Title
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STATUS OF GEOTHERMAL RESERVOIR ENGINEERING RESEARCH PROJECTS
SUPPORTED BY USDOE/DIVISION OF GEOTHERMAL ENERGY

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ABSTRACT

In the fall of 1977, the U. S. Department of Energy (DOE), Division of Geothermal Energy (DGE) proposed that Lawrence Berkeley Laboratory (LBL) assume lead responsibility, on DGE's behalf, for geothermal reservoir engineering. This summary discusses briefly the DOE/DGE-sponsored geothermal reservoir engineering research program which includes LBL in-house research and research done by others through LBL. LBL in-house research has emphasized improvement of well test analysis methods and the development of geothermal reservoir performance simulators. Work by others has included 29 separate contracts on a variety of technical and scientific projects. Altogether, 29 distinguishable research topics have been addressed. Fourteen institutions, including eight private companies, have interacted with the program. Table 1, along with figures 2 and 3 summarizes the status of the work.

INTRODUCTION

The purpose of this paper is to review the program of geothermal reservoir engineering related research that has been supported by the U. S. Department of Energy, Division of Geothermal Energy, through Lawrence Berkeley Laboratory. Administratively, the program consists of two parts: (1) Work done at LBL, (2) work contracted for by LBL and done by a variety of organizations other than LBL. The primary responsibility assigned to LBL was (1) to define and resolve technical and scientific problems related to successful exploitation of geothermal reservoirs. In addition, implicit in the assignment was the desire that the program (2) help promote the establishment of an industry-wide geothermal reservoir engineering community and (3) help assure the education of personnel who would staff this community in the future. The document, LBL-7000 (Lawrence Berkeley Laboratory, 1978) explains details of the process that lead to the broad outline for research shown in Figure 1. This outline addresses all conceivable activities that relate to successful exploitation of a geothermal resource and goes beyond reservoir engineering in a restricted sense. Those activities in the top third of the figure (e.g., well logging) pertain to the acquisition, synthesis, and interpretation of information related to a working description of the reservoir, in particular to estimates of its size, and to a description of the distribution of temperature, porosity, pressure, and permeability within it. Those activities in the central third of the figure pertain to the development of the capability to reproduce and forecast reservoir performance. The two activities in the bottom third of the diagram, namely economics and exploitation strategies, must be factored into good planning for successful exploitation of a geothermal reservoir, which is the ultimate goal of the effort.

Fig. 1 Broad outline of geothermal reservoir engineering related research activities.
WORK ON TECHNICAL AND SCIENTIFIC PROJECTS RELATED TO SUCCESSFUL EXPLOITATION OF GEOTHERMAL RESERVOIRS

Although Fig. 1 provides a broad view of the various research areas considered when the program began, Figs. 2 and 3 are more useful in explaining the many projects that have been considered. Furthermore, these figures can be related to Table 1, wherein certain details on the work are given. The projects can be grouped as follows:

A. The synthesis of available sets of data and other information related to geothermal reservoir engineering: Items 1, 10, 11, 12, 14, 105, 106 (Table 1). For example, item 12 is a summary of all available data on the Wairakei, New Zealand, geothermal field.

B. The establishment of techniques of measurements of interest to geothermal reservoir engineers: Items 3, 4 (Table 1). For example, item 4 concerns measurements at the wellhead of noncondensibles in the flow-stream.

C. The analysis of measurements in order to define the characteristics of a geothermal reservoir: Items 2, 6, 15, 16, 17, 18, 101, 104 (Table 1). For example, item 2 is concerned with evaluating the theoretical basis of the James method.

D. The generation of new data important to geothermal reservoir engineering practice: Items 5, 7, 8, 9, 21, 22, 23 (Table 1). For example, item 7 is concerned with procedures to mitigate mud damage.

E. The establishment, improvement, or application of simulators that describe and forecast geothermal reservoir performance: Items 13, 20, 102, 103 (Table 1). Item 103 is the LBL-developed simulator "SHAFT 78," that models heat and fluid transport in porous media.

It is subjective and also difficult to measure the value of the overall program in terms of projects under way or completed since the beginning of the program. However, the following should be noted:

1. All identified major concerns have been addressed by qualified groups whose abilities to work on the project has been favorably reviewed by selection committees made up mainly of non-LBL personnel.

