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The LBL Geothermal Reservoir Technology Program

M.J. Lippmann

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The LBL Geothermal Reservoir Technology Program

Marcelo J. Lippmann

Earth Sciences Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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Marcelo J. Lippmann

Earth Sciences Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

Abstract

The main objective of the DOE/GD-funded Geothermal Reservoir Technology Program at Lawrence Berkeley Laboratory is the development and testing of new and improved methods and tools needed by industry in its effort to delineate, characterize, evaluate, and exploit hydrothermal systems for geothermal energy. This paper summarizes the recent and ongoing field, laboratory, and theoretical research activities being conducted as part of the Geothermal Reservoir Technology Program.

Introduction

Many U.S. and foreign areas with potential geothermal resources have yet to be thoroughly explored and evaluated, and other geothermal areas have not been fully developed or optimally exploited because they have never been properly characterized. We believe that the lessons learned from reservoir engineering studies of developed geothermal fields have applicability to the initial characterization of a field in the exploration and early development stages. By incorporating the knowledge of fluid flow in developed geothermal reservoirs, the evaluation and early operating strategy for geothermal fields can be optimized and the possibility of overdevelopment can be avoided. The Reservoir Technology research is designed to identify and test reservoir management practices that could reduce the rate of reservoir pressure drawdown and the impact of some of the deleterious effects associated with pressure decline: mineral precipitation which decreases reservoir permeability, and changes in the composition of the produced fluids.

The Geothermal Reservoir Technology Program at the Lawrence Berkeley Laboratory (LBL) is funded by the Geothermal Division (GD) of the U.S. Department of Energy (DOE). Our basic mission is the development, demonstration, and transfer to industry of improved methods for defining, characterizing, evaluating, and exploiting hydrothermal resources. Field investigations are carried out jointly with geothermal development companies on a cost-shared basis. The joint research is more effective in transferring new technologies and the cost sharing augments limited federal funding. A good example of present activities that benefit from joint research with industry and cost sharing is The Geysers Research project.

Geysers Research Activities

Research activities on The Geysers are directed toward the mitigation of several problems that have appeared recently because of the intense exploitation of the field. The goal of this work is to identify and determine the impact of reservoir management practices that might be implemented to (1) increase the extraction of the heat stored in the subsurface, (2) reduce the corrosiveness of the steam, (3) decrease the amount of noncondensible gases in the steam produced and (4) lengthen the commercial life of the field.

As a first step to understanding the processes taking place, LBL researchers are developing and testing conceptual models of The Geysers system to provide a frame of reference for predicting the effects of changes in the field development strategy. LBL seismologists are working with the Coldwater Creek Operating Company to monitor the microseismic activity associated with water injection and are analyzing and interpreting the data that is being collected to develop a velocity model of the area (Fig. 1) needed to trace the flow of injected water in the subsurface. The analysis of seismic activity will also provide a greater understanding of the stress system in The Geysers and will help map out the distribution of productive fractures.

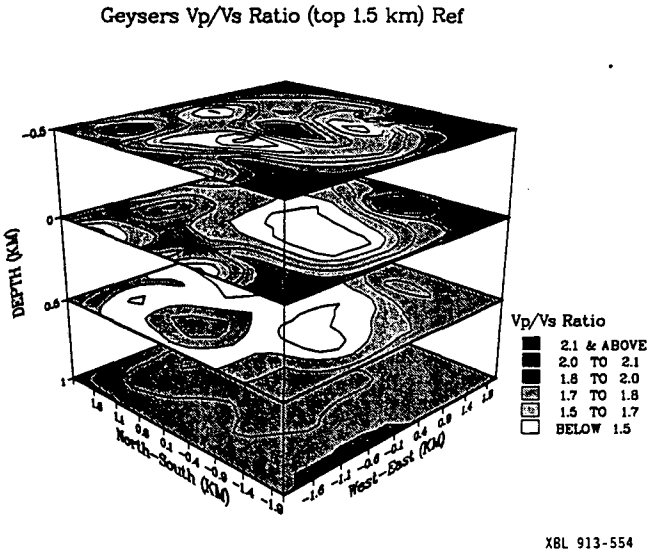

Figure 1. Three-dimensional distribution of the seismic velocity ratio (Vp/Vs) in the Northwest Geysers. One hundred master seismic events were used to develop the velocity model for this area (A. Schultz and E. Majer, pers. comm., 1991).

