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RESEARCH AND DEVELOPMENT ACTIVITIES IN
GEOTHERMAL DRILLING, COMPLETION AND LOGGING

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Sandia National Laboratories manages the Geothermal Drilling and Completion Program for the US Department of Energy. The primary purpose of this program is to expand access to the geothermal resource by reducing the cost of drilling and completing geothermal wells. This cost is typically two to five times that for an oil well of comparable depth, and well cost is usually about half the total capital investment for a geothermally-powered plant to generate electricity.

Geothermal drilling is plagued by a combination of problems not shared by the rest of the drilling industry. Formations are hard, abrasive, fractured, and frequently underpressured, which results in slow drilling and lost circulation. The fluids produced are often corrosive and high in dissolved solids. Completions are difficult, with casing failure a major cost in many geothermal wells. Aggravating this catalog of complications is the fact that the geothermal industry is so small compared to the oil and gas industry that oil tool manufacturers and service companies have little incentive to do research on geothermal problems. Thus, if we accept the premise that development of this alternative energy source is in the national interest, reduction of geothermal well cost is a legitimate expenditure of taxpayer's money.

Our principal goal in this program is the development of an advanced drilling system that can drastically reduce well costs. Since this is a large task, and we do not have the resources to attack the whole problem, we have chosen projects that would be part of an advanced system but would also have stand-alone value as successful research and development. Since a great variety of projects is available, we have conducted systems analyses to select work that is appropriate to the goal, scaled to our resources, and likely to have a high payoff.

Our program is defined in five basic elements:

- Rock Penetration Mechanics
- Fluid Technology
- Borehole Mechanics
- Diagnostics
- Permeability Enhancement

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Each of these elements will be briefly summarized with examples of typical projects in each area.

Rock Penetration Mechanics -

This element includes all the aspects of actually making a hole in the rock. In general, the work has been directed toward analytical and experimental investigation of rock breakage mechanisms and drill bit behavior. Some examples are:

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- Erosion drilling - A series of contracts with Hydronautics, Inc has led to the analytic description and experimental verification of cavitating and pulsating water jets. These jets produce a periodic train of ring vortices which can impinge on a wellbore surface. Jets of this type are interesting for several potential uses - direct rock breakage, augmentation of mechanical rock breakage, and improved bottom hole cleaning. A roller cone bit with pulsating jet nozzles has been commercially produced and shown to have performance superior to the same bit with conventional nozzles.
- Rock/cutter interaction - A finite element model of a drag bit cutter moving through rock has been developed and compared to laboratory experiment. The model gives forces on the cutter, stresses in the cutter, and fracture patterns in the rock. Qualitatively, the agreement with experiment has been good, although the calculated loads are lower than actual loads. All cutting tests have been done at atmospheric pressure, but model predictions should be better when there is borehole or confining pressure to suppress tensile cracks. A series of pressurized cutting tests to investigate cutter forces and rock damage patterns is imminent.
- Drill String Dynamics - A finite element model of a drill string - from the bit/rock interface to the surface - is under construction. This model incorporates user-definable formation, bit geometry, and drill string configuration. Knowledge of the dynamic behavior of the drill string is important when considering hole deviation, bit performance, and the environment to be imposed on potentially delicate downhole equipment. The elements of this model will be validated by lab experiment; parts of this have already been done. This project is being supported jointly by Sandia plus four oil and service companies.

Fluid Technology -

This element deals primarily with drilling fluid; its properties and its flow in the borehole.

- Aqueous foam - Because many geothermal formations are underpressured, the use of low density drilling fluids is either advantageous or necessary. Compared to air, aqueous foam has higher carrying capacity and lower air flow rate requirements. Early foam work investigated drainage times of various surfactants at high temperature; current work is focussed on heat transfer properties and rheology of flowing foam.
- Clay-based drilling fluids - Because some wells will be drilled with mud, we have measured properties of clay-based drilling fluids at high temperature, including the effects of several salts and hydroxides on viscosity. Current work includes a look at in-situ clay-to-cement conversion and the formulation of a high temperature bentonite mud.

