Effects of Induced Convection on Far-Field Groundwater Flow

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RESEARCH OBJECTIVES

In the safety assessment of nuclear waste disposal, the influence of heat convection on the groundwater flow field cannot be neglected. This influence should be estimated by conducting a thermal-hydrological (TH) numerical analysis at the site characterization stage. However, as a first step, it is worthwhile to estimate the influence of heat convection using only the thermodynamic parameters obtained from existing data.

The objective of this research is to estimate the influence of heat convection on the natural groundwater flow system, employing a dimensionless parameter from case studies using a TH coupled model.

APPROACH

For this sensitivity study, the coupled heat and hydraulic simulation code TOUGH2 is applied to a vertical two-dimensional model with an area 10,000 m long and 3,000 m deep. Induced convection is generated by the hydraulic gradient (0.01) dictated by the assigned topography. The model is saturated with water, with a constant pressure at the upper boundary and impermeable lower and side boundaries. The upper and lower boundaries are set at a constant temperature, while side boundaries are insulated.

In this study, we use representative physical properties of a sedimentary rock. The vertical temperature gradient is set at 0.02°C/m. Variable permeabilities within two orders of magnitude are assigned to the model. From the results of case studies, we extract the average velocity along the particle stream traces from six starting points and the maximum vertical velocity in the model, and use them as qualitative indicators to evaluate the relative influence of heat convection. For comparison, we carried out simulations with the same hydraulic properties and the initial temperature distribution without heat transfer as the uncoupled model for each respective case.

ACCOMPLISHMENTS

To estimate the influence of thermal convection, we used the Peclet number, which denotes the ratio between advection and thermal diffusion. Figure 1 shows representative results from three cases depicting temperature distributions and stream traces. From these results, we can see that when the permeability is large, the recharge zone becomes larger, and the low-temperature area also becomes larger because of the increasing recharge of low-temperature water. Both the average velocity along the stream traces and the maximum vertical velocity increase as the Peclet number increases. However, the velocity ratios of the TH coupled model to the uncoupled model both decrease when the Peclet number exceeds 2.0.

In a high-permeability condition, the flow of cold water from the surface dominates the temperature distribution, and almost the entire area becomes a low-temperature zone. On the other hand, if the Peclet number is less than 0.2, the velocity ratio is less than 1.1, which means that the error in the uncoupled model is only about 10%.

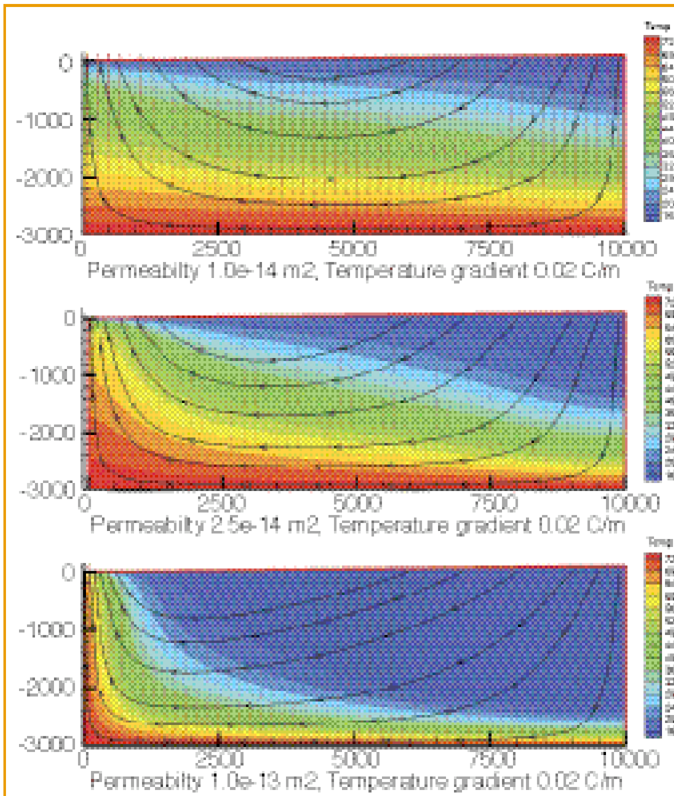

Figure 1. The temperature distribution and stream traces from three representative cases of coupled TH simulations with induced convection

SIGNIFICANCE OF FINDINGS

It was shown that the Peclet number is a useful indicator for predicting the influence of thermal convection on groundwater flow. When the Peclet number is small, the influence of heat convection is small because of the slow velocity. There is a critical Peclet number (a function of the topography) above which the influence of heat convection becomes significant.

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