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Testing a Thermal-Dispersion Upscaling Method for Geothermal Reservoir Simulation in Heterogeneous Reservoirs

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The lifetime of a geothermal doublet depends on the time it takes reinjected cold water to reach the hot production well. The spreading of the thermal front as it advances through the reservoir is therefore key to the lifetime of the project. Simulation of thermal dispersion in a heterogeneous reservoir is challenging. Refinement of the grid to incorporate all scales of heterogeneity is impractical. Conventional models take the arithmetic average of properties within an upscaled grid block. This causes underestimation of thermal dispersion in the flow direction.

We have developed an upscaling method that accounts for the increased "Taylor"dispersion that results from nonuniform velocities, reflecting permeability variation, within a grid block (Tang, 2022). With this method, for instance, we upscale a geothermal reservoir description with 91 layers, representing permeability values from a well log, to 12 layers (figures a and b in graphical abstract), with corrected thermal dispersion coefficients (figures c and d). The upscaled simulation model has increased thermal dispersivity in the flow direction.

In this study we examine the combined effects of improved upscaling and numerical dispersion (van Nieuwkerk, 2022) using the DARTS simulator (Khait, 2019). We use a 2D rectangular "layer-cake"model of 91 layers reflecting the permeability distribution at the well, with parallel flow to eliminate numerical dispersion from diagonal flow between grid blocks. We compare results of upscaled models to the original 91-layer description with sufficient grid resolution in the flow direction to minimize numerical dispersion overall. We examine the advance of cold water from one well to the other and, in particular, the arrival of the cold-temperature front at the production well. For simplicity, in this study we exclude heat transfer with over- and unburden to focus on dispersion within the reservoir.

With sufficient grid resolution in the flow direction, the corrected upscaling method gives a better fit to the 91-layer fine-grid model than simple arithmetic averaging within grid blocks. Upscaling in multiple stages using the new method appears to further increase thermal dispersivity by a modest amount. Arithmetic upscaling underestimates thermal dispersion.

However, coarser grid refinement (50 grid blocks between wells) increases the spread of the thermal front for both upscaling methods. As a result, combined with numerical dispersion, the arithmetic upscaling method gave a better fit in that case than the corrected upscaling. With 25 grid blocks between wells, numerical dispersion greatly distorts the results of both upscaling methods, spreading the thermal front much more than in the fine-grid 91-layer simulation.

These results show the complexity of predicting the breakthrough time of the cold-water front in a geothermal doublet. Current simulators do not account for increased dispersion arising from heterogeneity within grid blocks, but numerical dispersion greatly distorts results. Higher-order numerical methods designed to correct for numerical dispersion may help. Furthermore, if the simulator assigns the thermal conductivity automatically based on average fluid and formation properties within a grid block, it may be difficult to adjust the thermal dispersivity for Taylor dispersion.

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