SESSION 16

GEOTHERMAL DRILLING AND COMPLETION RESEARCH AND DEVELOPMENT PROGRAM

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ABSTRACT

One of the major factors presently inhibiting the exploitation of geothermal energy is the high cost of drilling and completing geothermal wells. The cost of these wells typically ranges from $1 M to $3 M, which are several times that of an oil or gas well of comparable depth. These high costs are primarily driven by the harsh environment associated with geothermal reservoirs. The high temperatures which are inherent to the resource cause rapid degradation of conventional drill bits and preclude the use of conventional drilling fluids. Geothermal formations are typically hard and highly fractured. This results in low rates of penetration, high rates of drilling fluid loss, and difficulties in obtaining competent completions. The chemical composition of the downhole geothermal fluids causes extensive scaling, and combined with high temperatures, cause corrosion of drill pipe, casing, and logging equipment.

Present research and development activities are underway to find solutions to these problems. Current activities include development of high temperature drilling fluids, methods for plugging lost circulation zones, advanced rock cutting techniques, and borehole instrumentation.

Three specific projects which are being pursued, each at a different stage of development, include: a method for locating fractures which do not intersect the wellbore, a laboratory for simulating lost circulation zones—to be used for development of new materials and techniques, and the understanding of the capabilities and limitations of PDC bits in the geothermal environment.

The technique for fracture mapping involves the use of a downhole electromagnetic device which transmits energy, radially focused, to fractures away from the borehole and receives reflected energy which can be processed to determine location and extent. This project is in the feasibility study phase, aiming at determining such factors as proper frequency, depth of penetration, and angular resolution. If laboratory and analytic results indicate, then prototype hardware will be built and tested over the next two years.

Lost circulation (loss of drilling fluid due to low pressured-fractured formations) is a problem which directly and indirectly represents 20 to 50% of geothermal well costs. The solutions (addition of particulate material to the drilling fluid) used by the oil and gas industry are not reliable in geothermal wells. To better understand why this is the case, and to develop new materials which are reliable, a large flow loop which incorporates a test cell simulating downhole loss zones has been built. This loop, known as the Loss Circulation Test Facility, has the capability of flowing 250 gpm of drilling fluid at 200°C and 1000 psi. A "new" material that shows promise is ground battery casings—a thermal setting resin which is stable to 400°C.

Polycrystalline Diamond Cutter (PDC) bits were pioneered by Sandia as a potential geothermal bit because the drag bit design entails no bearings, lubricants, or seals that fail at high temperatures. However, these bits, due to the high temperature environment, the abrasive rock, and the principal upon which they operate (shearing the rock rather than crushing it), lead to very high cutter temperatures which limit their lifetime. A combined laboratory and analytic effort has been conducted, aimed at identifying the limitations of these bits—hopefully pointing the way to solutions which will increase their operating range.
Some of the problems first encountered in geothermal drilling have been solved—by both industry efforts as well as DOE-sponsored research. Many problems remain and will be solved by future research. The program at Sandia is closely coupled to the geothermal drilling industry so that research and development advances are both supported and utilized by the group who will eventually benefit from them.
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I. INTRODUCTION

This report provides a summary of objectives and activities of the Geothermal Drilling and Completion (GDC) Program. Sandia National Laboratories provides the technical management of this program which is funded by the Department of Energy, Division of Geothermal and Hydropower Technology.

In order to stimulate utilization of geothermal resources in the United States, Congress enacted the Geothermal Energy Research, Development and Demonstration Act of 1974. This Act, as well as the Federal Nonnuclear Energy Research and Development Act of 1974 and the Geothermal Steam Act of 1970, authorizes federally-sponsored research, development, and demonstration activities to assist private industry in developing appropriate technology for utilizing geothermal resources. The Department of Energy (DOE), formerly the Energy Research and Development Administration (ERDA), was designated as the lead agency for the federal geothermal energy program.

The Geothermal Drilling and Completion (GDC) Program was established by the Division of Geothermal Energy, now renamed the Geothermal and Hydropower Technologies Division (GHTD). The overall goal of this program is to develop technology that could be used by private industry to reduce the costs of drilling, completing, and logging geothermal wells. Since these costs account for a substantial portion of the cost of generating electricity (approximately 50%), reductions in the cost of geothermal wells will have a major impact on accelerating the development of geothermal energy.

