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## GEOHERMAL DRILLING RESEARCH IN THE UNITED STATES\*

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**MASTER**Abstract

The high cost of drilling and completing geothermal wells is an impediment to the development of this resource. The Department of Energy (DOE), Division of Geothermal Energy (DGE), is conducting an R&D program directed at reducing well costs through improvements in geothermal drilling and completion technology. This program includes R&D activities in high temperature drilling hardware, drilling fluids, lost circulation control methods, completion technology, and advanced drilling systems. Sandia Laboratories manages this program for DGE. This paper presents an overview of the program.

Introduction

At the present time, geothermal wells cost several times as much as conventional oil wells of comparable depth, as shown in Figure 1. The high cost of these wells is an impediment to the timely development of geothermal energy in the U.S. These higher costs are attributed to temperature, formation, erosion, and corrosion effects which are encountered in current geothermal drilling operations. Geothermal formations are typically hard and hot (up to 350°C). These factors combine to cause low penetration rate and short bit life. In addition, most formations are sub-normally pressured. Drilling with air, mist, and other low density fluids is, therefore, a common practice and corrosion is a severe problem with these fluids. The Division of Geothermal Energy (DGE) of the U. S. Department of Energy (DOE) has initiated a program of drilling and completion technology development which is aimed at reducing the cost of geothermal wells. Specific goals have been set for this program. These are to develop the technology required to reduce the cost of drilling and completing geothermal wells by 25% by 1982, and by 50% by 1986.

Sandia Laboratories has been selected by DOE/DGE to manage this technology development program. The program is

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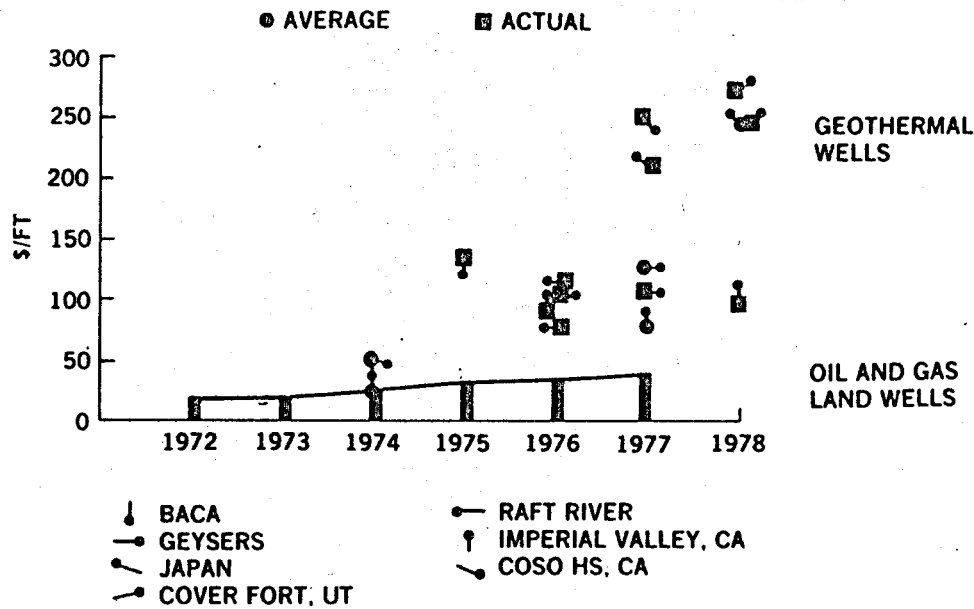


Figure 1. Trend in well costs

currently addressing the development of improved drilling hardware, drilling fluids, lost circulation control techniques, completion technology, and advanced drilling and completion systems. The research and development required in this program is conducted primarily through contracts with private industry, with some in-house research conducted at Sandia. An advisory panel composed of industry, university, and government participants has been formed to assist in the definition of the R&D tasks that are required to meet the goals of the program. This panel meets semi-annually to review the status of the program and to provide guidance to the program manager.

In order to assess the progress of the program toward the stated goals and to define areas for research and development that have high cost reduction potential, a geothermal well cost simulator has been developed. This computer model simulates the operations involved in drilling and completing a geothermal well and computes the cost associated with each operation. The model can then be used to assess the cost/benefit ratio of new technology prior to initiating the development of the technology. Based on the results of this type of analysis, elements in the program have been defined and will be presented in the remainder of this paper.

