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PHASE IV SEMI-ANNUAL REPORT

PROGRAM FOR THE IMPROVEMENT OF DOWNHOLE DRILLING MOTOR BEARINGS AND SEALS

Gordon A. Tibbitts
Peter H. DeLafosse
Alan Black
Sidney J. Green

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87185 and Livermore, California 94550 for the United States Department of Energy under Contract DE-AC04-76DP00789.

July 1980

Work performed under Sandia Laboratories Contract No. 13-8783 for the U.S. Department of Energy, Division of Geothermal Energy

Sandia National Laboratories

SF 2900-Q(3-80)

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Terra Tek, Inc.
Salt Lake City, Utah 84108

Printed in the United States of America
Available from:
National Technical Information Service
U. S. Department of Commerce
5825 Port Royal Road
Springfield, VA 22161
Price: Printed Copy $5.00; Microfiche $3.00

*Work performed under Sandia Contract 13-8783 for the United States Department of Energy, Division of Geothermal Energy.

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FOREWORD

This report summarizes the work performed for the first six month period of Phase IV of the DOE/DGE Contract Number 07-7298, "Program for the Improvement of Downhole Drilling Motor Bearings and Seals."

This reporting period saw four main areas of development for the project:

1. Design and fabrication of a dynamometer and a mud cooling system for the Bearing-Seal Package Test Facility;
2. Modification of the Bearing-Seal Package Test Facility based on test results;
3. Testing of new lubricant samples from Pacer Lubricants, Inc., in the Terra Tek High Temperature Lubricant Tester; and
4. Testing of new seal types in the Terra Tek Seal Tester.

This report will have four major sections: Seal Testing and Evaluation, Bearing-Seal Package Testing and Evaluation, Lubricant Testing and Evaluation, and Program Plans and Schedule. It will cover progress on the contract through April 30, 1980.

The Maurer Engineering Report, "Semi-Annual Progress Report on Improvement of Downhole Motor Bearings and Seals - Sandia Contract No. 46-3054" by Jeff L. Barnwell, has been included as Appendix B of this report.

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ILLUSTRATIONS

ILLUSTRATIONS (Continued)

TABLES

INTRODUCTION

This report deals with the work completed during the first six months of the DOE/DGE Contract Number 07-7298, "Program for the Improvement of Downhole Drilling Motor Bearings and Seals." The specific objectives of this program are:

(1) Develop a lubricated Bearing-Seal Package with a life of over 200 hours;

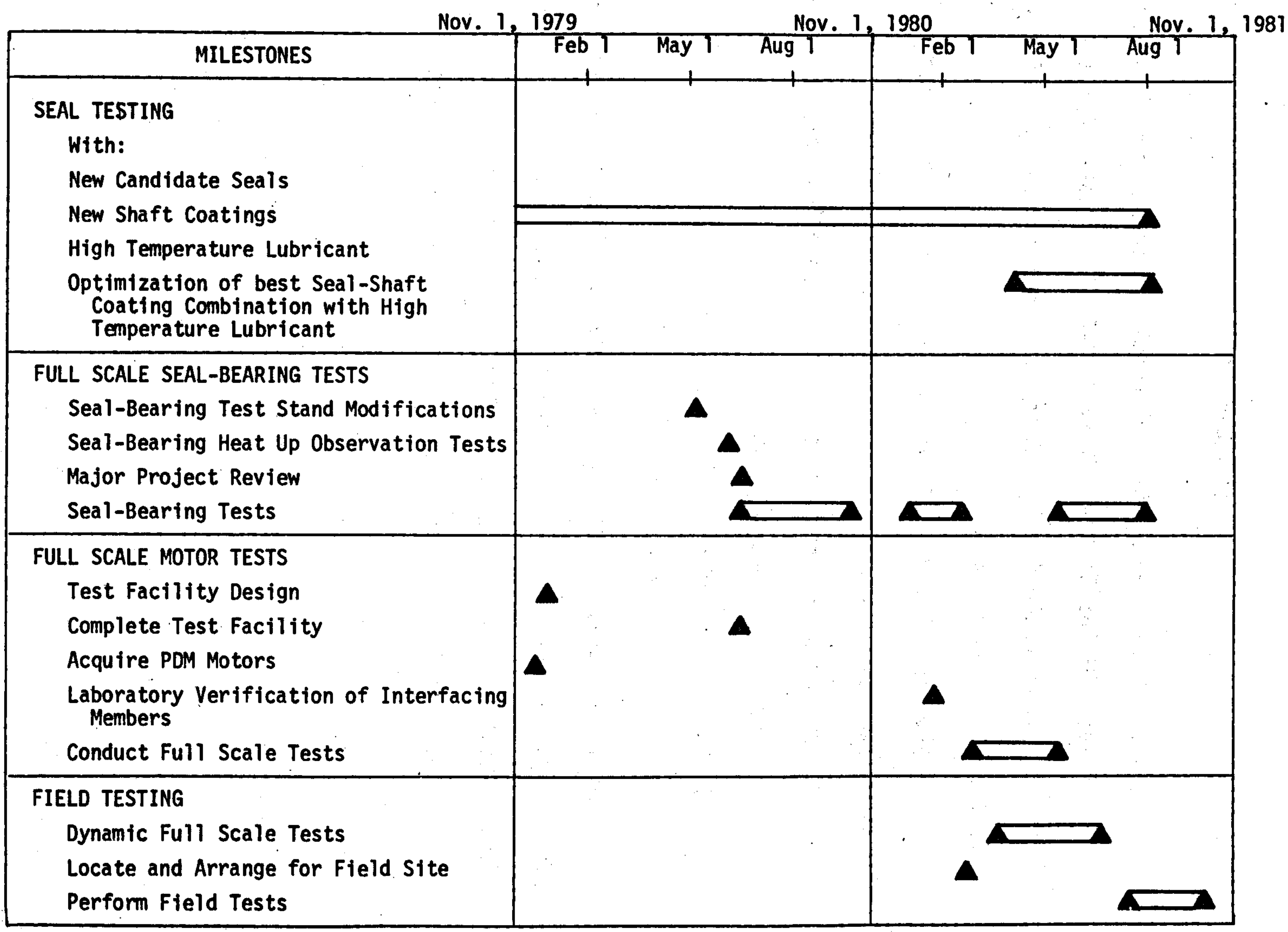
(2) Develop an improved rotary seal which allows bit pressure drops over 1,000 psi; and