These high well costs (typically 2 to 4 times those of oil and gas wells of comparable depth) are attributable, in part, to deficiencies in drilling and completion technology that arise from the temperature effects,
formation effects, and corrosion effects encountered in drilling geothermal wells. The high temperature of geothermal formations (250°C to 300°C) causes degradation of downhole drilling components, fluids, and instrument packages. These formations are typically composed of hard, abrasive rocks which cause low rates of penetration and reduced lifetime of drill bits and other downhole hardware. Since the formations are fractured and usually underpressured (sub-hydrostatic), frequent loss of drilling fluid circulation and incomplete cementing become costly problems. The chemical composition of the geothermal fluids cause extensive corrosion of drill pipe, casing, and all other metals which it contacts, and in addition to the cost associated with reduced lifetime, catastrophic failures such as drill pipe embrittlement can lead to much higher costs to recover the well.

II. RATIONALE

To reduce these high well costs and thus accelerate the development of geothermal energy, it will be necessary to develop new drilling and completion equipment capable of operating in this hostile environment. Since geothermal drilling activity is so much smaller than oil and gas activity (80 wells per year vs. 80,000 wells per year), and geothermal drilling needs are somewhat different than oil and gas (temperature, hard rock, etc.), private industry has shown little interest in developing the required technology because of this smaller market potential.

Another factor which inhibits involvement of private industry is the segmentation of the technical services associated with drilling. A brief description of this division of effort should serve to explain this point. The company which holds the land lease and the contract to deliver steam to the utility company is typically referred to as the "operator". The operator hires a drilling contractor, a company which owns and operates a
drilling rig, to actually perform the drilling operation. However, the drilling contractor is only responsible for the operations. The operator must deal with other distinct companies to supply the remaining drilling needs such as drill bits, drilling fluids, tubulars (drill pipe and casing), cementing services, logging and instrumentation, and directional drilling and surveying. While the technical capabilities of each of these service companies may be quite extensive, they have little incentive to integrate all of the various pieces into an efficient system.

Further rationale for federal participation in the area of drilling research and development is the desirability of using the technical data base which already exists within the national laboratory system. These laboratories possess technical expertise and facilities funded by the federal government to support national defense efforts. In order to transfer some of this technology to private industry, the technology must be focused on a specific area which has potential for commercialization—geothermal drilling and completion is one such area.

III. STRATEGY

The objective of the GDC Program is to facilitate geothermal energy utilization by ensuring the availability of economically and technologically suitable materials and techniques to the geothermal drilling industry. Achievement of this goal requires the effective management of a wide range of technological activities. The program strategy outlined below concentrates on developing an optimum balance between basic and applied R&D, between short-term and long-term results, and between government and private industry activities. In addition to the technical activities associated with this program, the additional effort to transfer these developments to private industry where they can be utilized to reduce costs is an important aspect of the program goal.
The basic strategy for achieving the program goals are outlined below.

- Identify primary technology deficiencies through a series of internal systems studies and confirm these priorities through interactions with industry representatives. (Industry Review Panel and professional technical groups such as the Geothermal Resources Council and the Society of Petroleum Engineers).

- Conduct analysis to quantify the impact of each technology on expanding the resource and once again confirm these results with industry contacts.

- Conduct specific research tasks that will lead to the development of high-priority technology. Some of these tasks will be carried out by Sandia researchers and some will be contracted to universities and private contractors.

- Develop specific prototype hardware and instrumentation if required to verify operational and accuracy parameters for economic consideration by private industry.

- Conduct laboratory and/or field tests of prototype technology to enhance technology transfer opportunities.

- Whenever possible, cost-share major R&D projects with industry, especially when full-scale field testing is involved.

- Interface with other DOE offices and federal agencies involved in similar technology development programs to avoid duplication of effort and to capitalize on other developments.

- And, through documentation and interactions at professional group meetings, or special symposia held for a specific program, transfer these technologies to private industry.

To assist in identifying appropriate research tasks, to evaluate the
results of these efforts, and to facilitate the transfer of appropriate
technology, an industry panel has been formed to meet these needs. The
members of this group and their company affiliation are listed below.

Tom Anderson - Venture Chemicals
Larry Diamond - Smith Dyna-Drill
Mel Friedman - Texas A&M
Tom Turner - Phillips Geothermal
Jim Langford - Dresser-Security
Harv Mallory - Consultant
Gene Polk - NL Faroid
John Rowley - Los Alamos National Laboratories
Dwight Smith - Halliburton
Jim Kingsolver - Smith Tool
Ed Pingleton - Shell
John Fontenot - NL Measurement While Drilling
Del Pyle - Union Geothermal
Bill Humbaugh - OTIS
Tom Warren - AMOCO
Ben Bradford - Dowell

IV. SCOPE

The Geothermal Drilling and Completion (GDC) Program is organized into
five elements, each incorporating a number of R&D activities:

1) Rock Penetration Mechanics - cavitating jet research, PDC cutter
heat transfer, drill string dynamics, rock/cutter interaction studies, downhole intensifiers.

