EGU General Assembly 2021

EGU21-10564, updated on 27 May 2022
https://doi.org/10.5194/egusphere-egu21-10564
EGU General Assembly 2021

Application of Thermal Taylor Dispersion to Upscaling of Geothermal Processes in Heterogeneous Formations

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Well-logging data show that geothermal formations typically feature layered heterogeneities. This imposes a challenge in numerical simulations, in particular in the upscaling of geothermal processes. The goal of our study is to develop an approach to (1) simplify the description of heterogeneous geothermal formations and (2) provide an accurate representation of convection/dispersion processes for simulating the up-scaled system.

In geothermal processes, transverse thermal conduction causes extra spreading of the cooling front: thermal Taylor dispersion. We derive a model from an energy balance for effective thermal diffusivity, α_{eff}, to represent this phenomenon in layered media. α_{eff}, accounting for transverse heat conduction, is much greater than the longitudinal thermal diffusivity, leading to a remarkably larger effective dispersion. A ratio of times is defined for longitudinal thermal convection and transverse thermal conduction, referred to as transverse thermal-conduction number N_{TC}. The value of N_{TC} is an indicator of thermal equilibrium in the vertical cross-section. Both N_{TC} and α_{eff} equations are verified by a match with numerical solutions for convection/conduction in a two-layer system. For $N_{TC} > 5$, the system behaves as a single layer with thermal diffusivity α_{eff}.

When $N_{TC} > 5$, a two-layer system can be combined and represented with α_{eff} and average properties of the two layers. We illustrate upscaling approach for simulation of geothermal processes in stratified formations, by grouping layers based on the condition of $N_{TC} > 5$ and the α_{eff} model. Specifically, N_{TC} is calculated for every adjacent two layers, and the paired layers with a maximum value of N_{TC} are grouped first. This procedure repeats on the grouped system until no adjacent layers meet the criterion $N_{TC} > 5$. The upscaled layer properties of the grouped system are used as new inputs in the numerical simulations. The effectiveness of the upscaling approach is validated by a good agreement in numerical solutions for thermal convection/dispersion using original and average layer properties, respectively (Figs. 1 and 2 in the Supplementary Data File). The upscaling approach is applied to well-log data of a geothermal reservoir in Copenhagen featuring many interspersed layers. After upscaling, the formation with 93 layers of thickness 1 – 3 meters is upscaled to 12 layers (Fig. 3 in the Supplementary Data File). The effective thermal diffusivity α_{eff} in the flow direction is about a factor of 10 times greater than original thermal diffusivity of the rock. Thus, α_{eff} should be used as simulation inputs for representing more accurately geothermal processes in the up-scaled system.