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ANNUAL REPORT ON THE PROJECT TO DESIGN
AND EXPERIMENTALLY TEST AN IMPROVED
GEOTHERMAL DRILL BIT

By
L. M. Barker
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June 1976

Work Performed Under Contract No. EY-76-C-07-1546

Terra Tek, Inc.
Salt Lake City, Utah

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

MASTER

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[ERDA Contract No. E(10-1)1546]

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June 1976

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FOREWORD

This report represents the annual progress report for ERDA Contract No. E(10-1)-1546, "To Design and Experimentally Test an Improved Geothermal Drill Bit." Work on the contract was started May 19, 1975; this report summarizes the progress to May 19, 1976.

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INTRODUCTION

The first step in tapping the energy of a geothermal reservoir, once it is located, involves the drilling of wells into the reservoir to allow the heat energy to be transported to the surface. Geothermal well drilling is currently done almost entirely with conventional oil-well drilling equipment and methods. However, the high temperatures encountered in geothermal reservoirs often cause overheating of drill bits, resulting in drastic reductions in drill-bit life. The expense of the drill bits and the added time required to replace worn-out bits at the bottoms of deep holes adds considerably to the cost of geothermal wells.

Although research is being conducted on a number of novel drilling techniques which may eventually become applicable to geothermal drilling, the most reliable approach to reducing drilling costs over the short term (and possibly over the long term as well) appears to be to retain the conventional oil-well drilling methods, but re-optimize the drill bits for operation at higher temperatures. To this end, a research and development program was started under ERDA support to design, build, and test an improved geothermal drill bit. Terra Tek, Inc., is the prime contractor, with Maurer Engineering as a subcontractor, and Reed Tool Company providing informal industry participation. The major tasks of the Phase I effort for the first year are entitled:

- Task I. Failure Mechanisms of Existing Bits
- Task II. New Steels and New Bearing Design
- Task III. New Seals and Lubricants

The first year's progress through January 1, 1976, is described in the "Semi-Annual Report on the Project to Design and Experimentally Test an Im-

proved Geothermal Drill Bit"⁽¹⁾ and its topical report attachments, "Geotechnical Studies of Geothermal Reservoirs," "Patent Search and Review on Roller-Bit Bearings, Seals, and Lubrication Systems," and "Temperature Distribution in Circulating Mud Columns".⁽²⁻⁴⁾

To make the present Annual Report comprehensive and complete, the work described in the Semi-Annual Report is briefly reviewed here, and is amended to include the additional progress through May 19, 1976. Three new topical reports have been prepared:⁽⁵⁻⁷⁾ "Examination of Failed Drill Bit from Geysers Field," "Geothermal Environment Effects on Drill Bit Life," and "Steady-State and Transient Well-Bore Temperatures During Drilling." These are included under separate cover as attachments to this report.

In addition to the above, reports of four major guidance meetings held for the project have been prepared. Three of the meeting reports are contained in an appendix of the Semi-Annual Report⁽¹⁾, and the fourth is contained as Appendix A of the present Annual Report.

The following pages discuss the work done on each of the three major tasks of the Phase I effort.

TASK I. FAILURE MECHANISMS OF EXISTING BITS

An understanding of failure mechanisms is assisted by a knowledge of the temperatures, rock types, and fluids encountered in drilling geothermal wells. The temperature environment is presented in two topical reports by W. J. McDonald,^(4,7) which show the results of calculations of temperature distributions in wells as functions of time, mud flow rate, well depth, bottom hole temperature, etc. Pratt and Simonson⁽²⁾ have contributed to a further understanding of the problem through geotechnical studies of a number of reservoirs; their summary and conclusions are as follows.

(1) Maximum temperatures found in the reservoir were approximately 370°C (700°F) in the Imperial Valley, California, but drill bit temperatures may be considerably higher in the Geysers geothermal area. Temperatures reached up to 480°C (900°F) because of frictional heating and possibly inefficient cooling.

(2) Rock types found in the high temperature environments range from hard abrasive granites and metamorphosed sandstones to unconsolidated sediments and friable sandstones. The rocks are normally highly fractured at reservoir depths.

