MOBILITY MISSION REPORT

This work has been partially supported by the EURAD project that has received funding from H2020-EURATOM 1.2 under grant agreement ID 847593.

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MISSION TITLE

Participation of the EGU General assembly 2024

DESCRIPTION

Concerned organisations

University of Liège (Research entitiy)

Concerned infrastructures or facilities

Not applicable.

Concerned phases

Not applicable.

Themes and topics

- Theme 4: Geoscience to understand rock properties, radionuclide transport and long-term geological evolution
    - Long-term stability (uplift, erosion and tectonics)
    - Perturbations (gas, temperature and chemistry)
    - Aqueous pathways and radionuclide migration

Keywords

EGU General Assembly; Geological disposal; thermal impact; thermal-mechanical coupling; cohesion variation; in-situ heating test.

EXECUTIVE SUMMARY

The objective of the mission is to attend the EGU General Assembly 2024, and to present the work performed in the framework of the EURAD Workpackage 7.

During 5-day academic stay, a poster entitled "A thermal-mechanical constitutive modelling for Callovo-Oxfordian Claystone in the context of nuclear waste disposal" was presented in the session "ERE5.4 Coupled Thermo-Hydro-Mechanical-Chemical (THMC) processes in geo-reservoirs with emphasis on clay behaviour".

This contribution deals with a thermal-mechanical constitutive modelling for Callovo-Oxfordian Claystone in the context of nuclear waste disposal. The heat generated by the nuclear waste decay brings elevated temperature increase, which may affect the thermo-hydro-mechanical (THM) behaviour of the host rock. A correct evaluation of the thermal impacts on the host rock behaviour is important for the design of the underground geological disposal. The study introduces a thermal-mechanical modelling involved with thermal plasticity. The cohesion of the host rock is defined as a function of the temperature to describe the thermally induced change of mechanical behaviour of the host rock. This model is validated against experimental observations in the laboratory and further applied to the large-scale heating test. The numerical results show that: 1) The cohesion dependency on temperature is introduced, and the parameters are calibrated based on triaxial test results; 2) The increase of the plastic zone after heating is observed, which is induced by the degradation of the cohesion; 3) The strain localisation phenomenon is observed, and the evolution of V-M equivalent strain is of the same pattern as cohesion evolution.

The applicant also followed some interesting sessions related to radionuclide transport and long-term geological evolution, which helped to promote professional knowledge and enhance EURAD community cooperation.

1. MISSION BACKGROUND

The EGU General assembly 2024 held in Vienna that proposes a session on Coupled Thermo-Hydro-Mechanical-Chemical processes in geo-reservoirs with emphasis on clay behaviour. This event provide the applicant with the opportunity not only to present the recent outcomes of my work in the framework of EURAD Programme, but also to stay abreast of the latest advancements in the field of RWM, to broaden expertise and to foster collaborations.

1.1. R&D background

Deep underground geological disposal is widely accepted as one of the most appropriate ways for the long-term safety and management of radioactive waste. The heat generated by the nuclear waste decay brings elevated temperature increase, which may affect the thermo-hydro-mechanical (THM) behaviour of the host rock. A correct evaluation of the thermal impacts on the host rock behaviour is important for the design of the underground geological disposal.

With the temperature increases, thermal pressurization is observed both in the small (laboratory) and large (in-situ) scale tests. Physically, the overpressure induced by the discrepancy of the thermal expansion coefficient between the solid and fluid phases may potentially induce fracture re-opening and propagation. The host rock located in the middle of two adjacent cells may suffer shear or tensile failure, which is dependent on the intensity of the thermal power and the distance between the neighbouring cells. Some research work also shows that soil characteristics like cohesion, elastic modulus and water viscosity are influenced by the rise in temperature. To investigate the thermally induced change on the mechanical property of host rock, triaxial compression tests were conducted at the University of Lorraine at different temperatures (20, 40, 60, 80, 100 and 150 °C), confining pressures (0, 4 and 12 MPa) and samples orientations (parallel and perpendicular to the bedding plane). The results showed the transitory overpressure induced by the thermal dilation during the initial heating, and the degradation of the mechanical strength of the host rock with the increase in temperature.

Based on the experimental observations, the triaxial compression tests are represented in a two-dimensional axisymmetric coupled THM model. The modelling is composed of the two steps: isotropic loading (increase confining stress and temperature), and shear process (increase axial loading). The numerical FEM code is LAGAMINE from the University of Liège. The Callovo-Oxfordian (COx) claystone, relying on its low permeability and good plasticity, has been selected as the host rock for the underground geological disposal in Meuse/Haute-Marne in France. The objective of this study is to introduce thermal-mechanical modelling involved with thermal plasticity. The cohesion of the host rock is defined as a function of the temperature to describe the thermally induced change of mechanical behaviour of the host rock. This model will then be validated against experimental observations in the laboratory and further applied to the large-scale heating test.

