MASTER

SEMI-ANNUAL REPORT

# SUPPORT RESEARCH FOR DEVELOPMENT OF IMPROVED GEOTHERMAL DRILL BITS

By

R. R. Hendrickson
A. H. Jones
S. J. Green
R. W. Winzenried



Submitted to

Department of Energy
Division of Geothermal Energy
20 Massachusetts Avenue, N.W.
Washington, D.C. 20545

DOE Contract EG-76-C-7-1546

Attention: Mr. Clifton Carwile
Dr. Samuel Varnado

Submitted by

Terra Tek, Inc.
420 Wakara Way
Salt Lake City, Utah 84108

TR 77-126
December 1977

## DISCLAIMER

## FOREWORD

This represents the semi-annual progress report for DOE contract EG-76-C-7-1546, aimed at research to support development of improved geothermal rolling-cutter drill bits.

TABLE OF CONTENTS

## LIST OF ILLUSTRATIONS

## LIST OF TABLES

# INTRODUCTION

This contract is a continuation of the program initiated under DOE contract E(10-1)-1546 entitled "Program to Design and Experimentally Test an Improved Geothermal Bit"; the program is now in its third year under DOE contract EG-76-C-7-1546. The objective of the contracts has been the acceleration of the commercial availability of a rolling cutter bit suited to the harsh thermal, abrasive, and chemical environment of the more problematic geothermal wells, including those drilled with air. Efforts were directed at the improvement of both the sealed and unsealed type of bits. The unsealed bit task included determination of the rationale for materials selection, the selection of steels and tungsten-carbides for the bit body, cutters, bearings, and drilling inserts, and full-scale drilling tests under simulated wellbore conditions. The sealed bit task provided for the evaluation of candidate high-temperature seals and lubricants, utilizing specially constructed test apparatus which simulated the geothermal bit/wellbore environment.

Phase I of the contract 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 separate facilities for testing both drill-bit seals and full-scale drill bits under simulated geothermal drilling conditions, and (3) fabrication of first-generation research drill bits from high-temperature steels, and testing in the geothermal drill-bit test facility. The work accomplished in Phase I is reported in References 1 through 9.

Phase II was directed at solving the materials problems for the unsealed bits and at the screening of elastomers for use as a high-temperature seal. The first generation experimental bits were tested in the newly constructed wellbore simulator. Test results indicated that retention of hardness at temperature, but not at the expense of fracture toughness, was a primary requirement for geothermal bits. Materials selections for the MK-II bits were made based on these results. References 10 through 13 give additional information on Phase II.

This report summarizes the progress made during the first half of Phase III, encompassing the period from May 19, 1977 to November 19, 1977. There are two major tasks in Phase III:

- Material selection, fabrication and testing of MK-III bits,
- Seal and lubricant evaluation

Candidate steel and carbide properties were evaluated in laboratory tests before final selections were made for the MK-III bit. The sealed bit program covers extensive testing of conventional elastomeric seals, experimental elastomeric seals, and experimental heterogeneous seals, as well as lubricant tests using a specially constructed test machine. The progress on each of the tasks of Phase III is presented in more detail on the following pages.

## TASK I - UNSEALED DRILL BIT DEVELOPMENT

### MK-II Drill Bits

Two second-generation experimental bits were completed and run in the Geothermal Wellbore Simulator during this reporting period. The results of these drilling tests will be detailed below, but the relevant efforts preceding the MK-II bits will first be reviewed.

In Phase I it was determined that the predominant bit failure modes at the problematic drilling sites (those involving air-drilling into hard, abrasive formations) were excessive bearing wear and loss of "gage", *i.e.*, bit diameter. The first-generation (MK-I) experimental drill bits were fabricated from steels known to retain hardness and strength at elevated temperatures, in order to reduce bearing wear. Two of these bits were subjected to full-load drilling tests at 317°C in the Drilling Research Laboratory, utilizing the Geotheraml Wellbore Simualtor. Wear Measurements on internal bearing surfaces revealed only one fifth to one tenth as much wear as was measured on a conventional Reed M83-JA bit, run under the same conditions. The MK-I bits did suffer from cracking of the cutters.

Fracture toughness tests performed on the steels used in conventional bits and the MK-I experimental bits over the temperature range of 20°C to 400°C showed that toughness levels for the conventional bit steels were substantially higher than those used in the MK-I bits.

Materials selections for the MK-II bits were made during Phase II and were based on results of the MK-I laboratory drilling tests, material hardness and fracture-toughness determinations. The data indicated a need for substantial improvements in toughness, especially for the cutters, rollers, and balls. The minimal wear experienced by the MK-I bearing components demonstrated the importance of retained hot-hardness, but also suggested that some of this hardness could be "traded off" for more toughness. The "manufacturability" of candidate steels was discussed with steel suppliers and Reed Tool Company personnel, since the bit components would have to be forged, heat-treated and machined utilizing existing factory facilities. The latter is the dominant factor for determining success of accelerated commercialization, as well as being a near-term necessity for fabrication of the MK-II bits. The materials used in the MK-II bits were as follows:

| | |
|---|---|
| Lugs: | H-13 Tool Steel |
| Cutters: | VASCO X2 CVM |
| Roller Bearings: | M 50 Tool Steel @ Rc 56 |
| Ball Bearings: | M 50 Tool Steel @ Rc 56 |
| Bushings: | None |
| Buttons: | None |
| Inserts: | Tungsten Carbide, Carboloy grade 231 |
| Design Configuration: | Reed Y73 JA 6-3/4" |

The composition of these steels, and others discussed herein, are given in Table 1.

Difficulty was encountered in fabricating the cutter cones from Teledyne-Vasco X2 CVM tool steel. The original plan called for case-carburizing and heat-treating to obtain a surface hardness of about Rc 56, while obtaining Rc 40 at depth. The actual values were Rc 57-58 in the carburized areas, and Rc 50 in the body, which was too hard to permit drilling holes for the tungsten-carbide inserts. Two subsequent tempering operations reduced the core hardness to Rc 40, allowing the drilling of insert holes; however, in the heat-treatment the hardness of the carburized

TABLE 1

NOMINAL STEEL COMPOSITIONS

| Steel | Composition (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | C | Cr | Mn | Mo | Ni | Si | V | W |
| AISI #8620 | 0.20 | | 0.80 | | 0.55 | | | |
| AISI #4820 | 0.20 | | 0.60 | 0.25 | 3.50 | 0.27 | | |
| AISI S2 (Solar Steel) | 0.50 | | 0.40 | 0.5 | | 1.00 | | |
| AISI M-50 | 0.80 | 4.00 | 0.25 | 4.50 | 0.10 | 0.25 | 1.00 | |
| AISI H-13 | 0.37 | 5.25 | 0.35 | 1.30 | | 1.00 | 1.00 | |
| Vasco MA | 0.51 | 4.50 | | 2.75 | | 0.22 | 1.00 | 2.00 |
| Vasco X2 | 0.22 | 5.20 | 0.25 | 1.30 | 0.06 | 1.00 | 0.40 | 1.35 |
| Vasco X2 Mod. | 0.13 | 5.20 | 0.25 | 1.30 | 0.06 | 1.00 | 0.40 | 1.35 |
| CBS-600 | 0.2 | 1.46 | 0.55 | 1.0 | -- | 1.1 | -- | -- |

areas was reduced to Rc 47. Note that these cutters were fabricated without the bushing and button that are press-fit into the friction-pin area of conventional cones, since the Vasco X2 CVM (at Rc 57-58) should have provided adequate wear resistance for the load-bearing surfaces. Hence, the deficient (Rc 47) case hardness could be expected to cause the greatest problem in the friction-pin area.

The roller bearings were drawn back to Rc 56 from the normal hardness of Rc 62-64 in order to increase toughness; fracture toughness data on M50 at Rc 56 are presented in another section of this report.

Lugs for the MK-II bits were identical to those of the MK-I bits, since the data suggested adequate toughness for H-13, although toughness values were somewhat less than for AISI 8620, used on conventional lugs.

Two MK-II bits (designated G and H) were fabricated in the take-apart configuration by Reed Tool Company, for evaluation in the Geothermal

Wellbore Simulator. These bits, like the MK-I bits, were similar in geometry to the Reed 6 3/4 inch M83-JA hard-formation bit.

Laboratory Drilling Tests on MK-II Bits

The two MK-II bits, and one conventional bit of the take-apart type, were run in the Drilling Research Laboratory in August, 1977. The Geothermal Wellbore Simulator was modified for these tests to permit rapid replacement of the mild steel drill pad; a new pad was used for each of the three bits. Drilling tests were run with water at 27.6 MPa (4,000 psi) and 316° in the Wellbore Simulator; each bit was scheduled to run for one hour at 22 KN (5,000 pounds) and six hours at 111 KN (25,000 pounds). The one-hour break-in period wore a pattern in the steel pad which provided more uniform support for the cones, which alleviated some of the axial thrust on the ball races; in field drilling situations this support is provided by the hole wall. The break-in was considered essential because tests run on conventional bits "E" and "F", which were run at full load without the pad break-in period, experienced breakage of the ball races on the lugs; these tests are described in the Phase II annual report[13].

MK-II Bit "G"

The first bit tested was MK-II bit G, which completed the break-in period and ran for two hours at 111 KN (25,000 pounds), at which time the torque increased suddenly and the test was terminated. Examination of the bit revealed that all three cones had "locked up" and skidded on the pad (Figure 1). The cones will normally leave a regular pattern of undulations in the pad, rather than the smooth grooves shown in Figure 1.

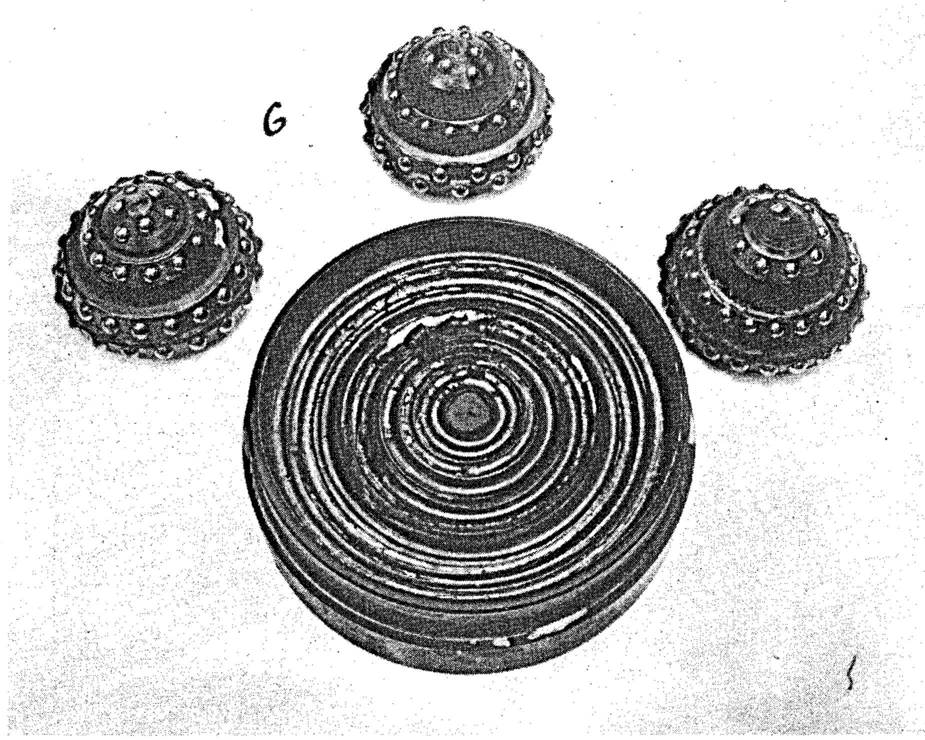


FIGURE 1
PAD AND CONES FROM MK-II BIT "G"

The lug/cone assemblies were soaked in solvent for several hours to loosen the ball bearings. Upon removal of the cones, the rollers were found to be immobile in the lug raceway due to the intrusion of fine steel particles. Wear of the internal components was very slight; surfaces of the friction pin, roller races, rollers and balls were smooth. The ball-bearing races on the lugs exhibited slight "orange-peel" effect. The low (Rc 47) hardness in the carburized areas of the cones (discussed previously) did not cause a major wear problem at the friction-pin as was originally feared. Comparative wear measurements for all three bits are given in Table 2.

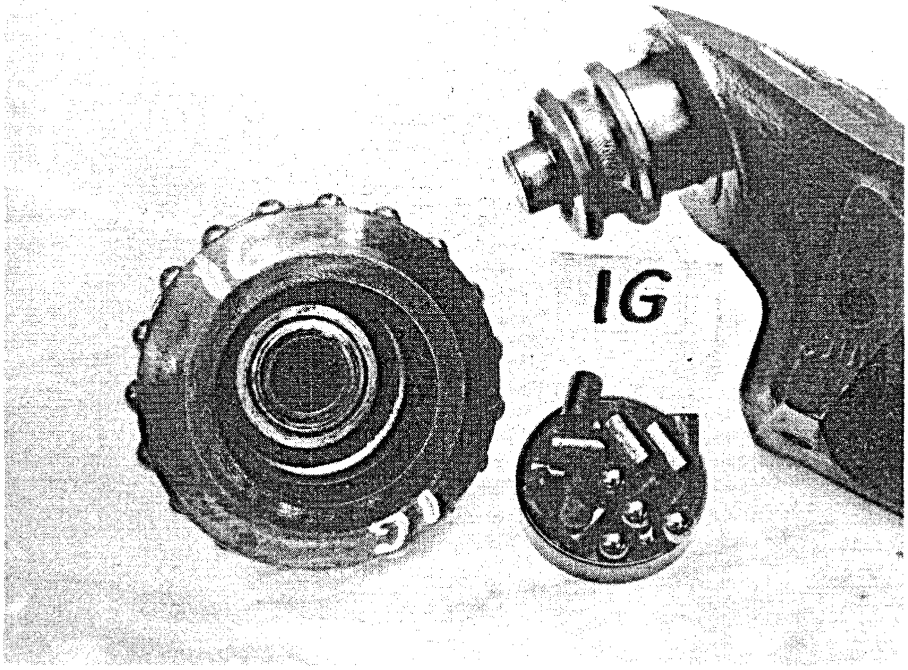


FIGURE 2
CONE, LUG, ROLLERS AND BALLS OF MK-II BIT "G",
LUG #1, SHOWING MINIMAL WEAR

The lack of any significant internal wear strongly suggested that the foreign matter responsible for the cone seizure came from outside the bit. This was possible since the bits were of the unsealed type and no circulating fluid was provided in the Wellbore Simulator. In a normal drilling situation, some of the drilling fluid is diverted by internal passageways to the ball races and out through the roller races; this flushing action keeps the detritus out of the bearings. The Wellbore Simulator was not designed to provide a flow of drilling fluid due to the technical difficulty of such a system (although a method of detritus removal was included and is discussed in another section).