A multi-disciplinary team of LBL researchers are working with most of the operating companies to analyze the pressure and geochemical changes measured during well tests and long-term production and injection operations at The Geysers in order to trace the growth of low-pressure regions in the field. The analysis of this data is important in reconstructing operating practices which had a deleterious effect on energy production. With the information produced by this study, the operators can be sure of the ramifications of changes to production and injection. LBL engineers are developing

equipment and procedures to sample corrosive gases as they enter the well from reservoir fractures. The occurrence of hydrogen chloride gas in the steam from wells in the northern area of The Geysers leads to a concern about corrosion of metal surfaces wherever steam condensate forms. By locating the reservoir source for the hydrogen chloride, it may be possible to prevent its entering the wells or to control its release from the reservoir.

Laboratory Research

In laboratory research, LBL scientists are investigating some fundamental reservoir characteristics and processes. Research has found that complex, coupled physical and chemical processes control the short- and long-term response of geothermal wells and reservoirs to production. For example, well productivities and injectivities are largely controlled by the permeability of the reservoir, and this permeability tends to vary with changes in the proportion of water and steam present (relative permeability effects) and with the precipitation or dissolution of minerals in the fractures and pore spaces (chemical effects). The high flow rates necessary for commercial production of geothermal energy depend on high permeabilities in the reservoir rocks, and any changes which decrease permeability can adversely effect production.

Laboratory experiments at LBL, under controlled conditions, allow researchers to study the flow of single- and multi-phase fluids through natural or man-made fractures. The purpose of these studies is to determine the interaction between geometric properties (aperture and roughness) and hydraulic properties (absolute and relative permeability) of fractures (Fig. 2). The results from these experiments will be combined with other investigations to identify and quantify the physical and chemical processes controlling the mass and heat transport in fractures. This information will expand our understanding of actual geothermal fields.

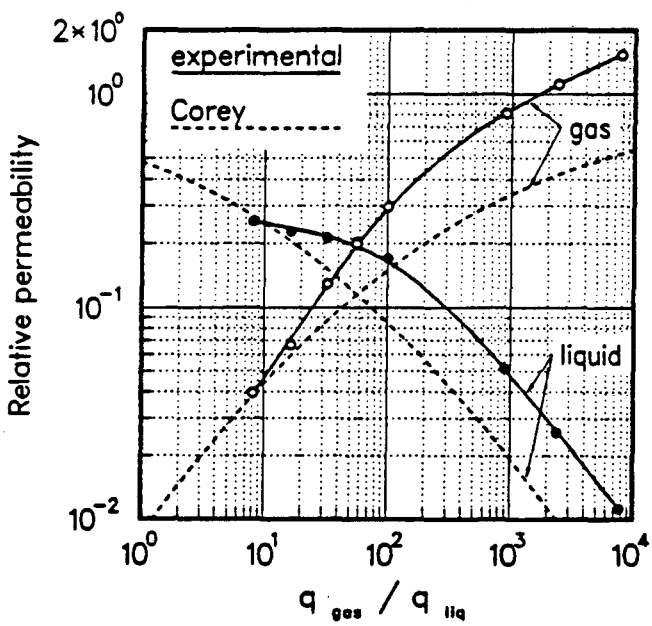

Figure 2. Relative permeabilities for rough-walled fractures measured with the LBL two-phase flow visualization apparatus. The experimental relative permeabilities are plotted against the ratio of gas and liquid flow rates. For comparison, Corey-type curves, typical of porous media, are also shown (from Persoff *et al.*, 1991).

