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SEAL/LUBRICANT SYSTEMS FOR GEOTHERMAL DRILLING EQUIPMENT

R. R. Hendrickson
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Terra Tek, Inc.

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ABSTRACT

The paper describes the development and testing of seals and lubricants for journal-type roller-cone rock bits for drilling into geothermal reservoirs at temperatures over 260°C (500°F).

The conditions experienced by seals and lubricants subjected to geothermal drilling are reviewed along with the basic design requirements for roller-cone bit seals and journal bearing lubricants. Two unique test facilities are described: a seal test machine which simulates pressures, temperatures, and mechanical eccentricities, and a lubricant tester capable of evaluating load-bearing ability at temperature and pressure.

Three candidate elastomeric compounds demonstrated 288°C (550°F) capability and several others demonstrated 260°C (500°F) or greater capability. Successful elastomeric seal candidates were proprietary compounds based on EPDM, Kalrez, and/or Viton polymers. Three mechanical seals for reservoir temperatures over 288°C (550°F) are presented. Lubricant screening tests on more than 50 products are summarized, and several newly developed lubricants which meet both the compatibility and lubrication requirements are described.

Several seal/lubricant systems are recommended for laboratory or field geothermal drilling tests in roller-cone drill bits. The future availability of drill bits for geothermal use is discussed, as well as the potential spin-offs of the program findings for nongeothermal roller-cone bits.

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CONTENTS

	<u>Page</u>
Introduction	9
Seal and Lubricant System Performance Goals and Design Criteria	12
Seal Development	17
Lubricant Testing and Development	26
Conclusions	30
Acknowledgements	31
References	32

ILLUSTRATIONS

<u>Figure</u>		
1.	Roller-cone rock bit.	10
2.	Temperature model for a hydrothermal well.	12
3.	Section of one lug/cone set of 200 mm (7-7/8 inch) journal bearing rock bit.	14
4.	Geothermal seal test machine.	17
5.	Detailed view of a typical elastomeric seal test.	18
6.	Lug simulator with replaceable sealing surface and jogger mechanism.	19
7.	The trip-in simulation seal test.	21
8.	The Fluorcarbon, Inc. radial lip seal, style RP.	22
9.	Face seal with elastomeric side seal installed in a journal-type bit.	23
10.	Force-deflection characteristics of two spring systems for the face-seal system.	24
11.	The all-metal face seal.	25
12.	Terra Tek high-temperature lubricant test facility.	27
13.	Lubricant tester schematic diagram.	27

TABLES

Table		<u>Page</u>
I	Geothermal Borehole Temperature Calculations	13
II	Seal Tester Capabilities	18
III	Recent Seal Test Results	21
IV	Stress-Relaxation at Temperature for Five Common Spring Alloys	24
V	Load Carrying Capacity of Eight Commercially Available Lubricants at 316°C and 0.70 MPa	28
VI	Load Carrying Capacity of Four Commercially Available Lubricants at 204°C and 0.70 MPa	28
VII	Load Carrying Capacity of Five Lubricants Developed for Geothermal Rock Bits	29

INTRODUCTION

In oil, gas, and geothermal drilling the overall well cost can be substantially reduced by using bits with longer life, primarily due to the saving of rig time otherwise wasted in tripping to replace the bit. This is particularly true where per diem costs are high as in deep wells, off-shore drilling, and most geothermal drilling. Two of the most significant advances in life expectancy for roller-cone bits were (a) the introduction of sealed, lubricated roller bearings in 1959, and (b) the development of journal bearings in 1967.

Because conventional seals and lubricants are limited to relatively low temperatures, sealed bits cannot be used in many geothermal reservoirs due to the high bottom-hole temperatures. Drilling must be done with the much older unsealed bit technology. The D.O.E. Division of Geothermal Energy therefore initiated a program to improve the temperature capabilities of seals and lubricants for roller-cone bits to facilitate their use in exploration and development of the nation's geothermal energy.