(3) Most of the wells drilled at higher temperatures are in the harder formations; this is primarily because the Geysers area is the only existing geothermal production field in the United States. Over 150 wells have been drilled there. Drilling and drill bit problems have proven to be significant and costly. The reservoir at the Roosevelt Hot Springs area, Utah, is also being drilled in hard fractured rock. The "hot dry rock" concept will also require drilling in a hard fractured granite.

(4) At the present time reservoir depths range from 760 m (2500 feet) to greater than 3000 m (10,000 feet) but average 1500 to 2100 m (5000 to 7000 feet).

(5) The effects of reservoir characteristics on drill bit performance are complicated. Reservoir temperature alone is not the decisive factor controlling drill bit wear. As typified by the Geysers area, the mechanical properties of the rock (abrasiveness, strength, ductility) affect drill rates and lead to frictional heating which may significantly reduce life.

(6) Drilling fluids play an important role in drilling and bit performance. The highest reservoir temperatures have been encountered in the Imperial Valley, where temperatures reach 370°C (700°F), yet because of the use of cooled drilling muds and the soft non-abrasive nature of the reservoir media, few drill bit and drilling problems have been encountered there.

(7) A plot of total footage drilled as a function of temperature for all geothermal areas is not a valid measure of potential drill bit problems. The real temperature environment that the drill bit sees may be significantly modified by frictional heating and drilling fluids. Each geothermal area must be considered individually.

(8) There are little geophysical logging data available, especially at high temperature.

(9) There is little mechanical property data available on reservoir rocks, and none of the tests currently being conducted are at temperatures and pressures simulating *in situ* reservoir conditions.

A summary of the reservoir characteristics of the geothermal areas investigated is given in Table I.

In the course of Pratt and Simonson's geotechnical study⁽²⁾, first-hand information was obtained on current geothermal well drilling problems by

visiting several drilling sites and talking to the engineers directly involved in drilling. Sites visited include the Geysers in Northern California, the Salton Sea area, the Cerro Prieto site in Mexico, Roosevelt Hot Springs site in Utah, and the Baca Ranch site in New Mexico. The most critical problems with drill bit failures are experienced at the Geysers site, where more than half of the current geothermal well drilling is done, and where all of the current geothermal drilling for power production (as opposed to exploration) is being conducted. A number of worn-out drill bits were obtained from the Geysers and other geothermal drilling sites in order to study the failure mechanisms of the bits (Figures 1 and 2).

TABLE I

Reservoir Characteristics of the Geothermal Areas Investigated

GEOHERMAL AREAS	RESERVOIR TYPE	RESERVOIR ROCK CHARACTER	RESERVOIR DEPTH (KM)	TEMP. °C
Geysers, Calif.	Dry steam	Hard	1.5-2.1	240
Imperial Valley, California	Hot water	Soft (shallow) to medium (deep)	0.7-3.6	190-370
Roosevelt Hot Springs, Utah	Hot water & steam	Hard	0.6-1.2	200-260
Baca Ranch, Valle Grande, New Mexico	Hot water	Medium	1.2-1.8	200-260
Raft River, Idaho	Hot water	Hard	1.2-1.8	143-150
Jemez Caldera, New Mexico	Hot dry rock	Hard	1.8-2.7	150-200
Marysville, Montana	Hot water	Hard	1.8-2.1	93

Figure 1. A rotary drill bit similar to those used for drilling geothermal wells at the Geysers north of San Francisco, California.

Figure 2. Cut-away view of a drill bit lug and cutter cone, showing the bearings which transmit the bit weight (thrust) to the cutter cone as the latter is rolled around the bottom of the well.

The study of the worn drill bits is reported in Reference 6, which is an attachment under separate cover to this report. Briefly, it was evident that the bit failure modes are both bearing wear and "gage" wear, which is wear of the outside diameter of the bit such that the diameter of the drilled hole becomes undersized. Furthermore, the gage wear and the bearing wear are related, such that improving the bearing life may automatically improve the gage life, or improving the gage life may automatically improve the bearing life. Several used drill bits were dismantled (Figure 3) and wear measurements were made of the bearings and bearing races. The results of these measurements are shown in Table II.

