SEMI-ANNUAL REPORT ON THE PROJECT
TO DESIGN AND EXPERIMENTALLY TEST AN
IMPROVED GEOTHERMAL DRILL BIT, PHASE II

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

By

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Submitted to

Energy Research and Development Administration
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Attention: Mr. Cliff Carwile

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TR 76-70
December 1976

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FOREWORD

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

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INTRODUCTION

Work began on an effort to design and test an improved geothermal drill bit [ERDA Contract No. E(10-1)-1546] on May 19, 1975. Phase I of the contract, which lasted for one year, was devoted largely to (1) the study of the geothermal environment and the failure mechanisms of existing geothermal drill bits, (2) the design and construction of test facilities for testing both drill-bit seals and full-scale drill bits under simulated geothermal drilling conditions, and (3) the procurement of research drill bits of high-temperature steels for the initial testing in the geothermal drill-bit test facility. The work accomplished in Phase I is reported in References 1 through 8.

The present semi-annual report describes the progress made during the first half of Phase II of the program, covering the period from May 19 to November 19, 1976. Some of this work has already been described in two bi-monthly progress letters which are included as Appendix A.

During the period of this report, the test facilities (the geothermal drilling vessel and the geothermal drill-bit seal tester) were completed and "de-bugged", and the first tests were run on full-scale research drill bits and drill-bit seals. In addition, more materials information was gathered, and a number of additional seals of high-temperature elastomer materials were obtained for testing. Maurer Engineering, on a subcontract basis, has also been active in the design and procurement of candidate high-temperature drill-bit seals for testing, and has done a literature and patent search on the problem of drill-bit insert retention. Reed Tool Co. has cooperated in the fabrication of drill bits for testing, and has offered consultation on certain seal designs.

The progress on each of the tasks of Phase II is presented in more detail on the following pages.

TASK I - UNSEALED DRILL BIT

The study conducted in Phase I on unsealed drill bits from the Geysers area showed that the drill bit failure modes are both bearing wear and gage wear.* However, the two types of wear can be related since either one can cause the other. Thus, although the basic problem may involve both bearing wear and gage wear, it is quite possible that either bearing wear or gage wear, but not both, is the major problem.

The Phase I study indicated that bearing wear is the primary source of unsealed drill bit failure because:

1. The drill-bit bearing races, and the ball and roller bearings themselves decrease appreciably in hardness at temperatures of 260°C and above at which these drill bits operated.
2. It is well known that bearing wear rates increase rapidly with decreasing bearing hardness.
3. The bearing wear on the bits examined was more consistent than the gage wear. The gage wear depended on the pattern of the bearing wear, i.e., on whether the wear at the friction pin was more or less than the wear on the roller race. In one case there was zero gage wear.

For these reasons attention has been focused on improving the hot hardness of the steels used in the drill bit, with the expectation that the gage wear problem will also be mitigated by improving the bearing life.

Baseline Properties

The full-scale drill bit test results must be correlated with certain baseline material properties to provide a better understanding of the test

* Gage wear is wear of the periphery of the drill bit, causing it to drill an under-size hole.

results and to guide the selection of steels for additional research bits to be tested. The most pertinent material properties are the hardness, yield strength, elongation, fracture toughness, and thermal expansion, each as a function of temperature. Except for the fracture toughness, these properties were all collected from the literature or measured at Terra Tek for standard drill-bit steels and for the steels used in the first research drill bits procured during Phase I. No fracture toughness data were available for the steels of interest, however, and the fracture toughness therefore had to be measured. These measurements were carried out during the period of this report using the short rod technique^{9,10} developed recently at Terra Tek. It is doubtful whether the standard ASTM tests could have measured the fracture toughness of the bearing steels because of their brittleness. The short rod technique is applicable to both brittle and ductile materials, and the specimen configuration (Figure 1) was particularly well adapted to the tests of the two drill-bit bearing steels, inasmuch as the specimens could be made from actual drill-bit roller bearings.

Figure 1. Short rod specimen configuration.
The shaded area denotes the crack.

The fracture toughness test results are shown in Figure 2, in which all of the data represent valid measurements except for the AISI 8620 data points. These are erroneous because the high temperature toughness and lower yield strength of the material dictate a larger sample size than used in these tests for valid measurements. Room temperature measurements on some larger samples of AISI 8620 indicate a fracture toughness of at least 100 MPa $\sqrt{m}$, and the toughness may increase with temperature.