Conventional sealed journal-type roller-cone rock bits (Figure 1) are restricted almost exclusively to fluid-drilled wells, because of temperature limitations for the seals and lubricants, and because of the limited cooling provided when air, mist, or light foams are used as the circulating fluid. Most, if not all, of the rock bit manufacturers have recently increased research and development on seals and lubricants with improved temperature capability in response to four important market factors:

Figure 1. Roller-cone rock bit.

- (1) One manufacturer has introduced a line of sealed bits with increased penetration rate, made possible by seals which permit rotational speeds in excess of 120 RPM (60 RPM is generally recommended for conventional sealed bits).
- (2) A sealed roller-bearing bit was recently introduced for blast-hole (air) drilling in hard formations such as taconite.
- (3) Downhole mud motors require bits that can operate at 300 RPM or greater.
- (4) Deep oil and gas drilling frequently involves formation temperatures over 200° (392°F).

The geothermal applications of immediate interest are similar to the fourth nongeothermal application above, but may involve formation temperatures to 350°C (662°F).

The nongeothermal applications are mentioned because they provide the economic incentive for the production of sealed bits suitable for geothermal drilling. Seal designs which do not require changes to existing lug or cone configurations are preferable.

SEAL AND LUBRICANT SYSTEM PERFORMANCE GOALS AND DESIGN CRITERIA

The primary objective is for a system which will provide 100 hour life for fluid-drilling of 350°C (662°F) formations.¹ The capability to drill 175°C (350°F) formations at 300 RPM is sought, in conjunction with a related D.O.E. program for geothermal mud motors.² Foam or air drilling of 300°C (572°F) reservoirs is also required. Two important conclusions can be made at this point:

- (1) The design goals require mechanical seals since elastomers cannot withstand 350°C (662°F), and,
- (2) Elastomeric seals should be pursued since they do not require changes to bit design, and therefore have the best chance of commercialization.

Fortunately, in fluid-drilled wells the bit is exposed to the full formation temperature only when circulation is absent, such as when "tripping". The cooling provided by the drilling fluid was characterized by a previous study,³ and a typical time-temperature relationship is shown in Figure 2. The highest steady-state circulating bottom-hole temperature noted in this study was 175°C (348°F). Several simulations are detailed in Table I.

Figure 2. Temperature model for a hydrothermal well.

TABLE I
GEOTHERMAL BOREHOLE TEMPERATURE CALCULATIONS

CASE NUMBER	DEPTH, METERS (FEET)	STATIC BOTTOM-HOLE TEMPERATURE °C (°F)	CIRCULATION RATE $l s^{-1}$ (GPM)	GEOTHERMAL GRADIENT °C/km (°F/100 ft)	CIRCULATING BOTTOM-HOLE TEMPERATURE °C (°F)	INLET TEMP. °C (°F)	OUTLET TEMP. °C (°F)
1	1524 (5,000)	260 (500)	12.6 (200)	153 (8.4)	68 (154)	57 (135)	69 (157)
2	" "	" "	25.2 (400)	" "	" "	" "	66 (151)
3	3048 (10,000)	" "	12.6 (200)	76.6 (4.2)	126 (258)	" "	81 (178)
4	" "	" "	25.2 (400)	" "	124 (255)	" "	75 (167)
5	1524 (5,000)	400 (750)	12.6 (200)	244 (13.4)	76 (169)	" "	80 (176)
6	" "	" "	25.2 (400)	" "	" "	" "	73 (164)
7	3048 (10,000)	" "	12.6 (200)	122 (6.7)	176 (348)	" "	101 (214)
8	" "	" "	25.2 (400)	" "	173 (344)	" "	91 (195)
9	1524 (5,000)	260 (500)	25.2 (400)	153 (8.4)	62 (144)	" "	73 (163)
10	3048 (10,000)	" "	" "	76.6 (4.2)	101 (213)	" "	66 (151)

RUN CONDITIONS:

HOLE DIAMETER: 219 mm (8 5/8 inches), CASES 1-8; 318 mm (12½ inches), CASES 9,10
 DRILL PIPE DIAMETER: 114 mm (4½ inches)
 MUD WEIGHT: 1,080 kg/m³
 MUD VISCOSITY: 30 CP
 SURFACE TEMPERATURE: 27°C (80°F)

Design Criteria for Geothermal Rock Bit Cutter Seals: The first four requirements below are common to geothermal and conventional bits, while the additional considerations for geothermal applications are covered in Item 5.