The worn drill bit report of Reference 6 includes results of a metallurgical examination of one of the drill bits by Prof. W. C. Leslie⁽⁵⁾, whose topical report is also attached under separate cover. Leslie's conclusions are as follows:

1. This drill bit (Reed 73JA) failed primarily because of severe frictional wear at the nose bearing.
2. The nose bearing area (friction pin) of the bit experienced a peak temperature of about 540°C (1,000°F). The temperature can be attributed to the combined effects of the friction energy release rate and the high well temperature of about 240°C (465°F).
3. The surfaces of the ball and roller bearing races reached a peak temperature of about 427°C (800°F).
4. With these exceptions, no part of the drill bit seems to have been exposed to temperatures greatly in excess of the tempering temperature of the carburized steel parts.

Figure 3. Used drill bit components from the Geysers geothermal area. The bit was disassembled for analysis of bearing wear conditions and causes of failure.

TABLE II
BIT WEAR MEASUREMENTS

BIT NO.	BEARING RACE DIA. DIFFERENCE			AVERAGE BALL DIAMETER WEAR (mm)	AVERAGE ROLLER DIAMETER WEAR (mm)	GAGE LOSS (mm)
	FRICTION PIN (mm)	BALL RACE (mm)	ROLLER RACE (mm)			
1	0.28	0.30	0.76	0.30	0.30	0
2	0.97	0.56	0.30	0.10 ^(a)	0.03	1.6
3	0.25	0.20	0.08	0.10 ^(a)	0	4.8
4	2.00 ^(b)	1.07	0.66 ^(b)	0.25 ^(c)	0.08	9.5
5	>1.30	0.38	0.20	0.20 ^(a)	0.03	16.0

(a) As much as 0.13 mm out-of-round

(b) Wear is slanted

(c) As much as 0.36 mm out-of-round

Since bearing wear rates are closely related to the hardness of bearing surfaces, and since the bearings were used at an elevated temperature, hot hardness measurements were made on the carburized bearing races of a different drill bit cone and lug, and on a roller bearing. The hardnesses after one hour at 260°C, 316°C, and 426°C are shown in Table III, along with hot hardness data to 560°C for the friction pin hard-facing material, stellite.

Comparing the data of Table III with the temperatures deduced by Leslie indicates that the use of steels which retain their hardness at high temperature may well improve the drill bit life in the geothermal drilling environment.

It is also notable that although oil well drill bits are made in both unsealed (open bearing) and sealed designs (with a lubricant sealed in the bearings), only unsealed drill bits are used in the high-temperature geothermal environment where the drill-bit temperature exceeds about 175°C (350°F). The reason is that the elastomers which are used for seal materials cannot withstand higher temperatures, and consequently, the bearings in geothermal

TABLE III

BIT COMPONENT HOT HARDNESS VERSUS TEMPERATURE
AFTER ONE HOUR AT TEMPERATURE

COMPONENT	HARDNESS (ROCKWELL C)				
	20°C	260°C	316°C	426°C	560°C
Cutter cone roller race	57	49	42	26	--
Lug roller race	59	53	47	28	--
Roller bearing	58	51	47	28	--
Friction Pin Hard Facing	59	--	--	55	51

drill bits are run without the benefit of a lubricant. In view of Leslie's findings of bit failure because of frictional wear and frictional heating, the lack of a good, high-temperature lubricant sealed in the bearing area can be considered as a major contributing cause of premature drill-bit bearing failure.

TASK II. NEW STEELS AND NEW BEARING DESIGN

Research Drill Bits

In view of the problem of the annealing of the bearing surfaces, it seems clear that a significant gain in drill bit performance can be made by re-optimizing the current unsealed drill bit designs (Figure 4) for operation at temperatures to about 427°C (800°F) through the use of high-temperature steels in place of currently used steels. Since currently used steels have low drawing temperatures (about 200°C), and since steels with a wide range of higher drawing temperatures are available, this method of improving drill bit life seems assured of some degree of success. Therefore, candidate high-temperature steels were selected for a pair of research drill bits in consultation with Prof. William Leslie, University of Michigan. The various drill bit components, the conventional steels for the components, and the steels selected for the research bits are listed in Table IV.

