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GEOTHERMAL DRILLING RESEARCH OVERVIEW

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ABSTRACT

Sandia conducts a comprehensive geothermal drilling research program for the U.S. Department of Energy. The program currently consists of eight program areas: lost circulation technology; advanced synthetic-diamond drill bit technology, high-temperature logging technology; acoustic technology; slimhole drilling technology; drilling systems studies; Geothermal Drilling Organization projects; and geothermal heat pump technology. This paper provides justification and describes the projects underway in each program area.

INTRODUCTION

The cost of geothermal energy must be reduced in order for this clean and reliable resource to expand beyond its current market in the United States. One significant area where costs could be reduced with improved technology is in drilling geothermal wellbores. Because of the high temperatures, hard rock, and fractured formations usually encountered in geothermal drilling, the cost of a typical geothermal well is roughly twice that of a petroleum well drilled to the same depth. The well field accounts for about 35-50% of the cost of a geothermal power project, and drilling costs are accrued early in the project, making their impact particularly significant. Advanced technology development and technology transfer has the potential for reducing geothermal drilling costs by at least 30%.

Because of this potential, the U.S. Department of Energy sponsors a comprehensive geothermal drilling research and development program at Sandia National Laboratories. The program contains a mixture of short-, medium-, and long-range projects aimed at developing new technology and transferring this technology, as well as technology developed by other drilling industries such as petroleum and minerals, to the geothermal industry. Past significant successes of this program include: advancement of polycrystalline diamond (PDC) drill bits; development of high-temperature drilling muds; development of high-temperature elastomers for downhole motors; and development of a thermal simulator for predicting downhole temperatures while drilling. The current drilling research program is described below.

DESCRIPTION OF THE PROGRAM

The current program consists of eight program areas:

- *Lost Circulation Technology;*
- *Advanced Synthetic-Diamond Drill Bit Technology;*
- *High-Temperature Logging Technology;*
- *Acoustic Technology;*
- *Slimhole Drilling Technology;*
- *Drilling Systems Studies;*
- *Geothermal Drilling Organization Projects; and*
- *Geothermal Heat Pump Technology.*

Each of these program areas is described below.

Lost Circulation Technology

Lost circulation is the loss of drilling fluids from the wellbore to the surrounding rock formation. This is a significant problem because it leads to wellbore instability, stuck drill pipe, inadequate casing cementing, and increased costs. Lost circulation accounts for about 10-20% of the total costs for a typical geothermal well. The objective of the lost circulation technology program at Sandia is to develop technology for diagnosing and treating lost circulation zones in order to reduce drilling costs by at least 10%.

Rolling Float Meter

The rolling float meter is a device developed at Sandia for measuring the outflow rate of drilling fluid from a wellbore during the drilling process (Glowka *et al*, 1992). Accurate measurement allows the rate of loss into the formation to be determined, which can provide information related to the location and severity of the loss zone and help the driller determine when and how the loss zone should be treated.

Sandia first field tested this meter in 1991 and has been in the process of improving its performance and transferring the technology to industry since then. We have recently completed the design of the second-generation rolling float meter, which has improved accuracy and is more rugged. We are currently working with several industry partners, CalEnergy, Epoch Well Logging, and Tecton Geologic, to demonstrate the proper use and utility of the meter in the field.

Acoustic Doppler Meter

The acoustic Doppler meter is a device for measuring the inflow rate of drilling fluid to a wellbore during the drilling process. Although Doppler flow meters have been commercially available for over twenty years, it was only recently that Peek Measurements, Inc., developed a Doppler meter capable of rejecting drilling rig noise and thereby providing accurate measurements of fluid flow rates in that environment. Accurate measurements are essential for comparison with outflow rates in order to accurately diagnose lost circulation problems.

Sandia is working with Peek Measurements and several geothermal industry partners, CalEnergy, Epoch Well Logging, and Tecton Geologic, to evaluate the use of the improved Doppler flow meters in geothermal drilling. Results to date indicate that the meter has a significant potential in this industry (Whitlow *et al*, 1996).