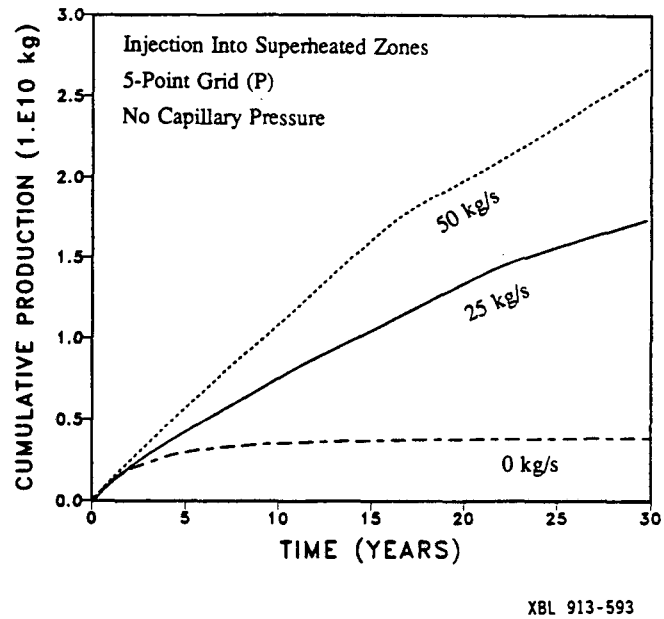

Figure 3. Modeling results showing enhanced cumulative steam production in response to water injection into superheated vapor-dominated zones; the assumed injection rates are indicated on the curves (after Lai and Bodvarsson, 1991).

Theoretical and numerical studies have been focussed toward the fundamental understanding of geothermal reservoir processes, especially those occurring in vapor-dominated systems. For example, computer calculations have shown that injection into superheated zones yields much greater recovery of the injected fluid (Fig. 3) than injection into two-phase vapor-dominated regions. The studies also showed the importance of grid refinement and orientation effects on these calculations. Possible means of overcoming them are being evaluated. The analysis of thermodynamic and transport aspects of vapor pressure lowering due to capillary and phase adsorption effects have been initiated with the purpose of evaluating their significance on production and injection operations in vapor-dominated reservoirs. Very preliminary results so far indicate that depletion behavior is not strongly affected by pressure lowering effects.

Upgrade of Reservoir Engineering Codes

Since the mid-1970s, LBL has been developing computer programs used in the simulation of the transport of heat, mass and chemical species in porous and fractured geothermal systems. Codes for modeling transport in wellbores and for interpreting geothermal well test data have also been produced. Among these programs are CCC, SHAFT79, TOUGH, ANALYZE, WELBORE, all of which are available to industry through DOE's National Energy Software Center.

Because of a better understanding of the behavior of geothermal reservoirs and wells, as well as the availability of new and faster numerical algorithms to solve mathematical equations, LBL continues to develop new geothermal reservoir engineering computer programs and to upgrade existing ones. A similar effort in geophysical codes is being carried out by other LBL scientists, but is being funded by other DOE programs.

Recently LBL's multi-feedzone geothermal wellbore model was expanded to include CO_2-water mixtures. Also, a major subset

of MULKOM modules have been prepared for release under the name TOUGH2 and an expert system for well test analysis has been modified to interpret data from geothermal wells.

Field Case Studies

A significant amount of information on the characteristics and operational history of U.S. and foreign geothermal fields is becoming available in the open technical literature. However, there is a wealth of data that can only be acquired through joint projects with the organizations operating the fields. This has led to (formal and informal) agreements between these organizations and DOE (or the groups funded by GD's Reservoir Technology Program) to jointly analyze existing data sets and to carry out field activities to obtain a new understanding of reservoir processes and behavior.