2) Borehole Mechanics - lost circulation test facility, casing
buckling analysis, fluid displacement modeling.
3) Fluid Technology - clay chemistry studies, aqueous foam characterization, bit hydraulics.

4) Diagnostics Technology - lost circulation tool, cement bond logger, far wellbore fracture mapping.

5) Permeability Enhancement - fracture characterization, finite element modeling, modified pressure pulse studies.

In more general terms, the program addresses those technology needs associated with drilling, completing, logging, and stimulating geothermal wells. These program elements represent approximately equal division of effort but are subject to change as priorities are modified due to budgeting or staffing considerations.

V. FUNDING

Figure 1 shows the annual budget authorization for the GDC Program since 1978. Note that these budgets include funding for Drilling and Completion, Logging and Instrumentation, and Stimulation activities.

These funds are used to support technical personnel at Sandia Laboratories (15 in FY'83) and outside contracts with industry and universities (approximately $1 million in FY'83). Funding for each of the program sub-elements outlined in Section IV is approximately equal.

VI. ACCOMPLISHMENTS

The GDC Program has been ongoing since 1978. Some major accomplishments since the program began are listed below.

- Pioneered design and use of PDC bits. Prior to Sandia involvement there were no PDC bits in the U.S.; now there are 15-plus companies marketing PDC bits (PCI, Stratabit, Davis Hicks, Security, Christensen, American Coldset, etc.).

- Developed new seals, lubricants, and materials for tri-cone bits
which enable survival at geothermal temperatures. Program was cost shared with Reed Tool Company.

- Developed computer code to place PDC cutters on bit to optimize cutter life. Code now used by several major bit companies (Reed, PCI, Smith, Security).
- Developed process for diffusion bonding of PDCs to bit studs. New company formed (PCI) to apply this technology.
- Developed cavitating jets to enhance cutting and cleaning ability of bi-cone and tri-cone bits. Nozzles now available in Smith A-1 bits.
- Developed and field tested new high-temperature drilling fluid using sepiolite clay. Formulation now available from NL Faroid.
- Developed transient heat transfer computer code for calculating wellbore fluid and formation temperatures. Code used extensively by oil and gas, as well as geothermal industry (Exxon, Shell, Union, Halliburton, NL Faroid) to calculate fluid temperatures and predict cementing conditions.
- Developed high-temperature elastomers for "O" ring applications (EPDM). Now available through L'Garde, Precision Rubber, and Parker Seal Company.
- Developed high-temperature lubricant for roller-cone bearings. Marketed by Pacer Industries as Geobond®.
- Designed and built high-temperature/high-pressure viscometer for evaluating drilling fluid at geothermal conditions. Prototypes now being used by Texas Tech University. Industry requests from Shell, Chevron, and Union.
- Developed an op-amp capable of operating at 275°C. Product now available from Harris Semiconductor, Inc.
- Developed 275°C hybrid circuitry for: voltage regulators, line
drivers, pulse stretchers, and V/F converters. Products are now available from Teledyne-Philbrick.

- Developed a 275°C multiplexer for use in downhole logging tools. Product available from GE.

- Designed inert gas generator which cleans diesel exhaust gas for use as a substitute for air (when air drilling) to reduce drill pipe corrosion.

- Developed and tested waterjet descaling system for cleaning scale from geothermal wells. Uses cavitating jets, minimizing casing damage and permits well to flow while being cleaned.

- Developed seals capable of sealing high-speed turbine/motor bearing packages at geothermal conditions. The HTCE-SF design has operated for 200 hours under laboratory conditions.

- Developed new carbide materials (NbC and TaC) for drill bit, pump, and other geothermal applications. Preliminary tests on these materials indicate promise of increasing toughness (over WC) while preserving hardness.

- Developed two-part polyurethane foam capable of foaming at 300°F while maintaining a compressive strength of 300 psi. This foam shows promise as a geothermal lost circulation material.

- Developed 300°C sheathed monocable which is resistant to geothermal environment.

VII. FY'83 ACCOMPLISHMENTS

Listed below are several major accomplishments that were successfully completed this fiscal year, including some that are scheduled for completion during the last quarter.

- Developed and field tested an inertial navigation wireline tool for spatial mapping of wellbores.
Developed high-temperature prototype logging tools for measurement of temperature, pressure, and flow.

Developed long-life, high-power electrical switching device. Sprytron tube is being modified to operate as SCR for primary use in cement-bond logging tool.