The two research bits have been constructed by Reed Tool Co. on a cost-sharing basis, along with two additional bits to serve as controls for the

TABLE IV
STEELS OF CONVENTIONAL AND RESEARCH BITS

COMPONENT	CONVENTIONAL STEEL	RESEARCH BIT STEEL
Cutter Cones	AISI 4820	Vasco MA
Lugs	AISI 8620	H-13
Roller bearings	Solar Steel	M-50
Ball bearings	Solar Steel	M-50
Hard facing	Stellite	Stellite

Figure 4. Unsealed drill-bit design.

testing. The control bits are identical to the research bits, except that they are constructed of the conventional steels listed in Table IV.

The test bits are especially designed so that the three lugs with their cutter cones are bolted together, rather than welded, to form the bit (See Figure 5). This allows the bits to be tested in a simulated geothermal drilling environment, then dismantled and examined for wear, and then reassembled for further testing. This slight modification should not affect performance of the bit since it involves no change in bearing or cutting structure loads.

Figure 5. Research drill bit and a disassembled lug and cone from another research bit. Special non-welded design allows bits to be taken apart to measure bearing wear, then reassembled for more testing.

Geothermal Drill Bit Test Vessel

A test vessel has been fabricated (Figure 6) for testing of the research drill bits under simulated geothermal well drilling conditions. The vessel can provide test pressures to 35 MPa (5000 psi) at temperatures up to 427°C (800°F). The geothermal vessel interfaces with the Terra Tek/Reed

Figure 6. Geothermal Drilling Test Vessel

Tool Drilling Research Laboratory which provides the torque, thrust (bit weight), RPM, and a number of instrumentation functions for the drilling tests. The test bits will drill on a mild steel drill block to keep the penetration rate very slow, thus allowing tests of significant duration at realistic thrust and RPM.

The instrumentation will record the vessel pressure and temperature, the drill bit thrust, RPM, and torque, plus the temperature inside the drill bit close to a bearing surface. Test runs will be made on the research bits, followed by identical tests on the control bits. Following each test, the bits will be taken apart, examined, and wear measurements will be made. Comparisons of performance and wear between the research bits and the control bits should give a quantitative indication of the value of the high-temperature steels chosen for the research bits.

The test bits have been received from Reed Tool Co., and the geothermal test vessel and its instrumentation are essentially complete; actual testing will begin shortly.

Base-Line Material Properties

The full-scale drill bit test results will be correlated with certain base-line material properties to provide a better understanding of the test results and to guide the selection of steels for the new research bits to be tested in Phase II of the geothermal drill bit program. The most pertinent material properties are anticipated to be the hardness, yield strength, elongation, fracture toughness, and thermal expansion, each as functions of temperature. Tables V, VI, and VII show the hardness, the yield/elongation, and the thermal expansion data, to 427°C (800°F). Some of these data were obtained from the literature and the manufacturers, but some had to be measured for lack of available information. No fracture toughness data

were found for the steels of interest; thus, this important material property remains to be measured. Fracture toughness samples and some remaining yield/elongation samples have been prepared, and the measurements will be made shortly.

TABLE V
HARDNESS VS. TEMPERATURE OF DRILL-BIT STEELS

BIT PART	BIT TYPE	MATERIAL	HARDNESS (ROCKWELL C)				
			ROOM TEMP.	260°C (500°F)	316°C (600°F)	371°C (700°F)	427°C (800°F)
CONES	CONVENTIONAL	AISI 4820 CARBURIZED	57	49	42		26
	RESEARCH	VASCO MA	59	57		55	53
LUGS	CONVENTIONAL	AISI 8620 CARBURIZED	60	53	47		28
	RESEARCH	H 13	54	49		46	44
BEARINGS	CONVENTIONAL	SOLAR STEEL	58	51	47		28
	RESEARCH	M 50	64	60		58	56

TABLE VI
YIELD STRENGTH/ELONGATION VS. TEMPERATURE
OF DRILL-BIT STEELS

BIT PART	BIT TYPE	MATERIAL	YIELD STRENGTH (KSI) / ELONGATION				
			ROOM TEMP.	260°C (500°F)	316°C (600°F)	371°C (700°F)	427°C (800°F)
CONES	CONVENTIONAL	AISI 4820	145/13%				
	RESEARCH	VASCO MA	292/6%	249/6%			245/6%
LUGS	CONVENTIONAL	AISI 8620	84/16%				
	RESEARCH	H 13	238/9%				
BEARINGS	CONVENTIONAL	SOLAR STEEL	312/2%		292/7½%		220/10%
	RESEARCH	M 50	338/1.6%	308/4%			262/6%