### Drilling Hardware

#### Geothermal Roller Cone Bits

A project to design and develop improved three-cone roller bits for geothermal applications is underway. The project has two thrusts -- one, to substitute high

temperature steels in unsealed bits, and two, to develop high temperature seals and lubricants for sealed bearing bits.

Experimental bits incorporating steels that have higher hardness at high temperature have been fabricated and have demonstrated improved performance in field testing at The Geysers. The experimental bits have unsealed bearings for use in air drilling. Figure 2 is a cutaway view of a bit lug showing the new materials used in the experimental (MK-III) geothermal bit. Of particular importance is the use of harder gauge row inserts to reduce loss-of-gauge problems. Table I lists the materials used in two versions of the experimental bit and in the conventional bit. Testing at The Geysers with these experimental bits has shown that the new design increased bit life by approximately 30% over the conventional design and could result in an overall reduction of 4% in geothermal well cost in The Geysers. Geothermal bits using these new materials are now commercially available from a leading bit manufacturer.

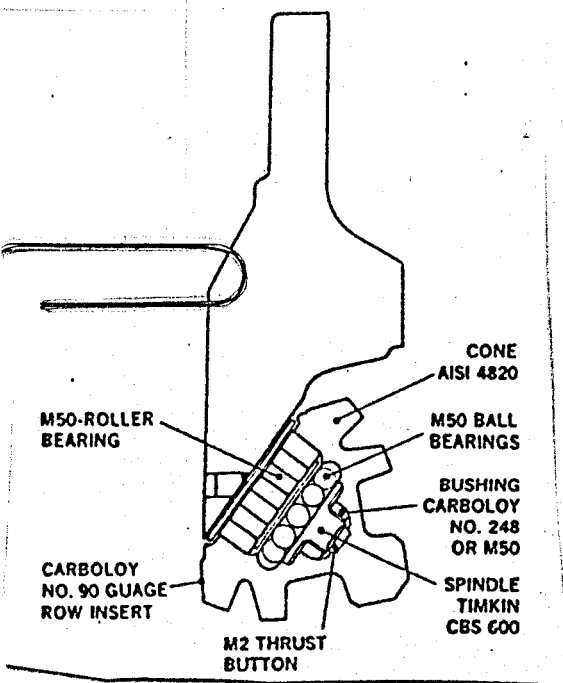


Figure 2. Geothermal roller cone bit cutaway showing new materials

The development of sealed geothermal bits is presently emphasizing the screening of high temperature seals and lubricants and the design and development of non-elastomeric seals for use in these bits. Both seal and lubricant testers have been fabricated, and these testers are presently being used to investigate the lifetimes of several different elastomeric seals and the performance of high temperature lubricants. To date, several fluorocarbon elastomeric seals have shown promise for long life at 200°C. Seal improvements have been achieved by coating Viton o-rings

with crosslinked teflon to provide a seal capable of operating at high temperature and high pressure. Further attempts at developing sealed bearing bits are emphasizing metal-to-metal and plastic seals.

Forty different lubricants have been tested at high temperature. The most successful high temperature lubricant to date is an experimental grease from Pacer Lubricants designated PLX014. A Viton o-ring seal (Parker No.4205) recently ran for 107 hours without failure at 150°C in the seal tester using this new lubricant. The seal had been soaked at 260°C for 2 hours prior to testing.

Table I. Bit component materials

Experimental MK-III Bits

Timken CBS-600 steel spindles  
M-50 steel rollers and balls  
M-2 steel thrust button  
Carboloy 90 gauge row inserts

Type OCR-763

Carboloy 248 bushing  
Reed "tube metal" hardfacing

Type OCR-764

M-50 steel bushing  
Cabot #1 Mod. stellite hardfacing

Control Bits

Reed Y 73 JA

8620 steel spindles  
S-2 solar steel rollers and balls  
M-2 steel thrust button  
Carboloy 231 inserts  
430 steel bushings  
Cabot #1 Mod. stellite hardfacing