Completed modeling of PDC bit frictional heating and hydraulic cooling. Used to predict optimum operating conditions for PDC bits.

Completed testing of aqueous foam convective heat transfer properties. Used to predict foam temperatures in geothermal wellbores.

Fabricated and began testing of Lost Circulation Test Facility (LCTF). Used to develop materials and techniques for lost circulation control.

Completed study of commercial pressure transducers at high temperatures and pressures.

Completed prototype development of high-temperature cement bond log tool.

Completed Phase I of Drill String Dynamics Program. Development of predictive computer program, jointly funded by Sandia, NL Industries, and Superior Oil Company.

VIII. TECHNOLOGY TRANSFER

The accomplishments noted in the previous sections have been documented (Sandia reports, technical journal articles, and technical meeting presentations) and made available to industry. All Sandia documents are disseminated through the NTIS.

Specific communication has been made with industry through the technical review panel cited in Section III. In addition, a technology transfer meeting was held at Sandia to discuss the wellbore inertial navigation
system. Approximately 20 industry representatives attended this meeting.

One of the major formats for technology transfer has been person to person communication. During FY'83 over 50 people have visited Sandia to learn of the R&D activities that are in progress. Similar visits have been made to other industry labs to share technical information.

IX. FUTURE EFFORTS

In order to realize the program objectives of reduced well costs, a number of areas requiring research and development have been identified. These efforts have been divided into intermediate and long-range research and development programs. The GDC Program has made significant progress in developing cost reducing technologies, but further work is required to enhance the attractiveness of geothermal energy to private investors. The intermediate and long-range R&D programs are summarized below.

Intermediate Term Programs

- Develop reliable techniques to predict rock fracturing mechanisms. Specifically, this effort will aim at defining optimum methods for breaking/drilling rocks.

- Complete development of computer program to predict the dynamic response of drill strings as drill stem configuration and rock types are varied.

- Develop cavitating jet technology to be used to design optimum jet designs which could be used for pure water-jet drilling.

- Develop and field test an aqueous foam drilling fluid which can withstand high temperature, saline environments.

- Fabricate and test an acoustic tool to find/define lost circulation and production fractures which intersect the wellbore.

- Develop a particulate lost circulation material that can be used to
plug loss zones in geothermal wells.

- Expand the Lost Circulation Test Facility to include other efforts (mud rheology, cement displacement, etc.).
- Develop analytic model of lost circulation plugging phenomenon.
- Develop analytic model of cement/mud displacement process.
- Develop technology to apply modified Pressure Pulse Loading concept to geothermal wells.

Long-Range Research and Development Program

Early system analysis efforts revealed that significant well cost savings could not be realized without major technology advances in the art of drilling. Additionally, these studies indicated that revolutionary (as opposed to evolutionary) changes in drilling methodology would probably be required to meet these goals. For these reasons, the long-range objectives of the GDC Program are structured around the development of an advanced drilling system.

Listed below are the major system functions of an advanced drilling system and some ideas for technology development to perform each of the separate functions.

- Penetrate Rock - pure water-jets, friction drill, abrasive jets, acoustic drill.
- Transmit Power - electric cable/motor, downhole intensifiers, downhole power generation.
- Remove Debris - melting/densification, staged storage/removal, mechanical removal.
- Monitor/Control Trajectory - MWD inertial navigator, real-time directional control.
- Solve/Avoid Lost Circulation - combination chemical/particulate plug,
rubbilization of vugs, borehole plating.

- Determine/Predict Downhole Conditions - far wellbore sensing, fiber optics, downhole computers.
- Line borehole - case while drilling, chemical or mechanical liners, melt debris-line hole, cement alternatives.
- Maintain/Enhance Productivity - electrical scale/corrosion control, chemical scale/corrosion control, acoustic scale removal, water-jet underreaming.

Little or no development of these ideas has been pursued to date. Successful development of such an advanced drilling system will require approximately five years of continuous effort. This program would involve laboratory experiments, analytical investigations, prototype hardware development and testing, and, finally, full-scale hardware development and field test verification. Exclusive of the full-scale hardware costs, such an effort is estimated to cost approximately $5 M per year (for 5 years). The full-scale hardware is estimated to cost $10 M, which would include preliminary system testing.
BUDGET HISTORY AND FORECAST

LEGEND
- GEOTHERMAL LOGGING INSTRUMENTATION PROGRAM
- DRILLING AND COMPLETION PROGRAM
- COMBINED PROGRAM

ANNUAL BUDGET AUTHORIZATION (MILLIONS OF DOLLARS)

FISCAL YEAR


Figure 1