1. Space - The most common seal gland cross-section for rock bits is approximately 4.7 mm (0.19 inches) square, as shown in Figure 3. Deepening the gland reduces the area of the journal bearing, which would decrease the load-bearing ability of the bit. Widening of the gland reduces the protection of the seal from detritus invasion, and from contact with the hole wall as the cone and lug "shirt-tail" wear away.

FIGURE 3.

Section of one lug/cone set of 200 mm (7-7/8 inch) journal bearing rock bit.

2. Eccentricities - Radial runout is on the order of ± 0.13 mm (± 0.005 inches), and is caused by the shifting loads on the drilling inserts; very rapid accelerations exist which tend to invite detritus invasion. The axial runout is approximately ± 0.13 mm (0.005 inches), but is less detrimental to the seal than the radial motion, due to the lower rate of change. Both, however, cause bi-directional pressure pulsations in the grease which can reach ± 0.7 MPa (± 100 psi),
3. Abrasive Media - The drilling process generates a broad size spectrum of sharp, crystalline detritus. The high level of bottom-hole turbulence can cause abrasion of the seal. Mechanical seal systems must

also be designed to prevent a build-up of particles which could inhibit the flexing action and cause leakage or fatigue-failure of the seal.

4. Lubricant Compatibility - The seal must be unaffected by the lubricant's base oil, extreme-pressure (EP) additives, and suspended solids. The seal should be capable of operating with the lubrication provided by the base oil since the EP additives may not function under the low contact pressures at the seal interface.
5. Geothermal Drilling Conditions - Elevated temperature is the single most important aspect of the geothermal environment, regardless of the drilling fluid used. Problems generally associated with geothermal brines, such as corrosion and hydrogen embrittlement (stress corrosion cracking) are mitigated by the following factors:
 - a. Oxygen and brine are generally not present at the same time: the drilling fluid tends to purge the reservoir fluid from the bottom of the hole.
 - b. Most suitable high-temperature materials for seal components are resistant to corrosion.
 - c. Stress corrosion cracking tends to diminish at elevated temperatures.

The elevated temperatures, on the other hand, greatly restrict the choice of materials. The seal must be capable of withstanding the effects of thermal expansion without permanently deforming; elastomeric materials have expansion rates which are an order of magnitude greater than steel.

Lubricant Performance Criteria: Journal-type rock bits intended for geothermal service require a grease which can provide elevated-temperature lubrication similar to that provided by conventional journal bit lubricants at normal operating temperatures. The severe requirements for high load carrying ability are at least partially offset by the beneficial effects of a pressurized, oxygen-free atmosphere. A performance criterion for bit lubricants was established by running a series of "ring-and-block" type tests (discussed below) on a conventional journal grease at room temperature and pressure. It should, however, be noted that standard laboratory lubricant tests cannot predict success or failure in the field. Bit manufacturers utilize large full-scale journal-bearing simulators to further evaluate a lubricant prior to conducting field drilling tests. Both of these procedures are costly, time-consuming and frequently difficult to repeat. The standard lubricant tests, particularly the "ring-and-block" method are viewed as a valuable screening procedure by the bit manufacturers.

SEAL DEVELOPMENT

Test Machine: A geothermal seal test machine (Figure 4) was constructed to duplicate the conditions previously described; test parameters are detailed in Table II. Seals tests are run in water, with a mixture of sand and Geysers abrasives in a small reservoir directly over the seal (Figure 5); the lower side of the seal is exposed to lubricant. Seal failure is detected by application of 0.7 to 1.4 MPa (100-200 psi) of differential pressure for fifteen minutes each hour. Loss of more than 1.0 ml of grease during the 15-minute interval indicates failure and the test is terminated. At all other times the differential pressure is zero. The radial eccentricities present in drilling are duplicated by the mechanism shown in Figure 6.

