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IMPROVEMENTS IN ROTARY SEALS FOR DOWNHOLE MOTORS IN GEOTHERMAL APPLICATIONS

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ABSTRACT

The major limitation of downhole mud motors for geothermal well drilling as well as straight-hole and oil well drilling is the bearing section. Reduced bearing life has been a direct result of the inability to seal lubricant in the bearing section. A reliable rotary seal is needed to extend bearing life and to allow high pressure drops across the drill bit for improved bottomhole cleaning and increased drilling rate. The endurance of "high temperature" rotary seal candidates is being measured in a full-scale laboratory seal tester capable of simulating the pressures and temperatures of geothermal well drilling. A description of the currently most successful "high temperature" seals and seal test results and findings are presented.

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INTRODUCTION

The paper describes work continued from a paper presented at the Geothermal Resources Council annual meeting, 1978. (Black, et. al. 1978) The baseline tests performed in an early phase of this work were on an elastomer seal. This was an off-the-shelf seal in a standard compound. The emphasis on seals to be tested is presently being placed on non-elastomer materials that have higher temperature limits.

An additional limitation on the life of downhole motors has been the thrust bearing package. The result has been the restricted use of the downhole motors to deviated hole operations.

The limiting factors in the life of the bearings are the mud environment that they operate in and the high loading they are subjected to. The drilling mud may contain sand, cuttings from the well bore, other solids, and caustic chemicals. The bearings are much more dependable, stable and predictable when operated in a lubricant, and a roller thrust bearing with higher load capability can be substituted for a ball thrust bearing. Testing is being done to screen and formulate high temperature lubricants. (Tibbitts, et.al. 1979) for this application.

This paper discusses the testing and work done to develop a rotary seal to be used with downhole drilling motors in geothermal wells. Two seals made from high temperature materials, an elastomer seal and a special back up system have been tested and the results are discussed.

TEST CONDITIONS

Conventional drill bits require a pressure drop across the bit of approximately 1,000 psi for good bottomhole cleaning. The differential pressure carried by the rotary seal is equal to the pressure drop across the bit.

The test system is capable of testing seals at temperatures of 500°F. The subject seals were tested at ambient temperatures of 250°F on a 5 inch diameter shaft turning at 412 rpm (Table 1). Rotary speed can be varied up to 1,500 rpm. A pressure differential up to 5,000 psi can be applied to the test seal.

Test ID	Ending Date	Seal Type	No. of Pressure Rings	Back Up Rings	ΔP (psi)	RPM	Duration (hrs.)	Shaft Coating Finish (rms)
019	10/27/78	I. Graphite-Metal Matrix	3	Aluminum Bronze	1500	412	4.55	16
020	11/6/78	I. Graphite-Metal Matrix	1-Top 2-Bottom	Aluminum Bronze	1500	412	13.05	13
021	11/16/78	*Grafoil*[R]-BeCu	3	Aluminum Bronze	1500	412	5.90	17 - 18
022	11/22/78	J-M *Uneepac*[R]	3	Aluminum Bronze	1500	412	10.62	17 - 18
023	12/6/78	J-M *Uneepac*[R]	3	Aluminum Bronze	1500	412	26.55	17
024	1/15/79	*Grafoil*[R]-BeCu	3	Phosphor Bronze	1500	412	40.9	4
025	1/25/79	II. 171 Graphite-Metal Matrix	3	Teflon & Phosphor Bronze	1500	412	(2.03)	4 - 8
026	2/20/79	II. 171 Graphite-Metal Matrix	3	Teflon & Phosphor Bronze	1500	412	1.98	4 - 8
027	5/4/79	III. 194 Graphite-Metal Matrix	3	Phosphor Bronze	1500	412	23.5	4 - 8

Table 1
Seal Test Record with Test Parameters

The surface of the shaft which rotates against the seals can be varied. Initially, all seals were tested on a finish of approximately 16 μinches. The non-elastomer seals are now being tested on surface finishes of 4 μinches.