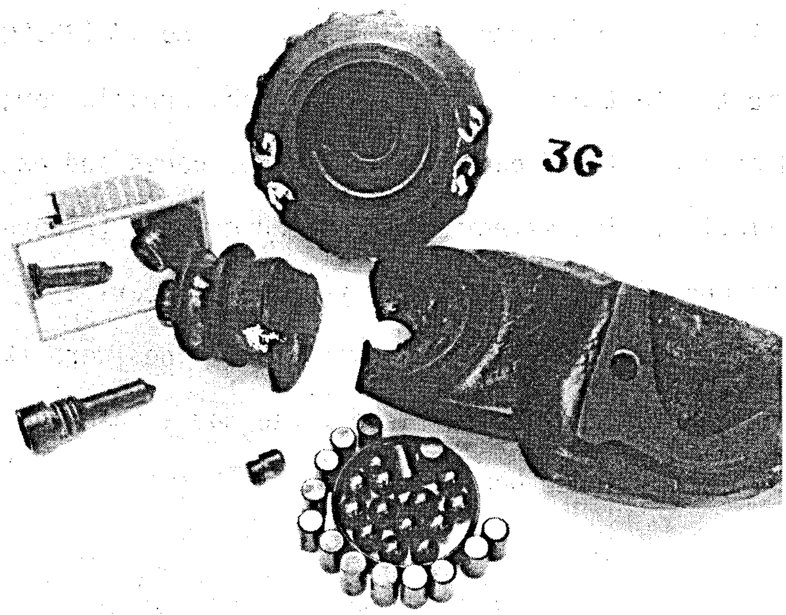


FIGURE 3
MK-II BIT "G", LUG #3 COMPONENTS,
INCLUDING BROKEN LUG

A brittle failure was experienced on one of the three lugs of bit "G" (Figure 3), which was discovered while removing the bit from the drill pipe. The lug may have cracked during drilling or during the skidding. Alternately, the crack could have been caused by "hydrogen embrittlement", *i.e.*, stress-corrosion cracking (see Appendix B) during cool-down of the bit, and not during the drilling; this would explain why the parts had not totally separated during rotation. Both scenarios are indicative of insufficient toughness for the H-13 tool-steel lugs.

Conventional Bit "A"

The second bit to be tested was conventional bit "A"; in view of the lock-up problem experienced on bit "G", a lower "full load" value was selected*. Bit "A" completed the one-hour break-in period and ran for an additional five hours and sixteen minutes at 89 KN (20,000 pounds), at which time the test was stopped due to high, erratic torque data. Examination of the bit and pad revealed locked cones and extensive wear caused by skidding. The extent of the skidding wear (Figure 4) indicated that at least one of the cones had locked up much earlier. Subsequent examination of the torque graph suggested that cones were skidding intermittently between two and one-half and three hours into the test, and had totally locked up by three hours.

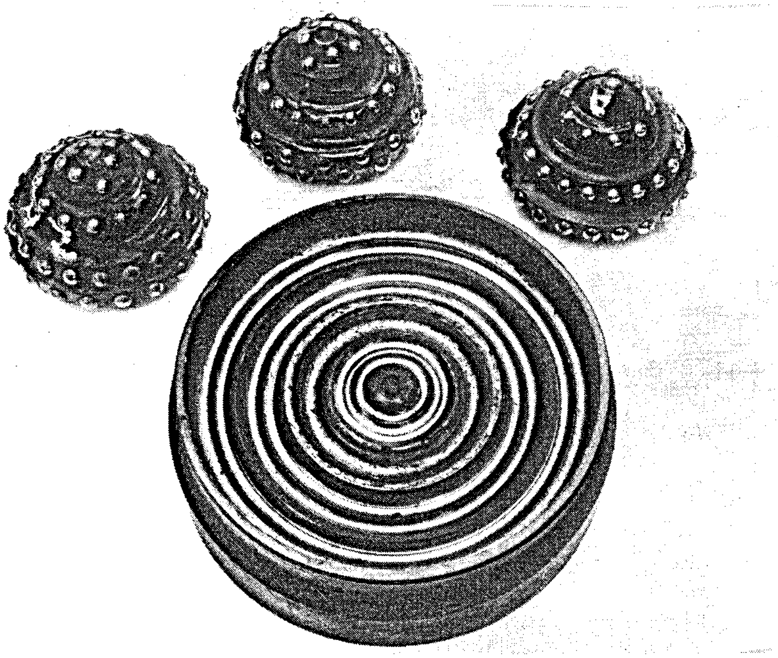

FIGURE 4

PAD AND CONES FOR CONVENTIONAL BIT "A"

---

* It was then believed that bit "G" had seized due to breakage of the ball-race on the lug, caused by excessive axial loading of the cones.

Disassembly revealed detritus intrusion, and subsequent jamming of the roller race, as described for bit "G"; difficulty was experienced in removal of the cones due to the steel detritus particles; some of the particles were slivers over one quarter inch in length. On lug 3 of bit "A", the rollers jammed severely (Figure 5), and remained on the lug despite the soaking in solvent. Flats on the rollers indicate that at one time the cone slid over the rollers. The balls and ball races exhibit more surface damage than the Mk-II bits; detritus was heavily embedded in the cone ball races (Figure 6).

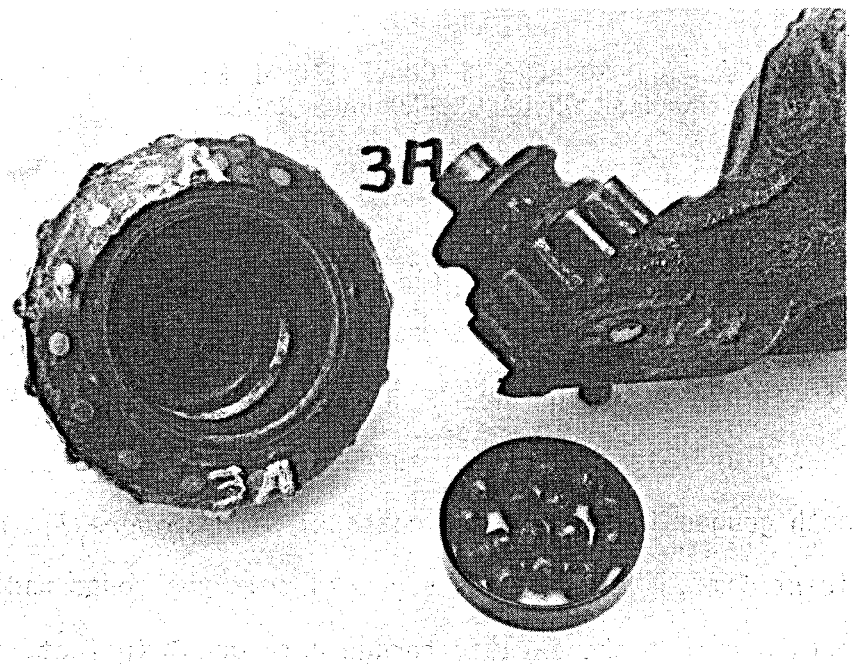


FIGURE 5

CONE, LUG AND SEIZED ROLLERS OF CONVENTIONAL BIT "A", LUG 3

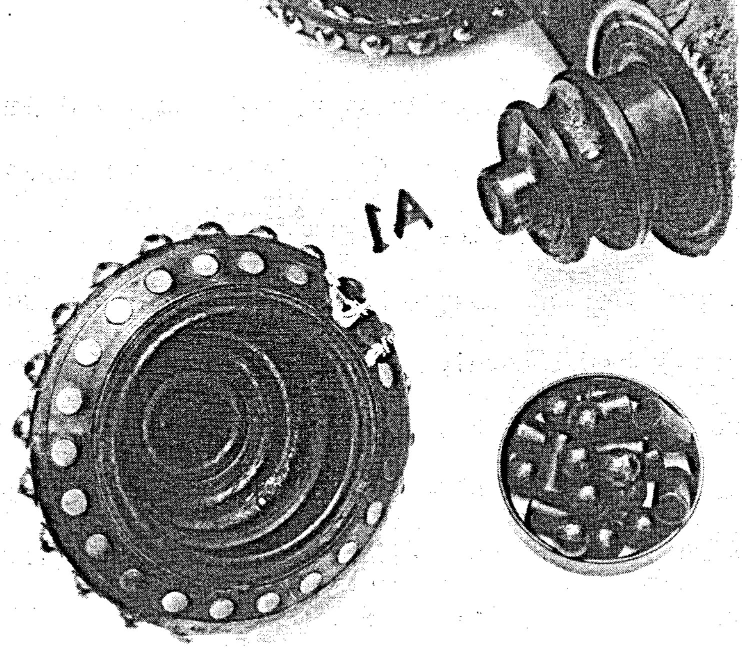


FIGURE 6

CONE, LUG, BALLS AND ROLLERS OF CONVENTIONAL BIT "A", LUG #1
SHOWING WEAR ON BALLS AND BALL RACES

MK-II Bit "H"

The third bit tested was MK-II experimental bit "H"; this bit completed the one-hour break-in period and was run for an additional one hour and forty minutes at 89 KN (20,000 pounds). The test was terminated when the torque increased and became erratic, as occurred with the previous two tests. The smooth gouges in the pad indicate skidding (Figure 7), but the lack of significant damage to the cones suggests that the cones had not skidded very long, and that the erratic torque data does, in fact, indicate cone lock-up. Examination of the bearing surfaces (Figure 8) revealed almost no wear, including the friction-pin areas of the cones, discussed previously; some "orange-peel" wear was evident on the lug ball races. Disassembly was difficult due to the steel detritus particles, as with the previous two bits; nearly all of this foreign matter was removed

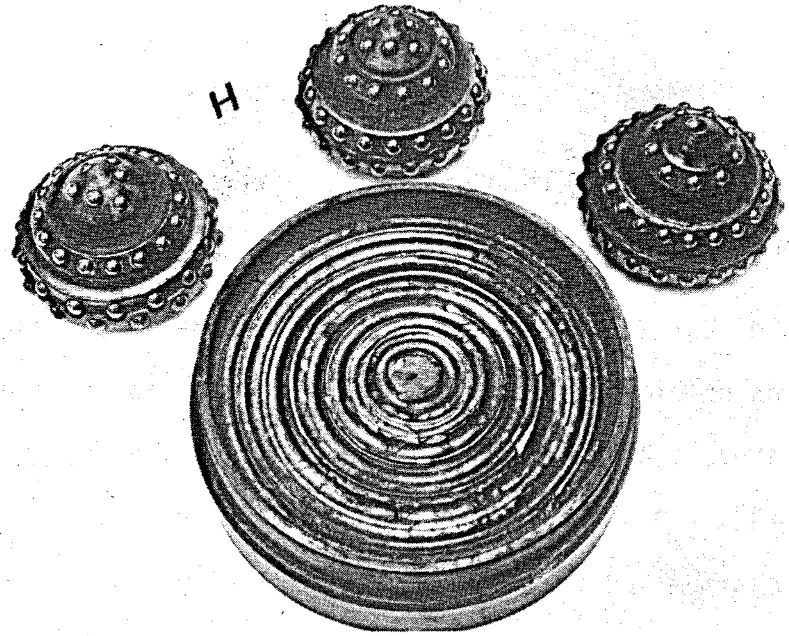


Figure 7

PAD AND CONES FOR EXPERIMENTAL MK-II BIT "H"

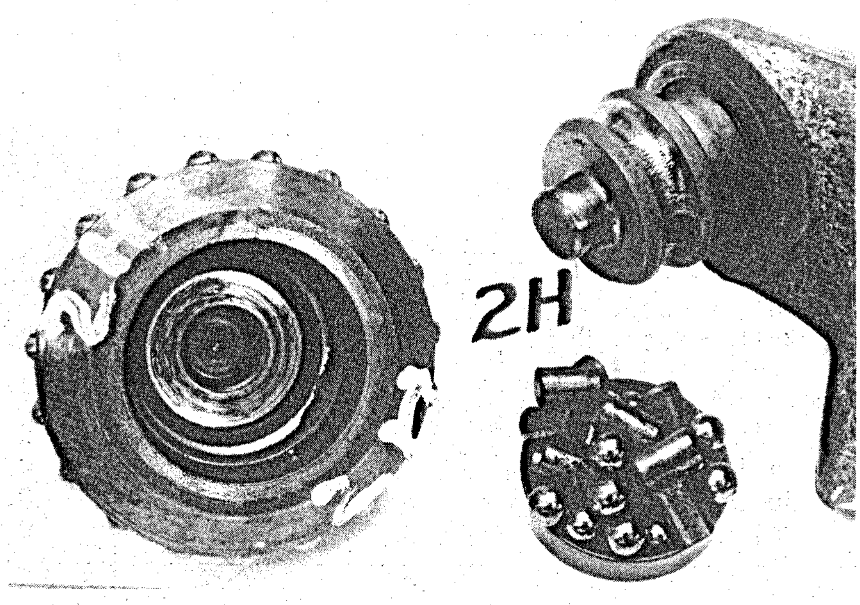


FIGURE 8

CONE, LUG, BALLS AND ROLLERS FROM EXPERIMENTAL MK-II BIT "H", LUG #2 from the parts shown in Figure 8, although some remains in the ball race on the cone.

Table 2 lists the wear measurements made on the three bits. Each bit was completely torn down and measured prior to the drilling tests described above. At the completion of the tests, each bit was disassembled, cleaned, and all bearing surfaces were measured at several points to determine minimum and maximum wear; for clarity, Table 2 lists only the maximum values.

