UNIVERSITY OF NEVADA RENO

NEVADA BUREAU OF MINES AND GEOLOGY

Mail Stop 178
Reno, Nevada 89557-0088
Telephone: (702) 784-6691
FAX: (702) 784-1709
lisa@geyser.nbmg.unr.edu

January 14, 1997

Dr. Marshall Reed
U.S. Department of Energy
Forrestal Bldg, EE-122
1000 Independence Ave, SW
Washington, DC 20585

Dear Dr. Reed,

Enclosed is the final summary for the geothermal research program update for Task Order No. 6, Subcontract C85-110656 with the University of Nevada, Reno. The DOS disk contains WordPerfect 5.1 files for the document (annsum.w51) and table (table1.w51), as well as an autocad file for the figure (nevada.dwg).

If you have any questions, please do not hesitate to contact me.

Sincerely,

Lisa Shevenell

Lisa Shevenell

cc: Dr. Joel Renner
Dr. Alex Moore

UNIVERSITY OF NEVADA RENO

NEVADA BUREAU OF MINES AND GEOLOGY

Mail Stop 178
Reno, Nevada 89557-0088
Telephone: (702) 784-6691
FAX: (702) 784-1709
lisa@geyser.nbmg.unr.edu

January 13, 1997

Dr. Alex Moore
Princeton Economic Research, Inc. (PERI)
1700 Rockville Pike, Suite 550
Rockville, MD 20852

Dear Dr. Moore,

Enclosed is the final summary for the geothermal research program update for Task Order No. 6, Subcontract C85-110656 with the University of Nevada, Reno. The DOS disk contains WordPerfect 5.1 files for the document (annsum.w51) and table (table1.w51), as well as an auto-cad file for the figure (nevada.dwg).

If you have any questions, please do not hesitate to contact me.

Sincerely,

Lisa Shevenell

Lisa Shevenell

cc: Joel Renner, INEL

GEOCHEMICAL MODELING OF PRODUCING GEOTHERMAL RESOURCES IN NEVADA : CALIBRATION AND TESTING OF THE DOE BRINE CHEMISTRY MODELS GEOFLUID AND TEQUIL

Ted De Rocher and Lisa Shevenell
University of Nevada, Reno

KEY WORDS
SCALE PREDICTION, GEOTHERMAL FLUIDS, ROCK/WATER INTERACTION, AQUEOUS GEOCHEMICAL MODELS

PROJECT BACKGROUND AND STATUS

Carbonate, sulfate, silicate, or metal sulfide scales have the potential to build up during energy extraction at all Great Basin geothermal resources. These problems range from calcium carbonate scale formation in non-pumped production wells to stibnite deposition in binary heat exchangers. Although various chemical additive strategies such as inhibitors and crystallizers are available to help control scaling problems, these methods generally require substantial cost in chemicals, additional equipment, and maintenance. Because of this expense, it is important to fully assess both the nature and the magnitude of the scaling potential anticipated during geothermal energy production and the effectiveness of various strategies to mitigate the problems.

The DOE Geothermal Division has supported the development of the computer models GEOFLUID and TEQUIL, which have demonstrated the ability to accurately reproduce the measured laboratory behavior of simple brines, the solubility and liquid / vapor coexistence of gases, and other thermodynamic properties of aqueous systems (Weare, 1987; Moller, 1988; Duan et al., 1992b). In addition to modeling mineral-brine behavior, these programs (developed by the University of California San Diego Chemical Modeling Group (UCSD CMG)), also have the capability to predict the behavior of gas phases of most compositions associated with geothermal formations (Duan et al., 1992a; Duan et al., 1992c). A summary of this computer modeling project is included in this volume of the Research Program Update.

These calibrated and field tested models should provide the geothermal industry with:

* A cost effective method of predicting production problems related to brine chemistry during the resource site assessment phase
* A method of identifying causes of chemical scaling problems in systems already in operation
* An inexpensive means for testing strategies to abate these problems
* A tool for simulating brine behavior for optimal plant performance.

Work on the current project began in April 1995 and the anticipated completion date is

11/30/97. To date, duplicate samples have been collected over two field seasons for chemical analysis from production wells located at Beowawe, Bradys, Desert Peak, Dixie Valley, Empire, Soda Lake, Steamboat Terrace, Steamboat Hills, and Stillwater (Figure 1). Production fluids were sampled using a mini-steam separator and a condenser coil (Giggenbach and Goguel, 1989). One representative production well was sampled at the power plants utilizing flashed-steam technology. Binary power plants were sampled at both the entrance and exit of a single heat exchanger. Separated water and condensed steam and gas samples were sent to Los Alamos National Laboratory for analysis. Separated water and condensed steam samples were analyzed for the following constituents: Al, Ar, B, Br, Ca, Cl, CO_3, Cs, Fe, F, HCO_3, K, Li, Mg, Mn, Na, NH_4, NO_3, pH, PO_4, Rb, Sb, Si, SO_4, S_2O_3, Sr, and TDS. Evaluation of the results of these analyses began in December, 1995, and continues with the most recent analysis. Deuterium and oxygen-18 isotope analyses were performed on separated water and condensed steam samples. Condensed steam and non-condensible gas samples were analyzed for NH_4, Ar, CO_2, He, H, H_2S, CH_4, N, and O.