(3) Develop a Bearing-Seal Package to operate at 250°F circulating bottomhole temperature.

This report presents recent test results on seals and high temperature lubricants, and work on the Bearing-Seal Package Test Facility. An overall program summary is given in Appendix C, and the major milestones of this phase of the program are shown in the following chart, Table I.

TABLE I

MAJOR MILESTONES



SEAL TESTING AND EVALUATION

SEAL TESTER

A major modification to the Seal Tester was made during this reporting period. This modification involved the complete redesign of the heating system for the tester.

The Downhole Motor Seal Tester was originally designed for a maximum operating temperature of 600°F. This high temperature requirement resulted in a design heat capacity for the tester of 30 kilowatts. This high heat capacity prevented the use of band heaters in the original design because of the limited watt density that can be obtained from this type of heater. As a result, the heater system incorporated 30 one-kilowatt cartridge heaters in the heater carrier which surrounded the main vessel seal carrier.

There is an inherent problem in using cartridge heaters in the Seal Tester. Space is limited inside the tester vessel, and the leads from the cartridge heaters must be bent at the junction with the heater in order to fit. This causes cracking of the ceramic insulation, which allows the heaters to short.

All of the seal tests are run at a temperature of 250°F. This temperature was established after the original design of the Seal Tester. Thus, the original design heat capacity of 30 kilowatts is no longer required.

To solve the problem with the cartridge heaters the heater carrier was removed from the main vessel seal carrier and a band heater system was designed to fit directly around the main vessel seal carrier. These heaters have a watt density of 35 watts per square inch and are

1.5 inches wide. There are a total of six band heaters, and the total heat capacity is 8.2 kilowatts. Surrounding the band heaters is a blanket of insulation.

Figure 1 shows a photograph of the main vessel seal carrier with the new band heater system installed. Figure 2 shows a photograph of the insulation blanket around the band heater system.