TABLE VII
COEFFICIENT OF LINEAR THERMAL EXPANSION
OF DRILL-BIT STEELS

BIT PART	BIT TYPE	MATERIAL	COEFFICIENT OF LINEAR THERMAL EXPANSION				
			ROOM TEMP.	260°C (500°F)	316°C (600°F)	371°C (700°F)	427°C (800°F)
CONES	CONVENTIONAL	AISI 4820	← ————— $12.6 \times 10^{-6}/^{\circ}\text{C}$ ————— →				
	RESEARCH	VASCO MA	← ————— $12.2 \times 10^{-6}/^{\circ}\text{C}$ ————— →				
LUGS	CONVENTIONAL	AISI 8620	← ————— $12.7 \times 10^{-6}/^{\circ}\text{C}$ ————— →				
	RESEARCH	H 13	← ————— $12.4 \times 10^{-6}/^{\circ}\text{C}$ ————— →				
BEARINGS	CONVENTIONAL	SOLAR STEEL	← ————— $13.7 \times 10^{-6}/^{\circ}\text{C}$ ————— →				
	RESEARCH	M 50	← ————— $12.8 \times 10^{-6}/^{\circ}\text{C}$ ————— →				

TASK III. NEW SEALS AND LUBRICANTS

Drill bits can be further improved by the development of sealing methods to allow the bits to operate at high temperatures with a lubricant sealed in the bearing area. Oil-well experience indicates that bits with sealed and lubricated bearings last five to ten times longer than unsealed bits. However, conventional drill-bit seals and lubricants have maximum temperature limitations of about 175°C (350°F), and thus cannot be used in the hot geothermal drilling environment.

During Phase I the following work was done on the seal and lubrication problem. An extensive study was completed of the past and current state of the art. The major result of this study was the report⁽³⁾ "Patent Search and Review on Roller-Bit Bearings, Seals, and Lubrication Systems" (Maurer, 1975). We feel that this, along with a search of the open literature and discussions with representatives of rubber, seal, and bit manufacturers, has given us a good overview of the state of the art, what has been proposed in the past, and what the potentials are for various seal materials and configurations under geothermal conditions.

We have had rather extensive discussions with manufacturers of new high-temperature and anti-corrosive elastomers that might be used in future seals. This includes discussions with officials in the research and development laboratories of 1) Firestone Tire and Rubber Co., Akron, Ohio; 2) B. F. Goodrich Tire and Rubber Co., Avon Lake, Ohio; 3) PRC Co., Gainesville, Florida; 4) Horizons Res. Corp., Cleveland, Ohio; 5) Union Carbide Corp., Bound Brook, N.J.; 6) Dow Corning Corp., Midland, Michigan; 7) DuPont, Wilmington, Delaware; 8) Hercules Chemical Co., Wilmington, Delaware. Discussions were also held with university and government researchers who were known to be active in this field.

A number of elastomer and seal manufacturers have indicated interest in providing candidate seals for testing. They have been requested to provide estimates of what it would cost to prepare a limited number of seals falling in two classes: 1) Improved elastomeric materials and 2) seal designs incorporating non-elastomeric materials. The first class would have the obvious advantage of being most easily adaptable to current drill bit design. Hopefully, other than some substitution of higher temperature metals and lubricant for their more commonly used counterparts, replacement of the conventional seal rubber by the high temperature elastomer seal should facilitate the use of well tested and proven designs. Unfortunately, our study of high temperature elastomers has led us to believe that even the best currently available material will not be very useful above 230-260°C (450-500°F). Fluorocarbon (non-elastomeric polymer) seals might possibly be useful for an additional 50°C or so. These may require only slight modification of presently used bits. Still higher temperatures are probably going to require non-polymeric seals. While metallic o-rings will be explored, their successful usage in the past has been almost exclusively confined to static seals. Teflon or other "soft and tough" polymer coatings may be helpful and will be explored. Once again this type seal will require a minimum of modification of the design of the bit. The most attractive seal, it appears to us, for the highest temperatures is likely to be a bellows type seal. Such seals have been used (in other applications) at temperatures above 800°F. This type seal will, of course, require the most extensive modification or redesign of the bit.

