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INTERNAL TECHNICAL REPORT

Low-To-Moderate Temperature Reservoir Engineering
Research Program - Fiscal Year 1982

Earth and Life Sciences Office
in conjunction with
Energy Programs Division

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Sent: Thursday, December 07, 2006 8:43 AM
To: Simmons, Patty
Cc: Claflin, Dale; Flynn, Vesta; Ponce, Linda
Subject: Re: EG&G Idaho Geothermal Reports
Attachments: EG&G Patent Docs.doc

Patty,

The 13 reports listed are all OK for unrestricted release. Please remove (cover up) the patent caution wording, as well as any other statements concerning restricted distribution. We don't have a concern with the "Internal Technical Report" words, but if you feel it would eliminate confusion by removing that term, please do so. Let me know if you need anything else.

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12/06/2006 12:34 PM

cc "Ponce, Linda" <poncel@osti.gov>, "Flynn, Vesta" <flynnv@osti.gov>

Subject EG&G Idaho Geothermal Reports

Dale,

OSTI has been working on a project for the last year or so to collect geothermal documents. At the STIP meeting in April, I sent out a plea to the DOE labs to identify and send to OSTI any geothermal documents that we did not already have in our database. I have a problem with a group of reports from EG&G Idaho. I am not sure you are the person correct person to ask for help on this issue. If not, maybe you can direct me to the responsible individual.

Attached is a list of documents that were sent to OSTI as part of that special geothermal project. All of the documents in this list have a patent caution as well as 'Internal Technical Report' stamped on the front of the report. The date on each of the documents is well past the sunset date for patentable material. If there is no other reason for control, I would like permission to cover up the patent caution and release each as unlimited. Would we also need to cover 'Internal Technical Report'?

If you need me to, I will be happy to fax you a copy of the covers of the reports.

Please let me know if you can help me out with this problem, or advise if I should communicate with someone

12/7/2006

else - and who

Thanks ahead for your help,
Patty

Patty Simmons

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865-576-1290

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Low-To-Moderate Temperature Reservoir Engineering
Research Program - Fiscal Year 1982

Numerous low- ($<90^{\circ}\text{C}$) to-moderate (90°C - 150°C) geothermal resources occur in many areas of the United States. The reservoir research conducted at the Idaho National Engineering Laboratory (INEL) is designed to develop innovative techniques that can be used to evaluate reservoir characteristics and improve reservoir management for low-to-moderate temperature resources.

The purpose of this report is to review the program accomplishments for FY 1982 and present the initial data and results obtained from the on-going research program. The project tasks reported in this document are:

1. Low-To-Moderate Temperature Hydrothermal Reservoir Engineering Handbook
2. Reservoir Assessment Technique Development
 - A. Data Analysis
 - B. Reaction Kinetics

1. Low-to-Moderate Temperature Hydrothermal Reservoir Engineering Handbook

To bridge the disparity between the hydrologic and petroleum engineering fields, and the reservoir engineering theories and methodologies employed, a Low-to-Moderate Temperature Reservoir Engineering Handbook was prepared. The Handbook was prepared jointly by scientists at Lawrence Berkeley Laboratory (LBL) and the INEL. The Handbook is designed to provide guidelines to developers and consultants in evaluating low-to-moderate temperature reservoir characteristics. Overall, the Handbook provides

information on reservoir classification, conceptual modeling, testing during drilling, theory of testing, test planning and methodology, geochemistry, reservoir monitoring, instrumentation, and a sample computer program. Whenever possible, "how-to" discussions and demonstrations are presented to the reader.

Copies of the Handbook were provided to members of the geothermal and professional communities, including petroleum engineers and groundwater hydrologists. Due to significant demand for the Handbook, all INEL copies were depleted but additional copies are available through the National Technical Information Service (NTIS). The degree of interest associated with the Handbook suggests that the project objective was achieved.

2. Reservoir Assessment

The objective of this task is to improve upon existing methodologies to evaluate reservoir size and characteristics. Data obtained from this task is intended to assist commercial operators in managing geothermal resources development.

A. Data Analysis

This task is designed to develop improved reservoir engineering techniques by learning from field experiences. Low-to-moderate temperature hydrothermal development has been impeded by the high cost of resource development and the uncertainties in short and long-term resource definition. One problem is due to the typically fractured-nature of the reservoir and the associated difficulty in interpreting fracture-flow hydraulics. Another problem is that well-head pressures, used for hydraulic analyses, are dependent on fluid temperature. Interpretation of the hydraulic characteristics for a fractured reservoir, especially one with time-dependent borehole density changes, has induced uncertainties and high

testing costs for the geothermal industry. The research conducted at the INEL is directed toward the development of new well test analysis techniques.