Polycrystalline Diamond Compact Bits

Polycrystalline diamond compacts (PDC) are man-made diamonds that have demonstrated superior performance in cutting both rock and metal. A project is underway to develop and demonstrate the performance of bits using these cutters in the geothermal environment. Figure 3 is a picture of a bit using all-PDC cutters. This bit was designed by General Electric and fabricated by Smith Tool Company. This bit was tested in a geothermal well in November, 1978, however, catastrophic failures of the posts used to support the cutters occurred. The cause of the failure has been attributed to stress raisers which occurred because of the pocketed design of the tungsten carbide posts. A new post design has been used in the fabrication of a new bit of

similar design. Recent testing of this bit in a geothermal well in New Mexico has indicated that increases in penetration rate of factors of two to four over that achieved with conventional bits are obtainable.

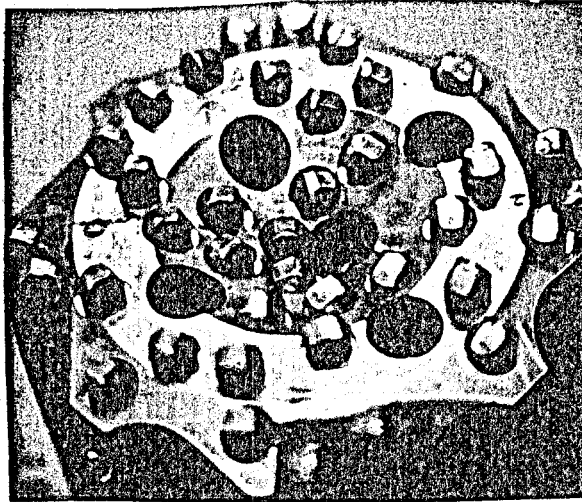


Figure 3. Bit using stud-mounted PDC cutters

#### Continuous Chain Drill

The Chain Drill is a concept that allows replacement of the bit cutting surfaces without removing the bit from the hole. The system is designed to reduce well cost by reducing the time spent in replacing worn bits. The system utilizes a continuous chain of cutting surfaces. Individual links of the chain are impregnated with diamonds, and PDC cutters are utilized in the nose of the bit. As the cutting surfaces become worn, a cycling mechanism can be activated from the surface which will advance a new set of links into the cutting position. At the present time, 15 sets of new chain links can be carried in one cartridge. The cycling sequence involves the proper application of mud pressure and the use of a coil spring in the bit assembly to produce the cycling force. Figure 4 indicates the overall layout of the system, while Figure 5 shows a close-up of the chain links and the diamond cutting surfaces. This bit has recently been field tested with very good results.<sup>1</sup> The bit was tested at the Nevada Test Site in granite with a compressive strength of approximately 15,000 psi. During this test the bit was cycled 85 times downhole, demonstrating the overall reliability of the cycling mechanism. Six sets of chain links were used to drill a total of 250 feet which yields an average of 41.6 feet per link set. Conventional diamond bits averaged 28 feet of drilling in this formation. Problems with the mud system were encountered which led to plugging of the hydraulic nozzles in the bit on several occasions. This forced a removal of the bit from the hole more frequently than was desired. However, this was a problem with the mud system and not with the bit itself. Currently, efforts are underway to transfer the technology utilized in this bit to private industry.

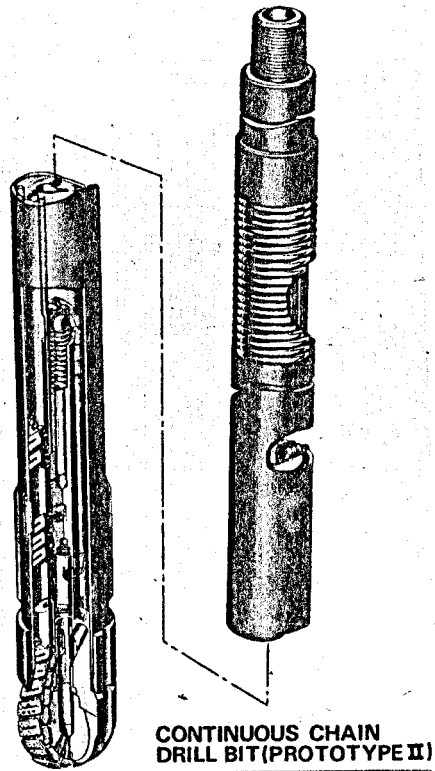


Figure 4. Artist concept of chain drill (Prototype II)