The first non-elastomer seals, *Grafoil*^{R}- BeCu, are made with a material manufactured by Union Carbide and a preformed beryllium-copper ring. The seal is formed by sandwiching a 0.005 inch thick "V" ring of beryllium-copper between two layers of *Grafoil*^{R} (fig. 1).

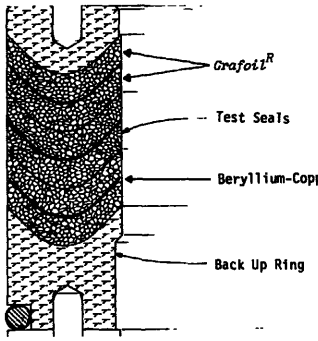

Figure 1
Grafoil^R- BeCu Seal Pack with New Back Up System

The graphite-metal matrix seal, the second non-elastomer seal, is formed from powdered graphite which is cold pressed into a woven metal core and held together in a "V" cross section with an adhesive binder. The assembly is heat cured and results in a relatively hard and brittle ring. It has a high gloss surface; the pattern of the metal mesh is visible on the surfaces; and free ends of the metal mesh protrude from the surface (fig. 2). There have been three generations of this seal type tested so far. Each utilizes a different binder with the graphite powder.

Figure 2
Graphite-Metal Matrix Seal Ring

The only elastomer seals tested since the baseline tests were the Johns-Manville *Uneepac*^{R} seals. These seals are formed in a "W" cross section and nest readily in a seal pack (fig. 3). The elastomer tested was neoprene with flocked asbestos reinforcing.

Early in the testing, the inside diameter of the aluminum-bronze back up ring was reduced to minimize the clearance to the rotating shaft. Due to thermal expansion, the back up ring closed down on the shaft and stopped rotation. Tests were continued at that point with the manufactured back up rings providing a 0.010 - 0.015 inch diametrical clearance.

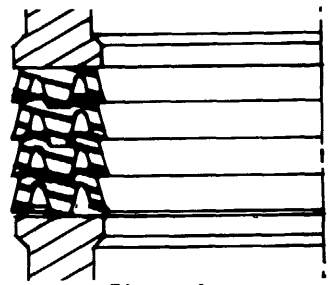

Figure 3
Johns-Manville *Uneepac*^{R} Seal Pack

The failed seals from tests DMT-019 through DMT-021 exhibited a loss of *Grafoil*^{R} or graphite. The metal reinforcement in both types of seals was intact and still in the seal cavity, but a noticeable amount of the material was missing from the failed seal.

The back up system was examined and means were discussed by which to contain the seal material. Several designs were proposed and the two most promising were fabricated and have been tested.

The first new back up system consists of an SAE 660 bearing bronze seal ring and an O-ring (fig. 1). The lip on the inside diameter of the bronze ring is undercut to minimize contact area with the rotating shaft and to introduce a weak area into the ring that will allow it to flex under pressure, effectively reducing the clearance to zero between back up ring and rotating shaft.

The position and depth of the undercut in the back up ring can be optimized for contact area, wear compensation and operating pressure. These parameters will be varied as this back up system increases the life of the non-elastomer seal types.

The second back up system consists of a TFE ring and an SAE 660 bronze ring (fig. 4). The TFE ring is soft and will flex under pressure, forcing the bronze ring to zero clearance with the rotating shaft.

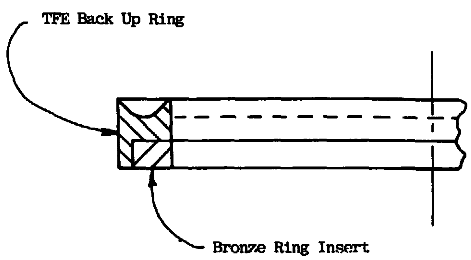

Figure 4
TFE Back Up System

TEST RESULTS

Nine seal tests were performed on five different seals and three different back up systems with duration varying from two hours to forty-one hours.