The fracture toughness values of the high temperature research drill bit steels are considerably smaller than the fracture toughnesses of the conventional drill bit steels (Figure 2). Since the toughness values of the research bit steels increase significantly with increasing temperature, higher temperature tests of the research bits are less severe than lower temperature tests as far as fracture is concerned. The fracture toughness measurements of the research bit steels and the Solar Steel are reported in a paper¹¹ to be presented at the Fourth International Conference on Fracture to be held in Waterloo, Canada, in June, 1977. This paper is included as Attachment 1 of the present report.

Geothermal Vessel

A pressure-temperature vessel has been designed and constructed in which tests of full-scale research drill bits can be made under simulated geothermal drilling conditions. The vessel is capable of pressures to 35 MPa (5000 psi) and temperatures to 427°C (800°F). The drill bit bearing wear is tested in the vessel by drilling against a mild steel drill pad at full-scale drill bit thrust forces. Figure 3 shows a drawing of the geothermal vessel.

Figure 2. Fracture toughness of drill-bit steels to 427°C. All data points are valid except those of AISI 8620, which are significantly lower than the actual fracture toughness (see text).

Figure 3. Geothermal drilling test vessel. The vessel is about 2 m tall.

Considerable effort has been devoted to the completion and debugging of the geothermal vessel during the past half year. The problem of sealing the rotating shaft in the vessel with an internal temperature of 316°C (600°F) proved particularly challenging. Solutions to this and other problems have been obtained, however, and the vessel currently operates reliably. The entire full-scale drill bit test facility performed admirably during the initial tests of research bits and standard control bits, and now constitutes a valuable high temperature, high pressure facility for future testing.

Drill Bit Tests

The initial tests of full-scale research drill bits of high temperature steels was accomplished during the period of this report. In addition, identical tests were run on control drill bits made of standard drill-bit steels. Wear comparisons between the control bits and the research bits were then made to evaluate progress in obtaining longer bearing life by using high temperature drill-bit steels.

The research bits and the standard control bits were especially designed to enable them to be periodically dismantled and examined for wear, and then reassembled and subjected to further testing. Figure 4 shows a research drill bit and a portion of a dismantled research drill bit.

The first drill-bit test runs in the geothermal vessel were made for short times and at light drill-bit thrust loads to assure examination of the drill bits before any catastrophic failure. The first research bit was tested for five minutes at a load of 22 KN (5000 lb), a temperature of 316°C (600°F) and a hydrostatic pressure of 28 MPa (4000 psi). During the test, the roller cones developed fractures between almost every adjacent

pair of tungsten carbide inserts in the cones (Figure 5). The fracture pattern was dictated by the residual stresses due to pressing of the inserts, and the actual fracture resulted from the combination of these stresses and the stresses due to drilling. As a result of the failure of the research bit roller cone material, no further tests were conducted on the first research drill bit for fear of catastrophic failure of the roller cones.

The possibility of failure of the roller cone material had been foreseen. Therefore, the second research drill bit had been held at Reed Tool Co. pending a decision on the pressing of inserts. Since the inserts caused early failure of the first drill bit, the roller cones of the second drill bit were left without inserts. The drill bit was assembled and was run in the geothermal vessel with bare roller cones, thus avoiding the problem of roller cone fracture due to residual stresses from insert pressing. The second drill bit was also tested at 316°C and 28 MPa for time periods and load levels which were gradually increased to two hours at 90 KN (20,000 lb) plus an additional two hours at 110 KN (25,000 lb) (full design bit load). The first control bit of conventional steel materials was then subjected to the identical test runs as the second research drill bit. Each test bit was disassembled and measured for bearing wear after each test run (Figure 6). Comparisons of total cumulative wear, along with hot hardness values, are shown in Table I. It is apparent that the control drill bit experienced 5 to 10 times as much wear as the research drill bit. This result seems to support the contention that bearing wear has been the principal cause of failure of geothermal drill bits.

Future Plans

The above test results were presented at the drill-bit guidance meeting

Figure 4. Research drill bit and 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.

Figure 5. First research drill-bit cutter cone after first test. Cracks can be seen between adjacent insert pairs.

Figure 6. Friction pin region of second research bit after 2 hour test at 90 KN (20,000 lb) thrust.

