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Analytical simulations on the role of mechanical dispersion in temperature plumes

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The effect of mechanical thermal dispersion on the simulation of temperature plumes in aquifers that evolve from vertical ground source heat pump (GSHP) systems is evaluated. Traditionally, mechanical thermal dispersion is neglected in analytical solutions for the simulation of heat transport in aquifers, due to the dominance of thermal diffusion. This is reflected by remarkable thermal diffusion coefficients, which are commonly much higher than those coefficients describing solute diffusion. One further argument for such simplification is that acquisition of reliable dispersivity values would imply additional field measurements and/or calibration procedures. In this study an existing two-dimensional analytical approach is extended in order to account for mechanical thermal dispersion. The model is solved for transient and steady state conditions. Moreover, an equation to calculate the length of the temperature plume for steady state conditions is developed. To study the interplay between mechanical thermal dispersion and hydraulic conductivity, the transverse dispersivity is increased from 0.05 m to 0.2 m and the Darcy velocity is varied from 10^{-8} m s^{-1} to 10^{-4} m s^{-1}. Our criterion for assessing if mechanical thermal dispersion can be neglected is the calculated error that would be introduced. Two types of evaluations schemes were used, modeling efficiencies and relative error. What is more, modeling efficiencies are evaluated as a function of the Peclet number in order to account for dependencies on the thermal conductivity. All model results are discussed with respect to their implications for the operation of GSHP systems. Mechanical thermal dispersion causes dissipation of energy. Temperature plume lengths become shorter with increasing transverse dispersivity. Apparently, a dispersion-dominated regime yields lower temperature changes close to the source, i.e. the borehole heat exchanger (BHE), in comparison to scenarios without mechanical thermal dispersion. In general, based on a field scale of 10 m, the consideration of the mechanical thermal dispersion is an important factor for the prediction of shape and extension of temperature plumes only for coarse sand and gravel aquifers. From the perspective of environmental regulators, such assumptions might be crucial for further licensing applications of neighboring GSHP systems. In comparison, ignoring mechanical thermal dispersion provides appropriate predictions of the temperature plume length for geological conditions dominated by medium and fine sands, clays, and silts. Accordingly, the range of hydrogeological conditions, where the thermal dispersivity can be neglected is quite large. This might be the reason of why mechanical thermal dispersion has been traditionally neglected in heat transport simulation problems.