Expert System

With the development and use of accurate methods for measuring drilling fluid inflow and outflow rates, it is possible to develop a software package that monitors the flow rates, detects circulation problems, alerts the driller of the problems, and provides assistance to the driller in correcting the problems. Such a system, known as an expert system, is currently under development as a Geothermal Drilling Organization (GDO) project (more about the GDO in a later section).

The system is being developed by Tracor, Inc. under contract to Sandia, building on their existing expert system for detecting and treating gas kicks in petroleum wells. CalEnergy is participating in the project by providing field data for validating the software package.

Drillable Straddle Packer

The drillable straddle packer is a low-cost, drillable packer assembly developed at Sandia for isolating lost circulation zones and improving the efficiency of cementing operations for lost circulation plugging (Glowka, 1995). Such zonal isolation is necessary in large-diameter wellbores when a loss zone is off bottom because of the tendency of cement to channel through the drilling fluid to the bottom of the wellbore, thereby increasing the number of cement plugs that must be set before sufficient cement flows into the loss zone to plug it. The drillable straddle packer accomplishes zonal isolation with a low-pressure, dual-packer assembly that is inflated with cement, forces cement into the loss zone, and is left downhole to be drilled out when the cement sets.

Significant effort was spent in the laboratory developing and testing with water the various components of the drillable straddle packer, including the fiberglass-fabric packers bags, the packer shroud deployment mechanism, and the grapple mechanism for remotely detaching the packer assembly from the bottom of the drillstring. A recent test of the packer at full-scale flow rates with cement in the Engineered-Lithology Test Facility (see next section) was successful. This test provided an intermediate step between lab tests with water and field tests with cement. It will be used as a demonstration of the packer's capabilities in convincing a geothermal operator to field test the packer.

Engineered-Lithology Test Facility

The ELTF is an outdoor test facility at Sandia for conducting large-scale experiments related to lost circulation control and other below-ground testing where the capability for emplacing a known lithology, conducting a test, and excavating the lithology to evaluate the results is needed (Glowka, 1995). The ELTF consists of a 15-ft X 15-ft X 15-ft concrete structure in which, for example, alternating layers of gravel and clay can be emplaced to simulate permeable and impermeable rock zones, respectively. Pipes penetrating the vertical walls connect the permeable gravel zones to an external plumbing system through which fluid can be pumped in various configurations. Sections of concrete pipe stacked vertically and spaced apart at the gravel zones simulate a wellbore with fractures connecting to the permeable zones.

In the three ELTF tests conducted to date, three horizontal gravel layers were emplaced, with the bottom layer simulating additional, closed wellbore volume, the middle layer simulating a loss zone, and the upper layer simulating a production zone. Two tests were conducted with an open-end drill pipe positioned at the loss zone, and cement was pumped into the wellbore in a manner similar to that used in conventional lost circulation zone treatments in geothermal drilling. These tests showed that the cement flowed down into the lower gravel zone before it flowed into the loss zone.

In the third ELTF test, a drillable straddle packer assembly was emplaced in the wellbore, straddling the middle gravel layer. As the cement was pumped, it inflated the packer bags and flowed into the middle gravel layer. Thermistors emplaced in all three gravel layers to measure cement exotherm temperatures indicated that the packer assembly was effective in isolating the loss zone and forcing all of the cement into that zone. At the time this paper was prepared, the facility had not yet been excavated to confirm this.

Cementitious LCM Field Evaluation

Halliburton Services has developed a new cementitious lost circulation material (CLCM) that could replace the conventional Portland cement currently used to treat lost circulation zones encountered in geothermal drilling. The CLCM has the advantages of faster setting and better chemical compatibility with bentonite drilling fluids, thereby potentially reducing loss-zone treatment costs.

Field testing of the CLCM has been undertaken as a GDO project, with participation by Halliburton, CalEnergy, and Sandia. Halliburton is providing the research and development of the CLCM, CalEnergy is providing the use of wells in which to test it, and Sandia is providing surface instrumentation (rolling float meters and Doppler flow meters), downhole logging (televiewer and temperature), and coordination support of the field tests.

