評估用於封閉地熱系統熱傳輸模擬的 MT3DMS

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摘要

由於熱傳播和溶質傳輸之間的數學式相似，在浮力和黏度變化的影響很小的情況下，多物種傳輸數值模式 MT3DMS 應該能夠用於模擬熱傳輸行為。因此，本篇文章以單鑽孔地源熱泵 (Ground source heat pump, GSHP) 系統模型，來驗證 MT3DMS 模式與解析解和其他數值解的差異。本研究建立大小為 300 公尺×200 公尺且等間距的二維網格，及 13 層 1 公尺厚的三維模型，並依佩克萊特數 (Péclet number, P_e)訂定三種不同的情境，分別為熱傳導主導情境($P_e = 0$)、中間情境($P_e = 1$)、熱對流主導情境($P_e = 10$)。且採用兩種評估方法，將 MT3DMS 熱傳輸結果分別與解析解和數值解(如：SEAWAT、FEFLOW)進行比較。

本研究利用效率方法(efficiencies)分別比較 MT3DMS 值與解析解和數值解之間的相似程度。當效率值趨近 1，表示兩者的結果相似；當效率值為 0 時，則表示兩者結果間存在差異。結果顯示，MT3DMS 在和解析解和 SEAWAT 數值解的結果比較中有著高度的相似，但和 FEFELOW 數值解有些微的差異。本研究更進一步估算出 SEAWAT 的運算時間大約是 MT3DMS 的 1.5 倍，換句話說，MT3DMS 可以以更快的運算方式獲得相同的結果。整體來說，MT3DMS 可以成功地應用於模擬 GSHP 系統。未來希望能進一步將 MT3DMS 應用於其他的淺層地熱技術，如地源熱泵(GWHP)系統。

關鍵字: MT3DMS、FEFLOW、SEAWAT、效率方法、單鑽孔地源熱泵系統

ground water

Evaluating MT3DMS for Heat Transport Simulation of Closed Geothermal Systems

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Abstract

Owing to the mathematical similarities between heat and mass transport, the multi-species transport model MT3DMS should be able to simulate heat transport if the effects of buoyancy and changes in viscosity are small. Although in several studies solute models have been successfully applied to simulate heat transport, these studies failed to provide any rigorous test of this approach. In the current study, we carefully evaluate simulations of a single borehole ground source heat pump (GSHP) system in three scenarios: a pure conduction situation, an intermediate case, and a convection-dominated case. Two evaluation approaches are employed: first, MT3DMS heat transport results are compared with analytical solutions. Second, simulations by MT3DMS, which is finite difference, are compared with those by the finite element code FEFLOW and the finite difference code SEAWAT. Both FEFLOW and SEAWAT are designed to simulate heat flow. For each comparison, the computed results are examined based on residual errors. MT3DMS and the analytical solutions compare satisfactorily. MT3DMS and SEAWAT results show very good agreement for all cases. MT3DMS and FEFLOW two-dimensional (2D) and three-dimensional (3D) results show good to very good agreement, except that in 3D there is somewhat deteriorated agreement close to the heat source where the difference in numerical methods is thought to influence the solution. The results suggest that MT3DMS can be successfully applied to simulate GSHP systems, and likely other systems with similar temperature ranges and gradients in saturated porous media.

Introduction

MT3DMS (Zheng and Wang 1999) is a widely used program for simulation of solute transport in porous media. Since the governing equations for solute transport are mathematically identical to those for heat transport, this program appears also applicable to simulation of thermal transport phenomena in saturated aquifers. This is demonstrated in recent case studies. Martin et al. (2001) used MT3DMS to simulate heat transport on Grand Cayman Island. Cathomen (2002) and Cathomen et al. (2002) applied MT3DMS to assess the groundwater temperature distribution in an urban area of the Altach Municipality (Austria) under the influence of several ground source heat pump (GSHP) systems.

Using MT3DMS for heat transport in aquifers has limitations, because it is decoupled from the flow model. MT3DMS uses the flow regime predicted by flow simulators such as MODFLOW (Harbaugh et al. 2000) without feedback. However, in principle this is necessary, because temperature variation affects water viscosity and density, which effect hydraulic conductivity. Temperature variations in the shallow subsurface commonly are small, so simulation errors produced from using constant viscosity and density often are small and acceptable. Shallow geothermal systems produce conditions for which

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