TABLE 2

WEAR MEASUREMENTS FOR CONVENTIONAL AND MK-II EXPERIMENTAL BITS TESTED AT 316°C IN GEOTHERMAL WELLBORE SIMULATOR

| | CONVENTIONAL BIT "A"" | MK-II BIT "G" | MK-II BIT "H" |
|---|---|---|---|
| LOAD, POUNDS | 20,000 | 25,000 | 20,000 |
| RUN-TIME, MINUTES | 150-180[3] | 120 | 100 |
| LUG WEAR[1] | | | |
| Friction Pin | 0.012 | 0.002 | 0.000 |
| Ball Race | 0.030 | 0.016 | 0.040 |
| Roller Race, IN[2] | 0.044 | 0.004 | 0.007 |
| Roller Race, OUT[2] | 0.060 | 0.003 | 0.003 |
| CONE WEAR[1] | | | |
| Friction Pin | 0.001 | 0.001 | 0.000 |
| Ball Race | 0.018 | 0.000 | 0.004 |
| Roller Race, IN[2] | 0.025 | 0.006 | 0.007 |
| Roller Race, OUT[2] | 0.033 | 0.005 | 0.015 |

1. All wear measurements in inches; values shown are maximums.
2. Wear causes taper, two measurements are made; see Figure 9 for illustration of "IN" and "OUT" designations.
3. Bit "A" ran for five hours and 16 minutes, but cones locked between 150-180 minutes into test, at which time wear on bearing surfaces would have stopped.

The roller races on the cones and underside of the lugs on all three bits experienced tapered wear, hence two measurements, designed "IN" and "OUT" are listed in the table. Figure 9 illustrates where the measurements were taken, and also gives the nominal dimensions for the 6 3/4 inch Reed M83-JA bit.

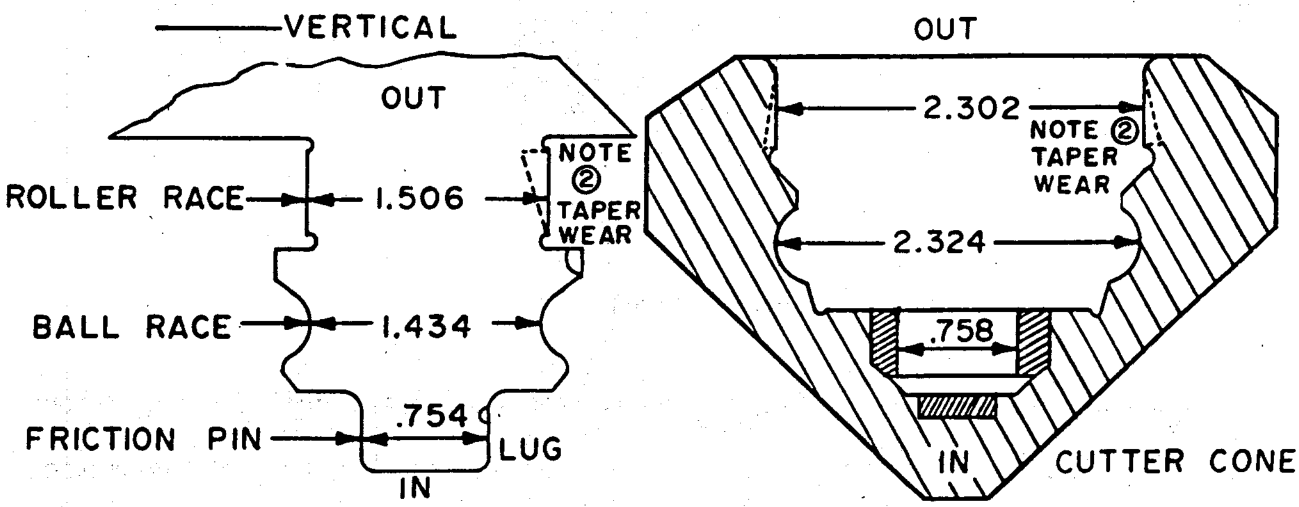


Figure 9

LOCATIONS FOR WEAR MEASUREMENTS OF TABLE 2

The most significant differences in wear between the conventional bit and the experimental bits was found in the friction-pin and roller races of the lugs. The roller races of the cones also showed significant differences. Wear of the roller races is of particular concern, since it generally results in a change of the effective "journal angle" of the cones (Figure 10).

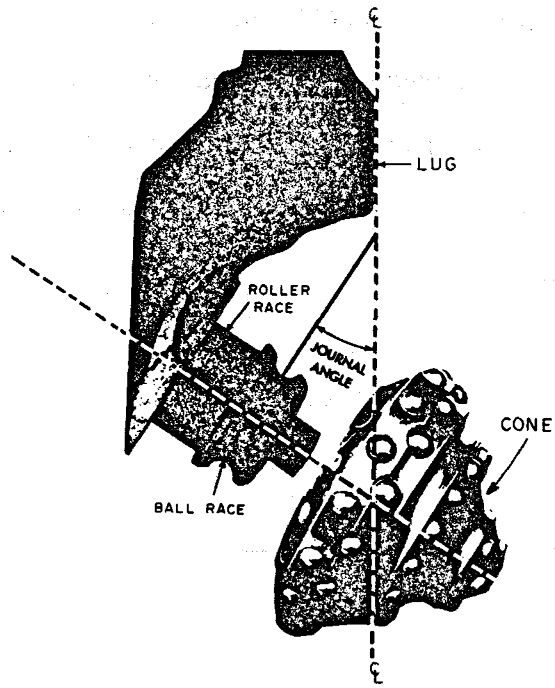


Figure 10

DEFINITION OF JOURNAL ANGLE

All but one of the failed bits recovered from geothermal drilling operations during Phase I were found to have tapered wear which resulted in a decrease in the effective journal angle; these bits also exhibited excesssive gage wear.

The journal angle must be maintained at its designed value; a decrease in this angle will result in accelerated gage wear since it decreases the angle at which the gage inserts meet the hole wall, causing shearing of the rock to take place before sufficient compressive loading can be reached to cause crushing. Crushing is preferable, since tungsten-carbide is excellent in compression, but wears rapidly in scraping applications. Thus, the tapered wear of bit "A", and the greatly reduced amount of such wear in the two experimental bits, is probably the most significant finding of these tests.* The amount of wear on the races and friction-pin of the cones of the experimental bits would probably have been less if the intended surface hardness of Rc 57-58, rather than Rc 47, had been attained. The breakage of the lug on experimental bit "G" indicates insufficient fracture-toughness for the H-13 tool steel. The implication of these test results for selection of materials for the next generation of experimental bits will be discussed under "Materials Selection for MK-III bits".

---

* It should be noted that the taper-wear experienced by the laboratory-tested bits resulted in an increase in journal angle rather than a decrease, as was the case for the field bits. This was probably due to the fact that the mild-steel pad did not support the out-thrust of the cones as well as the rock walls of an actual wellbore.

## MATERIALS SELECTIONS FOR MK-III EXPERIMENTAL DRILL BITS

A planning meeting was held at Reed Tool Company on August 9, 1977, to finalize the materials selections and heat-treat specifications for the MK-III experimental bits; the minutes of that meeting are given in Appendix A.

It was agreed that Terra Tek would provide the balls, rollers, nose bushings, and materials for the lugs, and Reed would provide the cones and carbide drilling inserts, as well as all of the manufacturing, on a no-cost basis. The program included six bits for field-testing, and two for evaluation in the Drilling Research Laboratory.

The materials selected for the MK-III bits are illustrated in Figure 11.

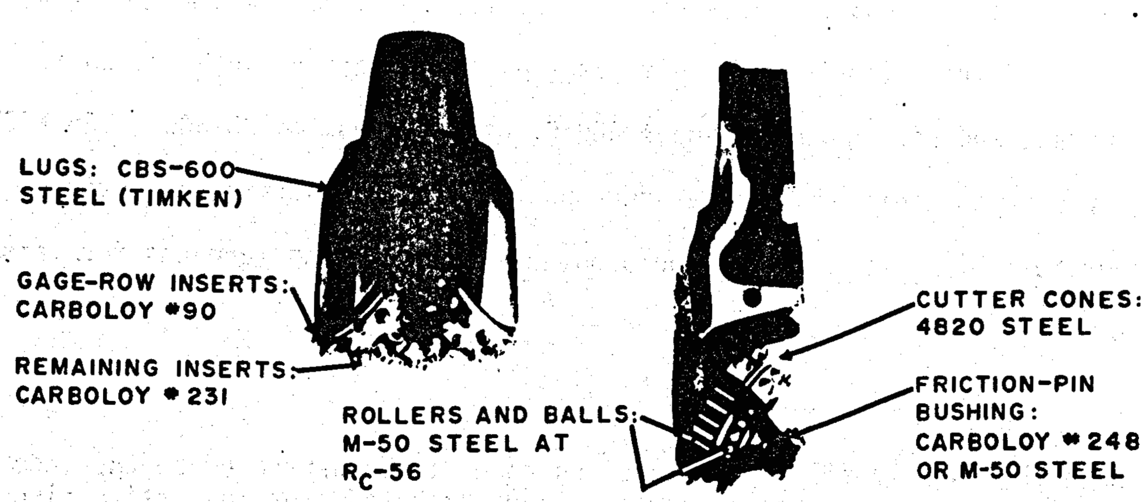


Figure 11

MATERIALS SELECTED FOR THIRD GENERATION OF EXPERIMENTAL UNSEALED BITS

*Lugs* - The selection of the steel for the lugs was considered most critical, since hardness must be maintained on the bearing surfaces*, and sufficient strength and toughness must be maintained in the core. The Timken CBS-600 provides strength levels and heat-treating properties similar to AISI 8620 steel used in conventional lugs, but retains nearly all of its hardness to at least 300°C (600°F). The composition of these, and other steels used in the program are given in Table 1.

It should be recognized that the "manufacturability" of a candidate steel is of particular importance, since geothermal bit components must be manufactured on the same production equipment as conventional bits; the present geothermal bit market is not large enough to justify large expenditures for tooling. Any candidate steel must therefore lend itself to forging, heat-treating, carburizing, and machining in a manner similar to AISI 8620 (lugs) and AISI 4820 (cones).

One steel should be given future consideration as a lug material, if the higher heat-treating costs can be justified: Vasco** X2CVM "Modified", with 0.15% carbon (Table 1). This material should offer longer retention of surface and core hardness above 300°C, as compared to CBS-600. The X2CVM requires an austenitizing temperature near 1,100°C to attain the desired properties; bit manufacturers could not utilize existing furnaces for this task.

---

* Note that nearly all wear on the lug races is concentrated on the underside, whereas the wear of the cone races is distributed over the entire circumference, an area which is roughly six times as large as the load-bearing area on the lug.

** Teledyne Vasco, Incorporated
Latrobe, Pennsylvania

The question of hydrogen embrittlement was considered, due to the presence of hydrogen-sulfide gas in many geothermal wells. A thorough investigation of the subject was made and is presented in Appendix B. The report concludes that there is no known defense against hydrogen embrittlement, other than keeping the strength of the steel as low as possible. Since brittle failure was not a common failure-mode for bits used in geothermal wells, it was concluded that strength levels in experimental steels should be held to approximately the same levels as conventional bits (at lower temperatures), to minimize risk of brittle failure.

*Cones* - The steel selected for the cones was AISI #4820, the same steel used on conventional bits. The cone wear measured on laboratory-tested conventional bits ("A", "B"[13], "E"[13], and "F"[13]) was considered less significant than the wear on the lug, balls and rollers (see Appendix "A"). In addition, it was believed that the uneven or "tapered" wear observed on the cones of these bits was primarily a result of uneven wear on the lugs; the CBS-600 selected for the MK-III lugs was expected to reduce lug roller-race wear to the low levels observed on the MK-I and MK-II bits, thereby reducing wear in the cone races to acceptable levels. Special nose bushings (see Figure 9) of full-hard M50 tool steel (four bits) and tungsten-carbide (remaining four bits) were selected to reduce wear in the friction-pin area.

*Rollers and Balls* - M50 tool steel was selected because of its excellent retention of hardness at temperature; the parts were drawn back to a hardness of Rc 56 to increase toughness. Fracture-toughness tests were run on M50 roller bearings using the Terra Tek FRACTOMETER* system. Figure 12 gives the results of these tests as well as data presented previously for M50 at Rc 64, and S2 steel used for the balls and rollers of conventional bits.

In addition, Reed Tool Company ran a test on the M50 at Rc 56 known as the "three-ball crush test", in which a stack of three balls in a tube are loaded until the center ball shatters. The ball (diameter of 12.7 mm or 0.500 inch) failed at 173 KN (39,000 pounds), which is at the lower limit of what is acceptable for the S2 balls used on conventional bits.

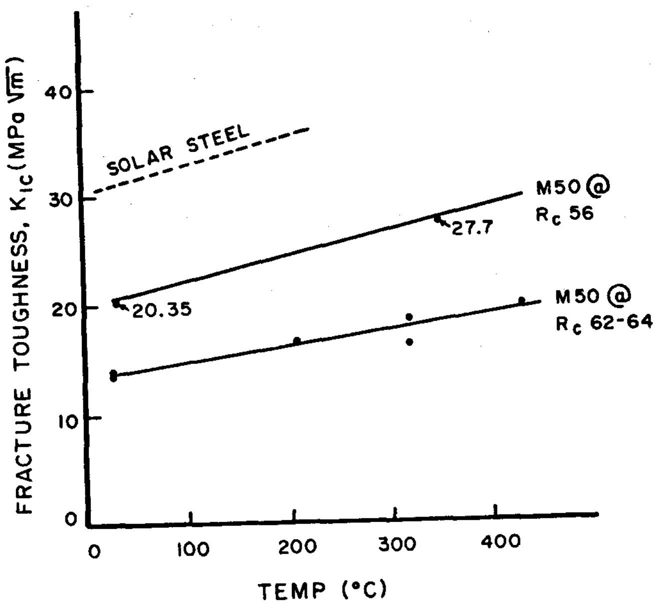


FIGURE 12

FRACTURE TOUGHNESS FOR ROLLER BEARING STEELS

*Inserts* - A harder grade of tungsten-carbide was selected for the gage-cutting inserts, since gage wear is a major problem at some geothermal drilling sites. Figure 13 gives fracture-toughness values at various temperatures, and

---

* This technique is presently being evaluated for ASTM acceptance, but a standard has not yet been issued.

hardness values at room-temperatures, for three grades of tungsten carbide.