Two field tests have been conducted thus far. In the first tests at the Coso geothermal field, the CLCM was effective in plugging small fractures but not large ones. Halliburton concluded that this was a problem with viscosity control and worked to improve the product. The second field test, at the Newberry geothermal field, did not encounter any loss zones where use of the CLCM would have been appropriate. We are currently awaiting the availability of another well at Coso for further field testing of this material.

Advanced Synthetic-Diamond Drill Bits

PDC bits have had a significant impact on the petroleum drilling industry because of the large increases in penetration rates and bit life that can be achieved in soft and medium-hard formations over those of roller cone bits. PDC bits are currently not successful in hard-rock drilling, however, because of thermally accelerated wear and impact damage that occurs when drilling rocks with compressive strengths greater than about 20,000 psi. The objective of the advanced synthetic-diamond drill bit program at Sandia is to extend the benefits of PDC and other synthetic-diamond drill bits to harder rock applications, such as geothermal drilling.

This program currently consists of four cost-shared projects with industry. Brief descriptions of these projects are given below. More detailed descriptions are given in a companion paper in these proceedings (Glowka, 1996).

Claw-Cutter Optimization

This joint project with Dennis Tool Co. is optimizing the design of PDC claw cutters. These cutters differ from conventional PDC cutters in that the tungsten carbide substrate on which the synthetic-diamond layer is sintered is machined with grooves prior to the sintering process. This results in diamond-filled grooves that become "claws" along the cutter wearflat that concentrate stress on the rock surface and improve cutter effectiveness. Under this project, the number, width, depth, and spacing of these claws are being optimized with numerical stress modeling and cutter wear testing.

Track-Set Optimization

This joint project with Security DBS is developing design information for optimizing Track-Set PDC bits. These bits differ from conventional PDC bits in that the cutters are more widely spaced in the radial direction, resulting in deeper tracks in the rock in which the individual cutters run. This "locks" each cutter in place and prevents or significantly reduces lateral bit vibration, which can lead to cutter damage. Under this project, linear single-cutter tests are being conducted to provide design information on the optimal spacing of cutters for Track-Set bits.

TSP Bit Optimization

This joint project with Maurer Engineering and SlimDril International is optimizing the design of thermally stable polycrystalline (TSP) diamond bits for hard rock drilling. TSP cutters differ from conventional PDC cutters in that the cobalt used in the diamond sintering process is subsequently chemically leached from the diamond structure. This improves the thermal stability of the diamond layer and thereby the drillability of hard rock under certain conditions. Under this project, cutter wear testing is being conducted to identify the TSP cutter shapes that are most effective in drilling hard rock.

Impregnated-Diamond Bit Optimization

This joint project with Hughes Christensen Co. is optimizing the design of impregnated diamond drill bits for hard rock applications. This type of bit consists of small natural or synthetic diamonds imbedded in a tungsten carbide substrate. As the tungsten carbide wears, it exposes new diamonds, which cut the rock until they fracture or fall out of the substrate. Further wear then exposes new diamonds, and the process continues until the bit is consumed. Under this project, bit design parameters are being optimized, such as tungsten carbide grade, diamond grade, diamond size, and diamond concentration.

Cutter Wear Test Facility Development

Sandia has developed a unique laboratory test facility for wear testing synthetic-diamond and other drag-type rock cutters. This facility, the CWTF, consists of a small drill rig that utilizes a three-cutter core bit in which test cutters can be used under highly controlled conditions to determine relative wear rates compared to baseline wear rates of conventional PDC cutters. A 3-ft X 3-ft X 3-ft rock sample, usually Sierra White Granite, is placed on an air pallet that allows the rock to be easily moved between holes. This allows up to 85 holes to be drilled in each rock sample. The facility can be operated in either a constant penetration-rate or constant weight-on-test-cutter mode. Multiple slip rings allow data measured at the test cutter, such as cutting forces and temperatures, to be taken off the rotating drill string.