We suggested in the Semi-Annual Report that, from our discussions with lubrication experts, we have concluded that obtaining lubricants cap-

able of operating in geothermal drill bits should not be a major problem. This statement may have been a little over-optimistic, but it does appear that, as suggested, some oils and greases are commercially available that are stable to 260°C (500°F). Samples of petroleum-base greases good to about 260°C have been obtained from Lubriplate, of the Fiske Brothers Refinery Co. In addition, we have explored geothermal needs with a number of other lubricant manufacturers. Most of these felt that they had no products that would be useful at these temperatures. There were some notable exceptions, however: 1) Dow Corning, Inc., has silicone greases that can reportably be used continuously to 260°C (500°F), and intermittently to 400°C (750°F). They also manufacture very attractive solid lubricants. 2) Elastomers Products, Inc., also produces solid lubricants capable of service at temperatures of 540°C (1000°F) and higher. They also market Teflon base greases which they report have excellent lubrication properties to 316°C (600°F). In addition, they have a Molycoat suspension (inorganic) that has good high temperature properties. We have also had informative discussions with personnel at the Air Force Office of Scientific Research. They report that the polyperfluoro alkyl ethers have good lubrication properties at temperatures of -54 to 343°C (-65 to 650°F). Above this temperature they normally use various dry lubricants (e.g. graphite or molybdenun disulfide). They have offered to provide us with reports on their studies, which, when received, we will carefully assess to see how well the lubricants and methods might be applicable to geothermal technology needs. We also plan on contacting experts on high temperature lubrication at NASA Lewis and NASA Huntsville.

It is recognized that the seal and lubricant must be considered from

a systems viewpoint, since some seal materials are attacked by certain kinds of lubricants, and since some lubricants may present easier sealing problems than others. In order to test various seal/lubricant combinations, a seal tester is being fabricated to simulate the known aspects of the geothermal drill-bit environment (Figures 7 and 8). The tester will provide for temperatures to 427°C (800°F), pressures up to 14 MPa (2000 psi), axial and eccentric motion of the rotating shaft through the seal, and pressure fluctuations of ± 0.7 MPa (± 100 psi) across the seal in drill mud environments. The RPM, which is variable, can be selected to match the RPM encountered in the field. The facility can test full-scale seal materials and designs in drill-mud environments. Completion of the seal test facility is estimated for August 1, 1976, and testing of candidate seal materials and designs will begin immediately thereafter. Seals of two candidate high-temperature elastomer materials, viz. fluorosilicone and ethylene propylene, have already been obtained for testing.

Figure 7. Seal Test Vessel

Figure 8. Seal Test Facility
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SUMMARY AND CONCLUSIONS

The problem of short drill bit life in the drilling of geothermal wells has been reasonably well defined. The geothermal area of current primary concern is the Geysers field in Northern California, where 20 to 30 drill bits are generally consumed in drilling each well, and where perhaps 300 to 500 wells remain to be drilled. The bit failure modes are both bearing wear and gage wear, but there are indications that improving the bearing life will automatically improve the gage life as well. The high bearing wear rates are attributable to a large extent to the softening of the steel bearings and bearing races as a result of exceeding the design operating temperature of the drill bits. The high bit temperature, in turn, is attributable to both the high formation temperature and to the friction heat generated in the drill bit. The friction heating is high because the bits have no lubricant sealed in the bearings; and no lubricant is sealed in the bearings because even a lubricated bit runs hotter (due to the high formation temperature) than the temperature limits of currently used seals and lubricants.

Thus, it appears that a significant gain in drill-bit life can be attained by the use of higher-temperature steels which retain more hardness at temperatures above 260°C (500°F). Such steels are available, and two research bits of high-temperature steels have been made and will shortly be tested in a laboratory-simulated full-scale geothermal drilling environment. Two control bits of the same design, but made with conventional drill-bit steels, have also been obtained for identical laboratory test runs, so that the performance of the research bits can be meaningfully assessed. Base-line properties of the steels, such as hardness and fracture toughness as functions of temperature, are being measured to further assess the value

of the high-temperature steels selected for the research bits.