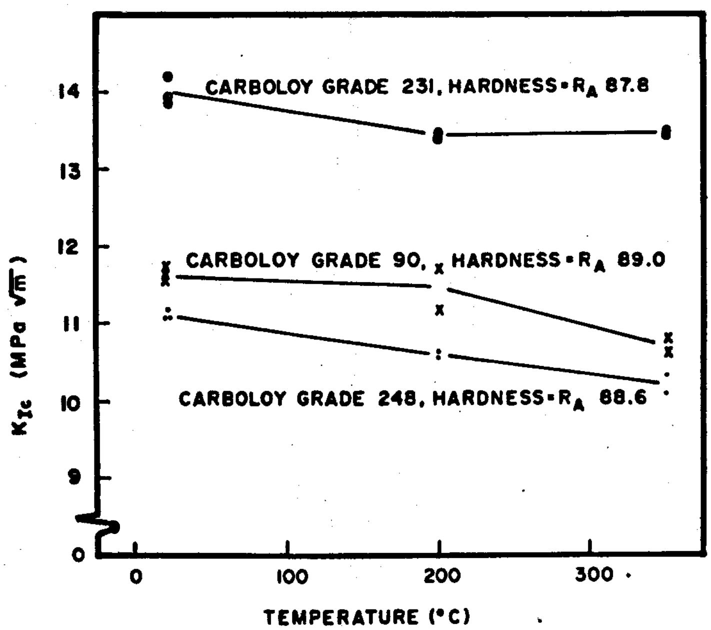


FIGURE 13

FRACTURE TOUGHNESS FOR TUNGSTEN CARBIDE COMPONENTS

Carboloy grade #231 is recommended by the manufacturer for drilling inserts, due to its high toughness. The data indicate, however, that grade #90 could provide 83% of the toughness of grade #231 at 300°C, and a significant gain of 1.2 points on the Rockwell-A hardness scale. Gage-row inserts of grade #90 may exhibit a slightly greater tendency to break, but should provide much better maintenance of hole diameter. Data are also given for Carboloy grade #248, which was used for nose-bushings for four of the eight bits; breakage of the nose bushings is not anticipated.

The two take-apart bits for laboratory evaluation, and the six welded-construction bits for field testing should be available in April of 1978.

## FACILITIES FOR TESTING MK-III EXPERIMENTAL BITS

Testing of the MK-II bits in August, 1977, (previously described) revealed a problem with the Wellbore Simulator which had gone undetected in the five tests run previously: debris from the mild-steel pad, created by the drilling action, worked back into the bearings of the unsealed bits, causing the cones to seize. The first three bits tested in the Wellbore Simulator (two MK-I experimental, and one conventional) had escaped this problem because they were periodically removed, disassembled, cleaned, and measured for wear; the cleaning apparently prevented significant buildup of debris. The wellbore simulator was equipped with a magnet to trap the debris, but this was only partially successful. An ideal system would provide circulating fluid,* but the cost of such a system at the temperatures and pressures involved would have been prohibitive.

Several meetings were held to discuss modifications to the Wellbore Simulator or other alternatives, to facilitate testing of the unsealed Mk-III bits. It was determined that the least expensive and most timely approach would be the construction of a new test station utilizing hot compressed air. The air would be supplied by a rented diesel compressor and heated by a specially constructed, gas-fired heat exchanger (Figure 14).

The system is to be used with the Drilling Research Laboratory (Figure 15), utilizing the drill tower and instrumentation system. Part of the

---

* In an unsealed bit, part of the circulating fluid is directed through the three cutters to cool and purge the bearings.

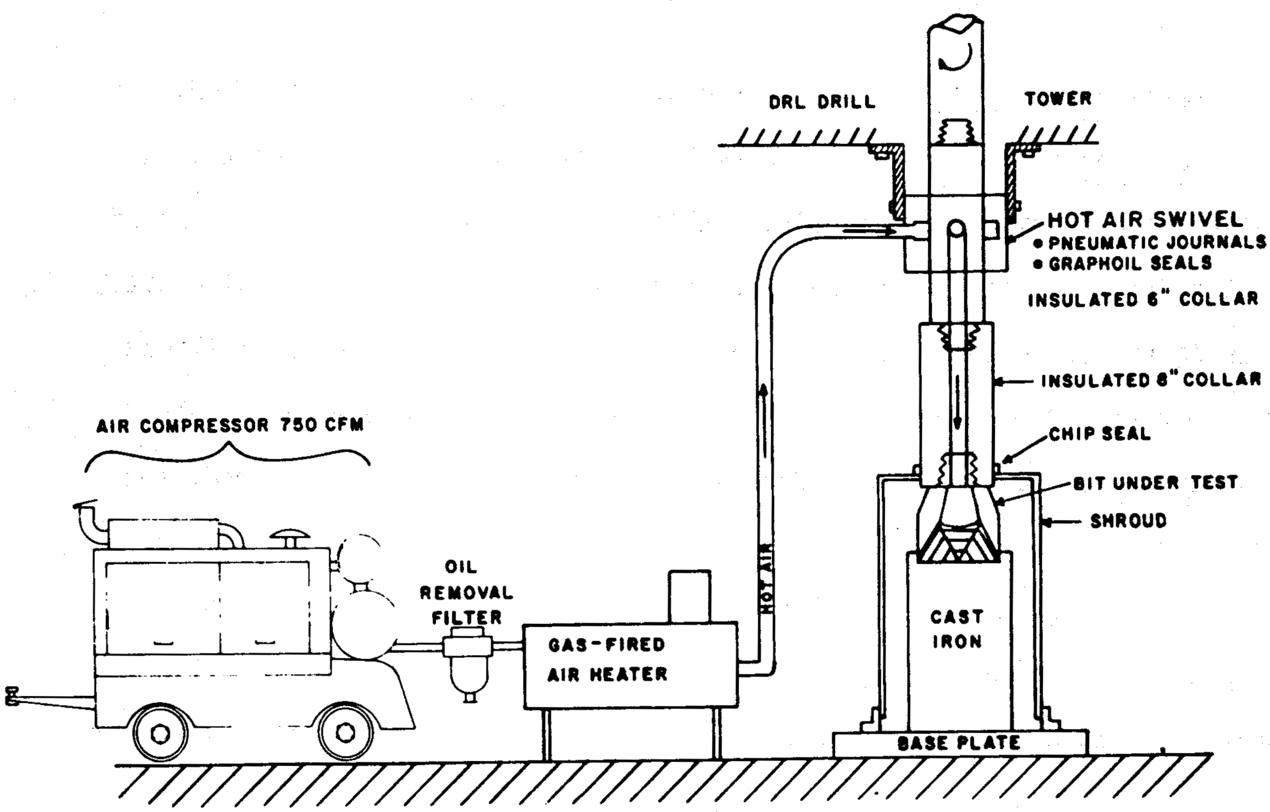


FIGURE 14
GEOTHERMAL AIR DRILLING TEST FACILITY

drill tower descends as drilling progresses, thus the hot-air swivel moves down with the shaft, and the insulated eight-inch collar gradually passes through the chip seal. The cuttings and hot air exit downward between the cast-iron billet and the shroud, and out through slots in the bottom of the shroud. Note that the required test temperature is maintained solely by the air. Rock could be substituted for the cast iron, although a lengthy test would require a great number of prepared rock samples, resulting in higher costs and necessitating frequent change-overs; cast-iron is expected to outlast granite by a factor of eight to one. Rock samples would be useful for evaluating penetration rate, specific drilling efficiency, or life of the cutting structure. The air-drilling test facility is expected to be ready for testing of the MK-III bits in April, 1978.

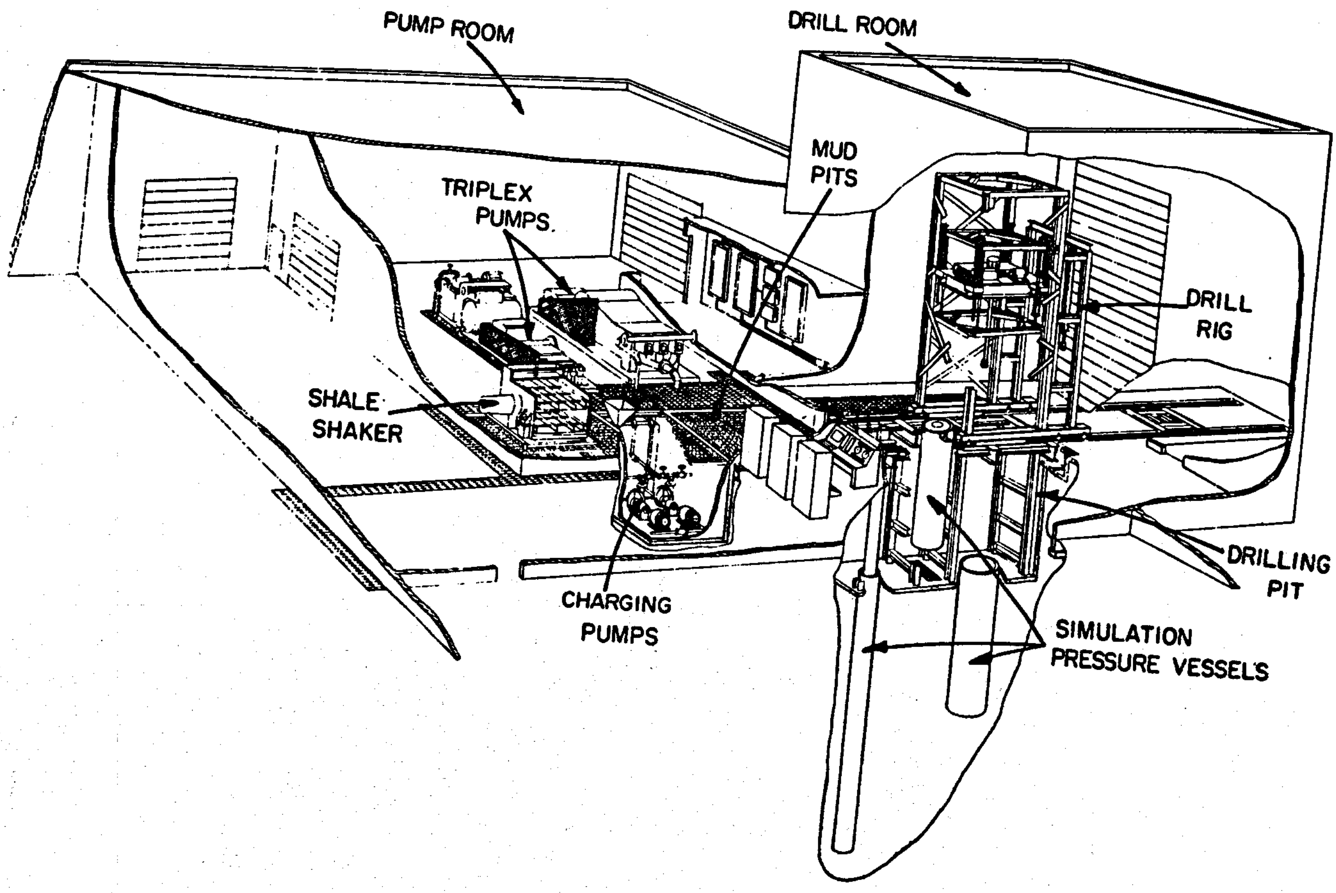


FIGURE 15

DRILLING RESEARCH LABORATORY

## The Seal Test Facility

This subject is covered extensively in reference 13, including design rationale, capabilities, testing procedures, and detailed descriptions of the hardware and instrumentation. The basic capabilities of the tester (Figure 16) are listed in Table 3.

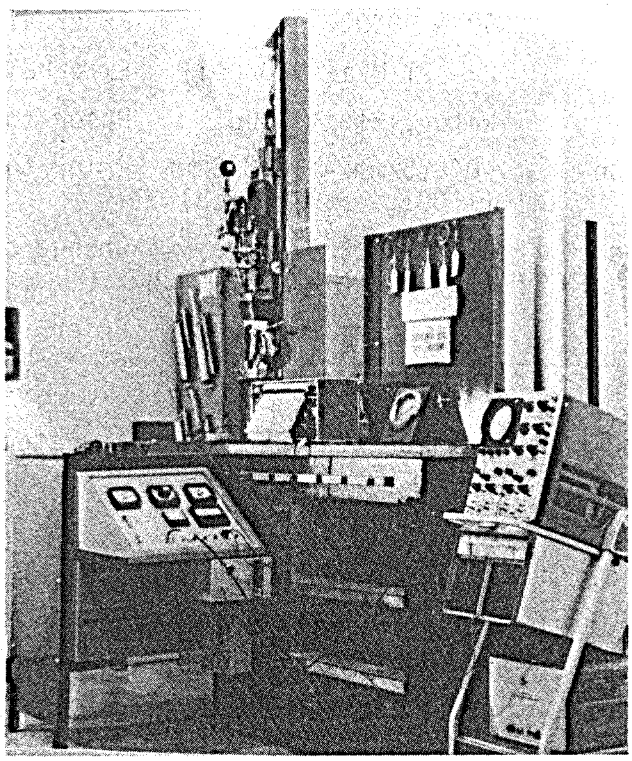

FIGURE 16
SEAL TEST FACILITY

The anticipated mechanical eccentricities encountered in drilling are accurately duplicated in the tester; these can be highly significant to seal life, expecially when abrasives are present. The pressure on both the lubricant side, and "wellbore" side of the seal can be controlled and monitored; differentials as low as 0.07 MPa (10 psi) can be observed in the presence of

TABLE 3

SEAL TESTER CAPABILITIES

| Parameter | Range | Type of Adjustment |
|---|---|---|
| Temperature | 20°C - 425°C | External |
| RPM | 50 - 2000 | External |
| Pressure | 0 - 21 MPa(3000 psi) | External |
| Well Fluid | Water, Steam, Mud | Prior to Test |
| Radial Motion | ±0.025 mm - ±0.043 mm (±.001 - ±.017 inch) | Prior to Test |
| Axial Motion | 0.08mm - 1.27mm (.003 inch - .050 inch) | Change cam |
| Abrasives | any | Prior to test |

a common 21 MPa (3000 psi) pressure. Seal failure is detected by continuous monitoring of the fluctuations in the differential pressure which are caused by the axial stroke of the drive shaft (Figure 17).