Development of this facility is now complete, and baseline wear rate data are now being established. This facility will be used in several of the ongoing synthetic-diamond cutter studies as well as in future studies on advanced cutter materials.

High-Temperature Logging Technology

Knowledge of geothermal reservoir conditions is essential to their proper development and operation. Because of the extremely high temperatures and corrosive fluids that can be encountered in these reservoirs, conventional logging tools used by the petroleum industry cannot be used. Even expensive, multi-conductor wirelines are susceptible to rapid degradation and add to the high cost of logging geothermal reservoirs. The objective of the high-temperature logging technology program at Sandia is to develop dewared memory logging tools that can be run on inexpensive slicklines (i.e., no conductors) and survive downhole temperatures long enough to obtain the needed data.

The logging technology program currently consists of three projects. Brief descriptions of these projects are given below. More detailed descriptions are given in a companion paper in these proceedings (Normann *et al,* 1996).

Temperature/Pressure Memory Tool

The temperature/pressure memory tool is a dewared tool developed at Sandia that can be run on either slicklines or conventional multi-conductor wirelines. It employs a RTD temperature probe with a resolution of +/-0.005°C and an accuracy of +/-0.3°C, traceable to NIST standards. The pressure transducer is a quartz crystal oscillator with a resolution of 0.01 psi and an accuracy of 0.1 psi, also traceable to NIST standards.

The tool is 6 ft long, 2 inches in diameter, and is enclosed in a stainless steel dewar that permits operation at 400°C for 10 hours. It is capable of storing up to 3000 each pressure and temperature data points that can be downloaded to a computer at the surface with a Windows-based program.

More than 30 downhole logs in geothermal wells have been successfully run with this tool. We are currently seeking technology transfer opportunities to make the tool available to the geothermal industry on a routine basis.

Downhole Steam Sampler

The downhole steam sampler is a tool developed at Sandia for obtaining uncontaminated steam samples from any location within a geothermal well. Developed primarily for use at The Geysers, the tool operates on a slick line and is capable of downhole operation at 400°C for 10 hours. The tool is 6 ft long, 2 inches in diameter, and employs a commercially available stainless-steel valve and eutectic material for condensing and capturing up to 50 ml of condensed steam downhole.

The steam sampler has been successfully tested at the surface on a geothermal well at The Geysers. We are currently seeking the opportunity to test the tool downhole.

Spectral Gamma Memory Tool

The spectral gamma memory tool is a dewared tool developed at Sandia for detecting trace radioactive elements that often plate out on fracture surfaces in geothermal wells. The tool is therefore useful in fracture detection. It is 10 ft long, 2 inches in diameter, and employs a sodium iodide spectral gamma detector. The tool has been successfully tested at The Geysers, where it revealed increased levels of potassium at a loss zone.

Acoustic Technology

Transmitting data from downhole to the surface is a problem in any type of wellbore. Wires are often difficult or impossible to emplace and are subject to degradation and breakage. The objective of the acoustic technology program at Sandia is to develop data transmission systems for various applications using acoustic technology, where sound waves transmitted up a steel pipe or shaft carry the needed information. There are currently three acoustic technology projects underway.

Core-Tube Latching Detector

The core-tube latching detector is a device developed at Sandia for detecting when a core tube used in wireline coring has landed downhole at the bit. Proceeding with drilling before the core tube has landed can cause significant problems, including jamming of the core and the need to trip the drillstring to correct the problem. Similarly, waiting extra time for the core tube to land because of uncertainties in the fall rate of the tube down the drillstring wastes time. Accurate detection of the core tube's landing could therefore same time and money in drilling geothermal exploratory holes with wireline-coring rigs.

The core-tube latching detector consists of a sensitive accelerometer mounted on the top drive, noise-filtering circuitry, and a set of noise-canceling headphones. In operation, the driller wears the headphones as the core tube falls and listens for the characteristic sound as it lands at the bit. The noise-canceling headphones eliminate most of the environmental rig noise, and the noise-filtering circuitry isolates the sound of the core-tube landing.

