A SYSTEMATIC APPROACH TO GEOCHEMICAL MODELING OF COMPLEX GEOTHERMAL SYSTEMS

C. W. Klein and J. R. McNitt
GeothermEx, Inc.
Richmond, California
(USA)

Chemical modeling of geothermal systems is the primary tool for detecting, locating and quantifying the heating, cooling, mixing, boiling and condensing processes occurring in the reservoir.

Typically, the geochemical data base from which the model must be developed is very large. Each chemical analysis contains from 12 to 30 pieces of information, and by the time a project reaches the development stage, hundreds of chemical analyses have been made. Reduction of this vast database into a form that can be quickly assimilated is the first task of the geochemical modeler. At GeothermEx, this is accomplished by entering the data into a customized database system that allows for easy storage, manipulation and retrieval of information. The database not only includes the analyses themselves, but information on the physical conditions associated with sample collection that can affect interpretation, including time of sampling, sample location, temperature, pressure and enthalpy, etc.

Once the data are entered into the computerized database, statistical programs designed by GeothermEx are run to verify data quality. These verification routines are based both on ion balance and calculated conductivity. Graphical representations or other statistical programs are then used to reveal and determine the causes of large errors or systematic biases.

Once spurious analyses have been identified and eliminated from the database, specially adapted graphic programs are used to generate scatter diagrams that illustrate diagnostic ratios and concentrations of ions, isotopes and gas species. Some of the more important diagrams include: Na vs K; CO_3 vs Cl vs SO_4; CO_3 vs B vs Cl; SiO_2 vs enthalpy, and Cl vs enthalpy. GeothermEx has found that each geothermal system often has individual characteristics that require the development of customized plots in addition to the standard ones mentioned above. The computerized database makes such customization efficient and affordable.

Routine tasks which are performed with GeothermEx's in-house software include: rapid interconversion of units of concentration such as meq/l from ppm, ppm from mg/l, molal concentrations from ppm; rapid checks of data quality as discussed above; calculations of all known geothermometers; and correction of analyses to reservoir concentrations. More specialized software tasks often performed include: calculations of excess steam in samples from flowing wells, calculating reservoir steam quality, and identifying end members of mixed fluids.

Based on the above steps GeothermEx develops a geochemical model of the geothermal system under study. Such models incorporating conductive cooling, mixing, boiling and condensation have been developed for numerous hot water and two-phase (steam/water) geothermal reservoirs. Numerical modeling also allows calculating Rayleigh condensation and evaporation effects on the composition of steam reservoirs. This has been done for parts of The Geysers steam reservoir in California, to show that condensation processes can explain gradients in steam composition and stable isotopes.

As special projects require, our software is used to calculate solute speciation at reservoir temperatures and mineral solubilities in the reservoir, during cooling, and during boiling. One recent application of this work has been to calculate corrections to the cation and silica geothermometers required for analysis of a very unusual high temperature reservoir fluid which carries over 20,000 ppm of SO_4. Another recent application has been to model the deposition of stibnite (antimony sulfide) scale in binary heat exchangers. A third recent application has been to model the homogenous and heterogeneous equilibrium of scale deposition from heated seawater and mixtures of seawater with reservoir fluid.

In summary, a systematic approach to geochemical modeling has made it possible for GeothermEx to reduce vast quantities of often incomprehensible raw chemical data into a coherent and interpretable form. This effective method of data reduction makes it possible to develop a geochemical model which illustrates the processes controlling the evolution of thermal fluids as they migrate from source to discharge area or production well. Numerical modeling is an essential tool in development of the geochemical model, and also is used to study processes of scale deposition during well production, boiling, cooling, and injection of foreign fluids into the reservoir.