Seal Test Results

The results of the first one-hundred fifteen seal tests were reported in reference 13. These tests indicated that Viton and Buna-N were the best available high-temperature elastomeric seal materials, having a temperature limit of about 235°C and 225°C, respectively, in the standard four-hour screening test.

Most of the thirty-seven tests run in the present reporting period were life tests, which tend to be longer than the four hour screening test. The significant findings from these tests are as follows:

1. The lubricants used were found to have a large effect on seal life; the standard drill bit grease, used in most of the first 120 seal

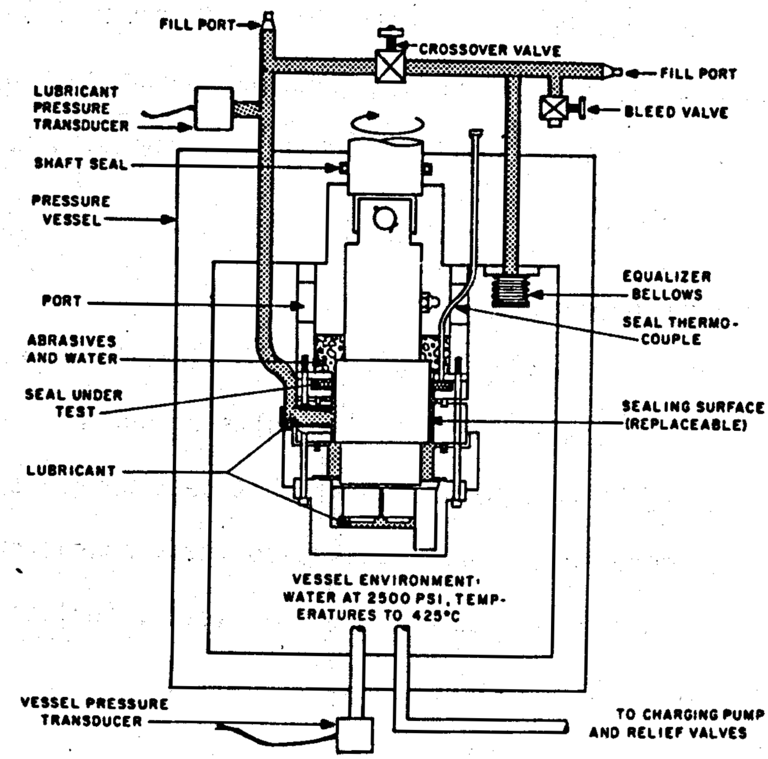


FIGURE 17

DIFFERENTIAL PRESSURE SYSTEM FOR SEAL FAILURE DETECTION

tests, was particularly detrimental to seal life at these temperatures.

2. Viton (including peroxide-cured Viton) and Buna-N remain the best elastomeric seal materials tested.

3. 200°C is the approximate maximum service temperature for these elastomers; seal lives of 50 to 100 hours were observed when a bentonite-base mineral-oil lubricant was used.

A protective coating of a teflon-like material, Parylene-C, was applied to several types of seals; this technique had proved beneficial[17] elsewhere for protecting static seals in geothermal applications. The Parylene-C can protect the elastomer from chemical attack, allowing the use of an elastomer which may have superior tensile strength at temperature, but poor chemical resistance. In all of the six tests run, the relatively thin (0.04 mm or 0.0015 inch) coating wore through at the seal interface; bonding of the coating to the elastomer was marginal. Thicker coatings and improved bonding techniques are currently being studied.

Fluoronated Polyphosphazene Rubber

*Firestone PNF-200.* This elastomer is an inorganic-backbone polymer based on a phosphorous-nitrogen group. The results of one test (#12) appeared in reference 13; although results of that test were not encouraging, it was felt that more tests were required to fully characterize the material. Table 4 gives the results of three new tests, including two Parylene-C coated seals.

TABLE 4

TEST DATA FOR FLUORONATED POLYPHOSPHAZENE ELASTOMERIC SEAL

| Test # | Temp °C | Installed Compression, % Note 1 | Stroke mm and (inches) | Wobble mm and (inches) | RPM | Lube | Abrasives yes/no Note 3 | Durometer, Shore A Before/After Note 4 | Seal Life Hours | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 200 | 6.4 | 0.25 mm (0.010 ") | ±0.18 mm (±0.007") | 90 | RRB[2] | no | 63,59/50,39 | 4:00[5] | 95% of grease-seal I.D. ruined since this test was run with a cold start - it will be repeated later with a warm start. |
| 143 | 200 | 5.5 | " | ±0.13 mm (±0.005") | " | V-70[6] | yes | 66,64/50,40 | 8:37 | Seal failure was gradual. I.D. showed definite deterioration. |
| 147 | 200 | 8.7 | " | " | " | LHT[7] | yes | 87,80/30,10 | 15:45 | Parylene coating, 0.04 mm thick. Coating disintegrated, elastomer totally degraded. |
| 148 | 200 | 6.7 | " | " | " | " | no | 85,35/60,30 | 14:45 | Parylene coating stayed on seal except on I.D. Elastomer heavily degraded on I.D. |

1. Percent compression = $\frac{\text{seal thickness - gland depth}}{\text{seal thickness}}$ X 100%, where "seal thickness" is one half of the difference between outer and inner diameter of the entire seal.
2. Conventional Reed rollerbit grease.
3. Abrasives are a mixture of repulverized Geyser's Graywacke sandstone and common feldspar sand.
4. Durometer values are given for initial reading, and after 30 seconds.
5. Fixed-interval test.
6. Valvoline 70-weight motor oil.
7. Lubriplate "Hi-Temp" bentonite-base mineral-oil by Fiske Refinery.

All of the PNF-200 seals experienced severe molecular degradation, as evidenced by the durometer shifts, and general appearance, expecially on the sealing surfaces. Figures 18, 19, and 20 illustrate the final condition of the seals tested.

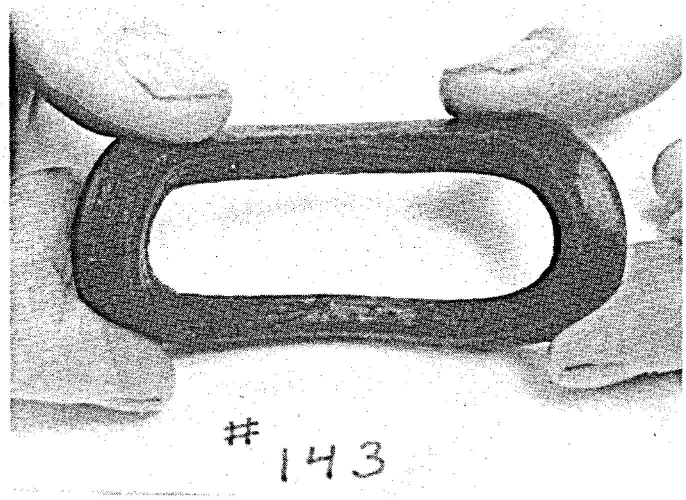


FIGURE 18

PNF-200 SEAL; 8 HRS 37 MINUTES AT 200°C USING 70-WEIGHT MOTOR OIL

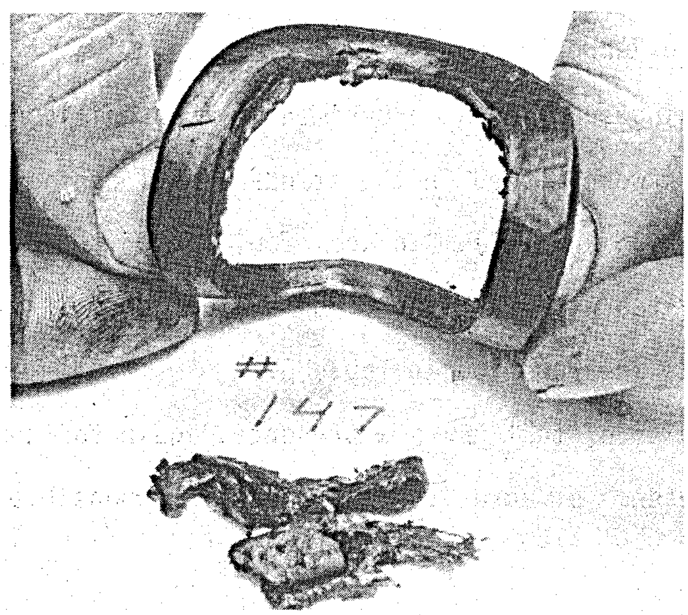


FIGURE 19

PNF-200 WITH PARYLENE-C COATING (FOREGROUND); 15 HRS 45 MINUTES AT 200°C USING BENTONITE-BASE GREASE

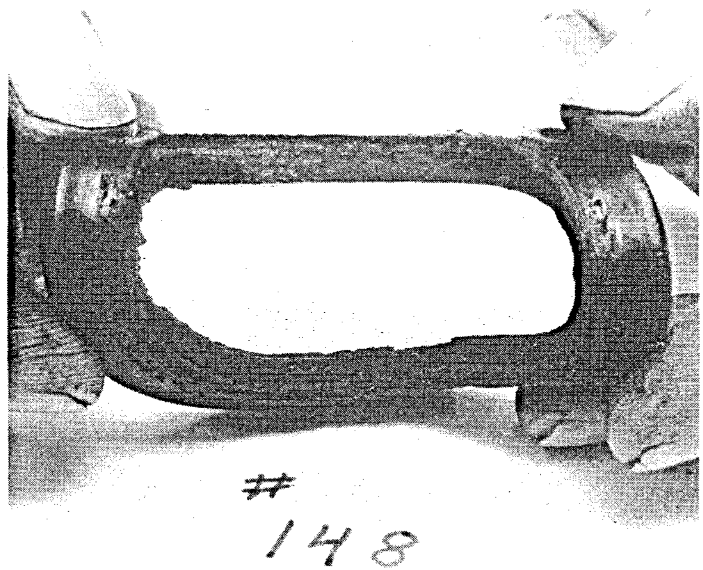


FIGURE 20

PNF-200 WITH PARYLENE-C COATING; 14 HRS 37 MINUTES AT 200°C WITHOUT ABRASIVES, USING BENTONITE-BASE GREASE

Fluorosilicone Rubber

Dow-Corning supplied an experimental fluorosilicone compound designated "TR-70"; seals were molded in the standard oval configuration, and two were tested (tests 136 and 137). In addition, one of the Parker fluorosilicone seals* was coated with Parylene-C and evaluated (test #142). The results of these tests are reported in Table 5.

The results of test #5 are presented again for comparison with test #142; the presence of abrasives is probably responsible for the shortened

---

* Results of four tests on this proprietary material were reported in Reference 13.

TABLE 5

TEST DATA FOR FLUOROSILICONE RUBBER

| Test # | Temp °C | Installed Compression, % | Stroke mm and (inches) | Wobble mm and (inches) | RPM | Lube | Abrasives yes/no | Durometer, Shore A Before/After | Seal Life Hours | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| 136 | 200 | 8.7 | 0.18 mm (0.010") | ±0.13 mm (±0.005") | 90 | V-70[1] | yes | 76,75/73,71 | 6:35 | Dow-Corning material. Seal failed due to wear at the sealing surface. Note good durometer retention |
| 137 | 200 | 8.3 | " | " | " | " | yes | " " — — | — | Dow-Corning Material. Test invalid due to equipment malfunction |
| 5 | 200 | 7.8 | 1.02 mm (0.040") | ±0.10 mm (±0.004") | 200 | L.H.T. | no | 73,67/57,53 | 4:00 | Parker Material, fixed duration test. 15% grease loss. |
| 142 | 200 | 7.8 | 0.18 mm (0.010") | ±0.13 mm (±0.005") | 90 | L.H.T. | yes | — — | 2:00 | Parker material with Parylene-C coating. Coating wore through at seal I.D., sealing surface wore out. |

1. V-70: Valvoline 70 wt. motor oil; L.H.T.: Lubriplate "Hi-Temp" bentonite grease.

life in test #142. The Parylene-C coating was not of much benefit. The comparatively favorable results of the "TR-70" in test #136, namely the six-hour life and small durometer shift, suggest that more tests should be run using the Lubriplate "Hi-Temp" lubricant, or promising candidate lubricants, located with the lubricant tester (to be discussed).

Kalrez compound #1050, Sealol Metal Bellows, and Wire-Mesh reinforced Buna-N

The results of three previous tests on wire-mesh reinforced Buna-N seals were reported in Reference 13. These seals experienced severe mechanical problems, *i.e.*, large segments of elastomer separated from the stainless-steel wire mesh. Since these seals were slightly out of tolerance due to molding problems caused by the wire, they experienced more compression than was desired. Seal test #138 (Table 6) utilized a specially modified seal carrier to provide about seven percent compression. The test lasted only twenty minutes, with pitting of the elastomer at the sealing surface, similar to that observed in previous tests.

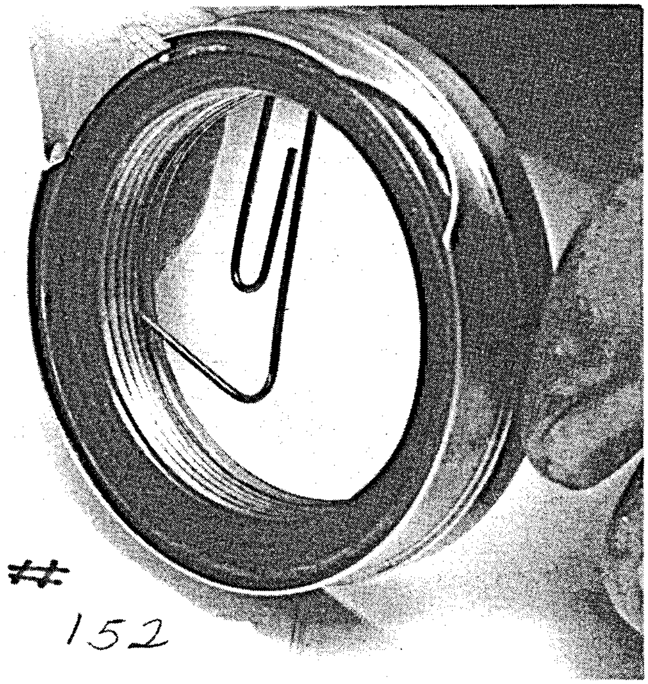


FIGURE 21

METAL BELLOWS FACE SEAL

The sealol metal bellows face-seal (Figure 21, Table 6) was a sample of a standard product provided by the manufacturer. It was tested to gain insight into the problems and capabilities of both the face-seal and the metal bellows. Since the space available in the bit is very limited, a new, highly compact metal bellows face seal would have to be developed. This test was thus required to help determine the feasibility of such a seal. The seal provided exceptionally low leakage until the bellows ruptured; since the unit tested was a reject, judgement on the bellows is reserved. The overall concept appears feasible, and work is proceding with Sealol on the joint development of a scaled-down face-seal.