Development of a prototype latching detector has been completed, and field tests with Tonto Drilling, the industry partner on this project, are scheduled for the summer of 1996.

Wireless Telemetry System

The wireless telemetry system is a hardware and software system for oil production applications that is under development by Sandia and its industry partner, Baker Oil Tools. This tool transmits downhole pressure and temperature data to the surface via acoustic waves traveling up the production tubing. This system will replace wires that are currently used to power the downhole system and transmit the data uphole. These wires are subject to costly emplacement and breakage. Although the system is most immediately useful for producing oil wells, with temperature upgrading it also has a significant potential for use in the geothermal industry.

The system consists of a battery-operated downhole device for coding the data and generating the sound waves, a surface accelerometer for receiving the data, and data acquisition hardware and software for decoding the sound waves. The low-power downhole components are designed for a six-month life. The system is still under development. Prototype tests are planned for the fall of 1996.

Line-Shaft-Pump Position Detector

The line-shaft-pump position detector is a device under development by Sandia and its industry partner, Johnston Pumps. It detects the relative position of the rotor and stator in line-shaft pumps used in geothermal wells. Current practice is to provide large clearances between these pump components so that when the pump begins to operate, causing differential thermal expansion between the production tubing and the pump drive shaft, there is sufficient play to prevent the rotor from interfering with the stator. A technique for detecting the relative position of these components while the pump is running will allow the position to be continuously adjusted, thereby permitting smaller clearances to be employed and resulting in smaller and more efficient pumps.

The position detector under development consists of a very simple downhole device for generating a sound wave whose frequency is a function of the relative rotor/stator position, a surface accelerometer for detecting the sound wave that travels up the drive shaft, and data acquisition hardware and software for decoding the sound waves. This project has only recently been initiated and is still in the design stage.

Slimhole Drilling Technology

Geothermal exploration has traditionally entailed the drilling of large-diameter (production-sized) wellbores for production testing in order to prove a resource. Given that production-sized wellbores typically cost over $2 million, a more cost-effective means for proving a viable geothermal reservoir is to drill smaller-diameter (slimhole) wells that can be produced to obtain reservoir data. If a resource is proven and financing for a geothermal project can be secured, then production-sized wellbores can be drilled to actually recover the geothermal energy. Although this approach seems apparent, there has been some skepticism in the geothermal industry and among financiers that viable reservoir production data can be obtained from slimholes.

The objective of the slimhole drilling program at Sandia is thus twofold: 1) to prove that viable reservoir production data can indeed be obtained with slimholes; and 2) to develop improved slimhole drilling technology in order to reduce geothermal exploration costs by 25%. A summary of this program is provided below. A more detailed description is given in a companion paper in these proceedings (Finger, 1996).

Steamboat Hills, NV, Slimhole

A 4,000-ft exploratory slimhole (3.9-inch diameter) was drilled in the Steamboat Hills geothermal field near Reno, NV, in July-September, 1993, in cooperation with Far West Capital. Four series of production and injection tests were conducted while taking downhole and surface data, such as temperatures, pressures, and flow rates. Continuous core with a detailed log were taken, and borehole televiewer images were obtained in the upper 500 ft.

The reservoir data obtained in these tests showed the reservoir to be of essentially infinite productivity. This agrees with data obtained from full-sized production and injection wells in the same field. A detailed report was written that summarizes this data and includes daily drilling reports and a detailed narrative of the drilling and testing operations (Finger *et al*, 1994).

Vale, OR, Slimhole

In April-May, 1995, a 5,826-ft exploratory slimhole (3.85-inch diameter) was drilled in the Vale Known Geothermal Resource Area near Vale, OR, in cooperation with Trans-Pacific Geothermal Corporation. Several temperature logs and injection tests were conducted. Over 2,700 ft of continuous core were obtained; the top portion of the well was drilled with conventional rotary drilling techniques to reduce cost.