TABLE I

Measurements of Drill-Bit Wear After Testing at 316°C (600°F).
 Each bit was subjected to a 2 hour test at
 90 KN (20,000 lb) bit weight, plus an additional
 2 hour test at 110 KN (25,000 lb) bit weight.

		Conventional Bit	Research Bit
Ball Bearings	R _C Hardness at 316°C	47	59
	Wear (mm)	.240	.025
Roller Bearings	R _C Hardness at 316°C	47	59
	Wear (mm)	.080	.005
Cutter Roller Race	R _C Hardness at 316°C	42	56
	Wear (mm)	.43	.06
Cutter Bushing	R _C Hardness at 316°C	?	56
	Wear (mm)	.08	0
Lug Roller Race	R _C Hardness at 316°C	47	50+
	Wear (mm)	1.09	.22
Friction Pin	R _C Hardness at 316°C	57	57
	Wear (mm)	?	.11

held November 11, 1976 (Appendix B). At the meeting it was decided to test two more research bits made with a new roller cone material and a new ball and roller bearing material during the second half of Phase II. In addition, Reed Tool is to supply two standard drill bits for testing at different temperatures to determine the temperature limit at which standard drill bits can operate successfully. Also, Smith Tool Co. has been requested to supply two additional standard drill bits for testing of insert retention during high temperature drilling. These tests plus the tests of base line properties for the new roller cone and bearing materials will complete the Phase II effort on the unsealed drill bit.

TASK II - ELASTOMER SEALED DRILL BIT

Drill bits can be further improved for geothermal applications 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 several times longer than unsealed bits. However, conventional drill-bit seals have maximum temperature limitations of about 175°C (350°F), and thus cannot be used in hot geothermal drilling environments. During the last half year (after a literature search and discussions with researchers and rubber producers), test seals made of a number of new high temperature elastomer materials have been obtained for testing. Table II enumerates the seal materials on hand together with some of the pertinent seal material properties.

In addition to testing high temperature seal materials, high temperature lubricants are of concern for the geothermal drill bit. It appears that good lubricants have temperature limitations comparable to those of elastomer seal materials. Table III lists a number of candidate lubricants which have been obtained for evaluation, together with some pertinent properties. The temperature limitations of the seal materials and lubricants listed in Tables II and III indicate that the elastomer-sealed drill bit temperature limitation will probably be in the range of 200 to 260°C (400 to 500°F).

The seal test facility which was designed and partially fabricated during Phase I has now been completed (Figures 7 and 8). The first tests with the seal facility were made on seals of fluorosilicone and of ethylene-propylene elastomers. The fluorosilicone test at 200°C (400°F) was unsuccessful due to catastrophic failure of the seal (see Figure 9). A similar test was performed on the ethylene-propylene seal which appeared to survive the test, but nonetheless failed to prevent the lubricant from escaping from the sealed area.

TABLE II

High-Temperature Elastomer Seal Materials

Product Name	Producer	Material Class	Probable Temp Limit	Cost/Lb	Potential Compatability Problems	Potential Physical Properties Problems
Buna N (Nitrile)	At least 6 Co.'s	Butadiene & acrylonitrile	150°C (300°F)	Low	High temp water and steam	Low temp limit
Ethylene-propylene	At least 5 Co.'s	Ethylene-propylene	180°C (350°F)	Low	Petroleum base fluids	None
Viton	Du Pont	Fluorocarbon	260°C (500°F)	Low	High temp water and steam	Tear resistance
Fluorosilicone	Dow Corning	Fluorosilicone	260°C (500°F)	Low	Silicone lubes, water and steam	Tear & abrasion resistance; etc.
PNF-200	Firestone	Phosphonitrilic Fluoroelastomer	200°C (400°F)	\$100	None expected	Unknown
Kalrez	Du Pont	Perfluoroelastomer	260°C (500°F)	\$2000	None	Unknown
5AD-7004	Custom Rubber Products	Modified Buna N	230°C (450°F)	Low	None	Unknown

TABLE III
High-Temperature Lubricants

Product Name	Producer	Material Class	Probable Temp Limit	Remarks
1200-2	Lubriplate	Petroleum grease	230°C (450°F)	
930-AA	Lubriplate	Petroleum grease	200°C (400°F)	
High Temp	Lubriplate	Petroleum grease	260°C (500°F)	
APG-90	Lubriplate	Petroleum grease	200°C (400°F)	
AF-419C	Gulf	Silicone grease	290°C (550°F)	Poor load capability; poor response to additives.
LS-1850	Graphite Products	Anti-seize compound	260°C (500°F)	Contains MoS ₂ . May go to 430°C (800°F). Oil base.
Molykote 710G	Dow Corning	Silicone oil & 5% graphite	260°C (500°F)	May go to 370°C (700°F); may have poor load capability.
Dow Corning 44 Grease	Dow Corning	Silicone grease	200°C (400°F)	Poor load capability; poor response to additives.
Molykote 321R	Dow Corning	Dry lubricating film	430°C (800°F)	High coef. of friction (0.1).
SS-21	Oil Center Research	Teflon base dry lubricating film	290°C (550°F)	Poor load capability.

