CONF-971048--6 SAND97-1382C

SUBSURFACE STEAM SAMPLING IN GEYSERS WELLS

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ABSTRACT

A new downhole sampling tool has been built for use in steam wells at The Geysers geothermal reservoir. The tool condenses specimens into an initially evacuated vessel that is opened down hole at the direction of an on-board computer. The tool makes a temperature log of the well as it is deployed, and the pressure and temperature of collected specimens are monitored for diagnostic purposes. Initial tests were encouraging, and the Department of Energy has funded an expanded effort that includes data gathering needed to develop a three-dimensional model of The Geysers geochemical environment. Collected data will be useful for understanding the origins of hydrogen chloride and non-condensable gasses in the steam, as well as tracking the effect of injection on the composition of produced steam. Interested parties are invited to observe the work and to join the program.

INTRODUCTION

Last Spring, the Department of Energy, Unocal Geothermal and Power Operations Group, Inc., Thermochem, Inc., and Sandia National Laboratories instituted a new program to develop the technology and methodology to obtain representative steam and non-condensable gas (NCG) samples from wells in The Geysers reservoir. The resulting samples will be used to delineate reservoir chemistry with depth, and ultimately to build geochemical models in three-dimensions. This program differs from previous efforts in that it features a newly-demonstrated downhole sampling tool having the potential to obtain accurate depth profiles of geochemical phenomenon. Such profiles have not yet been obtained for any geothermal system. Geochemical depth profile data will be especially useful in studying: a) the generation of hydrogen chloride (HCl) gas that leads to the corrosion of tubular materials and turbine components, b) the production of NCGs that degrade turbine efficiency, and c) the influence of injected fluids that extend well life and mitigate the HCl and NCG problems. The purpose of this paper is to report on progress to date, and to invite other interested parties to join the program.

The program is an extension of an effort funded by the Department of Energy, Office of Basic Energy Sciences/Geoscience, and it should evolve into new interactions between academia, geothermal operators and service companies, and national laboratories. The program emerged from the efforts of the US Continental Scientific Drilling Program and the international Ocean Drilling Program; it was molded into its present form by the needs of the geothermal industry through support of the Department of Energy, Office of

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Geothermal Technologies. Transfer of technologies between institutions and disciplines is inherent in the project due to the composition of the implementation teams. The work is timely in that other geothermal reservoirs such as Coso, and perhaps even the Imperial Valley, could evolve along paths similar to that of The Geysers. The tool would be immediately useful in existing vapor-dominated fields in Indonesia and Italy.

Initial drilling in The Geysers occurred in the 1920s, while major development of power generation stations occurred in the 1960-1989 time frame. Even though some 400 production wells have been drilled, major questions remain as to the mechanisms for heat transfer and non-condensable gas generation, as well as contributions from different possible steam sources within the reservoir. For example, studies of materials produced at the surface indicate that major changes in steam isotopic concentrations occur over laterally short distances, especially in the northwest portion of the field. Furthermore, while isotopic evidence from the southeast part of the field suggests recharge from meteoric source, steam isotopes and noble gas isotopic data (Kennedy and Truesdell, 1994) suggest possible input of magmatic materials.

Recently such seemingly academic issues have become increasingly important due to the accelerated rate of reservoir pressure decrease first noted in The Geysers in the mid 1980s. This pressure decline is attributed to a net loss of water through production, and has caused a reduction in produced electricity. In some locations, reduced pressures have been accompanied by an apparent increase in HCl and NCG concentrations. Remediation of these apparently coupled problems is one motivation for a major effort to bring waste water to The Geysers as an injectate. Many studies, some experimental others theoretical, have been made to address the afore-mentioned questions e.g. Truesdell, 1991; Truesdell, et al, 1986; Truesdell, et. al 1989; Simonson and Palmer, 1993; Simonson and Palmer, 1994.

EVOLUTION OF SAMPLER TECHNOLOGY

Geochemical studies of hydrothermal systems in the United States have been of active interest for many decades. Pioneering work was conducted by the Carnegie Institution of Washington at The Geysers in the 1920s (Allen and Day), and by the USGS in Yellowstone National Park in the 1970s (Fournier and Truesdell, 1970; White, *et. al.*, 1975; Truesdell and Fournier, 1976); the pace accelerated with geothermal drilling in The Geysers, the Imperial Valley, and at Coso during the 1980s. Currently, world-wide geothermal resources are receiving attention from the industrial-academic-governmental community. This includes systems active at oceanic ridges as studied by the Ocean Drilling community as well as more pragmatic efforts in France, England, Japan, Germany, Indonesia, the Philippines, and the United States.

A difficulty common to all of these studies is obtaining pristine samples. An ideal sample would be in equilibrium with its environment, and it would not be perturbed by drilling activities, sampling techniques, and inter-formation flow systems. Perhaps someday true *in situ* monitoring stations will provide such data. Until recently, investigators must rely on well-head samples that provide only an integrated view of downhole conditions, or material obtained from downhole samplers that behaved erratically.