A geothermal test vessel has been designed and fabricated in which the full-scale research drill bits will be tested. The vessel is capable of temperature to 427°C (800°F) and pressures to 35 MPa (5,000 psi). In the vessel, the test bit will be subjected to the same loads and RPM as are expected in field service. The value of such a research test vessel cannot be overemphasized, not only in providing economy of testing, but also in allowing highly-controlled, completely instrumented tests which are simply not possible in the field.

Although the re-optimization of the unsealed tri-cone drill bit for higher temperatures offers the surest approach to extending geothermal drill-bit life, the largest gain in drill bit life, may well be attained through high-temperature seal and lubrication techniques to allow the construction of bits with sealed, lubricated bearings. To this end, seal and lubrication designs have been studied, and the state of the art in high-temperature seals and lubricants has been assessed. Some candidate seals and lubricants have been obtained for testing, and others are being procured. In addition, a seal test vessel has been designed and will soon be completed which can simulate the geothermal drilling environment in full-scale testing of seal and lubricant designs and materials. The vessel will not only simulate pressure and temperature conditions, but also axial and radial motions of the shaft, and pressure fluctuations across the seal. Again, the importance of such a laboratory test facility cannot be over-emphasized. The highly-controlled test conditions and the complete instrumentation which are possible in such a facility greatly enhance the accuracy of test results, and thereby speed progress.

In addition to the progress already described, the Phase I effort has contributed greatly to the expertise of the investigators in drill bit technology. This fact should contribute to the progress anticipated in Phase II of the program to design and test an improved geothermal drill bit.

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APPENDIX A

This appendix contains the report of the Fourth Program Discussion Meeting for the Geothermal Drill Bit Program. Reports of the first three program discussion meetings are contained in an appendix of the Semi-Annual Report.⁽¹⁾

TERRA TEK CONTRACT E(10-1)-1546

"DEVELOPMENT OF AN IMPROVED
GEOTHERMAL DRILL BIT"

Fourth Program Discussion Meeting for
the Geothermal Drill Bit Program

April 21, 1976

Signed: *Lynn M. Barker*
Lynn M. Barker

TR 76-27
June 1976

Fourth Program Discussion Meeting for the Geothermal Drill Bit Program

ATTENDEES:

Terra Tek

Sidney Green
Arfon Jones
Lynn Barker
Alan Black
William Leslie, Consultant (University of Michigan)

Maurer Engineering

Bill Maurer, Houston
Bill McDonald, Houston

Reed Tool Company

Clayton Mandrell, Houston
Jim Peck, Houston
Dewey Thiessen, Houston
Bill Schumacher, Houston

Kobe, Inc.

John Erickson, Huntington Park, Ca.

ERDA/Geothermal Division

Cliff Carwile
Morris Skalka

FOREWORD

The Fourth Program Discussion Meeting was held in Houston at Reed Tool Company on April 21, 1976. The program included presentations by ERDA, Terra Tek, Maurer Engineering, and Reed Tool Company, plus a tour of Reed manufacturing facilities.

TOPICS COVERED

1. ERDA Geothermal Programs

Morris Skalka and Cliff Carwile reviewed ERDA's organization and its charter for stimulating the development of geothermal energy resources. ERDA's policies in funding research and development, and some of the current geothermal programs were also discussed.

2. Drill Bit Program Overview

Lynn Barker reviewed the geothermal drill bit problem, and the current and anticipated efforts to improve designs to extend drill bit lives in the geothermal drilling environment.

3. Downhole Temperature Calculation

Bill McDonald gave the results of computer calculations made with Exxon's finite difference computer code for calculating temperature profiles and temperature histories in wells with circulating mud. Both transient and steady state temperatures were calculated for a variety of conditions.

4. Metallurgical Study of Used Drill Bit

Bill Leslie gave the results of his metallurgical examination of a drill bit which had been used in the Geysers geothermal field. He found evidence of peak temperatures to 1000°F or more in certain areas of the bit, although most of the bit had apparently not been above about 500°F. A special topical report containing Prof. Leslie's study will be issued by Terra Tek.