2. A steady stream of publications, including both volumes in the GREMP (Geothermal Reservoir Engineering Management Program) series and in the quarterly Newsletter from GREMP, has been established.

CONCLUDING REMARKS

Our own judgment of the program is that it is progressing well. However, two aspects that need more attention are as follows:

1. Relating the results of research to identified technical problems at specific geothermal sites. As an example, it would be useful to know from industry how critical are concerns over mud damage at their specific development sites, how important are readings on wellhead enthalpy, and so on. Cooperation from industry in providing such feedback is vital.

Fig. 2 Summary diagram of well system and near-bore research projects.

2. Economics. Although conceived as an area of work in the original program plan, no effort has been put on this topic in keeping with the recommendation of the advisory group to GREMP. It is very difficult, therefore, to place other research in an economic framework and judge its importance with respect to the crucial questions of economics and geothermal resource development.
Future work of the program should emphasize the application of research and heavier support to problems of major economic consequence.

ACKNOWLEDGMENTS

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REFERENCES

Note: Space allows for listing of only final GREMP series documents. A complete bibliography, including referenced progress reports, is available from the authors.


Harrison, Roger and Randall, Georgia, 1979, Annotated research bibliography for geothermal reservoir engineering: Lawrence Berkeley Laboratory, GREMP Series #1, 261 p. (LBL-8664).


Lamers, Michael D., 1979, An appraisal of measurement methods for geothermal well system parameters: Lawrence Berkeley Laboratory, GREMP Series #6, 40 p. (LBL-9090).