Following some minor modifications of the seal test facility, an extensive period of testing of elastomer seal materials is contemplated for the remainder of Phase II.

Figure 7. A drawing of the seal test vessel.

Figure 8. A photo of the seal test facility.

Figure 9. A photo of the failed fluorosilicone seal.

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TASK III - HIGH TEMPERATURE SEALED DRILL BIT

Since it appears that elastomer materials for conventional seal designs may not be suitable for temperatures above 200 to 260°C (400 to 500°F), an effort is being made to design and test new drill-bit seal concepts for service in the 260 to 430°C (500 to 800°F) temperature range. Maurer Engineering is assisting Terra Tek on a subcontract basis in the design and procurement of candidate seals for the higher temperature environment. Figures 10, 11 and 12 show three seal types which are being investigated. Twenty-seven seals of the type illustrated in Figure 10 are being procured, each seal containing a different design and/or elastomer material modification. In addition, five identical seals of the type shown in Figure 11 are being made. These seals will all be tested in the same seal test facility as used for the conventional elastomer seals.

Figure 10. Elastomer and stainless steel wire mesh composite seal. The stainless wire mesh provides the required resilience at high temperature.

Figure 11. The Schumacher face seal. The "O" ring with the original cross section of the dashed circle is compressed in the space shown, causing the face seal of high temperature material to push against the mating surface on the cutter. The elastomer "O" ring is not subjected to sliding contact in this design.

Figure 12. Bellows face seal. The bellows is easily deformed in response to pressure fluctuations, thus minimizing transient pressure variations across the face seal. The stainless wire mesh acts as a spring to push the face seal against the mating surface on the cutter. No elastomers are used in this design.

TASK IV - DRILL-BIT INSERT RETENTION

Because tungsten carbide inserts have much smaller thermal expansions than the steels in which they are held, there has been concern that the inserts may fall out of their holes when the temperature is increased. An extensive literature and patent survey has been conducted by Maurer Engineering regarding the insert retention problem, and results are currently being prepared in report form. In addition, Smith Tool Co. may provide two standard drill bits for study of the insert retention problem at high temperatures. Tests of these drill bits will be performed during the second half of Phase II.

As a result of the initial tests of the research drill bits and the failure of any inserts to work loose from the drill bit roller cones, it appears that the insert retention problem may not be as severe as formerly anticipated. Calculations involving actual insert pressing interferences now indicate that the inserts will not loosen at the temperatures anticipated in geothermal drilling, provided that the pressing interferences are not significantly decreased. Insert loss at high temperature is probably controlled more by the softening of the drill-bit roller cone steel, allowing plastic deformation, and the consequent working loose of the inserts, than by the difference in thermal expansion of the insert material and the retaining steel material. Thus, following the Maurer Engineering report of the literature and patent survey, and following the tests of the Smith drill bits (if provided) for insert retention, no further effort on the insert retention problem may be required.

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9. L. M. Barker, "A Simplified Method for Measuring Plane Strain Fracture Toughness," accepted for publication in Engineering Fracture Mechanics.
10. L. M. Barker, "Evaluation of a Simple Method for Measuring Fracture Toughness in Both Brittle and Ductile Materials," in Proceedings of the Second International Conference on Mechanical Behavior of Materials (ICM-II), Boston, Mass., 16-20 August, 1976, p. 1547.
11. L. M. Barker, "Short Rod K_{Ic} Tests of Several Steels at Temperatures to 427°C," to be presented at the Fourth International Conference on Fracture (ICF-4), Waterloo, Canada, June 19-24, 1977.

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APPENDIX A
Bi-Monthly Progress Letters

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August 2, 1976

Mr. Cliff Carwile
Division of Geothermal Energy
Energy Research and Development
Administration
Washington, D. C. 20545

RE: Bi-monthly progress letter on the program to develop and test an improved geothermal drill bit, ERDA Contract E(10-1)-1546.