FIGURE 4.

Geothermal seal test machine.

TABLE II
SEAL TESTER CAPABILITIES

Parameter	Range	Type of Adjustment
Temperature	20°C - 425°C	External
RPM	50 - 2,000	External
Pressure	0 - 21 MPa (3,000 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	0.08 mm - 1.27 mm (.003 - .050 inch)	Change cam
Abrasives	any	Prior to Test

FIGURE 5.

Detailed view of a typical elastomeric seal test.

FIGURE 6.

Lug simulator with replacable sealing surface and jogger mechanism. Seal carrier and spacers removed for clarity.

Elastomeric Seal Testing and Development: It should be noted that the elastomeric O-ring is the smallest type of seal in commercial use in bits. The first O-ring seal use in a rock bit was patented in 1964 (Smith Tool Co.)⁴ and represented a substantial improvement over the larger mechanical/elastomer types, which date back to 1932.⁴ The O-ring is used in the Hughes, Smith and Dresser journal type bits; Reed uses a somewhat larger oval elastomeric seal. Extensive screening tests were reported at the Energy Technology Conference and Exhibition in Houston (September, 1977).⁵ Since then, screening tests have been completed on seals made from most, if not all, high-temperature base polymers.^{6,7} These included two nitriles (Buna - N), two fluorosilicones, two fluorocarbons

(Vitons), one EPDM, and one inorganic polymer (Firestone PNF). Kalrez No. 1050 was also tested. Kalrez is not available as a raw polymer or as sheet molding stock; only finished seals are available. These screening tests, which were all conducted at 200° C (392° F) indicated that the best base polymer for development of an elastomeric compound specifically for geothermal bit seals was Viton (or Fluorel). Additional Kalrez grades were also recommended for further testing.

Within the last six months, the elastomeric seal development program has advanced to the point where full-scale geothermal drilling tests are warranted. Several manufacturers have submitted candidate seals which have the potential for drilling reservoirs in the 260-288° C (500-550° F) range.

A new seal test procedure has been introduced which more accurately duplicates the field application:

1. The lubricant used for the seal tests is a successful candidate high-temperature elastomer-compatible journal grease developed under the program (to be discussed).
2. The time-temperature profile experience by a bit when "tripping in" is simulated (Figure 7). A new seal, and successively higher soak temperatures are used for each test to determine the ultimate soak temperature for the candidate elastomer. The multiple trip-in tests are more time-consuming than a single constant temperature test; and the former are therefore reserved for only the most promising candidates.

Seal test results for the most successful elastomeric compounds are presented in Table III. Both constant-temperature and trip-in type tests are represented, and direct comparison should not be made between the two.

TABLE III. RECENT SEAL TEST RESULTS

DESIGNATION	MANUFACTURER	BASE POLYMER(S)	TEST TYPE ¹	SOAK TEMP. ° C (° F)	RUN TEMP. ° C (° F)	SEAL LIFE, HOURS ⁷
Kalrez No. 3072	DuPont, Inc.	Kalrez ²	Constant Temp	---	200 (392)	86+
Kalrez No. 3062	DuPont, Inc.	Kalrez ²	Constant Temp	---	235 (455)	63
266-IV-15 ⁵	L'Garde, Inc.	EPDM ³ /Viton ⁴	Constant Temp	---	200 (392)	47+
RD-176	Utex Ind. Inc.	Viton ⁴	Constant Temp	---	200 (392)	70+
Teflon coated ⁶	Sandia Laboratories	Viton ⁴	Trip-In	250 (482)	150 (302)	107
Viton No. 4205	Parker Seal, Inc.	Viton ⁴	Trip-In	260 (500)	150 (302)	107
267-II-35 ⁵	L'Garde, Inc.	EPDM ³	Trip-In	288 (550)	150 (302)	104
RD-227	Utex Ind. Inc.	proprietary	Trip-In	288 (550)	150 (302)	94+
DD-231	Utex Ind. Inc.	proprietary	Trip-In	288 (550)	150 (302)	92+