The test results indicated an extremely low formation permeability. Consequently, it was concluded that the reservoir is very tight and is unlikely to be an effective, developable, geothermal resource. This conclusion agreed with that drawn from a nearby large-diameter wellbore, which cost 39% more on a cost/ft basis than the slimhole. A detailed report was written that summarizes this data and includes daily drilling reports and a detailed narrative of the drilling and testing operations (Finger *et al,* 1996).

Newberry, OR, Slimhole

A 4,500+ ft exploratory slimhole (3.85-inch diameter) was drilled in cooperation with CalEnergy in the Newberry Known Geothermal Area near Bend, OR, in July-November, 1995. Several temperature logs and injection tests were conducted. Over 4,000 ft of continuous core were obtained; the top portion of the well was drilled with conventional rotary drilling techniques to reduce cost.

Test results from this well have not yet been released due to the proprietary nature of the field and CalEnergy's operations there. Appropriate data will, however, be released within two years, and a detailed report will be written.

Drilling Technology Demonstrations

In addition to demonstrating the capability for obtaining viable reservoir data from slimholes, the drilling conducted thus far under this program by Sandia has demonstrated the utility and advantages of using cost-saving technologies not usually employed by the geothermal drilling industry.

The use of magnetic flow meters and acoustic Doppler flow meters to measure inflow and outflow rates from wells during drilling was demonstrated and shown to be of significant benefit. Slimhole borehole televiewer logs were run that demonstrated the benefits of that technology in orienting the core and measuring the direction and dip of producing fractures.

High-temperature downhole instrumentation developed at Sandia was used to obtain downhole temperatures and pressures during injection and production tests, and advanced surface flow meters were used to augment the conventional surface equipment normally used to test well productivity. Finally, numerous examples of cost-saving techniques were demonstrated by Sandia during the drilling and plugging of these slimholes.

Evaluation of Japanese Slimhole Data

Under contract to Sandia, S-Cubed is evaluating production data from numerous slimholes and production-sized wellbores in several Japanese geothermal fields. The goal of this evaluation is to test the viability of reservoir data determined from slimhole production tests. Wellbore discharge and injection data have been characterized for wells in liquid-feedzone reservoirs at the Oguni, Sumikawa, and Takigama fields, where the reservoir pressure is sufficient to maintain the produced fluid in a liquid state at the feedzone of the well. Reservoir and wellbore flow models were used to analyze these data. It was shown that reservoir characteristics and production rates in such reservoirs can indeed be predicted using the slimhole data (Garg *et al*, 1995).

Work is now underway at S-Cubed to collect and analyze data from the Kirishima reservoir, where high temperatures and limited permeability cause *in situ* boiling. Wellbore modeling and data analysis of such flows are significantly more complex than in liquid-feedzone reservoirs.

Drilling Systems Studies

In order to ensure that Sandia is addressing the proper technology needs of the geothermal drilling industry, we are conducting several engineering systems studies of drilling and other well-related activities. The objective of these studies is to identify areas where improved technology or procedures would reduce costs. These results will be used to re-direct our R&D program to have maximum impact.

Hydrothermal Well Systems Study

The purpose of this study is to update the 1981 systems study conducted by Sandia and Livesay Consultants that presented a detailed analysis of the costs of drilling and completing geothermal wells (Carson *et al*, 1983). That study compiled the costs from eight geothermal fields in the U.S. and generated a computer-simulation-based model for each field that allowed sensitivities to variations in relevant parameters to be determined. This enabled the cost reductions due to various assumed technology improvements, such as increased penetration rates and bit life and reduced lost circulation costs, to be assessed for the various reservoirs. The results have guided Sandia's geothermal drilling R&D program over the past 15 years.

The planned update will include life-cycle costs of geothermal wells in addition to updated drilling technology. This will allow effects such as using more corrosion-resistant casing materials, for example, to be weighed against the costs of using conventional materials and replacing wellbores more frequently. This study update has only recently been initiated and will take approximately one year to complete.