Dear Mr. Carwile:

The following is a brief description of Terra Tek's progress during the two months from May 19 to July 19, 1976, on the program to develop and test an improved geothermal drill bit.

1. The geothermal vessel in which the research drill bits will be tested at temperatures to 427°C (800°F) and pressures to 35 MPa (5000 psi) is nearing completion. The final stages of fabrication and assembly have been considerably more time-consuming than anticipated, but no serious difficulties are foreseen. We now expect to begin testing by August 15.
2. The first research drill bit delivered by Reed Tool Co. was examined in preparation for the initial tests. A spattering of stellite hard-facing material was found on the thrust face bearing surfaces of two of the three drill-bit lugs. The spattered stellite build-up was up to 0.25 mm (0.01 in) high, and could have resulted in immediate excessive wear of the mating surface in the cutter cone, thus invalidating the test results. The two defective lugs were returned to Reed Tool, where the bearing surfaces were ground smooth. The finished drill bit is now ready for testing, and is believed to be free from defects except for a small crack in one of the three cutter cones between two of the gage row inserts.
3. Additional base-line material properties of the steels used in the standard and research drill bits have been measured. The base-line data are now complete except for fracture toughness values as a function of temperature. Fracture toughness samples have been prepared from the steels of interest, and fixtures for performing the tests at various temperatures have been designed and made. The fracture toughness tests will follow shortly.

Mr. Cliff Carwile
August 2, 1976
Page two

4. The seal test facility is in the final stages of assembly, and the testing of seal materials and seal designs under realistically simulated geothermal drilling conditions will begin shortly. Two candidate seal materials are ready for testing, and others are being procured. Reed Tool Co. has completed some preliminary screening tests of fluorosilicone seals provided by Terra Tek. Reed's results show that fluorosilicone seals tolerate temperatures to at least 288°C (550°F) for one hour, but that their abrasion resistance appears unacceptable.

5. Additional information has been gathered concerning candidate lubricants for use at the elevated temperatures at which the new seals will be tested. As a general rule, the commercial lubricants which withstand the higher temperatures (above about 300°C) have other disadvantages such as increased friction, which can lead to even higher temperatures. However, it does appear that good lubricants can be obtained for temperatures to about 260°C, which is probably at least as high as the temperatures that can be tolerated by suitable elastomer seal materials. The lubricants for use with higher-temperature, non-elastomer seals may still present a problem.

6. Some preliminary work has been done by Maurer Engineering with regard to gathering references for the patent search on the insert retention problem.

It was a pleasure reviewing the program with you in some detail July 29 and 30.

Sincerely,

L. M. Barker
Staff Consultant

LMB/sf

cc: Mr. Dave Letendre
Mr. Bob Doyle
Mr. Dewey Thiessen
Dr. W. C. Maurer
Dr. L. DeVries
Dr. W. C. Leslie

September 28, 1976

Mr. Cliff Carwile
Division of Geothermal Energy
Energy Research and Development
Administration
Washington, D. C. 20545

RE: Bi-monthly progress letter on the program to develop and test an improved geothermal drill bit, ERDA Contract E(10-1)-1546.

Dear Mr. Carwile:

The following is a brief description of Terra Tek's progress during the two months from July 19 to September 19, 1976, on the program to develop and test an improved geothermal drill bit.

Geothermal Drill Bit Test Vessel. A major effort has been devoted to the completion of the geothermal vessel in which research drill bits can be tested at temperatures to 427° C (800° F) and pressures to 35 MPa (5000 psi). Problems were encountered in sealing the rotating drill stem which turns the drill bit inside the vessel. After several design iterations, the seal now lasts long enough for the first full-scale tests. Further design changes to extend the seal life are under way. Attaining the desired temperature was also a problem requiring attention, and although the target temperature for the first tests, 316° C (600° F), can now be attained, some further reduction of heat loss is planned in order to reach the maximum design temperature of 427° C (800° F).