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- Bit hydraulics - We operate a Sandia-designed test stand that can be used to visualize flow across the face of a rotating bit. Identification of stagnant points in the flow is important when considering bottom hole cleaning, bit balling, and convective cooling of the cutters. The facility can also be used to study the effect of changing nozzle and junk slot placement.

Borehole Mechanics -

This element includes the factors which affect the integrity of the borehole. Past work involved such projects as casing stress analysis and a water jet casing de-scaler, but current activity is concentrated on problems of lost circulation. A Sandia-designed Lost Circulation Test Facility (LCTF) has been used to study the dynamic behavior of lost circulation material in a simulated borehole. The LCTF is a 1000 psi, 400°F flow loop which accurately simulates the movement of particles past, as well as into, a borehole crack. Well over 100 tests have been done and the data used to establish criteria for crack bridging. Development of an analytic model complementary to these experiments is under way.

Diagnostics -

The diagnostics element involves the techniques used for getting information out of the wellbore. Earlier work was concentrated on the development of a family of high temperature electronic components that would operate continuously at 527°F and could be used either for wireline logging or measurement while drilling (MWD). Other recent or current work includes:

- Lost Circulation Zone Mapping Tool - The low temperature acoustic televiewer commercially available from Simplec was extensively redesigned to operate for 5 hours at 527°F with the electronics in a dewar. The tool has been field tested in hot dry rock and commercial geothermal wells; it has provided information about fractures (location, density, orientation) as well as about cracks and corrosion in casing. The latest design iteration for the tool includes temperature logging capabilities.
- Wellbore Inertial Navigation System (WINS) - Based on Sandia weapons guidance technology, this tool gives a continuous survey of wellbore location. The important innovation was in software; signal processing uses Kalman filtering with periodic updates to give a position accuracy of one foot per 1000 feet of well depth. This tool has been field tested, but is not packaged to operate at high temperature.
- Cement Bond Log - Casing failure is a major geothermal problem and much of it is due to poor cement jobs. The bond log tool uses acoustic data to evaluate the bond between the casing and the cement. A dewar is not used here, the tool is designed to operate continuously at 482°F. The design is complete and has been bench tested.

Permeability Enhancement -

Increasing production from an existing well is the focus of this element. Assessment of natural and man-made fracture systems as well as actual stimulation techniques are being pursued.

- Fracture Assessment - Since most of the fluid in a geothermal well is produced through fractures, it is important to know both the natural fracture system around a well and how that system may have been altered after treatment. Fractures that intersect the wellbore can be detected by the televiwer described above, but that tool does not give significant definition beyond the wall. To detect non-intersecting fractures, we have tested a 30 MHz downhole radar with directional transmitter and receiver. This tool has detected a brine-filled fracture 35 feet away in granite; current effort is aimed at improving data interpretation and antenna directionality.
- Modified Pressure Pulse - If a wellbore is pressurized to fracture the formation, the pressure pulse rise time will control the way that the cracks are formed. If the rise time is long, as in hydraulic fracturing, a pair of cracks perpendicular to the least principal stress will form. If these cracks are parallel to the "natural" fracture system, production won't be significantly increased. If the rise time is very short, as in explosive fracturing, the rock near the wellbore may deform plastically, creating a "stress cage" that will actually inhibit production. There is an intermediate rise time, however, that will drive cracks in many directions. It is then more likely that the wellbore fractures will intersect the natural fractures and connect them for increased production. The rise time is tailored by adjusting the mixture of propellants that creates the pulse. The concept has been field tested and verified - a series of experiments to address specific geothermal problems will be done in late 1984.
- Modelling - The modified pressure pulse fracturing has been modelled in a finite element code so that performance can be predicted when key variables such as acoustic wave speed, rock strength, and in-situ stress are altered.

This outline of activities is not all-inclusive and project descriptions are necessarily minimal. Further information on these and other projects can be found in the References, which also include names and telephone numbers of the people involved in specific tasks.

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