模擬緻密膨潤土中的氣體移流：從不同數值方法中吸取經驗

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摘要

在黏土層中之放射性廢棄物處置場，由於金屬材料在缺氧條件下發生腐蝕、廢棄物放射性衰變或水輻解等等，可能會產生氫氣和其他氣體。當氣體產生速率超過黏土孔隙內的氣體擴散速率，會形成離散的氣體；當氣體壓力累積到足以超過作用在岩體上的應力，氣體會發生擴容性移流。

本文屬 DECOVALEX-2019 計畫中任務之一，目的為藉由數值模式更好地描述氣體在低滲透性泥質處置場主岩和黏土基工程障壁中之移流過程。本文特別關注控制氣體進入、流動和通道密封的機制及其對黏土基工程障壁性能的影響。過去研究顯示，氣體流動伴隨著膨脹通道的產生，而通道特性在介質內隨時間及空間改變。故此，團隊發展四類方法：(i) 標準兩相流模式（連續技術）考量多種力學變形行為；(ii) 加強式兩相流模式，將裂隙嵌入塑性材料（連續技術）或納入剛體彈簧（離散方法）網絡模式；(iii) 單相流模式，結合僅考慮氣體流動的潛變損傷函數(creep damage function)；(iv) 氣體流動的混沌性質概念方法。本文比較不同方法之結果，此步驟非常重要，因建模方法對於未來處置場中氣體流動的描述及預測有重大影響。此外，本研究所得經驗亦可應用於其他考慮氣體流動之黏土基工程相關議題，如碳氫化合物遷移、碳捕存、頁岩氣及垃圾掩埋場設計。

本文總結該任務在 2016 年 5 月至 2019 年 5 月期間進行的工作成果，並提供了實驗數據的簡要概述和綜合建模團隊工作的結果。

關鍵字： 氣體流動、擴容現象、兩相流模式、力學變形、連續方法、裂隙

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Modelling advective gas flow in compact bentonite: Lessons learnt from different numerical approaches

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ABSTRACT

In a repository for radioactive waste hosted in a clay formation, hydrogen and other gases may be generated due to the corrosion of metallic materials under anoxic conditions, the radioactive decay of waste and the radiolysis of water. If the gas production rate exceeds the gas diffusion rate within the pores of the clay, a discrete gas phase will form and accumulate until its pressure becomes large enough to exceed the entry pressure of the surrounding material, at which point dilatant, advective flow of gas is expected to occur.

The purpose of Task An under DECOVALEX-2019 is to better represent the processes governing the advective movement of gas in both low-permeability argillaceous repository host rocks and clay-based engineered barriers within numerical codes. In this paper special attention is given to the mechanisms controlling gas entry, flow and pathway sealing and their impact on the performance of the engineered clay barrier. Previous work suggests gas flow is accompanied by the creation of dilatant pathways whose properties change temporally and spatially within the medium. Thus, four new types of approaches have been developed: (i) standard two-phase flow models (continuous techniques) incorporating a range of different mechanical deformation behaviours, (ii) enhanced two-phase flow models in which fractures are embedded within a plastic material (continuous techniques) or incorporated into the model using a rigid-body-spring network (discrete approaches), (iii) a single-phase model incorporating a creep damage function in which only gas flow is considered, and (iv) a conceptual approach used to examine the chaotic nature of gas flow. The outputs from these different approaches are compared. This is an essential step as the choice of modelling approach strongly impacts the representation and prediction of gas flow in a future repository. In addition, experience gained through this task is of direct relevance to other clay-based engineering issues where immiscible gas flow is a consideration including hydrocarbon migration, carbon capture and storage, shale gas and landfill design.

This paper summarises the outcomes of work in Task A conducted between May 2016 and May 2019 and provides a brief overview of the experimental data and a synthesis of the work of the participating modelling teams.

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