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Porosity Dynamics through Carbonate-Reaction Kinetics in High-Temperature Aquifer Storage Applications

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While near-surface geothermal energy applications for the heating and cooling of buildings have been in use for decades, their practical adoption is limited by the energy transport rates through soils. Aquifers provide a means to use convective heat transport to improve heat transfer between the building and the aquifer. However, the solid matrix in the aquifer is carbonaceous in nature, and calcification prevention techniques in the heat exchangers for the building also lead to dissolution of the aquifer matrix. Due to the Arrhenius nature of the reaction, dissolution rates may decrease with increasing temperature. An effective medium model is derived for the energy, calcium species, and fluid transport through a dynamic calcite porous medium which undergoes a reaction between the matrix and fluid. To better discern how these competing phenomena affect thermal transport in the aquifer, a two-dimensional Cartesian system is considered, where the vertical axis is parallel to the borehole axis, and flow is in the horizontal direction. An effective medium model is derived for the energy, calcium species, and fluid transport through a dynamic calcite porous medium which undergoes a reaction between the matrix and fluid. Since the fluid velocity decays algebracially with radial distance from the borehole axis, two flow regimes are considered. One regime, far from the borehole where flow rates are small, conductive thermal transport acts faster than the species transport, leading to a case where precipitation dominates and regions of the smallest porosity contract to limit energy recovery. In regions with larger porosity, moderate advection of the species is sufficient to prevent significant pore closures over the time scale of exploration. The second regime, closer to the borehole, larger flow rates reduce species concentrations sufficiently to dissolve the solid phase between pores. In this second regime, Taylor dispersion effects in both energy and species transport compete, but thermal conduction acts more slowly than advection, promoting dissolution. The critical limitation in modeling the long-term evolution of the aquifer structure is the in situ dissolution rate.

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References

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