1. All tests run at 90RPM with abrasives present, ± 0.13 mm (± 0.005 inches) wobble and stroke.
2. Perfluoromethylvinyl ether-tetrafluoroethylene copolymer
3. Ethylene-propylene-diene monomer terpolymer
4. Fluorocarbon elastomer
5. The L'Garde seals were originally intended for static seal applications.
6. Capacitive Discharge method
7. Life tests were frequently terminated for scheduling reasons. These are denoted by a plus sign.

Note that three compounds survived 288° C (550° F) soak temperature and also met the 100-hour life goal.* The EPDM compound from L'Garde, Inc. was not harmed by the petroleum-based grease used for these tests.

FIGURE 7.
The trip-in simulation seal test.

* All seals were subjected to trip-in tests at 288° C, but only successful tests at the highest attainable soak temperature are shown in Table III.

Mechanical Seal Development: Mechanical seals are necessary for sealed bits required to drill hydrothermal reservoirs over 288°C (550°F), or for drilling with air, inert gas, mist, or foam. Extensive development and testing of mechanical, and mechanical/elastomeric seals has been previously reported.^{5,7} The mechanical face seal concept was most successful, although the prototypes evaluated were too large. Efforts were therefore directed at reducing the size of the face seal to fit the limited space. A spring-loaded radial lip seal is also under development.

The radial lip seal illustrated in Figure 8 is widely used for high temperature applications. The seal body is a proprietary filled teflon; the expander spring is type 301 stainless steel. The expander spring accommodates radial eccentricities and thermal expansion without overstressing the plastic body. Evaluation has been completed on the first generation, and two more iterations are in progress. Two constant-temperature tests run at 200°C (392°F) for 24 hours revealed very little damage to the seal surface. Trip-in tests at 288°C (550°F) caused failure due to shrinkage of the seal body. The next generation will utilize a stiffer spring of 17-7 Ph stainless, modified cross-section, and process changes which will eliminate shrinkage.

FIGURE 8.

The Fluorcarbon, Inc. radial lip seal, style RP. The seal lies in the horizontal plane.

The principal problem associated with putting a face-seal in a cutter cone is obtaining adequate spring force and compliance in the limited available space. The seal must also be adequately protected from exposure to the hole wall as the cones wear. One method of providing the required spring force is to recess coil compression springs in the cone body (Figure 9). It may or may not be possible to design a one-piece spring system such as a disc spring belleville washer, or wave spring for this application; force-deflection properties for the coil spring system and a suitable disc spring are compared in Figure 10. The coil system also permits rapid experimental alterations of the closing force.

FIGURE 9.

Face seal with elastomeric side seal installed in a journal-type bit.

FIGURE 10.

Force-deflection characteristics of two spring systems for the face-seal system.

The stress-relaxation properties of available high-temperature spring alloys was investigated¹(Table IV) to determine acceptable stress levels, and therefore spring size; 17-7 Ph was selected for the program. The spring system uses 18 springs of 3.2 mm (0.13 inches) to provide a 600N (135 lb) closing force.

TABLE IV

STRESS-RELAXATION AT TEMPERATURE FOR FIVE COMMON SPRING ALLOYS

STEEL	CLASS	COST FACTOR	STRESS RELAXATION TESTS			
			TEMPER	TEST TEMP. °C (°F)	INITIAL STRESS GPa (ksi)	RELAXATION, %
ASTM A286 Music Wire	High-Carbon Steel	1	Spring	93 (200)	10.3 (150)	12 ²
ASTM A286 Music Wire	High-Carbon Steel	1	Spring	149 (300)	7.9 (115)	13 ²
AISI 302 (18-8)	Austenitic Stainless	1.3	Spring	288 (550)	7.9 (115)	15 ²
17-7 PH	Ferritic-Austenitic Stainless	2.5	Spring	316 (600)	7.6 (110)	5 ^{1,3}
NS-A286 ¹	Austenitic Stainless	4	15% R.A.	538 (1000)	5.5 (80)	10 ^{1,3}

Notes:

1. National Standard Co., Niles, Michigan.
2. Metals Progress, June 1977. Wire diameter 1.57 mm (0.062 inches)
3. Wire diameter 2.03 mm (0.080 inches).