Figure 5. Head of chain drill

## Drilling Fluids

### Test Equipment

The high temperatures and corrosive environments encountered in geothermal drilling place severe requirements on the drilling fluids utilized. Commonly used drilling



muds, such as bentonite, are incapable of operating at the high temperatures encountered in geothermal wells. Sufficient mud testing has been accomplished to demonstrate the existence of a large discrepancy between ambient rheological data as normally taken in mud laboratories and the actual characteristics of the fluid under dynamic downhole conditions. To provide for an understanding of the characteristics of the drilling fluids under simulated downhole conditions, two test facilities have been constructed. The first, at the University of Oklahoma, is a flow-loop which can be used to measure the rheological properties of drilling muds at temperatures up to 288°C (550°F) and at pressures up to 20.7 MPa (3,000 psi).<sup>2</sup> This loop has been utilized to screen several commercially available drilling fluids and to test an experimental mud which was developed under the DOE/DGE program. This loop is now operational and is available for use by private industry. A test facility with increased capabilities, specifically, temperatures to 371°C (700°F) and 138 MPa (20,000 psi), is under construction by NL Baroid. This test facility is being constructed on a cost-sharing basis between DOE and Baroid. When complete, it will be used to test a variety of drilling fluids at simulated downhole conditions.

#### Mud Research

Static aging tests of commercially available muds indicate that all exhibit high temperature gelation, high viscosity, high filtration rates, and poor corrosivity characteristics at temperatures above 177°C (350°F). Maurer Engineering, under funding from DOE, has developed an improved drilling fluid for use under high temperature conditions. The composition of the fluid is shown in Table II. The major constituent of the fluid is sepiolite clay, and brown coal is used as a thinner. This fluid has exhibited good characteristics at temperatures up to 260°C (500°F). A field test of this mud is scheduled in the spring of 1980.

Table II. Composition of geothermal mud

Water	1.0 bbl
Sepiolite	15.0 lb
Bentonite	5.0 lb
Brown Coal	20.0 lb
Sodium	
Polyacrylate	2.5 lb
Sodium Hydroxide	2.0 lb

In addition to testing new formulations of muds, a basic research program directed at understanding clay morphology as a function of temperature is underway at Texas Tech University. Of specific interest are bentonite, sepiolite, and attapulgite clays. In preliminary testing,

it has been observed that sepiolite clay exhibits a needle-shaped structure at room temperature. Under exposure to temperatures of 250-300°C, however, the needle-shaped structure undergoes a transition to a flake-type (smectite) structure. This transition at least partially accounts for the good performance of sepiolite-based clays at high temperature. This work is in its infancy and is directed at an understanding of the basic chemistry involved in the formulation of geothermal drilling fluids.

### Inert Fluids

Because many geothermal reservoirs exhibit pressure gradients which are less than normal hydrostatic, and because they are typically highly fractured, it is frequently necessary to drill with air, mist, or foam. In general, when air drilling is utilized, the oxygen in the air, combined with the H<sub>2</sub>S, CO<sub>2</sub>, and water vapor present in the wellbore, provide a mechanism for significantly enhanced corrosion rates. To control this costly problem, efforts are underway to develop a portable nitrogen generation unit for providing an inert drilling fluid.

The design specifications for the unit are that it supply 1200 standard cubic feet per minute of nitrogen at pressures of 400 psi with less than 5 parts per million of oxygen. Two approaches are being taken. The first involves the conversion of diesel exhaust gas into a gas having low oxygen content by the combustion of the exhaust gas with diesel fuel in the presence of a catalyst. Laboratory studies utilizing a small diesel engine are underway to determine the constituents of the product gas and the lifetime of the catalyst. Should these tests prove encouraging, the scale-up of this system to a field portable unit will be initiated. The second approach involves the cryogenic separation of nitrogen from air. While this is commonly done in laboratory situations, the development of a portable unit which can be set up in a matter of hours has not yet been accomplished. Recently, Production Operators has acquired a small portable unit that utilizes an improved heat exchanger tray design. A field test of this unit is scheduled for the spring of 1980. During this test, corrosion rates with the standard drilling fluid and with the inert fluid will be measured and compared to determine the cost reduction potential of the concept.