Vetter, O. J., 1979, Scale inhibitor tests at East Mesa: Lawrence Berkeley Laboratory, GREMP Series #5, 52 p. (LBL-9089).
<table>
<thead>
<tr>
<th>ID #</th>
<th>Brief project name</th>
<th>Contractor</th>
<th>Brief summary of work</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Status of reservoir</td>
<td>Measurement</td>
<td>A comprehensive appraisal of reservoir needs and related measurements has been completed, indicating that commercially available technology and instrumentation are available for all wellhead and process plant measurements required for geothermal energy systems. (Kenny et al., 1978).</td>
</tr>
<tr>
<td>2.</td>
<td>Theoretical basis</td>
<td>University of Hawaii</td>
<td>This project has been started. Its purpose is to test experimental methods for understanding geothermal reservoir behavior and to develop a theoretical basis for applicability. Project has started.</td>
</tr>
<tr>
<td>3.</td>
<td>Measurement of</td>
<td>Battelle Pacific Northwest Laboratory</td>
<td>Several calorimeter methods for measuring geothermal wellhead enthalpies were evaluated. A mixing test condenser was recommended when cooling water is available. When not, a multiphase tank was recommended. Both have started on engineering drawings of a sampling system and mixing test condenser (Allen et al., 1979).</td>
</tr>
<tr>
<td>4.</td>
<td>Control of calcite</td>
<td>Vetter Research</td>
<td>Scales inhibitor tests performed at Republic Geothermal Inc. East Mesa wells have shown that Dequest can economically eliminate calcite precipitation in the discharge flow stream (Vetter, 1979).</td>
</tr>
<tr>
<td>5.</td>
<td>Analysis of well</td>
<td>Intercomp</td>
<td>Comparison of Intercomp's proprietary geothermal well bore and reservoir simulator with the experimental and numerical results from these other models has been completed. Data on volumetric well tests are currently being assembled for analysis (Fetter and Taylor, 1979).</td>
</tr>
<tr>
<td>6.</td>
<td>Formation damage</td>
<td>TerraTek</td>
<td>Laboratory simulation of drilling mud damage to geothermal reservoir rocks has been initiated. Parameters to be considered include pressure, temperature, reservoir fluid chemistry, mud composition, and time (Futter, 1979).</td>
</tr>
<tr>
<td>7.</td>
<td>Relative permeability of steam and water</td>
<td>Stanford University</td>
<td>Relative permeability data have been collected by Stanford University.</td>
</tr>
<tr>
<td>8.</td>
<td>Calcium formation</td>
<td>Republic Geothermal Inc.</td>
<td>Carbonate rich geothermal brine is being passed through containers of granular material in order to evaluate the mechanism and rate of calcite precipitation within the pore space. The ultimate practical purpose of the activity is to plan remedial &quot;acid jobs&quot; on calcite-fouled geothermal wells (Mitchell, 1979).</td>
</tr>
<tr>
<td>9.</td>
<td>Literature review of reservoir</td>
<td>TerraTek</td>
<td>An annotated bibliography covering reservoir modeling, exploration strategies, and interpretation of production trends has been prepared (Harrison and Handal, 1979).</td>
</tr>
<tr>
<td>10.</td>
<td>Study of the</td>
<td>Stanford University</td>
<td>Geology and pressure-production history of Serramonte reservoir has been reviewed. Bottomhole temperatures and pressures have been calculated from wellhead measurements. Areal distribution of pressure has been mapped for seven different times spanning the last 15 years. A conceptual model of the Serramonte reservoir field was developed on the basis of the available field data (Miller et al., 1978).</td>
</tr>
<tr>
<td>11.</td>
<td>Data collection for the</td>
<td>Systems Science and Software</td>
<td>All geological, geophysical, geothermal, and wellbore data from January, 1973 to December 1976 has been collected and synthesized (Fritchett et al., 1978).</td>
</tr>
<tr>
<td>12.</td>
<td>Simulation of past and future performance of Vekekeai</td>
<td>Systems Science and Software</td>
<td>With the data collected and synthesized (Item above), an attempt is under way to match the pressure and enthalpy history during past production of the Vekekeai field (Fritchett et al., 1978).</td>
</tr>
<tr>
<td>13.</td>
<td>Prototype of a fault-charged</td>
<td>University of Colorado</td>
<td>A physical, viable mathematical model of an unexploited geothermal system has been constructed in terms of a fault zone controlled charging of a reservoir (Barnes and Cloyd, 1979).</td>
</tr>
<tr>
<td>14.</td>
<td>Review of decline</td>
<td>E. J. Zola and Associates</td>
<td>This project is to review decline curve procedures used in the petroleum industry in order to determine which procedures are applicable to geothermal systems and evaluate the theoretical basis for applicability. Project has started.</td>
</tr>
<tr>
<td>15.</td>
<td>New analytical</td>
<td>Stanford University</td>
<td>The utility of parallel-tipped models has been investigated (Kenny et al., 1978).</td>
</tr>
<tr>
<td>16.</td>
<td>Study of the use</td>
<td>University of California, Riverside</td>
<td>The variation of radon associated with geothermal reservoir production has been analyzed and interpreted for several reservoirs throughout the world (Egger et al., 1978).</td>
</tr>
<tr>
<td>17.</td>
<td>Study of basic</td>
<td>Princeton University</td>
<td>Multiphase flow equations have been derived for a deformable porous medium. Solutions for heat and mass transfer in a fractured reservoir have also been formulated. A computer program (Black Interactive Finite Element Processed Scheme) has been developed to solve nonlinear transient problems with one or two free boundaries in two or three dimensions. (Findler et al., 1978).</td>
</tr>
<tr>
<td>18.</td>
<td>Analysis of effects of temperature and chemical composition of the rock on relative permeability has been investigated (Miller, et al., 1978).</td>
<td>Stanford University</td>
<td>Heat flow from rock to water has been studied as a function of a number of parameters including the size of rock fragments (Egger et al., 1979).</td>
</tr>
<tr>
<td>19.</td>
<td>Project completed.</td>
<td>LBL</td>
<td>Analytical analysis of reservoir well responses during testing using numerical models has been studied. Results were compared favorably with analytical solutions (Hasan and Panim, 1979).</td>
</tr>
<tr>
<td>20.</td>
<td>Study of the</td>
<td>Stanford University</td>
<td>A code simulating transient two-phase flow in porous media has been written and applied to hypothetical and real examples (Fuess et al., 1978).</td>
</tr>
<tr>
<td>21.</td>
<td>Study of Serramonte</td>
<td>Stanford University</td>
<td>The ANALYZE code has been proven capable of this kind of analysis (McBride, 1979).</td>
</tr>
<tr>
<td>22.</td>
<td>Study of the</td>
<td>Stanford University</td>
<td>A very comprehensive case study at Cerro Prieto is being carried out cooperatively with the Mexican government (Shayman et al., 1978).</td>
</tr>
</tbody>
</table>

* Project completed.
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