NUMERICAL MODELING OF HYDROTHERMAL REACTIONS IN GEOTHERMAL RESERVOIRS

Charles G. Sammis
Pennsylvania State University
University Park, PA 16802

Although the corrosion and scaling problems associated with handling geothermal fluids are well known, the effects of hydrothermal reactions are often overlooked in geothermal reservoir modeling. Water-rock chemistry can be expected to affect the evolution of a reservoir in at least three ways: (a) the thermodynamic properties of water are affected by the dissolved solids - this is especially important in two-phase regimes, (b) the porosity and permeability change with time due to dissolving and precipitation as well as due to the volume change associated with alteration, and (c) the heats of reaction may contribute directly to the energy production.

Table 1 summarizes the important hydrothermal reactions in a granitic source rock together with the heats of reaction and associated volume changes. Note that the available chemical energy is comparable to the thermal energy while the associated volume changes are an order of magnitude larger than those due to thermal contraction.

Although significant chemical energy exists, it cannot always be extracted. One of the first questions we addressed was the delineation of reservoir conditions under which one could expect to extract significant chemical heat. For the case of dissolving-precipitation reactions, a comparison of thermal energy with chemical energy leads to a simple relation between solubility and heat of reaction for a given ratio of chemical to thermal energy extracted. Because the rate of dissolving is controlled by the solubility at the outlet temperature, the resulting relation is independent of all crack and flow parameters. In the case of quartz, the solubility at 300°C is too low for chemical heat to make a contribution - thermal energy is extracted far faster than chemical in all cases.

In the case of alteration reactions, however, the reaction rate is not limited by solubility and, depending on the alteration rate, significant chemical energy may be extracted. We have delineated the combinations of flow parameters, crack parameters, heats of reaction and alteration rates for which chemical energy associated with the alteration may be extracted. One of the objectives of our experimental program is to determine alteration rates in typical reservoir rocks, and thus assess the importance of such reactions to the total thermal regime.

The changes in porosity and permeability associated with both dissolving and alteration reactions are easily incorporated into the standard finite difference schemes commonly used in numerical reservoir modeling. Our approach to the inclusion of such effects will be discussed.

IMPORTANT REACTIONS IN GRANITIC ROCK

(CHEMICAL REACTIONS TAKEN FROM HELGESON, 1969)

PROCESS	Heat released		Solid volume change per 100g of initial min. ΔV_S(cm^3/100g)
	per mole of initial min. ΔH(kcal/mole)	per 100g of initial min. ΔH(kcal/100g)	
HYDROTHERMAL ALTERATION			
$2NaAlSi_3O_8(s)+2H^+ + H_2O \longrightarrow Al_2Si_2O_5(OH)_4(s)+4SiO_2(s)+2Na^+$ Low Albite → Kaolinite + α-quartz	11.21	4.27	-1.882
$3KAlSi_3O(s)+2H^+ \longrightarrow KAl_3Si_3O_{10}(OH)_2(s)+6SiO_2(s)+2K^+$ Microcline → muscovite + α-quartz	2.96	1.063	-5.907
DISSOLVING AND PRECIPITATION			
$SiO_2(s) + 2H_2O \longrightarrow H_4SiO_4(aq)$ α-quartz	-6.22	-10.352	-37.760
COOLING			
GRANITIC ROCK (300°C) → GRANITIC ROCK (65°C) (ρ_R = 2.65 g/cm^3, C_R = 0.25 cal/g°C, β_R = 2.5 x 10^{-5}/°C)	-	5.875	-0.2217

TABLE 1.