The FY 1982 research focused on improving the ability to interpret early-time well-head pressure data, which often reflects both pressure changes and thermal effects in the wellbore. Downhole probes are the only available tools that may be used to compensate for thermal effects. Unfortunately, downhole temperature/pressure probes are costly and have limited utility (i.e., cannot be readily used with a downhole pump in place). Therefore, the need exists to identify the significant factor(s) controlling thermal effects in the wellbore and develop a simplified analytical or graphical technique that can be applied to data collected at the surface.

During FY 1982, field data collection was planned as part of the User Coupled Confirmation Drilling Program (UCCDP). However, because these field projects were not all carried through as planned, sampling occurred only at Wendel, California (WEN-1) and the Utah State Prison, Sandy, Utah. Downhole data collection was not successful in either case. The Geoproducts (WEN-1) downhole data collected proved uninterpretable due to a leak in the upper casing. At Utah State Prison, the principal problem arose from the failure of the downhole temperature/pressure tools. Supplementary data collected at these sites included surface annulus, bubbler tube, surface temperature, flow rates, and downhole temperature/pressure, but because of failure to obtain useful downhole data, the surface data proved useful only to the UCCDP evaluation for determination of cost share. We still consider this task as meaningful, but we will not be continuing this in FY 1983 because of budget constraints.

In addition to this field work, a simulation computer program for confined aquifers was adapted to a micro-computer. A discussion of the task is presented below.

Prickett and Lonnquist

The simulation computer code for confined aquifers written by Prickett and Lonnquist, has been adapted for use on an "Apple" micro-computer to make a readily-accepted code usable to the consultant. The program was rewritten in BASIC Computer Language from the original FORTRAN version. The code was validated by comparing numerical solutions from the computer to analytical solutions. The major limitation of the micro-computer model version is the number of nodes that can be simulated. The maximum size is a 20 X 20 node grid. A user's guide is in final draft form, containing a listing of the program. The guide will be printed in FY 1983 and should be a valuable tool to the reservoir consultant.

B. Reaction Kinetics

Reaction kinetics data are being obtained from the interactions of water and rocks representative of those found in typical geothermal reservoirs to determine residence times for geothermal fluids. Residence time is an integral component required to fully evaluate reservoir size. Reservoir size may be defined as a function of recharge rate and residence time. One can estimate reservoir size by evaluating the geologic structures; similarly, recharge rate can be estimated through a determination of a safe yield. However, both these values often suffer from large uncertainties. If a value for residence time can be determined, all the variables in the above equation are estimable, and through an iterative process, estimated values can be refined to lessen the degree of uncertainty. In addition, relative states of equilibrium may be compared within a reservoir to evaluate the direction of flow.

Methods used to estimate residence time for low-to-moderate temperature fluids are undeveloped and require additional research. Synthesis of the kinetic data with relative equilibrium and disequilibrium among geothermometer species having different reaction rates, may provide a means for evaluating the average residence time of geothermal reservoirs.

The principal behind geothermometers is the change in equilibrium between two phases or components as a function of temperature. For chemical reactions between a solution and solid phases, the temperature dependence of the equilibrium constant is related to the heat of reaction (enthalpy) as expressed by the Van Hoff equation:

$$\frac{d \log k}{d (1/T)} = \frac{- H^0}{4.5758}$$

Laboratory Work

Published hydrothermal alteration experiments on feldspar minerals have all been conducted at temperatures in excess of 300°C (Ellis and Mahon, 1964, 1967; Orville, 1963). These experiments reached steady state in a few days to a few weeks. A series of alteration experiments on granites conducted at 200°C indicate that steady state is reached in four to five weeks (Barnes and others, 1978). Extrapolation of these estimates to lower temperatures indicate that feldspar dissolution experiments at 100° to 150°C should take from four (4) to six (6) months. For this reason there are very few low-temperature experimental data. The calibration curve for the Na-K-Ca geothermometer is empirical and few of the points on which it is based occur at low temperature (Fournier and Truesdell, 1973).

The laboratory experiments conducted during FY 1982 consisted of reacting mixtures of feldspar minerals with 0.001 m acid solutions at 75° and 150°C. Hydrochloric acid, HCl, was chosen for the reaction solution in order to increase the amount of alteration of the feldspars and approximate the open system in nature. Previous investigators have demonstrated that feldspar alteration is a function of alkali/hydrogen ion ratio. When pure water is used as a reaction fluid, hydrogen ion is very quickly consumed and alteration remains extremely limited. By offering a much greater supply of hydrogen ions, approximately two orders of magnitude, alteration becomes more extensive.