Wellbore scale samples have been obtained from several facilities during well clean-out/milling operations, or scraped from downhole chemical injection tubing. If available, mineral scale samples were selected from the uppermost and lowest depths of scale formation and at the depth of maximum scale accumulation, for a total of three samples per well. In the 23-5 well at the Caithness site, wellbore scale occurs between a depth of 1,800 feet and the surface, with maximum scale formation occurring at 1,600 feet. This type of information is not available at all of the sites. Binary plants utilize pumped production wells and scale does not deposit in the wellbore. At these sites, scale samples were collected from the heat exchangers during maintenance cleaning periods when the scale was mechanically removed from the exchanger tubing. Chemical analysis of the scale samples show the following preliminary trend: Ca/$MgCO_3$ and SiO_2 complexes in unpumped flash-plant production wells; SiO_2 and aluminosilicate complexes in pumped flash-plant injection wells; and metal sulfide (predominantly antimony sulfide) complexes in the later heat-exchanger stages of binary power plants.

Preliminary modeling of injection fluid chemistry has begun. TEQUIL is being used to predict potential mineral precipitation with additional cooling.

PROJECT OBJECTIVES

* The objective of this project is to enhance the cost-effective utilization and development of Great Basin geothermal resources through the calibration and refinement of the GEOFLUID and TEQUIL geochemical models.

Technical Objectives

* The models will be applied to data collected from several geothermal power plants in Nevada in order to field calibrate the models and improve their ability to provide reliable predictions of chemical behavior in geothermal fields.

Expected Outcomes

* In their current state of development, the GEOFLUID and TEQUIL models should have the capability to describe the chemical behavior of Ca, Na, Cl, CO_3, HS, H_2S, and H_2O present in Great Basin geothermal brines. Based on the models' excellent predictive capability of experimental brines, it is anticipated that the models will simulate scaling problems in real systems.

* Prior knowledge of anticipated scaling problems will allow operators to consider alternative production scenarios to minimize cost associated with scale abatement.

It is hypothesized that;

* The GEOFLUID and TEQUIL models can be used successfully to predict existing mineral scale deposition at geothermal power production facilities;
* The GEOFLUID and TEQUIL models can be effectively applied to the analysis of existing scale deposition, and used as a tool to explore alternate production and injection strategies.

APPROACH

The solution, solid, and gas phase chemistry models GEOFLUID and TEQUIL will be applied to water and gas chemistry data collected from nine geothermal power plants across Nevada (Figure 1). Condensed steam and separated water samples were obtained from production wells and mineral scale samples have been gathered from wellbores in non-pumped fields and from the heat exchangers in binary plants. These data will be used to field calibrate the models and improve their ability to provide reliable predictions of the chemical behavior of the resource (potential for scaling and gas breakout) under a variety of conditions. The calibrated models will provide operators and engineers with the ability to rapidly analyze potential scaling and to test strategies for problem abatement and resource enhancement.

RESEARCH RESULTS

Trace mercury analysis of collected water samples revealed fluids are not fully mixed in production lines. Non-condensible gases stratify at the top of the gathering line significantly affecting geothermal fluid chemistry (Table 1)(Gustin and De Rocher, unpublished data). Gas samples should be collected from the top of the line, while water samples should be collected from both the bottom and mid-section of the line. This finding resulted in modification to the sampling of two-phase geothermal fluid methodology proposed by ASTM E1675-95.

Preliminary modeling of injection fluid chemistry at all sites has begun. TEQUIL is being used to predict potential mineral precipitation with additional cooling. Results to date closely approximate silica deposition present at some geothermal fields. For example, at the Caithness 23-5 well, the depth at which CO_2 is predicted to exolve from the geothermal fluid is 1,750 feet, which is near the observed 1,800 foot depth of the bottom of scale formation in this well.

FUTURE PLANS

Mineral scales will be mineralogically analyzed using x-ray diffraction at the Nevada Bureau of Mines and Geology, University of Nevada, Reno.

Computer simulations of scale formation will be completed for each site using GEOFLUID and TEQUIL. Model results will be compared to known conditions, and the performance of GEOFLUID and TEQUIL will be evaluated. Further simulations will be conducted covering a range of brine temperatures and pressures. A discussion of the chemical behavior of the geothermal brine will be conducted for all production fields. Selected sites will be compared for optimal operational conditions and predicted mineral solubility problems in a discussion of the hydrogeochemistry of Nevada's moderate-temperature geothermal fluids.