1.2. Mission objectives

The objective of the mission is to attend the EGU General Assembly 2024, and to present the work performed in the framework of the EURAD Workpackage 7. By attending relevant presentations and discussions, to gain insights into current advancements in the field.

1.3. Mission request

The mission request is to apply the EURAD Mobility Programme attending the EGU General Assembly 2024, to present the recent research progress and to promote professional knowledge in this field.

1.4. Mission composition

Host organisation

the European Geosciences Union (EGU)

Host facility

Austria Center Vienna in Vienna, Austria and online.

Mission dates

April 14th 2024 – April 18th 2024

2. MAJOR PRACTICES, TECHNIQUES, METHODS, TOOLS OR SYSTEMS OPERATED OR STUDIED

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2.1. Practice, technique, method, tool or system operated or studied during the mission

Applications of Thermo-hydro-mechanical and phase-field models in the context of radioactive waste disposal research.

Description

A phase-field model is a mathematical model for solving interfacial problems. This approach has been generally used in the fracture mechanics, and it can be extended with multiphase-field THM coupling process.

Usage

The method substitutes boundary conditions at the interface by a partial differential equation for the evolution of an auxiliary field (the phase field) that takes the role of an order parameter. This phase field takes two distinct values (for instance +1 and −1) in each of the phases, with a smooth change between both values in the zone around the interface, which is then diffuse with a finite width.

Benefits

Its main advantage is the possibility of modelling arbitrarily complicated crack patterns through the solution of partial differential equations. Phase-field models have a variational structure and do not need ad hoc criteria for topological changes in the crack pattern (branching or merging). The state of the material is characterized by the crack phase-field (or simply phase-field) with values ranging from 0 (intact material) to 1 (fully damaged material). A discrete crack is replaced by the steep variation of the phase-field from 0 to 1 with a characteristic width of the transition zone.

Limitations

A limitation of this approach is that nucleation is based on strain energy density and not stress. An alternative view based on introducing a nucleation driving force seeks to address this issue.

Applicability

Due to the relative simplicity of numerical implementation in standard finite element computer codes, the phase-field method has successfully been applied to various engineering problems including multi-physics coupling, finite deformation, and coupling between damage and plasticity. This approach is not only suitable for brittle cracking in elastic materials, but also for ductile cracking in plastic materials.

2.2. Practice, technique, method, tool or system operated or studied during the mission

Pore pressure evolution in media with isotropic and anisotropic permeability – analytical and numerical solutions.

Description

Understanding perturbations caused by underground fluid injection and extraction is essential for steady long-lasting operations of subsurface energy systems (e.g. geothermal systems). The systems are often too complex to obtain precise analytical solutions and computationally expensive to have fine numerical results.

Usage

A 3D finite element model with injection/production wells using a fully coupled multiphysic modelling, investigates where the numerical solutions of the spatial limited volume coincide and diverge from the analytical solutions of pore pressure in infinite media. Point source, extended source, half space, and anisotropic medium are taken into account.

Benefits

Numerical and analytical solutions of point sources and infinite medium well agree in the interest volume and time domain. This method provides an estimated solution of prediction for the pore pressure evolution in the pore pressure distribution analytically.

Limitations

The extended source effects are significant in the vicinity of the injection interval, but the results converge to the point source solutions at farther distances. The half-space model with zero pressure boundary condition at finite distance is underestimated by infinite medium solution.

Applicability

The anisotropic medium affects the spatial and temporal evolution of pore pressure, which is very interesting. In the direction of higher permeability, the pore pressure build-up happens faster, while long-time values converge to isotropic pressure level. In contrast, the points on the axis of the same permeability as in the isotropic model, have lower long-time pore pressure limit. These analytical formulas is possibly investigated with thermal pressurization, which is better for capturing pore pressure evolution from the in-situ.

Relevant literatures are availabe:

Rudnicki, J. W. (1986). Fluid mass sources and point forces in linear elastic diffusive solids. Mechanics of materials, 5(4), 383-393.

Jaeger J. C, Carslaw H, S (1959). Conduction of heat in solids. Oxford Science Publications.

2.3. Practice, technique, method, tool or system operated or studied during the mission

Not applicable.

Description

Not applicable.

Usage

Not applicable.

Benefits

Not applicable.

Limitations

Not applicable.