A mixture of two feldspars was chosen for the solid phases in order to provide a cation source that could be varied between experiments. Table 1 lists the compositions of the microcline (KAlSi_3O_8) and labradorite ($\text{CaAl}_2\text{Si}_2\text{O}_8/\text{NaAlSi}_3\text{O}_8$) used in these experiments. Each of the experiments conducted during FY 1982 contained 100 g of both microcline and labradorite. This combination produces a Na:Ca:K ratio of approximately 0.8:1:1.5. Because the Na:Ca:K geothermometer is projected to be applicable to geothermal fluids from a variety of rock types, the species in solution should be independent of feldspar ratio. This condition will be checked during the next fiscal year.

Since this was the first year on this program, it was necessary to order starting materials and instrumentation. Hydrothermal experiments did not actually start until early spring of this year. The results of the first experiment, 150°C , are plotted in Figure 1. Several observations can be made about these data. First, it should be noted that the mechanism for removing sodium from the solid differs from those for the removal of potassium and calcium. Sodium starts with a very high initial concentration and decreases over a period of several days. Calcium and potassium concentrations, however, start with very low concentrations and increase over several days. Initial sodium concentrations probably reflect ion exchange between the hydrogen ions in solution and the sodium in the feldspar. The release of potassium and calcium, on the other hand, may require the actual breakdown of the silicate structure.

Another observation that can be made about Figure 1 is the gross increase in sodium concentration after about 50 days of reaction time. This change is associated with a smaller increase in calcium concentration. This probably represents the physical degradation of an alteration mineral rind on the labradorite and the exposure of a fresh feldspar surface to alteration.

Figure 2 is a plot of the temperature function developed by Fournier and Truesdell for the Na-Ca-K geothermometer. The value for log K (equilibrium

TABLE 1: Chemical compositions of feldspar minerals used in alteration experiments

ELEMENT	MICROCLINE (wt. %)	LABRADORITE (wt. %)
Na	1.66	3.10
K	8.68	0.33
Ca	-	5.98
Al	10.05	14.57
Si	31.93	27.34
Mg	-	0.20
Fe	-	0.54
O*	47.68	47.93

*Determined by stoichiometry

Cation Concentration as a Function of Time

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Figure 1

constant) at 150°C should be 1.52 according to their empirical curve. Our experimental data indicates that the equilibrium value at 150°C is around 1.14. This represents a decrease of about 24%. Because the original publication based the geothermometer on analyses of hot spring and geothermal well fluids, this difference may represent effects caused by the more complex chemistries of natural samples.

A 75°C experiment is currently underway using the same solid phases and reaction solution. The chemical data from this experiment will be reported as soon as they become available.

Hydrothermal Reactant Model

A hydrothermal reactant model has been modified during FY 1982 for use in the reaction kinetics research. This model will be used to simulate various reactions in low-to-moderate temperature geothermal reservoirs. A graphical representation of a generic hydrothermal reservoir is provided in Figure 3. In this model, water and solutes flow into the hydrothermal reservoir (recharge) where chemical reactions take place prior to the migration of solutes/ reactants returning to the surface via wells or springs. The model assumes that the water flows through a temperature gradient throughout the reservoir.

The above graphical model was modified without changing its ability to predict the behavior of the various reactions in the reservoir. The modified graphical model is shown in Figure 4. The graphical model can be mathematically described by the Plug Flow Reactor (PFR) model. The depth of the various points in the PFR is set by an assumed temperature profile (since temperature is a function of distance from the heat source).

The mathematical model of the PFR depends upon the type of reaction to be modelled and the kinetics of that reaction. In a low-to-moderate temperature geothermal reservoir, several types of reactions occur

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Figure 2

Figure 3. Hydrothermal Reactant Model (HRM)

(i.e., liquid phase, gas-liquid phase, and gas-solid phase, both reversible and irreversible). For the most part, first order reaction kinetics are used for the Hydrothermal Reactant Model.

This model will be used in conjunction with field data collected during FY 1983 under the Reaction Kinetics research portion of the low-to-moderate temperature reservoir research program.

FY 1983 Plans

The Low-to-Moderate Temperature Reservoir Engineering research program will continue in FY 1983 with an emphasis on reaction kinetics. The laboratory work will focus on variations in rock composition and the comparison of new (FY 1983) data with that collected during FY 1982. By so doing, the significance of rock variation may be evaluated. In addition, limited field work will be conducted during the summer of 1983 to complement the results of the laboratory work.

Figure 4. Modified HRM Graphical Model

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