Flow-through samplers have openings at the upper and lower ends that are controlled by suitable valves. Typically, these valves are actuated by spring-loaded mechanisms that are tripped closed by a timing device, or by an electrical impulse. The latter method requires a electric wireline for deployment, the former a relatively simple "slick" line. A fundamental flaw of flow-through samplers is that steam condensation occurs on the inside of the sampler vessel when the cool sampler is placed in the lubricator prior to deployment in a well. The resulting condensate inside the vessel absorbs and concentrates gaseous HCl as the tool is lowered into the well. Consequently, flow-through devices were found to over estimate the chloride content by up to three orders of magnitude when used in Geysers wells.

Other samplers utilize evacuated vessels that are first opened, then closed when on station in the well. Like flow-through samplers, variations allow deployment by either electric or slick line cables. A difficulty with these tools is that liquids will flash when subjected to the pressure drop upon entering the sampling vessel. While there is evidence that this problem can lead to differences between liquid state wellbore fluids *versus* sampled fluids, the pressure drop is not a problem in superheated steam wells.

As part of the US Continental Scientific Drilling Program, a vigorous sampling effort was mounted in the VC-2B geothermal well located in the Valles Caldera of New Mexico. Three samplers were deployed in this effort: one originating from Lawrence Berkeley Laboratory (Solbau, et al, 1986), one from Los Alamos National Laboratory, and a third from Italy. After some effort, the Los Alamos Team (which led the thrust at VC-2B) noted that all devices captured too much material to be compatible with the pressure-temperature environment downhole (Goff, et al, 1990), and the sampler valves were recognized as a possible source of difficulty. Specifically, all samplers used valves that were similar to those found in internal combustion engines. When the pressure within the vessel is larger that outside, the valve is seated positively. When the inside pressure is less, the valve may be moved against a spring, and extraneous material added to the sample if the pressure differential is high enough. This pressure differential is a function of the exterior hydrostatic pressure, and the internal pressure which decreases due to thermal contraction as the sampler is withdrawn from the hole. A thermodynamic analysis demonstrated that the conditions in VC-2B were sufficient to cause significant leakage, and this analysis led to the generation of a proposal to the Department of Energy, Office of Basic Energy Sciences/Geoscience that supported the development of the present Sandia tool (Lysne, 1991).

THE SANDIA SAMPLER

The Sandia Sampler is easy to use, and does not require extensive training to qualify operators. The tool utilizes electrically actuated 500 psi valves that are suitable for steam zones in Geysers wells. High-pressure valves are in hand, and they will be incorporated into a second tool that will be built as part of the present program. This tool will be used to assess the flashing problem encountered when sampling geothermal liquids. Work on this subject may generate debate within the scientific community.

The basis for the Sandia sampler is a sample chamber surrounded by a low melting temperature (137°C) eutectic material that absorbs a large quantity of heat as it passes through the solid-liquid transition. All materials flow into the vessel, but the steam is condensed to liquid reducing its volume by a factor of approximately 60. Thus, a small vessel can be used to store a relatively large sample of condensed steam including dissolved species, and NCGs.

The Sandia tool is 50 mm (2 inches) in diameter by 2 m (6 feet long); dimensions compatible with slim, diamond-cored holes, and transportable by standard air carrier. The electronic components and the sampler vessel are contained within a Dewar. All power is supplied by readily-available photoflash batteries enabling use of the tool on a slick line. The computer is programmable in the BASIC language, and "instructions" to the tool can be changed in the field. The tool makes an external temperature measurement that is traceable to national standards. This temperature is recorded to provide a log of the well; it can also be used to "trip" the sampler valve if such action is important for geochemical sampling considerations. Alternatively, the valve can be tripped on time, time-rate-of change of temperature, or other input data. Sample flow into the 55 cm^3 (3.3 in^3) vessel of the tool is through a small, 0.75 mm (.030 inch) diameter, orifice so flow velocities are high and always directed inward. The orifice may be protected by an optional filter. Extensive tests of the tool were made at the Sandia steam heating plant to note the rate at which material could be drawn into the tool, and condensed. The pressure and temperature of sampled material are recorded for diagnostic, quality assurance, and geochemical purposes.

The sampler tool has many new attributes. The system is versatile in that the computer can accept other electrical inputs such as might be supplied by specific ion electrodes, and it can make "decisions" using "if-then" statements based on these inputs. Many components of the sampler are common with another Sandia tool that provides precision pressure-temperature measurements, and which has seen extensive testing in geothermal wells (Lysne and Henfling, 1994). The sampler tool, the pressure/temperature tool, and a spectral gamma tool under development at Sandia may be run in tandem so that detailed information may be obtained from a well.