INDUSTRY INTEREST AND TECHNOLOGY TRANSFER

After project completion, the results of this Great Basin modeling effort will be communicated to the geothermal industry. The calibrated computer model should provide geothermal developers and operators with a tool capable of predicting gypsum-anhydrite, carbonate, and silica scaling in geothermal systems, and assist in the design of optimum production strategies which would minimize production costs. The final results will be useful to all geothermal plant operators exploiting moderate-temperature resources, and particularly to the companies noted below.

Organization	Type and Extent of Interest
Oxbow (Beowawe, Dixie Valley)	Site specific data, predictive capabilities of model
Western States Geothermal (Desert Peak)	
SB Geo., Inc. (Steamboat)	
Caithness Corporation (Steamboat Hills)	
ESI Energy, Inc.	
Oxbow (Bradys)	
Nevada Operations, Inc. (Empire, Soda Lake, Stillwater)	
Ormat, Inc.	Predictive capabilities of model
Nalco Chemical Company	

REFERENCES

ASTM, Committee E-44. 1995. Standard practice for sampling two-phase geothermal fluid for purposes of chemical analysis. ASTM Standards 12:02, E 1675-95.

Duan Z., N. Moller and J.H. Weare. 1992a. An equation of state for the CH_4-CO_2-H_2O system: Pure systems from 0 to 1000°C and 0 to 8000 Bar. Geochim. Cosmochim. Acta 56: 605 -2617.

Duan Z., N. Moller and J.H. Weare. 1992b. An equation of state for the CH_4-CO_2-H_2O system: II. Mixtures from 50 to 1000°C and 0 to 1000 Bar. Geochim. Cosmochim. Acta 56: 2619-2631.

Duan Z., N. Moller and J.H. Weare. 1992c. The prediction of methane solubility in natural waters to high ionic strength from 0 to 250°C and from 0 to 1600 Bar. Geochim. Cosmochim. Acta 56: 1451-1460.

Giggenbach, W.F., and Goguel, R.L. 1989. Collection and analysis of geothermal and volcanic water and gas discharges. New Zealand and DSIR Rept. No. CD 2401, 4th ed., 81 p.

Gustin, M.S., and De Rocher, T.R. 1996. Mercury in productive geothermal systems of Nevada: Implications for sampling methodologies. Submitted for publication.

Moller, N. 1988. The prediction of mineral solubility's in natural waters: A chemical equilibrium model for the Na-Ca-Cl-SO_4-H_2O system to high temperature and concentration. Geochim. Cosmochim. Acta 52: 821-837.

Weare, J.H. 1987. Models of mineral solubility in concentrated brines with application and observations. Reviews in Mineralogy 17: 143-176.

CONTACTS

DOE Program Managers

Marshall Reed
Phone: (202) 526-8076
FAX: (202) 586-8185
Geothermal Division, EE-122
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

DOE Idaho Operations Office Program Manager:
Peggy Brookshier
U.S. Department of Energy
Idaho Operations Office
785 DOE Place, MS 1220
Idaho Falls, ID 83401-1563
Phone: 208-526-1403
FAX: 208-526-5964

Principal Investigators:

Ted De Rocher
Phone: (702) 849-1299
FAX: (702) 849-1328
email: Tderocher@aol.com

Lisa Shevenell
Phone: (702) 784-1779
FAX: (702) 784-1709
email: lisa@geyser.nbmg.unr.edu
Nevada Bureau of Mines and Geology, MS 178
University of Nevada, Reno
Reno, Nevada 89557-0088

Table 1. Total mercury concentrations in geothermal fluids sampled from different locations in the gathering line. Concentrations are in ug/L.

Geothermal Field	Production Well Type	Total Mercury (ug/L)
Beowawe *(Dual Flash)*		
Top		5.30
Bottom		0.05
Bradys *(Dual Flash)*	Pumped	0.03
Desert Peak *(Dual Flash)*		
Top		28.00
Bottom		0.13
Dixie Valley *(Dual Flash)*		
Top		26.00
Bottom		0.10
Empire *(Binary)*	Pumped	
Before Heat Exchanger		0.03
Soda Lake *(Binary)*	Pumped	
Before Heat Exchanger		0.03
Steamboat Hills *(Single Flash)*		
Top		67.00
Middle		2.10
Bottom		0.06
Steamboat Terrace *(Binary)*	Pumped	
Before Heat Exchanger		0.42
After Heat Exchanger		0.05
Stillwater *(Binary)*	Pumped	
Before Heat Exchanger		0.05

Figure 1. Producing geothermal fields selected for study.