Advanced Drilling Systems Study

This recently-completed study by Sandia and Livesay Consultants addressed the costs of novel drilling techniques that have been proposed in the past (Pierce *et al*, 1996). This study, conducted in support of the DOE's National Advanced Drilling and Excavation Technology (NADET) program, determined the drill rig, drilling procedures, and supporting requirements for ten different novel techniques. The study derived penetration rate improvements that would be necessary with each of these systems in order for them to compete with conventional drilling techniques. The results are useful as a guide for the type of advanced drilling research that has the most potential.

GHP Drilling Systems Study

This study was recently initiated to study the cost and technology elements associated with drilling boreholes and installing heat exchangers for geothermal heat pumps (see later section for a more complete description of GHP research at Sandia). This study is collecting data on drilling and heat exchanger operations in order to identify problems and costs. An economic model will be built that allows parametric analysis to be done in order to identify which technology or procedural improvements could have the greatest impact on heat exchanger installation costs. These results will be used to guide future R&D in this area.

Geothermal Drilling Organization Projects

The GDO is an organization consisting of 17 member companies and national laboratories that collaborate on short-term, industry-driven, cost-shared projects involving improved geothermal drilling technology. Sandia coordinates the GDO projects, provides DOE's cost-shared funding to the entities performing the research, and in some cases performs some of the work, often participating in field tests. A number of projects have been completed by this organization over the past 14 years. Recently completed and ongoing projects are listed below. Space limitations do not allow more detailed description of these projects.

- *High-Temperature Drill Pipe Protectors* - Joint project with Regal Inernational, Brookhaven National Laboratory, and Unocal.
- *Rotating Head Seal* - Joint project with Smith International and Unocal.
- *Retrievable Whipstock* - Joint project with Smith International and Unocal.
- *Downhole Air Motor* - Joint project with Baker Hughes Inteq and Unocal.
- *Cementitious LCM Field Evaluation* - Joint project with Halliburton Services and CalEnergy.
- *Downhole Mud Hammer* - Joint project with Novatek, Unocal, and CalEnergy.
- *Expert System for Lost Circulation Control* - Joint project with Tracor, Inc., and CalEnergy.

Geothermal Heat Pump Technology

Geothermal heat pumps utilize the low-temperature geothermal energy found near the surface of the ground almost worldwide. In support of DOE's goal of increasing the number of GHP installations in the U.S. from 40,000/year to 400,000/year by the year 2002, Sandia is conducting research and development in three areas.

GHP System Performance Measurements

In order to properly market GHPs, viable demonstration projects and system performance measurement projects are needed for locations nationwide. Sandia is involved in a number of such projects in several locations, including:

- Dyess Air Force Base - demonstration project;
- Fort Hood Army Base - performance measurement project;
- Selfridge Air National Guard Base - performance measurement project;
- Fort Polk Army Base - performance measurement project;
- Patuxent River Naval Air Station - performance measurement project;
- Stockton College - performance measurements project; and
- Sandia National Laboartories - performance measurement projects.

Some of these projects involve the use of cost-shared funds from the Department of Defense. Data obtained from these projects has and will be made available to the public (Phetteplace and Sullivan, 1996; and Martinez *et al*, 1996).

GHP Drilling Systems Study

This project was described in a previous section.

Replaceable-Cutter PDC Bit

A joint project with Dennis Tool Co. was recently initiated to develop a low-cost, replaceable-cutter PDC bit for GHP drilling. Such a bit would make the high-penetration-rate and long-bit-life advantages of PDC bits available to the GHP industry, allowing drilling costs to be signifcantly reduced in some rock formations. Such bits would employ low-cost, used PDC cutters reclaimed by Dennis Tool Co. from petroleum PDC bits. A technique developed by Sandia for mechanically clamping these cutters to a bit body will permit replacement of worn or broken cutters in the field by the driller. This project is still in the design phase.

CONCLUSIONS

A large number of geothermal drilling technology development projects are currently underway at Sandia in eight program areas. In light of a renewed emphasis by DOE on providing immediate assistance to the geothermal industry in reducing costs, we are currently re-examining the program and will re-direct it to provide more immediate results. Discussions with the geothermal industry will be an integral part of this re-direction effort.

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