5. Baseline Material Properties

Lynn Barker discussed the progress in obtaining certain material properties, such as hardness, yield strength, and fracture toughness, on the steels used in the conventional and the research drill bits to be tested in the present program.

6. Full-Scale Test Facility

Lynn Barker gave the design capabilities and the fabrication status of the geothermal vessel in which full-scale testing of the conventional and the research drill bits will be done. A proposed initial test matrix was discussed with the attendees.

7. New Drill Bits for Testing

Bill Schumacher described the fabrication problems encountered in Reed's manufacturing of the two research drill bits of high-temperature steels. Considerable effort was required to prevent cracking of the steels during the insert pressing operation. Mr. Schumacher's written report is included in the following pages.

8. Seal Test Facility

Lynn Barker described the test facility being fabricated by Terra Tek to test drill bit seal materials and seal designs in a simulated geothermal drilling environment.

9. Tour of Reed Tool Company Facilities

This very interesting tour of the drill bit manufacturing plant was hosted by Clayton Mandell, Bill Schumacher, and Jim Peck.

FABRICATION OF TEST BITS

P. W. Schumacher

Reed Tool Company

GEOHERMAL BIT PROGRAM

Introduction:

On January 12, 1976 Reed Tool Co. entered into a subcontract with Terra Tek which has an ERDA Contract No. E(10-1)-1546 to develop a bit capable of drilling geothermal wells. Reed agreed to supply two 6-3/4" Y-83 type bit assemblies from special materials specified by Terra Tek for high temperature (800°F) drilling. The bit assemblies were to be of bolted construction so that they could be easily disassembled for examination and then reassembled for further testing. Two 6-3/4" Y-83 bit assemblies made from conventional materials were also to be supplied for comparison testing.

Summary:

The two conventional bits have been completed.

The two bits which will have special materials are in the final stage of preparation. Dr. Bill Leslie of the University of Michigan specified the following materials as being most suitable for drilling at temperatures up to 800°F:

Cutters: Vasco MA tool steel

Lugs: H-13 tool steel

Ball bearings: M-50 tool steel

Roller bearings: M-50 tool steel

Inserts have been pressed into cutters; and the bores have been ground, so that the cutters are now complete. All bearings are completed. One set of three lugs which is to be given a standard hardening

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treatment for H-13 steel have been completed by Vasco Steel Co. and has been shipped to us, but not yet received. The second set of three lugs is to be lightly carburized on the roller bearing surface only. These lugs are still at Vasco Steel Co.

Technical Problems in Manufacture:

1. Forging the lugs.

The lugs were heated to forging temperature and forged without cracking. They were slow cooled in an insulated packing from forging temperature and then annealed for good machinability.

2. Welding stellite on the pin section.

The lugs were preheated to 1200°F, welded, and then post heated at 1200°F for several hours. No cracking was encountered.

3. Interference fit of inserts in cutters.

Due to the hardness of the cutter material (56 - 58 RC), it seemed advisable to determine how increasing interference fitting of inserts would affect cracking of the cutter. One cutter was completely machined (including insert holes) and hardened. Inserts were then interference fitted with increasing interference until cutter cracking was produced. It was learned that an interference of less than .002" on diameter is required, if cracking is to be prevented. Since the carbide insert has a coefficient of thermal expansion of 3×10^{-6} in./in./°F and steel has 6×10^{-6} in./in./°F, an interference of .0014" is required to maintain some interference

GEOHERMAL BIT PROGRAM

at 800°F. The insert holes have .0008" average ovality after hardening. The inserts were pressed by calculating the average diameter for each hole and grinding a special insert for each hole. The final hole in each insert row had to be measured after all other inserts were pressed and an insert ground to fit that hole.

Possible Problems During Drilling Using Tool Steel Materials:

1. Insert retention at 800°F is a potential problem. There will be only a few tenths of a thousandth of an inch interference fit at 800°F. Cutter flexing during drilling could result in loosening the insert so that it will fall out.
2. The tool steels have considerably lower toughness and ductile properties at the normal drilling temperatures for conventional rock bits. Cutter cracking and lug cracking are potential problems at temperatures up to 300 - 400°F.