### Foam Fluids

Foam drilling fluids are sometimes used in oil and gas drilling, but at high temperatures most of the available foams either become unstable or highly corrosive. Sandia Laboratories has initiated a program aimed at developing high temperature foams which are suitable for geothermal drilling. A number of existing surfactants have

been screened to determine their high temperature aging characteristics. The tests involve measuring the time required for the foam to lose fifty percent of its weight by drainage, before and after aging at 260°C for two hours. In addition, pH values are recorded before and after aging. Table III presents recent results of the initial screening tests. Surfactants which emerge from the initial screening process will be further tested in simulated geothermal brines and at higher pressure to determine the most promising candidates for a field test.

### Lost Circulation Control

Because most geothermal reservoirs are highly fractured in nature, the problem of lost circulation is encountered in practically every geothermal well. This problem adds significantly to the cost of drilling and completing the wells, not only because of the need to replace the lost drilling fluids, but also because of the extreme care required to properly complete the well through these lost circulation zones. The development of new lost circulation control materials which are capable of operating at high temperature has been initiated. In addition, mechanical techniques, such as the use of wellbore patches and concentric drill pipe, are under study. Instruments which can locate and define the width and orientation of fractures are being developed to assist in the design of placement tools to be used with the lost circulation materials.

### Completion Technology

The completion of a geothermal well involves the placement of pipe in the well and the attachment of the pipe to the formation. Because of the high thermal stresses induced in the casing when the well is placed on production, it is necessary to obtain very competent bonds between the pipe and the formation. The lack of a good cement bond can lead to casing buckling and collapse and can also allow for corrosion to occur behind the casing. To prevent this, high temperature cements are required. Currently, the Division of Geothermal Energy is funding research directed at developing improved high temperature cements. Most of these cements involve the use of polymers at some stage in their formation.<sup>3</sup> In addition to this development, analyses of thermally induced stresses and cement placement techniques are being conducted. A study of the failure modes of casing has recently been completed by Completion Technology Company. This study has identified the need for achieving high quality cementing and will be used in formulating the future completion technology development program.

In addition to assuring long-lived, competent completions for the well, the problem of wellbore scaling is being addressed. Several laboratories are investigating chemical techniques for controlling scale. Under the Geothermal

CHEMICAL TYPE	TRADE NAME	TIME TO 50%/WT. DRAINAGE (MIN.)		DELTA % DRAINAGE	pH		AGED FOAM CELL STRUCTURE
		ORIG.	AGED		ORIG.	DELTA	
ALPHA OLEFIN SULFONATE	SULFRAMIN 14/16 AOS	7.84	7.38	-5.87	5.66	-2.73	GOOD
PROPRIETARY	THERMOFOAM BW-D	8.63	7.16	-17.0	9.74	+0.23	GOOD
ALKYL ARYL SULFONATE	NINEX N-300	8.74	6.95	-20.4	6.65	-0.28	GOOD
ALKYL ARYL POLYETHER SULFONATE	TRITON X-200	5.12	4.94	-3.51	6.62	+0.78	GOOD
COCO BETAINE	VELVETEX BC	6.83	4.90	-28.3	6.94	+1.82	GOOD
ETHOXYLATED FATTY ALCOHOL	WITCONOL SN-90	3.42	4.11	+20.3	5.83	-0.02	GOOD

- NOTES: 1. DENSITY  $45 \pm 5.0 \text{ kg/m}^3$   
2. SOLUTION: 1.0%/WT AS RECEIVED  
3. INITIAL SCREENING CONTINUING

Table III. Initial screening tests on high temperature surfactants

Drilling and Completion Program, the development of equipment to remove scale from the wellbore is being conducted. Recently, Daedalean Associates, Inc., has demonstrated the use of high pressure cavitating water jets for removing scale from the pipes in a geothermal test facility.<sup>2</sup> During this test, silica scale was removed from the pipes at nozzle pressures of 8,000-10,000 psi. A preliminary economic analysis of the use of this system indicates that it provides a cheaper method for removing scale than the conventional process of acid presoak followed by wire brushing. In addition, this tool has been tested for wellbore descaling in a flowing geothermal well at shallow depths. The primary difficulty with using the cavitating system for cleaning deep wells is that the wellbore is under pressure, and this reduces the cavitation intensity. In general, it will be necessary to increase the pressure drop across the nozzle to provide for successful operation of the wellbore cleaning system. An investigation of the pressure requirements is presently underway.

