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Geochemical modeling of reactions occurring during geothermal heat exploitation using PHREEQC

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Geothermal heat is a promising source of sustainable energy. In the Netherlands, the first geothermal wells were drilled in 2010 and more geothermal projects are planned. The exploitation of geothermal heat is commonly arranged by a doublet of two boreholes. Hot water (brine) is produced from high temperature aquifers by a production well and, after usage of thermal energy, the cooled water is re-injected by an injection well. The production and injection of water is influenced by several processes that may reduce flow, i.e. mineral dissolution and precipitation, formation of gas bubbles, mobilization of fine particles and induced clay swelling.

This study focuses on the geochemical aspects of geothermal heat exploitation and specifically on dissolution and precipitation reactions within the doublet and the reservoir. Sets of reservoir and brine compositions are defined for systematic PHREEQC modeling of geochemical reactions with changing temperature, according to a standard workflow. Hypothetic reservoir and brine compositions are chosen to reflect clastic reservoirs applicable to aquifers in the Netherlands relevant for geothermal heat exploitation.

The modeling results indicate that geochemical reactions occur throughout the doublet and downhole of the injection well in the reservoir. Both cooling and heating of the brine leads to mineral precipitation, although precipitation dominates during cooling. The brine cools increasingly with flow though the production well and (predominantly) at the surface due to heat usage. The decreasing temperature of the brine generally causes increasing mineral precipitation while mainly aluminum and silica are lost from the brine. The non-precipitating phases show an increasing tendency to dissolve during production and heat usage, reflected by the decreasing saturation index with cooling. However, these minerals do not all dissolve upon subsequent injection of the cooled brine in the reservoir. In addition, minerals that precipitate during cooling may either continue precipitating from the brine after injection in the reservoir or, these minerals may dissolve from the reservoir rock. Injection of cooled brine in the reservoir results in both precipitation and dissolution reactions; reactions decrease further away from the well.

Although precipitation is expected within a geothermal doublet and in the reservoir, there are questions regarding the type and location of precipitation. Some minerals like quartz and iron oxides can precipitate in solid crusts or precipitate as amorphous minerals to form a gel-type deposit. Mineral particles can also remain in solution and clog surface installations or reduce the permeability and hence water flow. Such differences in scaling type can be of great influence on the actual reduction of flow through the system and should be considered in future study. Also the exact location of precipitation (i.e. pore throats) is important to know for computing the influence on the flow. If an equal amount of dissolution and precipitation of two minerals is modeled and no net increase of reservoir minerals, it is yet unclear if and how permeability is affected as the porosity may not change. Reactive transport modeling and laboratory experiments can provide further insights in these processes.