TABLE 6

TEST DATA FOR KALREZ COMPOUND #1050, SEALOL METAL BELLOWS, WIRE-MESH BUNA-N

| Test # | Temp °C | Installed Compression, % | Stroke mm and (inches) | Wobble mm and (inches) | RPM | Lube | Abrasives Yes/no | Durometer, Shore A Before/After | Seal Life Hours | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| 138 | 200 | 6.9 | 0.25 mm (0.010 ") | ±0.13 mm (±0.005") | 90 | V-70 | yes | — — | 0:20 | Wire-mesh reinforced Buna-N, using specially constructed seal carrier to provide 7% compression. Seal failed due to breakdown of elastomer on I.D.; chunks of material separated, exposing wire-mesh. |
| 151 | 125 | 21.7 | " | ± 0.025 (±0.001") | 200 | Note 1 | " | 82,79/82,79 | 31:40 | Kalrez #1050 in SAE #2-329 O-ring configuration. Seal failed due to compression-set of elastomer. Degradation and abrasive wear were minimal. |
| 152 | 200 | 3.8 mm (0.150") | " | " | 90 | LHT | no | n/a | 7:00 | Metal bellows seal with carbon face-seal ring. This test was run to gain experience for handling metal bellows face-seals. Failure caused by fatigue in bellows (unit was "factory reject"). |

The Kalrez compound #1050 was tested (Table 6) in the #2-329 O-ring configuration, using an exceptionally high compression of 22%. This was done at DuPont's recommendation, to accommodate the "wobble" eccentricity, although this was reduced to ±0.025 mm. The seal life of nearly thirty-two hours indicates no major problems; the durometer was totally unaffected, and the general appearance was good (Figure 22).

DuPont has submitted two new candidate Kalrez compounds, based on the results of test #152. The new seals are in the larger oval cross-section configuration to provide more radial compliance at lower stress levels. DuPont believes that while Kalrez cannot match Viton's mechanical properties at 200°C, it should be able to provide adequate tensile strength to 290°C.

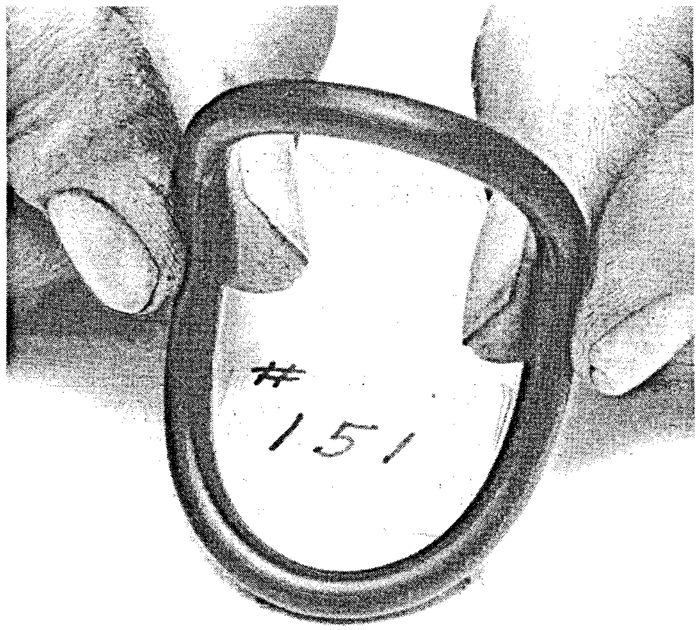


FIGURE 22

KALREZ O-RING, SHOWING COMPRESSION-SET AFTER 32 HRS AT 125°C

Buna-N. The results of forty-six tests on this elastomer, a proprietary compound formulated and molded by Parker Seal Company, were previously reported in Reference 13. The results of an additional nineteen seal tests are presented in Table 7.

Test #144 was run to check out part of the seal tester instrumentation, but it shows the detrimental effect of very high temperature. The seal was run at 200°C, using the conventional rollerbit grease, for one hour, at which time the test temperature was increased to 250°C; failure occurred in 25 minutes (Figure 23).

The seal shows signs of chemical degradation, as well as severe frictional wear (melt-flow), indicating rubber-to-metal contact due to insufficient lubrication by the rollerbit grease. Additional tests with a better lubricant

TABLE 7

TEST DATA FOR BUNA-N SEALS

| Test # | Temp °C | Installed Compression, % | Stroke mm and (inches) | Wobble mm and (inches) | RPM | Lube | Abrasives yes/no | Durometer, Shore A, Before/After | Seal Life Hours | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| 118-126 | 200 | 6.3 | 1.02 mm (0.040") | ± 0.18 mm (±0.007") | 90 | Note 1 | no | — — | — | Equipment checkout tests for refinement of seal failure detection. |
| 127 | " | 6.6 | 0.25 mm (0.010") | ±0.25 mm (±0.005") | 90 | V-70 | yes | 73,74/— — | 14:15 | Seal failed due to wear on I.D. |
| 128 | " | " | " | " | " | " | " | — — — — | 16:20 | Seal failed due to wear on I.D. |
| 138 | " | 6.9 | " | " | " | " | " | — — — — | 0:40 | Wire-mesh reinforced type. Seal I.D. experienced loss of large segments of material. |
| 139 | " | 9.4 | " | " | " | " | " | — — — — | 0:20 | Test never acted properly, cause unknown. |
| 140 | " | 8.9 | " | " | " | " | " | — — — — | 14:40 | Test terminated due to equipment malfunction. |
| 141 | " | 7.8 | " | " | " | " | " | — — — — | 14:00 | Exact time of failure uncertain due to equipment malfunction. |
| 144 | 250 | 5.5 | 0.38 mm (0.015") | ±0.18 mm (±0.007") | " | RRB | no | 67,64/71,69 | 1:40 | Seal tests started cold and run to 200°C, held at 200°C for 1 hour then increased to 250°C. |
| 145 | 200 | 5.1 | 0.25 mm (0.010") | ±0.15 mm (±0.006") | 90 | LHT | no | 69,65/75,70 | 1:00 | O-ring, SAE #2-329. Inadequate sealing, probably due to low compression, test halted. |
| 146 | 200 | 15.9 | " | ±0.13 mm (±0.006") | " | " | " | 69,65/80,70 | 13:50 | O-ring, SAE #2-329. Seal was run at 200 °C for 1 hour w0 min. then lowered to 125°C to simulate soak/run. Seal failed due to compression set. |
| 149 | 200 | 7.4 | " | " | " | LHT | ues | — — — — | 18:30 | Oval seal with 0.04 mm parylene-C coating. Coating wore through at sealing surface. Test caused exceptional wear on shaft. |

**Note 1.** Mobile - 1 synthetic oil, Dow-Corning #200 silicone oil, Valvoline 70-wt. non-detergent motor oil, and Lubriplate "Hi-Temp" grease were used for test #118-126. The motor oils tended to "crack" causing noxious odors.

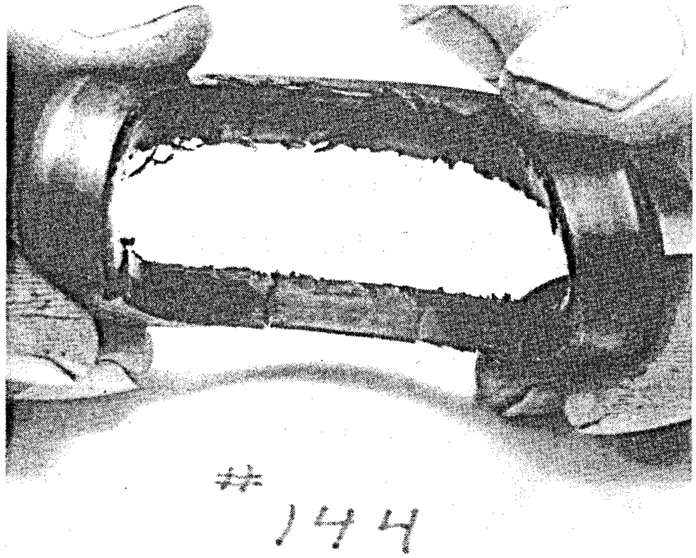


FIGURE 23

BUNA-N SEAL RUN AT 250°C WITHOUT ABRASIVES

might show some improvement in seal life, but probably nothing approaching a reasonable service life (50-100 hours) at this temperature.

Tests 127, 128, 140 and 141 indicate a life of abour 14 to 16 hours at 200°C, with abrasives, using the 70-weight motor oil. The use of the bentonite-base grease (#149) increased the life to 18 1/2 hours. This seal had a thin coating of Parylene-C, which wore through at the sealing surface (Figure 24).

The seal shows obvious signs of deterioration at the sealing surface indicating chemical degradation of the elastomer. The replaceable shaft used for this test showed excessive wear, probably caused by the Parylene-C coating holding abrasives in contact with the shaft. Hence, the coating may actually have enhanced the abrasive damage to the elastomer. The use of a lubricant which can provide adequate lubrication of the seal interface, with minimal mechanical and chemical attack on the elastomer, may permit continuous service of Buna-N at or near 200°C; interaction with the lubricant testing program is needed at this point.

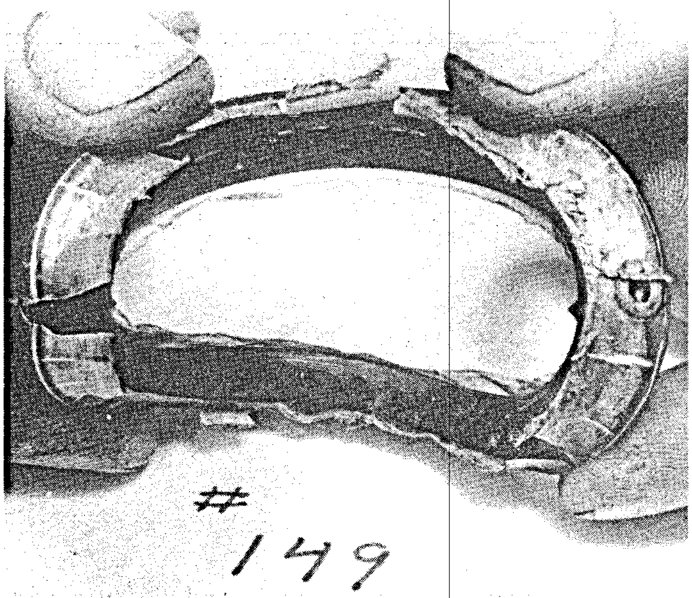


FIGURE 24
BUNA-N OVAL WITH PARYLENE-C COATING, RUN AT 200°C WITH ABRASIVES

Peroxide Cured Viton. This elastomer was recommended by the DOE/DGE-sponsored program on elastomers for geothermal applications (GEM program), under the direction of Dr. Robert Reeber, as having superior resistance to chemical degradation, when compared to Viton.

The two seals run in 70-weight non-detergent motor oil (Table 8) proved inferior to standard Viton (Table 9, tests 129-133). The use of the bentonite-based mineral oil lubricant provided a very large increase in life (test #153)

## TABLE 8

## TEST DATA FOR PEROXIDE CURED VITON

| Test # | Temp °C | Installed Compression, % | Stroke mm and (inches) | Wobble mm and (inches) | RPM | Lube | Abrasives yes/no | Durometer Shore A Before/After | Seal Life Hours | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| 134 | 200 | 8.7 | 0.25 mm (0.010") | ±0.13 mm (±0.005") | 90 | V-70 | yes | 77,74/79,76 | 4:30 | Seal failed due to wear on I.D. |
| 135 | " | 7.3 | " | " | " | " | " | 77,74/79,75 | 4:30 | Seal failed due to wear on I.D., wear pattern suggested elastomer was melting and flowing due to friction. |
| 153 | " | 7.4 | " | " | " | LHT | " | 78,76/81,79 | 53:20 | Seal failed due to degradation of elastomer, and wear. |

similar to the increase observed with Buna-N and Viton. Examination of the failed seal (Figure 26) revealed numerous small cracks indicating degradation of the elastomer; circular scaring suggests frictional wear caused by metal/elastomer contact; the durometer increased, indicating additional cross-linking (curing). The test data indicate roughly half as much life can be expected from this material, as compared to Parker #4205 Viton.

Viton. The viton seals were molded by Parker Seal Company from their proprietary blend #4205. The previously reported tests had shown this elastomer to have only a slight (10°C) advantage over Buna-N in the four-hour screening tests. Tests run during this reporting period are detailed in Table 9.

The tests run with 70-weight motor oil (#129, 130, 132 and 133) indicated seal lives which were less than those of Buna-N seals run in similar tests

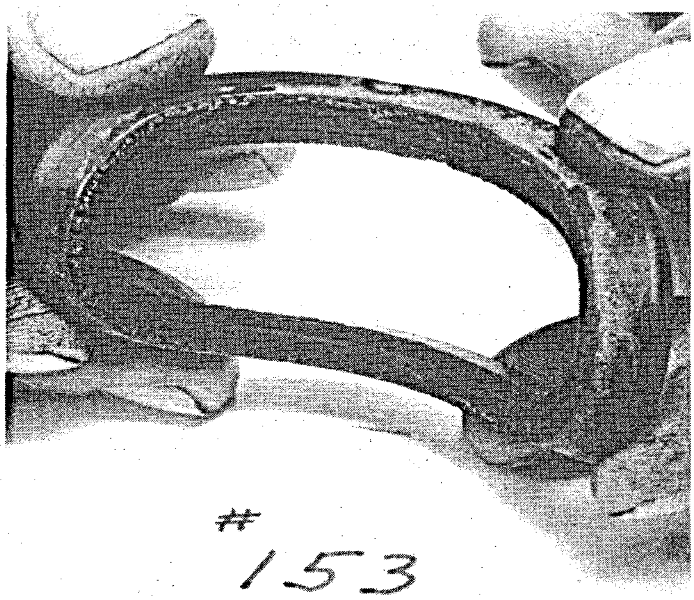


FIGURE 25
PEROXIDE-CURED VITON RUN 53 HOURS IN ABRASIVES AT 200°C

(Table 7, #127, 128, 140 and 141). One test run with the Bentonite-base grease (test #155) showed an exceptional seal life of 93 hours 30 minutes, whereas a similar test (#149, Table 7) on Buna-N resulted in a life of only 18 hours 30 minutes. The Viton seal (Figure 26) appears to have failed due to degradation of the elastomer, as evidenced by the numerous vertical cracks, which provided leakage paths.