The program goal is not aimed at optimizing a seal at this time with regards to torque, temperature, abrasion or other operating characteristics, but rather to develop a seal that will survive 200 hours downhole. A detriment to the life of the seal pack, particularly elastomer seals, has been that the seal rings at the low pressure side of the seal pack may never come in contact with fluid, but due to the transmission of fluid pressure through the stacked seals, the seal rings apply a radial pressure on the shaft surface. This generates heat, alters the surface finish and unnecessarily dissipates horsepower that could be delivered to the bit.

A single pressure ring of the Type I graphite-metal matrix was tested in DMT-020. An aluminum-bronze back up ring, identical to the one used in DMT-019, was used in this test. The surface finish of the rotating shaft was measured at 13 μinches. This single seal had almost three times the life of the three seals tested in DMT-019.

Type II graphite-metal matrix seals were tested in DMT-025 and DMT-026. The seal pack contained three pressure rings; the shaft surface finish was measured at 4 μinches; and the back up system was the second new design, i.e., TFE and bronze. The seals tested in DMT-026 had a life of about two hours. The leakage of lubricant began soon after the test started and was quite rapid to the end of the test. Test DMT-026 was a repitition of DMT-025, since the latter test was terminated after two hours because the seal was damaged in handling.

DMT-027 was a test of Type III graphite-metal matrix seals. The seal pack contained three pressure rings; the shaft surface was ground to a 4 - 8 μinch finish; and the back up system was the first new design, i.e., SAE 660 bronze and an O-ring. The life of this seal was 23.5 hours.

The *Grafoil*^{R}- BeCu seals were tested in DMT-021 and DMT-024. These seal rings were identical within manufacturing tolerances.

Test DMT-021 used a shaft surface finish of 17 - 18 μinches and the back up system was an aluminum-bronze ring supplied by the manufacturer. The seal had a life of almost 6.0 hours.

DMT-024 was also a test of a three seal ring pack. The shaft surface finish was measured at 4 μinches and the back up system utilized the first new design with bronze ring and O-ring. The life of the seal in this test was nearly 41 hours. It had been removed and reinstalled three times during the test.

The seal leaked about 4% in the first three hours, but did not leak again until the twenty-seventh hour. At that time, 35% of the lubricant leaked past the seal. Only 61% of the lubricant had been lost at 40 plus hours when the seal failed catastrophically.

The Johns-Manville *Uneepac*^{R} seals were tested in DMT-022 and DMT-023. The seal rings were identical within manufacturing tolerances. The surface finish of the shaft used in test DMT-022 was 17 - 18 μinches and that used in test DMT-023 was 17 μinches. The back up systems were both aluminum-bronze rings as supplied by the manufacturer of the seals. The ring used in the first test had a diametrical clearance of 0.003 inches and the ring used for the second test had a clearance of 0.015 inches.

The inside sealing surface of the pack tested in DMT-022 appeared worn smooth. Wear and distortion were more pronounced on the low pressure side of the seal pack. The corresponding surface of the seal pack tested in DMT-023 was more severely worn and distorted. The lip of the seal ring on the low pressure side of the pack was worn away completely.

Useful information is being gained from other rotating seals used in the test vessel. There are two such seals, each one a redundant seal composed of two sizes of Johns-Manville *Uneepac*^{R} seals, both with an inside diameter half that of the test seals. These test vessel seals rotate on replaceable chrome surfaced sleeves. Cooling water circulating constantly on the inside of the sleeves carries heat away from these seals.

A problem persisted of fretting and scoring of the chrome sleeves by the seals. Because of its high thermal conductivity, *Grafoil*^{R} was added to each vessel seal pack. While rebuilding the vessel seal packs for a test, a thin layer of *Grafoil*^{R} tape, was inserted between the eight seal rings of each seal pack in an attempt to solve this problem.

Post-test inspection of the vessel seals and the chrome surface showed a definite improvement in the condition of both components over the same components run approximately the same length of time without the addition of *Grafoil*^{R}.