Drill Bit Testing. The first test of a research drill bit in the simulated geothermal environment of the geothermal vessel has been conducted. As discussed and recommended at the geothermal drill bit program guidance meeting in Houston, Texas last April, the first test was conducted in water at 316° C (600° F), 28 MPa (4000 psi) pressure, 22 kN (5000 lb) thrust, and 60 RPM for a period of 5 minutes. The Vasco MA steel of the drill bit cutter cones was badly cracked by the test, with most of the cracks running between adjacent tungsten carbide inserts. The crack pattern was apparently dictated by the residual stresses from press-fitting the inserts into the cutter cones, and resulted from the combination of residual stresses and drilling stresses. Except for the Vasco MA of the cutting cones, the research drill bit steels appear to have performed satisfactorily, with some corrosion but no measurable wear. This would certainly be expected from such a short, light-load test, however.

These results have been communicated to Mr. P. W. Schumacher, Reed Tool, and to Dr. W. Leslie, University of Michigan. The consensus is that the failure of the Vasco MA is disappointing, but not entirely unexpected. The next iteration on drill bit steels will have to sacrifice some hot hardness for added toughness.

The tested drill bit will not be re-tested with its cracked cutter cones for fear the cones may break, resulting in damage to the inside of the geothermal vessel. Instead, the second research bit will be tested without any inserts pressed into the cutter cones. The second bit has been held at Reed Tool pending the decision on whether or not to press inserts into the cutters.

Base-Line Material Properties. An extensive series of fracture toughness tests has been performed to complete the base-line material properties data for the steels used in the standard and research drill bits. Tests were done on six different steels, all as functions of temperature from 24° C to 204° C (standard bit steels) or to 417° C (research bit steels). As far as could be determined, no fracture toughness measurements have ever been made on these steels. A new "short rod" method, recently developed at Terra Tek, was used to measure the critical stress intensity factors, K_{Ic} (fracture toughness). Because of the brittleness and small sample size of the high-strength bearing steels tested, it was not possible to make the K_{Ic} measurements by conventional techniques. The short rod method is especially suited to brittle materials and small samples, and can test ductile materials as well.

As seen in Figure 1, the fracture toughness of the research bit steels increased substantially with increasing temperature; however, even at the higher temperatures, they reached only somewhat more than half the low-temperature toughness of the corresponding standard bit steels. This result helps explain the failure of the Vasco MA steel of the research bit cutter cone.

Seal Test Facility. Additional progress has been made on the geothermal seal test facility, which should be completed within the next month. As with the geothermal vessel, the final stages of fabrication and assembly have been more time-consuming than anticipated, but no serious difficulties are foreseen.

Seals. The ethylene-propylene seals which were obtained for the initial testing in the seal test facility were made too large, and the manufacturer has now supplied the correct size at no additional charge. Fluorosilicone seals are also on hand, and nitrile, Viton, and Firestone PNF-200 seals are on order. Seals from DuPont and Dow Corning high-temperature elastomers are in the procurement stage. In addition, Maurer Engineering, on a subcontract to Terra Tek, is working on several different high-temperature seal designs which will be evaluated in our seal tester.

Mr. Cliff Carwile
September 28, 1976
Page three

Lubricants. A number of lubricants have been obtained for testing with the various seals in the seal test facility. These include products of Lubriplate (Fiske Brothers Refining Co.), Dow Corning, and Gulf Oil. Lubricants must be chosen not only for high temperature serviceability, but also for high load carrying capacity and for compatibility with the particular seal material.

Insert Retention. Maurer Engineering has gathered the patents pertaining to the insert retention problem, and is in the process of assembling the pertinent information in a topical report.

Sincerely,

L. M. Barker
Staff Consultant

LMB/sf

Enclosure

cc: Mr. Dave Letendre
Mr. ~~Bob Doyle~~
Mr. Dewey Thiessen
Dr. W. C. Maurer
Dr. L. DeVries
Dr. W. C. Leslie

Figure 1. Fracture toughness vs. temperature of drill-bit steels.

APPENDIX B

**Fifth Program Discussion Meeting for
the Geothermal Drill Bit Program**

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TERRA TEK CONTRACT E(10-1)-1546

"DEVELOPMENT OF AN IMPROVED
GEOTHERMAL DRILL BIT"

Fifth Program Discussion Meeting for
the Geothermal Drill Bit Program

November 11, 1976

Signed: _____

Lynn M. Barker

Lynn M. Barker

TR 76-64
November 1976

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Fifth Program Discussion Meeting for the Geothermal Drill Bit Program

ATTENDEES:

Terra Tek

S. J. (Sid) Green
A. H. (Arfon) Jones
L. M. (Lynn) Barker
A. D. (Alan) Black
R. R. (Bob) Hendrickson
R. R. (Randy) Nielsen
J. G. (Jim) Wilson
K. L. (Larry) DeVries, Consultant (University of Utah)
W. C. (Bill) Leslie, Consultant (University of Michigan)

Reed Tool Company

P. W. (Bill) Schumacher
T. (Terry) Mayo

ERDA/Geothermal Division

C. (Cliff) Carwile
D. (Dan) Hoggan

FOREWORD

The Fifth Program Discussion Meeting was held in Salt Lake City at Terra Tek on November 11 and 12, 1976, in combination with a meeting on the Downhole Motor project at Terra Tek. Presentations were made concerning all facets of these two projects. This meeting followed discussions on the same topics at Maurer Engineering in Houston, Texas, on November 9. Those present at Maurer Engineering included Cliff Carwile, Sid Green, Bill Maurer, Jeddy Nixon, Bill McDonald and Larry Matson. The discussions at Maurer Engineering are not specifically included in the following.

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TOPICS COVERED

1. Lubricants and Seals

The high temperature elastomer candidate materials for drill bit seals which have been obtained for testing were enumerated and discussed (Table I). Samples of the seals on hand were displayed. Similarly, high temperature lubricants were enumerated and discussed (Table II). It still appears that the practical upper temperature limit for effective lubricants and elastomer seals may be in the 400 to 500°F temperature range. Nevertheless, this may suffice for most current geothermal applications, and would be much better than the current limitation of 300°F or less.

2. Drill Bit Seal Test Facility

The newly completed drill bit seal test facility was described by Bob Hendrickson, and the participants were given a tour of the facility. The results of two initial tests of seals with the facility were presented. During a discussion a realistic test program was suggested in which candidate seal materials would be soaked at high temperature and then tested dynamically at somewhat lower temperatures to simulate the initial high temperatures encountered in tripping, followed by the lower temperatures (due to circulation of the drilling mud) encountered during drilling.

3. Lubricant and Seal Test Future Plans

An extensive program of elastomer testing in the seal test facility is just beginning. In addition, a number of new seal designs involving higher temperature materials will be tested in the same facility. Maurer Engineering is aiding in the design and procurement of high temperature seals for testing. A program of lubricant testing is contemplated for Phase

III of the drill bit program, including the design and fabrication of a lubricant tester to simulate the drill bit lubricant environment.

4. Geothermal Drill Bit Test Vessel

The geothermal vessel and the solution of the vessel seal problem were described by Randy Nielsen. The group was given an inspection tour of the test vessel.

5. Full-Scale Bit Tests and Correlation with Base Line Data

The test conditions of each bit tested in the geothermal vessel were reviewed. The cutters of the first research bit had fractured after only 5 minutes testing at 5000 lb bit weight. The second research bit and one of the control bits were each subjected to a two hour test at 20,000 lb bit weight plus an additional two hour test at 25,000 lb bit weight. The wear of the bearings and bearing races of these drill bits were then compared. The measurements of wear together with the Rockwell C hardness at 600°F of the components of interest are given in Table III. It can be seen that the wear of the conventional drill bit was 5 to 10 times as great as the wear on the research bit.

The results of fracture toughness measurements on the several drill bit steels were presented (Figure 1). The fracture toughness of the Vasco MA cutter cone material is considerably less than the fracture toughness of the standard cutter cone material. Since the Vasco MA fractured in the first research bit, Bill Leslie has suggested Vasco X-2 CVM steel has the follow-on material for new cutter cones. This steel has good high temperature properties, although not quite as hard as Vasco MA, and should be considerably tougher than Vasco MA. Samples of Vasco X-2 CVM and a modified low carbon version of X-2 CVM have been obtained for fracture

toughness tests in the laboratory before the fabrication of the new drill bit cutter cones.

Considerable discussion was held of high temperature bearing materials to replace the M50 bearing steel used in the research bits, since Reed Tool tests have indicated that the M50 as used in the research drill bits is too brittle to be used in drill bits in the field. For lack of a suitable alternative high temperature bearing steel, it was decided to use M50 tempered to a Rockwell C hardness of 59 instead of 64 to increase its toughness. These bearings will be obtained with the assistance of Bill Leslie for use in new research bits to be tested in a few months. The lugs of the new research bits will be the same as the lugs of the present research bits. One set of three lugs will come from the five-minute test bit in which the cutter cones fractured. The lugs from that test are essentially new and undamaged. Another set of lugs has been held at Reed Tool in the rough machined condition. This set will be heat treated and finish machined for construction of a second research bit with the new cutter and bearing materials. In addition, Reed Tool will provide two standard 6-3/4 inch M83 bits in December or January for testing in the geothermal vessel. These bits will be used to determine the temperature limit at which standard bits should operate successfully.