These observations indicate that useful service life at 200°C may be attainable with Viton, if a suitable lubricant can be found. Additional tests should be run under the same conditions as test #155.

TABLE 9

TEST DATA FOR VITON SEALS

| Test # | Temp °C | Installed Compression, % | Stroke mm and (inches) | Wobble mm and (inches) | RPM | Lube | Abrasives yes/no | Durometer Shore A Before/After | Seal Life Hours | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| 129 | 200 | 6.3 | 0.25 mm (0.010") | ± 0.13 mm (±0.005") | 90 | V-70 | yes | — — | 13:15 | Seal failure due to wear*. |
| 130 | " | 5.4 | " | " | " | " | " | — — | 4:45 | Seal failed due to wear on I.D. |
| 131 | " | 7.6 | " | | | | " | — — | 1:40 | Seal accidentally subjected to 6.9 MPa (1000 psi) differential pressure, causing damage to seal and excessive leakage. |
| 132 | " | " | " | " | " | " | " | — — | 9:05 | Seal failure caused by wear |
| 133 | " | 6.8 | " | " | " | " | " | — — | 7:45 | Seal failure caused by wear |
| 150 | 125 | 19.4 | " | " | 90, 200 | LHT | no | 73, 70/80, 77 | 54:00 | O-ring, SAE #2-329. Seal run alternately at 90 RPM, changing every eight hours. Failed due to wear on I.D. Degradation was minimal due to low test temperature. |
| 154 | 200 | 7.4 | " | " | 90 | " | yes | 78, 76/82, 80 | 4:15 | Defective seal, bubble developed and ruptured on sealing surface. |
| 155 | " | 6.9 | " | " | | " | " | 77, 74/82, 80 | 93:30 | Seal began slow leak at 88 hours. Failure due to degradation and wear. |

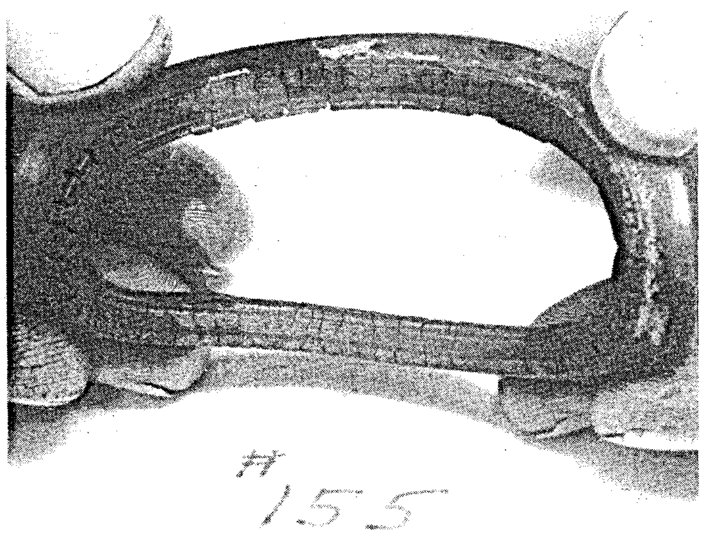


FIGURE 26

VITON SEAL RUN 93 1/2 HOURS WITH ABRASIVES AT 200°C

Conclusions. Chemical degradation of the elastomer by the lubricant, and/or insufficient lubrication of the sealing surface by the lubricant appear to have a very significant effect on seal life. Lubricants tested in the lubricant test apparatus which prove capable of supporting the high bearing loads at temperature should then be evaluated in the seal tester for compatibility with the more promising elastomers (Viton, Peroxide-cured Viton, and Buna-N). The elastomer and seal manufacturers should be consulted regarding possible beneficial modifications of the elastomer compounds, once the viable lubricants have been isolated.

## Lubricant Test Program

The program includes the construction of a unique facility (Figure 27) for the evaluation of fluid-type lubricants, such as greases, oils, and powders at temperatures to 427°C. The test utilizes a statically loaded wear block which contacts a rotating ring (Figure 28) in a pressurized (1.38 MPa, 200 psi), oxygen-free atmosphere. After 5000 turns, the wear block is removed, and the width of the wear scar is measured. The test is run in accordance with ASTM specification D 2714-68.

The candidate lubricants acquired for testing are listed in Table 10. Completion of the tester and evaluation of the candidate lubricants are scheduled for the latter half of Phase III. The tester will first be used to characterize the capabilities of conventional rollerbit greases at room temperature. The results of high-temperature lubricant tests will be evaluated based on a comparison with the low temperature performance of the grease. Promising lubricants will also be used in the seal tester to evaluate compatibility with the leading elastomers (Viton, Peroxide-cured Viton, and Buna-N).

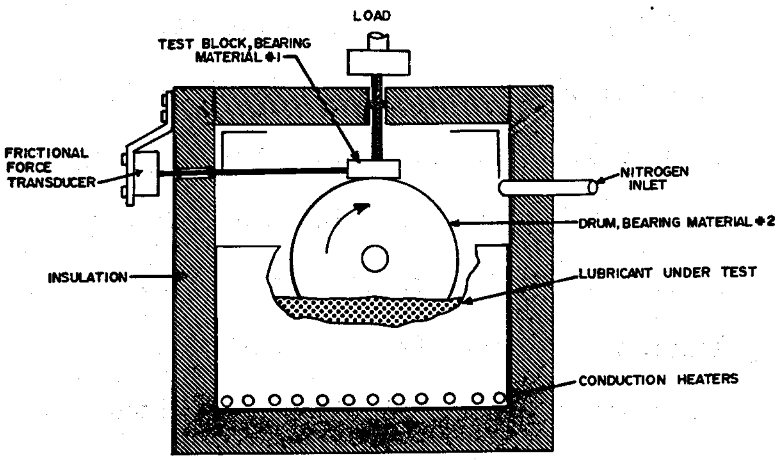


FIGURE 27 - LUBRICANT TESTER SCHEMATIC

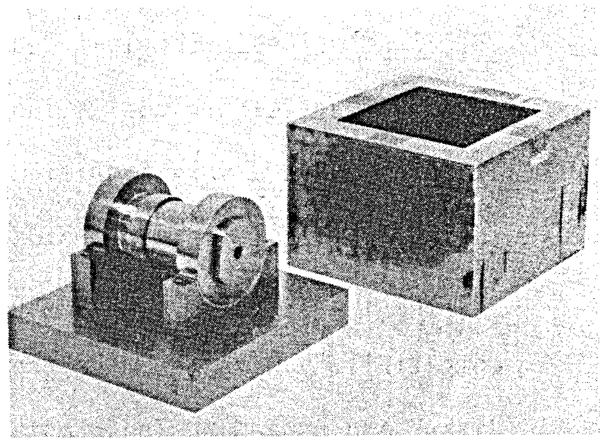

FIGURE 28 - TEST RING IN JOURNAL-BEARING RING-HOLDER, AND PARTIALLY COMPLETED PRESSURE VESSEL

TABLE 10

CANDIDATE HIGH-TEMPERATURE LUBRICANTS

| MANUFACTURER | PRODUCT |
|---|---|
| Atlantic-Richfield Co., Inc. | ARCO EP-Black Moly D |
| Dow-Corning, Inc. | #710-G Siliocne Oil with Graphite |
| Eon, Inc. | D-40 Synthetic |
| Fiske Refining, Inc. | Lubriplate Hi-Temp |
| Fiske Refining, Inc. | 604-D Hot Die Lubricant |
| Fiske Refining, Inc. | API Modified Thread Compound |
| Graphite Products Corp, Inc. | LS-11-1850 Anti-Seize |
| Graphite Products Corp, Inc. | LS-11-2100 Anti-Seize |
| Gulf Oil Corp., Inc. | 419-C Grease (Silicone) |
| Mobile Oil Corp. | Mobil-1 |
| Pacer Corp, Inc. | Pacer DH |
| Parr, Inc. | Plastilube |
| Wynn's Corporation | High-Performance Lube Supplement |
| Wynn's Corporation | Heavy-Duty Concentrate |

## REFERENCES


1. W. C. Maurer, "Patent Search and Review on Roller-Bit Bearings, Seals and Lubrication Systems," TR 75-55, Maurer Engineering, Inc., Houston, Texas (October 1975).

2. W. J. McDonald, "Temperature Distribution in Circulating Mud Columns," TR 75-67, Maurer Engineering, Inc., Houston, Texas (December 11, 1975).

3. H. R. Pratt and E. R. Simonson, "Geological Studies of Geothermal Reservoirs," TR 76-2, Terra Tek, Inc., Salt Lake City, Utah (January 1976).

4. L. M. Barker, S. J. Green, and W. C. Maurer, "Semi-Annual Report on the Project to Design and Experimentally Test an Improved Geothermal Drill Bit, Phase I," TR 76-3, Terra Tek, Inc., Salt Lake City, Utah (January 1976).

5. W. C. Leslie, "Examination of Failed Drill Bit from Geysers Field," TR 76-29, Terra Tek, Inc., Salt Lake City, Utah (February 1976).

6. L. M. Barker, S. J. Green, A. H. Jones, and M. Skalka, "Geothermal Environment Effects on Drill Bit Life," presented at the 11th Intersociety Energy Conversion Conference, Lake Tahoe, September 1976; also TR 76-19, Terra Tek, Inc., Salt Lake City, Utah (April 1976).

7. 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., August 16-20, 1976, p. 1547; also TR 76-22, Terra Tek, Inc., Salt Lake City, Utah (April 1976).

8. W. J. McDonald, "Steady-State and Transient Wellbore Temperatures During Drilling," TR 76-11, Maurer Engineering, Inc., Houston, Texas (May 1976).

9. L. M. Barker, S. J. Green, W. C. Maurer, and L. K. DeVries, "Annual Report on the Project to Design and Experimentally Test an Improved Geothermal Drill Bit, Phase I,: TR 76-32, Terra Tek, Inc., Salt Lake City, Utah (June 1976).

10. L. M. Barker and S. J. Green, "Semi-Annual Report on the Project to Design and Experimentally Test an Improved Geothermal Drill Bit, Phase II," TR 76-70, Terra Tek, Inc., Salt Lake City, Utah (December 1976).

11. W. C. Maurer, "Patent Search and Review on Insert Roller Bits,; TR 77-9, Maurer Engineering, Inc., Houston, Texas. (April 1977).

12. L. M. Barker, "A Simplified Method for Measuring Plane Strain Fracture Toughness," Engineering Fracture Mechanics, Vol. 9, p. 361 (1977).

13. R. R. Hendrickson, L. M. Barker, S. J. Green, R. W. Winzenried, "Annual Report, Support Research for Development of Improved Geothermal Drill Bits, Phase II, TR 77-44, Terra Tek, Inc., Salt Lake City, Utah (June 1977).

14. L. M. Barker, "Short Rod $K_{IC}$ Tests of Several Steels at Temperatures to 427°C," presented at the Fourth International Conference on Fracture (ICF-4), Waterloo, Canada (June 19-24, 1977).

15. R. R. Nielsen, L. M. Barker, and C. Carwile, "Geothermal Drill Bit Improvement - Speicfic Application to the Geysers," presented at the Energy Technology Conference and Exhibition, Houston, Texas, September 18-22, 1977, The American Society of Mechanical Engineers; also TR 77-17, Terra Tek, Inc., Salt Lake City, Utah.

16. R. R. Hendrickson, C. Carwile, L. Matson, and R. W. Winzenried, "Seals for Geothermal Roller Drill Bits," presented at the Energy Tehcnology Conference and Exhibition, Houston, Texas, September 18-22, 1977, The American Society of Mechanical Engineers; also TR 77-49, Terra Tek, Inc., Salt Lake City, Utah.

17. C. Arnold Jr., "Development of Environmentally Resistant Elastomers for Deep Oil/Gas Wells," status report to DOE Geothermal Elastomeric Materials Program (June 1977).

APPENDIX A

# TerraTek

September 20, 1977

Mr. Jon H. Barnette
Drilling Research Division
Geothermal Energy Technology Dept.
Sandia Laboratories
P.O. Box 5800
Albuquerque, NM 87115

Dear Jon:

This letter is intended to summarize the program review meeting on the ERDA/DGE Geothermal Drill Bit contract, E(10-1)1546, held at Terra Tek on September 7th, 1977, and should also serve as this month's progress letter.

Attendees:

| | |
|---|---|
| Jon H. Barnette | Sandia Laboratories |
| Harry L. Mauzy | Reed Tool Company |
| Larry Matson | Maurer Engineering |
| Lynn M. Barker | Terra Tek, Inc. |
| Robert R. Hendrickson | Terra Tek, Inc. |
| Bruce J. Sakashita | Terra Tek, Inc. |
| Richard W. Winzenried | Terra Tek, Inc. |
| Prof. William C. Leslie | University of Michigan, Consultant to Terra Tek |
| Paul J. Garmus | The Timken Co. (non-participating) |

The meeting opened with Jon Barnette giving a brief overview of Sandia's role as contract monitor for ERDA/DGE. I then reviewed the progress made during the year on the major tasks of the contract.