As part of this activity LBL continues its joint projects with U.S. and foreign organizations (such as CFE of Mexico) to collect and analyze exploration and developmental data from fields under evaluation or production. The goals of this work are: (1) to document the experiences learned by the field developers and operators during the different phases of a geothermal project, (2) to obtain actual field data that can be used in fundamental studies of geothermal systems and (3) to evaluate existing, and design new exploration and reservoir management methodologies for geothermal areas with given physical and geochemical characteristics (see Table 1).

For example, at Long Valley, CA, LBL operated and maintained a high-resolution seismic borehole array and acquired microearthquake data which was used to image the resurgent dome area. The P- and S-velocity structure of the caldera was investigated to determine the presence of hydrothermal activity and/or shallow magma bodies. The analysis of the behavior of the Cerro Prieto, Mexico, field continues, and production and well information is regularly updated and studied (Fig. 4). A two- and three-dimensional gravity study of the Coso, CA, geothermal area was completed. It revealed the presence of a large, deep low-density region underlying the area.

Technology Transfer Activities

The methodologies and instrumentation being developed by LBL with GD funding are made available to industry by way of collaborative efforts, workshops, publications and by distribution through DOE's National Energy Software Center.

Last September, a workshop on the TOUGH/MULKOM program, attended by more that 60 scientists from geothermal and other technical areas, was held at LBL. The assistance to the Geothermal Resources Council in planning courses devoted to technology transfer to industry continues. Several lectures during the October 1990 workshop on "Assessment of geothermal reservoirs and estimation of reserves" were presented by LBL scientists. Starting in

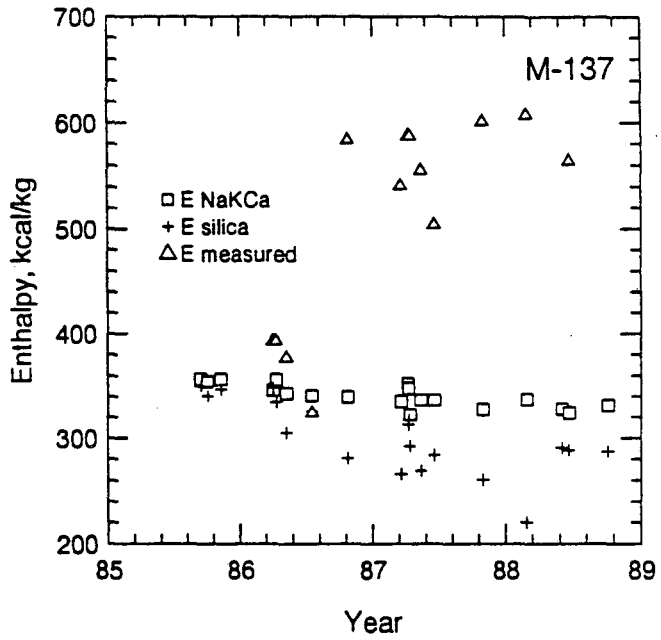

Figure 4. Enthalpy history of a well in the northeastern part of the Cerro Prieto field showing increasing reservoir boiling. E NaKCa is the enthalpy of liquid calculated from the Na-K-Ca geothermometer temperature; E silica is the enthalpy of liquid calculated from the quartz saturation geothermometer temperature; E measured is the measured wellhead total fluid enthalpy (from Truesdell and Lippmann, 1990).

April 1, 1991, the Secretariat of the International Geothermal Association (IGA) will be located at LBL. This will enhance the interaction between DOE-funded researchers and the IGA and its visitors.

A strong emphasis is placed on the publication of results obtained from this program. During 1990 and 1991, 28 papers and reports have been completed, so far. Twelve of them have been submitted to or published in referred journals (see List of Publications below).

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UNIVERSITY OF CALIFORNIA
INFORMATION RESOURCES DEPARTMENT
BERKELEY, CALIFORNIA 94720