Applicability

Not applicable.

2.4. Practice, technique, method, tool or system operated or studied during the mission

Not applicable.

Description

Not applicable.

Usage

Not applicable.

Benefits

Not applicable.

Limitations

Not applicable.

Applicability

Not applicable.

3. MISSION FINDINGS AND CONCLUSIONS

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3.1. Lessons learned and conclusions

Attending the EGU General Assembly 2024 was enlightening, offering valuable insights and lessons that deepened my grasp of multi-physical interactions in geo-reservoirs, specifically focusing on THMC coupling processes in clay formations relevant to radioactive waste containment. Engaging with presentations, posters, and discussions exposed me to state-of-the-art research, methodologies, and progressions within the geosciences domain. Interacting with peers enabled fruitful knowledge sharing and potential collaborations, enhancing comprehension of the complexities and potentials involved in managing geological repositories.

The build-up of temperature has a non-negligible impact on the in-situ behavior of host rock, such as volume change behavior (elastic expansion vs. plastic contraction depending on the OCR), strength (preconsolidation pressure, compression and swelling index, and shear strength), thermal pressurization behaviour. The introduction of the cohesion dependency on the temperature helps the development of thermal plasticity. The database involved with this implementation is limited. Moe data and advanced thermal-mechanical modelling should be investigated.

Meanwhile, multi-phase and multi-scale modeling left the applicant deep impression. They play a vital role in advancing scientific understanding, optimizing engineering designs, and addressing complex challenges across a wide range of disciplines.

3.2. Relevant findings and conclusions for home organisation

The phase-filed approach is an interesting method that could be integrated into the FEM code developed in the home organization.

The analytical prediction of pore pressure is of great interest in the current project, which could be investigated together with the thermal pressurization mechanism.

3.3. Relevant findings and conclusions for host organisation

Not applicable.

3.4. Relevant findings and conclusions for other organisations

Not applicable.

4. POTENTIALS FOR IMPROVEMENT OR DEVELOPMENT

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4.1. Generic potentials

Not applicable.

4.2. Potentials for home organisation

Not applicable.

4.3. Potentials for host organisation

Not applicable.

APPENDICES

Mission journal

April 14th, Sunday:

Take the train from Liege (9 am) to Vienna (8 pm).

April 15th, Monday:

The poster "A thermal-mechanical constitutive modelling for Callovo-Oxfordian Claystone in the context of nuclear waste disposal" was presented. The modelling approach about in-situ ALC1605 heating test was discussed with the researchers from BGR (Australia). The comparison between the FEM code Lagamine and Moose was carried out with the researchers from RWTH (Aachen). The discussion about the physical properties of Callovo-Oxfordian claystone involved with the project of NWS (UK) was made with the researchers from Manchester Unversity. The participation of oral presentation in the session ERE5.4 "Coupled Thermo-Hydro-Mechanical-Chemical (THMC) processes in geo-reservoirs with emphasis on clay behavior" was conducted.

April 16th, Tuesday:

The participation of poster and oral presentations in the session ERE3.2 "Radioactive waste repositories - Geosciences in the assessment of the long-term evolution of the geosphere" was conducted. In this session, geoscience knowledge is investigated to safely construct a geological or surface disposal facility for radioactive waste in a specific selected site. The safety requirements include i) isolation of the nuclear waste from humans and the accessible biosphere, ii) containment by retention and retardation of contaminants, iii) limited water flow to the geo-engineered facility and iv) long-term geological stability of the site.

April 17th, Wednesday:

The participation of poster and oral presentations in the session ERE2.7 "Shallow geothermal energy: geoscience and engineering approaches at different scales" was conducted. The session contributes about shallow geothermal energy applications, including traditional closed- and open-loop borehole heat exchangers as well as so-called energy geostructures. Small scale (system) and Large scale (city or larger) based on experimental, analytical, numerical modelling and artificial intelligence techniques are presented with a great interest.

April 18th, Thursday:

Take the train from Vienna (9 am) to Liege (7 pm).

Mission bibliography

Not applicable

MISSION BENEFICIARY

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PARTNER EXPERTS CONTRIBUTING TO THE MISSION

Host organisation experts

- Silvia De Simone (Spanish National Research Council)
- Session ERE5.4 convener

Home organisation experts

- Frédéric Collin (Professor, University of Liège)
- Supervisor of the work

Other organisations experts

- Not applicable

REPORT APPROVAL

Date	Beneficiary	Home mentor/supervisor	Host mentor/supervisor
25/04/2024	Hangbiao Song	Frédéric Collin	Not applicable
	[signature]	[signature]	See letter of acceptance