An all-metal face seal system which should be capable of withstanding a 427°C (800°F) soak cycle, has been built and tested (Figure 11). Chrome oxide hard-coating was plasma-deposited on the seal ring and lapped to within two light-bands.

The mating surface used in the laboratory tests is carburized steel (CBS-600), in anticipation that the seal system will run directly on the lug (leg) of the bit, in actual service. To date, seal lives as long as 77 hours have been achieved, but the leakage rate was unacceptable and development is continuing.

FIGURE 11. The all-metal face seal.

LUBRICANT TESTING AND DEVELOPMENT

Test Machine: The high temperature lubricant test machine (Figure 12) was constructed to facilitate screening tests on candidate lubricants for geothermal rock bits.⁷ The test is based on the widely used "Ring and Block" method described in ASTM specification D 2714-68*, and illustrated in Figure 13. The facility evaluated boundary-layer and bulk film lubrication at temperatures to 427° C (800° F) in a nitrogen environment at 0.70 MPa (100 psi). The pressure capability permits evaluation of many lubricants which would otherwise boil off and/or oxidize during the test.

The ring is rotated at 72RPM for 5000 revolutions (69 minutes), which causes wear on the block. The load-bearing ability is determined by dividing the static load by the area of the wear scar; uniform stress is assumed. After each test the pressure vessel and all internal components are cleaned thoroughly, first with a cleaning solvent, then with chlorathane - NU; the ring and block are replaced.

It was not possible to run valid calibration tests because the calibration fluid (white mineral oil conforming to U. S. Pharmacopeia, Vol. XVII, p. 399) could not be obtained. However, a sufficient quantity of a pharmaceutical mineral oil was obtained and used to establish the repeatability of the tester. The reader is cautioned against making direct comparisons of the following test results with data generated on Alpha LFW-1 of Falex Model 1 machines. The screening test results provided relative performance data which isolated grades for further development, or for recommendation for full-scale tests under geothermal drilling conditions.

* ASTM specification D 2714-68, "Calibration and Operation of the Alpha LFW-1 Friction and Wear Testing Machine," also applies to the successor to the Alpha tester, known as the "Falex Model No. 1 Ring and Block Test Machine" manufactured by Faville-LaVally Corporation, Downers Grove, Illinois.

FIGURE 12.

Terra Tek high-temperature
lubricant test facility.

FIGURE 13.

Lubricant tester schematic diagram.

Lubricant Screening Tests: Lubricants for conventional journal-type bits were developed by the bit manufacturers; lubricant manufacturers are therefore unfamiliar with either geothermal or non-geothermal bit journal lubrication, which have little in common with other commercial applications. It was therefore possible that an existing high-temperature lubricant could meet the screening test criterion. A total of 31 commercial products, representing 21 manufacturers, have been tested at 316° C (600° F), and/or at 204° C (400° F). The lubricants which met the requirement are presented in Tables V and VI. (referenced 1 and 2).

TABLE V

LOAD CARRYING CAPACITY OF EIGHT COMMERCIALY AVAILABLE LUBRICANTS,
AT 316° C (600° F) and 0.70 MPa (100 psi)

PRODUCT	TYPE	MANUFACTURER	LOAD CAPACITY MPa (KSI)
D. H.	GREASE	PACER LUBRICANTS, INC.	83 (12.0)
MODIFIED D. H.	GREASE	PACER LUBRICANTS, INC.	68 (9.9)
SUPREME OIL SUPPLEMENT	OIL	WYNN OIL COMPANY	68 (9.8)
LS-11-2850	ANTI-SEIZE	GRAPHITE PRODUCTS CORP.	62 (8.9)
LS-11-2100	ANTI-SEIZE	GRAPHITE PRODUCTS CORP.	57 (8.3)
HIGH PERFORMANCE LUBRICANT SUPPLEMENT	OIL	WYNN OIL COMPANY	52 (7.5)
LUBRIPLATE HI-TEMP	GREASE	FISKE BROS. REFINING, INC	46 (6.7)
API MODIFIED THREAD COMPOUND	ANTI-SEIZE	FISKE BROS. REFINING, INC	40 (5.7)

