乾熱岩地熱儲集層的熱水力學模型

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摘要

對於地熱電廠之選址及開發，數值模式建模及耦合模擬可有效幫助相關單位預期此電廠的產能、溫度、預期影響等，可作為此電廠之重要參考依據。有了足夠的數據和適當的建模工具，就可以建構出和真實案例相似的地熱系統。本文以熱-水-力耦合(Thermo-hydro-mechanical, THM)理論為基礎，建立一個三維數值模型，針對乾熱岩(Hot dry rock, HDR)地熱儲集層進行開發評估。該研究使用以有限元素法(Finite element, FE)為基礎之 COMSOL Multiphysics 軟體進行模擬及分析，探討開採過程中影響儲集層性能的不同因素，並探討建模工具及技術的有效性及正確性。本文研究了裂隙孔隙、裂隙可透性、注水井位置及裂隙滲透率四個因素，並使用單一平面和多個平面裂縫系統的鑽井排列和位置，於新墨西哥州芬頓山一處 HDR 地熱儲集層進行驗證研究，以確定模型的可靠性。驗證模型後，本文使用單一平面裂縫 HDR 系統和多個平面裂縫系統進行分析，以確定鑽井排列和位置對儲集層參數和產能的影響。結果顯示，鑽井的排列不會影響裂縫性質和儲集層產能的變化，但鑽井位置則顯著影響儲集層產能及數據。整體而言，在模型中，以一定的時間尺度比較下可得知，溫度下降較小及注水井在模型的下方而生產井(抽水井)在模型的上方之方案，生產性能及效能是較佳且有利的。此研究也顯示，當有了足夠的資料和適當的建模工具，便可模擬 HDR 地熱系統的行為並預估其長期產能。

關鍵字: 乾熱岩、地熱儲集層、熱-水-力模型、芬頓山、單一平面裂隙、多個平面裂隙系統

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A thermo-hydro-mechanical model of a hot dry rock geothermal reservoir

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ABSTRACT

With sufficient data and the appropriate modelling tools, it is possible to replicate the real-life behaviour of geothermal systems. Modelling tools could guide geologists, engineers and decision-makers in developing an optimal design for these systems. In order to explore the effectiveness of the modelling techniques, this paper presents a new three-dimensional (3D) numerical model of a hot dry rock (HDR) geothermal reservoir using coupled thermo-hydro-mechanical (THM) processes. The model is implemented in the COMSOL Multiphysics Finite Element (FE) solver, and its reliability is confirmed by conducting a validation study using field measurements from the Fenton Hill Phase I HDR system in New Mexico. After confirming the model's reliability, two case studies are analysed to determine the different factors affecting reservoir performance during exploitation. The factors analysed for the two cases are wellbore alignment and placement, using single and multiple planar fracture HDR system configurations. The results show that wellbore alignment does not affect changes in fracture properties and reservoir productivity. Wellbore placement, however, is found to affect reservoir performance significantly. The simulation analysis performed shows that knowledge of injection/production wellbore placement could be a significant asset to reservoir engineers/managers during the planning, exploration, design, and exploitation stages.