#### Advanced Drilling and Completion Systems

The major emphasis in the Geothermal Drilling and Completion Technology Development Program is currently on the 25% cost reduction goal. In order to achieve the 50% cost reduction goal, it is felt that the problems of lost circulation, drilling fluids, and completion technology must be solved, but in addition, extremely rapid rates of penetration must be achieved. Current estimates are that the penetration rate must be increased by factors of 5 to 10 over the existing rate in order to achieve the goals of the program.

To assist Sandia and the DOE in formulating a program directed at achieving the stated goals, a workshop was

recently held with 50 participants from government, universities, and private industry. Many advanced and novel drilling systems were discussed. In view of the program goals, the workshop recommended the development of the following systems:<sup>5</sup> 1) high-speed downhole motors and bits, 2) high pressure water jet drilling used in conjunction with mechanical rock breakage schemes, and 3) percussion drilling systems.

In support of the first system, geothermal turbodrills have been built by Maurer Engineering and are being developed by several other motor manufacturers. The Sandia/DOE program is supporting the design, development, and testing of bearing and seal packages for use on downhole motors in the geothermal environment. The Drilling Research Laboratory has fabricated a bearing and seal tester as well as a very large facility for testing an entire downhole motor under simulated geothermal drilling conditions. Current seal designs are utilizing grafoil and beryllium copper Chevron seals, and the use of non-elastomeric seals in this application is also being investigated. The goal of this program is to develop seals capable of operating for 200 hours under circulating temperatures of 125°C. Several seal designs have been tested.<sup>2</sup> The most promising appears to be a canted radial lip seal using grafoil and beryllium copper as the sealing element. The maximum lifetime achieved to date is approximately 45 hours. A bearing and seal package designed under this program has been utilized in field testing of the Maurer turbodrill at Los Alamos Scientific Laboratory's Hot Dry Rock experiment in July of 1979. Performance of the turbodrill and bearing and seal package was very satisfactory; however, the bit life was extremely short due to the high rotational speeds involved. Recently, polycrystalline diamond compact bits have been fabricated for testing with high speed downhole motors. Testing of these bits is planned for the spring of 1980.

High pressure water jet drilling has been under study by several different major oil companies for approximately fifteen years. Recently, however, the use of jets which are designed to create cavitation in the flowing fluid have shown the ability to reduce the pressure which is required to cut hard rock. The design and use of these jets in conjunction with conventional roller cone bits and polycrystalline diamond compact bits is presently under study. Hydronautics, Inc., is studying the cavitation phenomena as a function of wellbore pressure.<sup>6</sup> The design of high pressure surface equipment, i.e., 5000-7500 psi, is thought to be necessary to develop a drilling system. This work will be included as a future activity in the Sandia/DOE program.

Percussion drills have been developed and tested in oil and gas drilling for a number of years. The systems offer little or no improvement in penetration rate in ductile rocks.

However, brittle rocks are frequently encountered in geothermal drilling. Percussion hammers offer the potential for improving penetration rates in these types of formations. The use of percussion hammers at high temperatures, however, requires further study. Several hammers have been purchased and will be evaluated in laboratory testing under simulated geothermal conditions to identify the failure modes in the hammer and the bits. Should these tests prove encouraging, field tests will be conducted to determine lifetime, penetration rates, and other performance parameters.

### Conclusion

The Sandia/DOE program is a broadly based technology development program directed at improving techniques for drilling in hostile environments. Specific goals have been set for the program, and private industry is participating with Sandia in conducting the R&D required to meet these goals. The problems of bits, drilling fluids, lost circulation control, and completion technology in high temperature, corrosive environments are being addressed at present. The development of advanced drilling systems will be emphasized in future program activities.

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