TABLE VI

LOAD CARRYING CAPACITY OF FOUR COMMERCIALY AVAILABLE LUBRICANTS,
AT 204° C (400° F) and 0.70 MPa (100 psi)

PRODUCT	TYPE	MANUFACTURER	LOAD CAPACITY MPa (KSI)
UNIVERSAL MOTOR OIL	OIL	UNITED LUBRICANTS, INC.	43 (6.2)
GLEITMO 500	GREASE	SCHMIERSTOFFE (W.GERMANY)	32 (4.6)
API BUL 5A2	GREASE	FISKE BROS. REFINING, INC.	32 (4.6)
NO. 1157	OIL	AMOCO OIL COMPANY	31 (4.6)

Lubricant Development: Lubricant manufacturers were generally reluctant to develop a new product specifically for geothermal rock bits due to the limited market potential. Pace Lubricants, Inc., however, supplied a total of 17 developmental grades on a reiterative basis, to meet the requirements of the rock bit program and the mud-motor program mentioned previously.² The results of extensive tests are presented in Table VII.¹ Note that all lubricants listed surpassed the 30 MPa (4.3 ksi) criterion by a substantial margin. The lower performance of PLX-014 oil at 204° C (400° F), relative to the performance at 316° C (600° F), is due to the temperature range of the principal EP additive. The PLX-014 grease has been used extensively in the seal test machine in tests on elastomeric and mechanical seals. No harmful effects have been observed on any of the tests listed in Table III, which includes several 288° C (550° F) soak cycles.

TABLE VII

LOAD CARRYING CAPACITY OF FIVE LUBRICANTS DEVELOPED FOR GEOTHERMAL ROCK BITS

DESIGNATION	TYPE	VISCOSITY ² SUS (CST) OR WEIGHT	ELASTOMER COMPATIBILITY	TEST TEMPERATURE °C (°F)	LOAD CAPACITY MPa (KSI)	NUMBER OF TESTS
PLX - 014	OIL	190 (40.4)	YES	316 (600)	73 (10.6)	15
PLX - 014	OIL	190 (40.4)	YES	204 (400)	52 (7.6)	4
PLX - 014	GREASE ¹	NLGI No. 2	YES	316 (600)	62 (9.0)	10
PLX - 022	OIL	180 (38.3)	NO	316 (600)	81 (11.7)	12
PLX - 023	OIL	254 (54.5)	NO	316 (600)	67 (9.7)	5
PLX - 024	OIL	286 (61.4)	YES	316 (600)	69 (10.0)	3

1. Available commercially as Geoband Grease.

2. Saybolt Universal Seconds at 210°F, or Centistokes at 100°C.

CONCLUSIONS

Seals and lubricants are needed for journal-type rock bits for geothermal applications. The capabilities to drill into 350° C reservoirs using mud, and to drill into 300° C reservoirs with air or foam are required. High-speed (mud-motor) drilling at 175° C (350° F) is also required.

A plastic-bodied radial lip seal with internal expander spring is being developed which will permit higher soak temperatures and rotational speed than the elastomeric seals, without necessitating changes to the lugs or cutters.

An all-metal face seal system is under development to meet the most difficult requirements. Changes to the lugs and cutters are necessary to accomodate the face seal.

Laboratory tests indicate that seals and lubricants have been developed which will permit existing sealed journal-bearing rock bits to drill hydrothermal reservoirs as hot as 288° C (550° F). Commercial production of such bits appears economically viable since no other modifications would be required. Full-scale drilling tests are needed to verify the laboratory seal and lubricant tests.

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