Dick Winzenried gave a detailed analysis of the drill-bit tests run in the geothermal wellbore simulator. These included the MK II bits run in August, and two conventional bits run last April. The two bits tested in April were run at intermediate geothermal temperatures of 300°F and 450°F, at loads of 20,000# for two hours and 25,000# for two hours. The bit tested at 450°F experienced severe wear but did complete the test sequence. The bit run at 300°F completed the 2 hours at 20,000# but locked up after 40 minutes at 25,000#. Upon analysis, it was discovered that the wall between the ball race and roller race had broken, and the chips had jammed the rollers, causing the cone to seize. This was most likely caused by excessive axial force on the ball race, since the back (outside) edge of the



UNIVERSITY RESEARCH PARK · 420 WAKARA WAY · SALT LAKE CITY, UTAH 84108 · (801) 582 2220

cutter cone is unsupported by the steel pad, but would receive some support from the outer wall of the hole in an actual drilling situation. Reed Tool said that this raceway breakage was one of the more common drill bit failure modes. The next test sequence was run in August, and consisted of two MK II research bits and one conventional bit. To avoid the raceway breakage problem, these bits were given a one hour progressive break-in sequence. This was intended to wear a pattern into the pad which would provide more support for the cone, and hopefully alleviate some of the axial thrust on the ball raceways. The first bit tested was a MK II experimental which locked up after two hours at 25,000# at 316°C. It was originally hoped that each bit could be run for six hours. The second bit run was a conventional unit; in view of the lockup of the first bit, the load was reduced to 20,000#. This bit was run five hours, but examination of the bit and the torque graph indicated that intermittent locking of the cones may have been taking place for the last two hours of the test. The final test was the second MK II bit, which seized after one hour and 45 minutes at 20,000#. It is now believed that these premature failures were caused by the lack of circulating fluid in the wellbore simulator, which allowed internally generated wear debris to jam in the roller raceways. Proposed modifications to the tester are covered later in this report. Wear analysis of the three bits revealed results similar to the MK I tests last November; roughly one-fifth to one-tenth as much wear on the research bit as on the conventional bit.

Bill Leslie reviewed the materials selected for the third generation of research drill bits. These were decided upon at a meeting between Reed Tool and Terra Tek on August 9th at Reed Tool in Houston. This subject is best summarized by my letter to Bill Schumacher dated August 18th (copy attached), since we are holding almost exactly to those selections. The most significant decision was the selection of Timken CBS-600 steel for the lug material. This material was selected after a detailed analysis of the hydrogen sulfide embrittlement problem by Prof. Leslie and myself; I have attached a copy of our letter to Cliff Carwile, dated September 7th, which details our findings. This steel should be capable of supplying the hot hardness, fracture toughness, and resistance to hydrogen embrittlement that is required.

Lynn Barker reviewed the fracture toughness program at Terra Tek and outlined his proposed tests for the materials to be used on the MK III drill bits. These include fracture toughness tests on the M50 roller bearings, the tungsten carbide for the gage row inserts, the carbide for the other drilling inserts, and the carbide for the pilot bushing. Fracture toughness tests are also planned for the CBS-600 alloy which will be used for the MK III lugs and 8620 steel which is used for conventional lugs. Due to their high toughness, these tests may not be entirely valid as a true measure of $K_{Ic}$, but should provide good data on the relative toughness of the two steels.

Dick Winzenried reviewed the current status of the seal tester. The most significant development came early this summer when Dick perfected a technique for detection of seal failure. The tester continues to operate reliably, and over 140 seal tests have been run to date. The results of 17 "test-to-failure" seal tests were discussed. These tests were run at 200°C, and show Buna-N to be slightly better than Viton, whereas earlier tests at 235°C had shown Viton to have a slight advantage over Buna-N. Since this temperature region is still inadequate for geothermal applications, it was agreed that future testing should move almost exclusively to the heterogeneous sealing systems. (Some testing will be done on Kalrez and paralene-coated seals.)

Larry Matson of Maurer discussed the current status of some of the heterogeneous sealing concepts, and outlined plans for new seals. Terra Tek will continue work on materials for its "Spider" face seal, testing of the Sealol metal bellows face seal, and possible testing of the Parker "Geopak" seal. The Parker "Geopak" will utilize a "Vespel" plastic (polyamid-imid) lip seal driven by a metal spring; Parker is experiencing delays with their molding equipment, however, and the "Geopak" is not the first seal in line for fabrication once production is put "on line".

R. Hendrickson reviewed the geothermal lubricant tester. This is a block-and-ring tester similar to the Alpha LFW-1, but designed for service to 800°F. It is exactly as described in the proposal for this year's contract. At the present time there is very little information on lubricant performance at temperatures much above 400°F, and very little consensus from lubricant experts on how extensive a problem H.T. lubrication will be. Completion and operation of the tester is scheduled for November.

The final discussion centered around proposed modification to the geothermal wellbore simulator. Design changes had been initiated prior to the MK II bit tests to increase the simulator's capacity from 6-3/4" out to 8-3/4" so that two of the MK III bits could be lab-tested prior to taking the remaining six to the Geysers for testing. However, the MK II bit tests, with their frequent cone lockups, indicated that some form of fluid circulation is needed to flush wear particles from the bit. This is a formidable engineering task which we are now working on. The most promising solution discussed so far would utilize a positive-displacement pump inside the vessel (such as a gear pump) driven by the drill shaft.

The pump would draw water in through a porous bronze filter and down through the lugs to provide the flushing action. This, coupled with the one hour wear-in procedure, should allow long duration geothermal well-bore simulation tests.

The following conclusions and agreements were reached prior to the close of the meeting.

1. Reed Tool would provide Bill Leslie with drawings of the pilot-pin bushing for both the tungsten carbide and the tool-steel versions of the MK III bits. (Bill informs me these have been received, and he is proceeding with the purchase of thirty of each type.)

2. Harry Mauzy would look into having Reed do a complete inspection on all drill bits to be run in the field tests: both the research type and conventional units. (He has since informed me that Reed would inspect, i.e. measure, the research bits, but that they need a firm order for the conventional bits from Union Oil before considering inspection of those.)

3. Bill Leslie will procure three types of carbides, probably G.E. #'s 248, 90 and 231 for fracture toughness testing by Lynn Barker of Terra Tek. These are the grades to be used in the gage row inserts, pilot bushing, and other rows of drilling inserts.

4. Larry Matson will do a detailed investigation into the face seals currently on the market, with the goal of adapting them for high-temperature service. Larry also agreed to get some exact specifications from Reed on the maximum amount of space that can be usurped from the rest of the drill bit, should the need arise.

5. Dick Winzenried agreed to pursue modifications to the seal tester which would include a system for bearing purge action, as well as enlargement to the 8-3/4" size.

6. Lynn Barker agreed to do fracture toughness tests at temperature on three samples of tungsten carbide. In addition, Lynn agreed to attempt a measurement of the core toughness of the CBS-600 steel, providing that Bill Leslie could provide three samples of at least 2" diameter x 3" long. Bill also agreed to prepare the samples to the proper heat treat in his lab.

7. Jon Barnette requested that Terra Tek provide him with a monthly progress letter rather than a bimonthly report. (I have discussed this with Sid Green, and we will now provide a monthly letter.)

Sincerely,

Robert R. Hendrickson/jlg

Robert R. Hendrickson
Project Engineer

RRH/jlg

Enclosures: Letter to P. W. Schumacher, 8-18-77
Letter to C. Carwile, 9-7-77

cc: C. Carwile, ERDA
M. M. Newsom, Sandia
W. C. Leslie, University of Michigan
Dewey Thiessen, Reed Tool
P. W. Schumacher, Reed Tool
Terry Mayo, Reed Tool
Harry Mauzy, Reed Tool
S. J. Green, Terra Tek
A. H. Jones, Terra Tek
L. M. Barker, Terra Tek
B. J. Sakashita, Terra Tek
R. W. Winzenried, Terra Tek

APPENDIX B

TerraTek

September 7, 1977

Mr. Clifton Carwile
Project Manager
Exploration Technology Branch
Energy Research and Development
Administration
20 Massachusetts Ave., N.W.
Washington, D.C. 20545

Subject: Hydrogen Sulfide Embrittlement

Dear Cliff:

Prior to selecting the steels for the third-generation drill bits, a thorough investigation was made into the nature of hydrogen embrittlement as it relates to oilfield products in general, and geothermal bits in particular. This was in response to questions raised by Bob Reeber of ERDA, and several people from the drilling industry. We talked with Prof. A. R. Troiano of Case Western Reserve, and also with key people in the metallurgical departments of three of the bit manufacturers.

We have studied two recent comprehensive reviews of hydrogen embrittlement in steels.[1,2] Although it must be clearly recognized that no high-strength steel is immune to hydrogen embrittlement, we have selected steels that have no history of such embrittlement when used in drill bits.

## The Basic Problem

There is no general agreement in the metallurgical community as to the exact mechanism or mechanisms of hydrogen embrittlement. It is, however, generally agreed that the process is greatly accelerated if the $H_2S$ is dissolved in water. Since this allows the hydrogen ions to dissociate from the sulphur, the hydrogen ions or "atomic hydrogen" can then freely penetrate

---

1. C. S. Carter and M. V. Hyatt, "Review of Stress-Corrosion Cracking in Low-Alloy and Low-Strength Steels," Proceedings Firming Conf., Stress Corrosion Cracking and Hydrogen Embrittlement of Iron Base Alloys, June, 1973.

2. I. M. Bernstein and A. W. Thompson, "Effect of Metallurgical Variables on Environmental Fracture of Steels," Int. Met. Rev., 21, p. 269, 1976.



UNIVERSITY RESEARCH PARK · 420 WAKARA WAY · SALT LAKE CITY, UTAH 84108 · (801) 582 2220

the crystal lattice of the steel. One theory holds that the atomic hydrogen collects in micro-voids within the steel, where it recombines to form diatomic hydrogen, i.e. $H_2$ gas, thereby producing a localized stress and perhaps initiating a crack. The embrittlement problem increases as the stress on the steel increases, and is known to be worse in steels lacking in fracture toughness.

## Prevention

In oil and gas well drilling, $H_2S$ is a frequent problem which is usually controlled with mud additives. According to John Day of Maurer/MudTech, the usual choice is a mixture of zinc chromate or sodium chromate in combination with zinc oxide or zinc carbonate. Typical concentrations of these additives are about 500 ppm by weight. This approach points up the fact that there is no effective way to create a barrier to hydrogen. There is no known electroplate, dip, impregnation or other coating that will stop hydrogen diffusion and which is also reasonably resistant to shock and abrasion; glass and thick rubber coatings provide some protection, for example. Hydrogen embrittlement can be minimized by controlling metallurgical variables. The residual stress pattern induced by carburizing results in parts which are less susceptible to embrittlement: the case is in compression, whereas the embrittlement crack usually originates in an area of tension. Fine grain size and a tempered martensite structure are beneficial; these are always present in conventional drill bit steels.

Coating amines may be used as additives when drilling with mud or air. In mud, the coating action of the amines provides some protection from hydrogen diffusion to the drill pipe and casing. When used with air drilling, its primary function is to surround the abrasive cuttings, thereby reducing abrasion of the tool joints and casing by the cuttings as they leave the well. For example, a Union Oil product known as Unisteam is injected into the drilling air at the Geysers geothermal wells. According to Delbert Pyle of Union, Unisteam does contain amines and should provide some $H_2S$ protection for the drill pipe and casing, in addition to reducing abrasion. However, amines cannot provide significant protection for the drill bit due to the constant scraping, whether drilling with mud or air.

## Mitigating Factors

Although true geothermal drilling muds are not yet available, the MudTech division of Maurer Engineering is developing this technology. Larry Reamont, head of the MudTech group, states that zinc chromate, sodium chromate, zinc oxide and zinc carbonate chemistry should work well at geothermal temperatures for the neutralization of hydrogen sulfide.

The primary concern, therefore, is the air-drilled geothermal well. There are two factors here that work to our advantage. First, the drill bit is only exposed to steam as it passes through a steam entry point, or when tripping, since the drilling air provides a constant purging action. Secondly, the $H_2S$ embrittlement problem usually decreases with increased temperature (although it is uncertain as to whether this is due to the greater mobility of hydrogen, or to an increase in the fracture toughness of the steel). Brittle failure of drill bits at the Geysers has been almost non-existent, according to Kelsey Lumen of Union Geothermal.

## Materials Selection

The bit components exposed to the wellbore fluids are the cones and lugs. Of these two, the lugs are generally more prone to cracking. The material selected for the MK III drill bit cones is 4820 steel. Since this material has been used extensively at the Geysers, no problems are expected from the cones. The lug material selection was more critical, since greater retained hardness is needed at temperature in order to reduce bearing wear. Thus, the material selected had to have fracture toughness equal to or greater than that of the conventional 8620 steel. The material selected is Timken CBS-600, which, according to C. F. Jatzcak of Timken, should meet these goals. The CBS-600 should allow a retained case hardness of $R_c58$ at 600°F, but with a core hardness in the area of $R_c30$. The lug steel used on the MK I and MK II drill bits, H13 tool steel, could not provide nearly as wide a core/case differential.. Vasco X2CVM carburizing steel (also considered) had hardnesses of about $R_c58$ case/$R_c50$ core, although its retained hardness is better than CBS-600 at 800°F. The core hardness of 8620 steel is about $R_c25$ at room temperature. Unfortunately, it is difficult to make fracture toughness measurements on steels as tough as 8620 or CBS-600; the required sample size is too large. Lynn Barker of Terra Tek has indicated that he may be able to devise a test that can at least provide relative fracture toughness measurements for 8620 versus CBS-600, at temperature.

We therefore conclude that the MK III drill bits should be no more susceptible to embrittlement failure than conventional bits, when run at the Geysers at typical loads of 25,000#-35,000#. It is hoped that fracture toughness data, to be generated at Terra Tek, will show the toughness of CBS-600 relative to 8620 steel. If CBS-600 is tougher in the temperature range of interest, we would then probably recommend that the bit load be increased to the neighborhood of 40-45,000 pounds in order to attain the higher penetration rates that these bits are capable of, as exhibited in non-geothermal applications.

Sincerely,

Robert R. Hendrickson
Project Engineer
Terra Tek, Inc.

Prof. William C. Leslie
Consultant to Terra Tek
University of Michigan

RRH-WCL/jlg

cc: J. Barnette,Sandia Laboratories
M. M. Newsom, Sandia Laboratories
W. C. Maurer, Maurer Engineering, Houston
L. Reamont, Maurer Engineering, Houston
S. J. Green, Terra Tek
A. H. Jones, Terra Tek
L. M. Barker, Terra Tek
R. W. Winzenried, Terra Tek
B. J. Sakashita, Terra Tek