A hybrid seal offers the possibility of increasing the life of elastomer seals and extending the upper temperature limits for elastomers. The pressure rings could be of any of the higher temperature elastomeric compounds alternated with rings of solid *Grafoil*^{R} material. This seal concept for the Johns-Manville seals, utilized in the test vessel, proved a successful solution for extending seal life.

DISCUSSION

The elastomer seals were tested on shafts of 12 - 16 μinches finish as recommended by the manufacturer, and the carbon seals were tested on shafts of 4 - 8 μinches finish, except as noted. Between tests DMT-019 and DMT-020, the surface finish was improved from 16 to 13 μinches. The number of pressure rings was decreased from 3 to 1, but the seal life increased by nearly a factor of three. The life of non-elastomer seals is enhanced with the surface finish of the shaft. Of the two parameters that were changed (i.e., the shaft surface finish and the number of pressure rings) between DMT-019 and DMT-020, it is believed the greater effect on the seal life was due to the improved shaft finish because reducing the amount of seal material should reduce the life of the seal. Further work may reveal an optimum finish, but for the present, the surface finish will be 4 μinches for all shafts.

As stated earlier, it is believed decreasing the number of seals or amount of sealing material would have a negative effect on the life of non-elastomer seals. Conversely, it appears that with elastomer seals, one pressure ring will perform longer than three pressure rings under the same conditions. In a seal pack of more than one ring, the first ring carries all of the pressure initially. This pressure differential on the first ring is transmitted to the rest of the rings, effectively loading those rings and creating higher than normal radial forces on the shaft due to the Poisson effect. Consequently, the torque is higher and the pressure rings not sealing any fluid are heated, worn and destroyed first.

Both the *Grafoil*^{R} and graphite deteriorated when in contact with heated lubricant. The *Grafoil*^{R} tended to come apart in small flakes. In the graphite seals, the heat weakened the adhesive binder resulting in the release of graphite powder. Both the *Grafoil*^{R} flakes (fig. 5) and graphite powder migrated to the low pressure side of the seal pack. Due to additional design changes, the later generation graphite-metal matrix seals are sustaining longer seal life than their predecessors.

It is believed that an area of great importance to the life of the *Grafoil*^{R} and graphite seals is the number of seals in a pack or the amount of material in the seal cavity. Thus it appears that the cross sectional geometry of the non-elastomer seal is not as critical as it is for elastomer seals.

Figure 5
Grafoil^R Build Up at the Back Up Ring

Progress has been made to increase the life of the non-elastomer seals by concentrating on the design of a back up system. By custom machining a back up ring to fit each shaft sleeve within 0.001 inch clearance on the diameter, the loss of seal material has been reduced; and, consequently, the endurance of non-elastomer seals has been significantly improved. The longest lived *Grafoil*^{R}- BeCu seal (more than double the life of the next longest test of this seal type) and the longest lived graphite-metal matrix seal (an increase of 55% over the next longest test of this seal type), were both backed up with the bronze ring with the flexing lip.

The TFE and bronze back up system, as described, does not improve the life of non-elastomer seals. This conclusion is demonstrated in tests DMT-025 and DMT-026.

CONCLUSIONS

(1) The non-elastomer seals as tested have inherent lubricating qualities and are not as damaging to the surface finish of the rotating shaft as the elastomer seals tested. The non-elastomer seals can operate without the introduction of external lubricants. This allows the non-elastomer seals to operate on a highly polished shaft, generating less torque and heat, wearing less and exhibiting longer life.

(2) The life of non-elastomer seals is increased with improved shaft surface finish.

(3) Tests show that the life of non-elastomer seals is directly related to the amount of material in the seal cavity at the beginning of a test. Increasing the amount of seal material increases the life of the seal given that the rate of migration of material out of the seal cavity is constant.

(4) Reducing the clearance between back up system and rotating shaft to essentially zero increases the life of non-elastomer seals.

These conclusions are based on the tests performed to date.

High temperature, rotary seal testing is an ongoing project. As developments are forthcoming in the area of high temperature materials, the direction of the test matrix can be altered. For the present, however, testing will continue to focus on the non-elastomer seals and on improvements in the geometry of the back up system.

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