Recent, near-surface tests of the sampler were conducted by Unocal, Thermochem, and Sandia. In these tests, standard industry techniques were used to obtain an initial well-head sample prior to the insertion of the sampler. Three deployments of the sampler were made, and they produced identical amounts of condensed steam. Finally, a second well-head sample was obtained for comparison purposes. Results of these tests were encouraging in that the maximum discrepancy between sampler specimens and well-head specimens was significantly less than the three order-of-magnitude chloride discrepancy observed for flow through devices (see Table 1.) It should be noted that the prime thrust of these tests was to evaluate the functionality of the sampler tool; quantitative chemical techniques were not used in preparing the sampler or recovering the condensate samples, and NCGs were not collected. The apparent improvement of the tool over the course of the three deployments may be attributed to an *ad hoc* improvement of procedures and/or *in situ* seasoning of the tool.

The Sandia sampler may be unique in its ability to sample fluids from steam wells. To the best of the knowledge of this investigative team, other samplers have failed to produce specimens with the precision and repeatability illustrated in Table 1. This is not to say that the sampler is not in need of improvement. It is recognized that the tool is a prototype, and the tool as well as deployment procedures need to be vetted.

PROGRAM DIRECTION

On the basis of the above work, Unocal (the lead institution), Thermochem and Sandia felt confident that an advancement of the sampler program was warranted, and the Department of Energy supplied the resources so that it could move forward. The resulting program consists of two phases with a decision point for continuation separating them. In Phase 1, refinements to the sampler and sample recovery techniques will be made including six deployments at depth so as to exercise the technology in a variety of Geysers environments. Phase 2 work will be the subject of a future proposal that will feature expanded deployment at depth in numerous Geysers wells leading to the establishment of a data base of geochemical depth profiles. These data will be used with appropriate geochemical models and interpretive techniques to address the issues of HCl and NCG, and the recovery of injectate from the reservoir.

Specific questions to be answered by the overall program are:

Phase 1.

What fundamental differences are there between samples obtained with the Sandia sampler and samples obtained using well-head techniques?

How is the sampler performance affected by saturated versus superheated steam?

How is the sampler performance affected by high levels of non-condensable gas?

Are any spurious contaminants introduced by the sampler or the sample recovery techniques?

Which elements and compounds are most useful in delineating the geochemistry of The Geysers with depth?

How are non-condensable gasses to be recovered from the sampler, including those dissolved in the liquid fraction?

Are the samples best recovered directly in the field or at a laboratory, using sample vessels removable from the tool?

What other measurements (pH, well-bore pressure, etc.) by the sampler tool might be useful?

What impediments to routine deployment at depth are raised by hardware limitations?

Are other Geysers operators interested in participating in a field-wide sampling exercise?

Specific plan of tasks for Phase 1 is:

Complete modifications to the Sandia sampler and uphole hardware. While this work will include the addition of high-pressure valves to a second sampler tool so as to sample fluids below the water table, the main thrust will concentrate on samples in the steam zone.

Design and fabricate a non-condensable gas extraction system for the downhole sampler. Determine the minimum sample volume necessary to obtain accurate gas analyses. Develop appropriate analytical techniques to accommodate the extracted gas samples with accuracy and precision comparable to current industry-standard methods.

Develop and execute a plan for testing the sampler in six representative Geysers holes. This thrust will concentrate on data appropriate to geochemical models for the reservoir, and it will set the stage for a more comprehensive study in Phase 2.

Initiate pertinent discussions on remedial actions to geochemical problems in The Geysers, and use the outcome of these discussions to plan Phase 2 work.

Envisioned tasks for Phase 2 are:

Development and execution of a plan to better understand injection flow paths in three dimensions at The Geysers.

Development and execution of a plan to define the generation of volatile chloride and non-condensable gasses with depth in The Geysers.

Commercialize the Sandia tool so that downhole geochemical sampling services are available for The Geysers.

Export the Sandia tool technology through service companies to other vapor-dominated geothermal systems in the world (Lardarello, Italy; Darajat, Indonesia; etc.)

TABLE 1.

Field Test of Sandia National Laboratories' Downhole Sampler, 11/28/95 Geochemical Results

Analyte	Wellhead Calorimeter Port Base Run #1 mg/kg	Sandia Tool Run #1 mg/kg	Sandia Tool Run #2 mg/kg	Sandia Tool Run #3 mg/kg	Wellhead Calorimeter Port Base Run #2 mg/kg
Sodium	0.012	0.416	0.089	0.061	0.013
Boron	26.8	25.8	26.4	25.4	26.1
Silica	<0.05	1.90	0.777	0.419	<0.05
Chloride	0.241	1.05	0.369	0.346	0.127
volatile Cl (calc.)	0.222	0.409	0.231	0.252	0.106
Flowrate, kph	16.1	16.1	16.1	16.2	16.2
WHP, psig	71	71	73	73	72
WHT, deg F	367	379	379	379	371
Comments	probe	filter	filter	no filter	probe

ACKNOWLEDGEMENTS

This work was sponsored by the U.S. Dept. of Energy, Office of Geothermal Technologies. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-ACO4-94AL85000.

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