Numerical Simulation of the Evolution of Gas Migration in Bentonite

Presenter: Yu-Sheng Lin
Advisor: Prof. Jui-Sheng Chen
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Abstract

The final disposal method for high-level waste is Deep Geological Disposal. This is where nuclear waste is buried in geological formations at depths greater than 300 meters, and canister and buffer materials are used to cover and secure it. By the principles of isolation, retardation and dilution, the waste decays harmlessly, isolating it from the biosphere and ensuring human health and environmental safety. However, after hundreds of years of disposal, gas may be generated due to the corrosion of metallic materials under anoxic conditions, radioactive decay of waste, or the radiolysis of water. When gas production rate is slow, gas dissolves in porewater and migrates by advection and diffusion. If the gas production rate exceeds the gas diffusion rate, a discrete gas phase forms, displacing parts of porewater. With continuous gas pressure accumulation, the stress on bentonite can no longer withstand it. This might lead to pathway dilation and tensile fractures, allowing gas to escape from the bentonite. As gas degrades the barrier's capability, endangering the safety of the repository. Therefore, this study utilizes the THMC7.1 numerical model to simulate gas migration in bentonite, aiming to explain the gas migration process in bentonite more clearly. When subjected to gas pressure, it leads to the displacement of the bentonite and alters the size of pore apertures, which are related to permeability. Consequently, this study investigates the variation of permeability over time and analyzes the effects of hydraulic-mechanical coupling.

Keyword: High-level waste, Deep Geological Disposal, Buffer materials, Bentonite, Gas migration, Numerical simulation, Coupled hydraulic-mechanical.

利用數值模擬膨潤土中氣體遷移之演變

報告者：林禹昇
指導教授：陳瑞昇 老師
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摘要

高放射性廢棄物最終處置方式為深層地質處置，以多重障壁概念，將廢棄物包覆在處置罐中，利用豎井運至地層至少三百公尺以下的岩體中，再填滿緩衝材料，藉由隔離、遲滯及稀釋等原理，以確保廢棄物衰變到無害程度，與生物圈隔離，保護民眾健康及環境安全。然而，經處置數百年後，廢棄物自身衰變產生熱，會讓處置系統溫度上升，熱膨脹使力學應力改變，進而造成水力及化學之作用產生，在低氧環境下金屬容器腐蝕、廢棄物自身放射衰變、水輻射分解均可能產生氣體，當氣體生產率較低時，氣體會溶解於水中並經由移流與擴散方式遷移，而氣體生產率大於擴散率時，氣體離散相將形成，緩衝材料內的水逐漸被氣體取代。氣體持續累積，一旦作用在緩衝材料上的應力無法承受氣體壓力，孔隙會慢慢地擴張並產生裂隙，氣體藉此流出至岩體，影響處置系統之能力，造成安全性的危險。因此，本研究利用 THMC7.1 數值模式模擬氣體在緩衝材料內遷移的過程，並透過實驗室的氣體灌注實驗數據進行驗證，更清楚地了解氣體壓力的累積和氣體突破的過程。在受到氣體壓力影響時，緩衝材料會產生位移，改變孔隙間孔徑的大小，而孔徑大小與滲透率相關。因此，本研究將探討滲透率隨時間變化的情況，並分析水力與力學之間的相互作用。

關鍵字： 高放射性廢棄物、深層地質處置、緩衝材料、膨潤土、氣體遷移、數值模擬、水力力學耦合