothermal production projects (e.g. in the Rhénan Basin), different types of problems arise at different timescales. In longer term, the water circulating in the fracture network, charged with various minerals and undergoing significant temperature changes on its trajectory between injection and production wells, may have physico-chemical interactions with the surrounding rocks and modify the hydraulic properties of the network. Dissolution-precipitation phenomena can occur in this context and, in the medium to long term, have significant effects on the hydraulic properties of the fracture network. It has already been observed that the chemical reactivity of fluids can have an impact on fluid injectivity in these contexts. In softer rocks (limestone), internal erosion and particle deposition may also occur. The phenomena of evaporite dissolution or internal and surface erosion affect the flow or infiltration characteristics and mechanical behaviour of the medium but also raise the question of the spatio-temporal evolution of these discontinuities. In the case of geothermal energy, the quality and performance of the process itself can be strongly affected by the change in the structure of the medium caused by erosion. Erosion as a perturbing mechanism of the fractured rock environment (perturbation in terms of geomechanical properties, hydraulic conductivity, etc.), as well as possible clogging mechanisms, has been the subject of various experimental and numerical studies, enabling us to highlight the mathematical and physical formalisms describing surface erosion (at the level of discontinuities) and matrix erosion (at the level of rock pores).
The main studies presented in the literature are based on different numerical approaches to analyse the influence of various parameters, in particular the intensity of the hydraulic gradient and the particle size of the particles circulating within the fractures of the medium, as well as the morphology and characteristics of the fracture. Several experimental studies have also been carried out, demonstrating the influence of similar parameters. Experimental results have highlighted several clogging and unclogging mechanisms depending on various parameters associated with the nature of the fracturing (roughness, tortuosity, network), the nature of the particles (size, gradation, concentration, ...) and the fluid flow (hydraulic gradient, fluid viscosity, ...). The various numerical modelling approaches presented in the literature take some of these parameters into account more or less directly.

AIM OF THE RESEARCH

The thesis will focus on one component of the THMC (thermo-hydro-mechanical and chemical) behaviour of a multi-fractured medium under hydraulic and thermal loading, representing the injection of fluids at a temperature different from that of the geological medium and corresponding to the context of geothermal production.
The aim is to explore different modelling approaches (continuous and/or discrete) in order to highlight the main mechanisms governing the behaviour of the fractured rock mass at different spatial and time

scales. The approach will be based firstly on a deterministic framework and then, if necessary, on a probabilistic one, to take account of uncertainties in fault geometry, density and spatial distribution, as well as on the effects of non-planarity discontinuity and fracture persistence.

Several directions of research are already emerging and could be investigated, based on CFD-DEM (Computational Fluid Dynamics - Discrete Element Method) numerical simulations, continuing the work of Wang et al (2024). This involved the study of particle migration in a fracture by investigating the influence of various fracture characteristics and resulted in a formula for calculating particle velocity across the fracture.

The study's perspectives include the influence of fracture tortuosity, the influence of relative particle-wall friction, fracture wall erosion due to attrition and/or impact of particles circulating in the medium, and the consequences for fluid flow.

Moreover, in the more specific case of geothermal energy, dissolution phenomena can arise, in particular as a result of temperature changes in the fluids circulating in the fissures, as well as recrystallization phenomena resulting in solid deposits in the cracks. The effect of temperature change on the properties of the medium and on erosion will also be taken into account in the numerical simulation.

Thesis chronology:
1. Literature review
2. Formalization of the problem for a medium containing a single fracture: one- and two-dimensional problem
3. Extension of the approach to a medium containing several fractures: 2D and 3D analyses
4. Numerical modelling of coupled THMC boundary problems using discrete and continuous approaches and different computational software.

COLLABORATION

In previous research, we collaborated with Professor Yin's team at PolyU Hong Kong to complete the study of particle migration in a fracture, studying the influence of different fracture parameters on particle migration, and obtaining the expression of particle velocity through the fracture. The perspectives of the present thesis topic are a continuation of this collaboration undertaken several years ago.
Regular working meetings will be organized between Ineris, Centrale Nantes and PolyU. Hong Kong Polytechnic University will be mainly involved in research related to numerical simulation techniques, while Centrale Nantes and Ineris will be responsible for the analysis of numerical results and theoretical development. The aim is to produce a comprehensive set of erosion simulation methods for geothermal engineering, as well as a theoretical framework for quantitatively assessing the degree of erosion during the geothermal exploitation of a site.

REFERENCES

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POSITIONING AND CAREER PROSPECTS FOR THIS RESEARCH

The double advantage of this exploratory and operational thesis is that the PhD student will be able to pursue his or her career path and apply the work and themes developed during the thesis both in an industrial environment (fields related to fractured rock mass issues, acquisition of scientific bases with high added value), and in an academic environment (increasing complexity of coupled modeling approaches: continuous, discontinuous, mixed).

This research, with its fundamental and applied components, is part of a virtuous process for the environment: the use of decarbonized green energy.

LOCATION

The thesis will be carried out in Verneuil-en-Halatte (Oise) and at Ecole Centrale de Nantes (Nantes).

CANDIDATE PROFILE

The candidate holds a Master 2 and/or an Engineering degree in Geosciences, with an honors degree and a solid base in mechanics of continuous media, geomechanics and transfers in fractured porous media and in numerical analysis. He/she is interested in modeling and numerical developments to provide an in-depth understanding of the mechanisms involved in coupled multi-scale and multi-physics phenomena. He/she is fluent in English. He/she is able to take the initiative, work in a collaborative team and exchange results with the partners involved in the project, both orally and in writing.

GENERAL INFORMATION

Thesis start: September/October 2025
Duration: 3 years
Gross salary: around 2200 € / month
Type of contract: Limited term contract

APPLICATION FORM

The application must include: a curriculum vitae, copies of certificates for each university degree and grades obtained, a letter describing your motivation and interest in working on the proposed subject, and any letters of recommendation from your teachers and/or supervisors.

SUPERVISORS / CONTACTS

Supervision: Ineris
Dr-HDR Farid Laouafa (Thesis Director),
Ineris

Co-supervision:
Prof. P-Y Hicher, Centrale Nantes (Thesis Co-Director)
Ecole Centrale Nantes

Additional supervisor
Prof. Zhenyu Yin
Hong Kong Polytechnic University

Note that this research work will be carried out in close collaboration with ENPC and IFPEN.

CONTACTS

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This position is open to people with handicaps.