6. Drill Bit Insert Retention

Smith Tool Co. has agreed to supply two standard drill bits for our study of the insert retention problem during high-temperature drilling. However, considering all information available at the present time, it was the opinion of the participants that the insert retention problem for a geothermal drill bit is probably no more severe than the retention problem

in conventional drill bits. It is anticipated that tests of the Smith bits will confirm this judgment. Therefore, following these tests and the completion of the insert retention literature survey being conducted by Maurer Engineering, no further action may be required on the insert retention problem.

7. ERDA Geothermal Drilling Projects

The ERDA Department of Geothermal Energy Drilling Technology Projects in FY 1977 were described by Cliff Carwile. Major areas of interest are in drilling hardware, drilling fluids, and data telemetry. The longer range geothermal drilling technology program was also described.

TABLE I
High-Temperature Elastomer Seal Materials

Product Name	Producer	Material Class	Probable Temp Limit	Cost/Lb	Potential Compatibility Problems	Potential Physical Properties Problems
Buna N (Nitrile)	At least 6 Co.'s	Butadiene & acrylonitrile	300°F	Low	High temp water and steam	Low temp limit
Ethylene-propylene	At least 5 Co.'s	Ethylene-propylene	350°F	Low	Petroleum base fluids	None
Viton	Du Pont	Fluorocarbon	500°F	Low	High temp water and steam	Tear resistance
Fluorosilicone	Dow Corning	Fluorosilicone	500°F	Low	Silicone lubes, water and steam	Tear & abrasion resistance; etc.
PNF-200	Firestone	Phosphonitrilic Fluoroelastomer	400°F	\$100	None expected	Unknown
Kalrez	Du Pont	Perfluoroelastomer	500°F	\$2000	None	Unknown
5AD-7004	Custom Rubber Products	Modified Buna N	450°F	Low	None	Unknown

TABLE II
High-Temperature Lubricants

Product Name	Producer	Material Class	Probable Temp Limit	Remarks
1200-2	Lubriplate	Petroleum grease	450°F	
930-AA	Lubriplate	Petroleum grease	400°F	
High temp	Lubriplate	Petroleum grease	500°F	
APG-90	Lubriplate	Petroleum grease	400°F	
AF-419C	Gulf	Silicone grease	550°F	Poor load capability; poor response to additives
LS-1850	Graphite Products	Anti-seize compound	500°F	Contains MoS ₂ . May go to 800°F. Oil base.
Molykote 710G	Dow Corning	Silicone oil & 5% graphite	500°F	May go to 700°; may have poor load capability
Dow Corning 44 Grease	Dow Corning	Silicone grease	400°F	Poor load capability; poor response to additives
Molykote 321R	Dow Corning	Dry lubricating film	800°F	High coef. of friction (0.1)
SS-21	Oil Center Research	Teflon base dry lubricant	550°F	Poor load capability

TABLE III

Measurements of Wear After Testing at 600°F.
Each bit was subjected to a 2 hour test at 20,000 lb bit weight,
plus an additional 2 hour test at 25,000 lb bit weight.

		CONVENTIONAL BIT	RESEARCH BIT
BALL BEARINGS	R _C HARDNESS AT 600 ⁰ F	47	59
	WEAR (IN)	.0094	.0010
ROLLER BEARINGS	R _C HARDNESS AT 600 ⁰ F	47	59
	WEAR (IN)	.0032	.0002
CUTTER ROLLER RACE	R _C HARDNESS AT 600 ⁰ F	42	56
	WEAR (IN)	.0186	.0024
CUTTER BUSHING	R _C HARDNESS AT 600 ⁰ F	?	56
	WEAR (IN)	.0032	0
LUG ROLLER RACE	R _C HARDNESS AT 600 ⁰ F	47	50+
	WEAR (IN)	.0429	.0086
FRICTION PIN	R _C HARDNESS AT 600 ⁰ F	57	57
	WEAR (IN)	?	.0042

Figure 1. Fracture toughness vs. temperature of drill-bit steels.