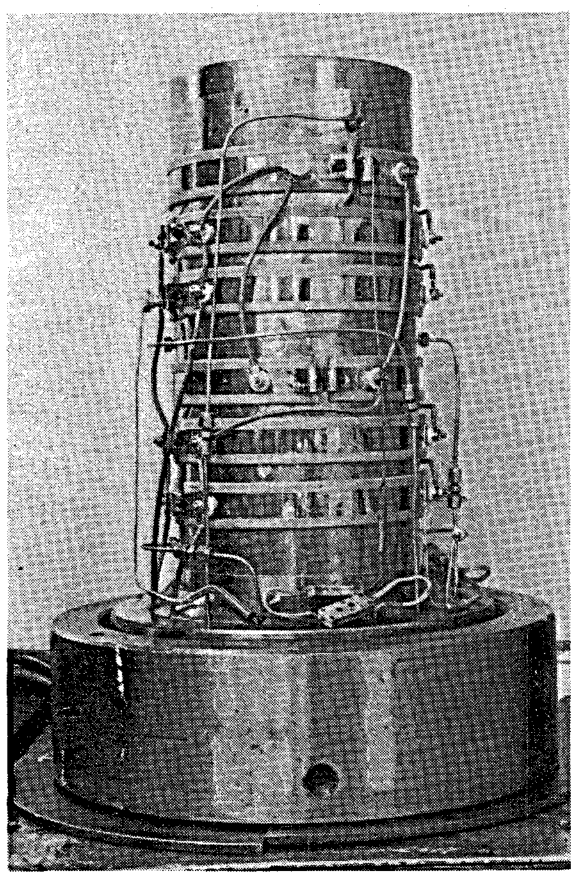


Figure 1

Seal Tester Band Heater System

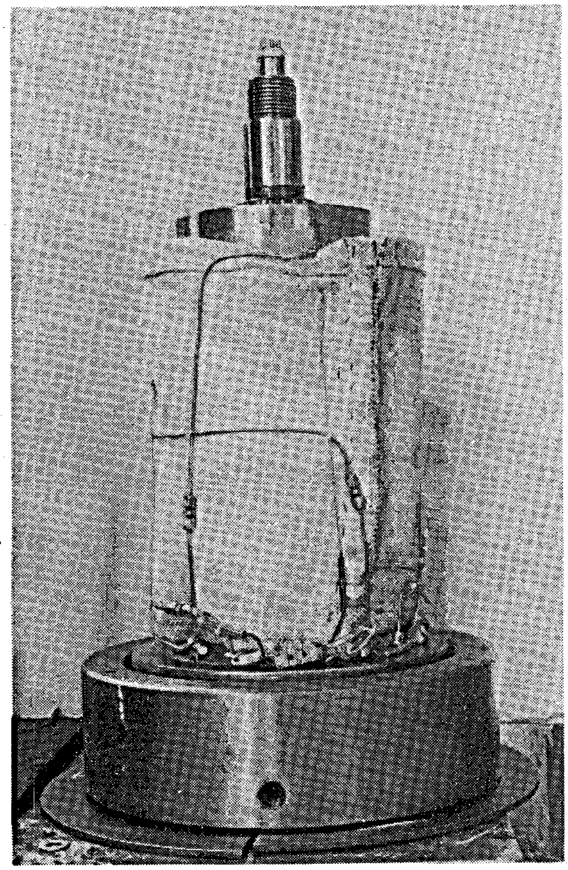


Figure 2

Insulation Blanket
For Band Heater System

The controls for the band heater system were also redesigned. The old controller was a Phase Angle Fired SCR Power Controller. This type of controller has some inherent problems for the Seal Tester heater system. A phase angle controller can cause RFI (Radio Frequency Interference) which will affect all of the other instrumentation in the Seal Tester. Also, the phase angle fired controller is complicated and difficult to troubleshoot. This type of controller is primarily used in a situation where the resistance of the heater changes with temperature. The band heaters do not change resistance with temperature.

A Zero Voltage Switched SCR Power Controller was ordered and installed in the new heater system. This type of controller turns on when the waveform is near the zero voltage point, eliminating the RFI problem connected with the phase angle fired controller. Also, the zero voltage switched controller is simpler and easier to troubleshoot than the phase angle fired controller.

The new band heater system and SCR power controller will increase the number of tests that can be performed in the seal tester and will allow the completion of all scheduled tests in the program. The equipment has been installed and is functioning properly.

SEAL TEST RESULTS

Four seal tests were completed during this reporting period. Two tests were run with *Grafoil*^{R}-Phosphor Bronze seals with Zero Clearance Back Up System III (flexing leaves), one test was run with *Grafoil*^{R}-Phosphor Bronze seals with Zero Clearance Back Up System I and one test was run with the generation II Canted Seal - Buna-N. The test results are shown in Table II and Appendix A.

<u>*Grafoil*^{R} with Zero Clearance III</u>

Two tests were run with the *Grafoil*^{R}-Phosphor Bronze seals with Zero Clearance Back Up System III. DMT-034 tested the seals with three-1/32" thick flexing leaves, and the test lasted 3.48 hours. The following is a brief description of the test:

a. 0 to 0.83 hours, ΔP-1500 psi

   The test seal was leaking substantially and the dummy seal had a very small leak. If the test were continued at the present leak rate the test seal would fail in a very short time. Therefore, at 0.83 hours it was decided to increase the ΔP to 1750 psi to see if this had any affect on the test seal leak rate.

b. 0.83 to 2.75 hours, ΔP=1750 psi

   During this same time period the test seal leak rate dropped off significantly. One possible explanation for this is that the three-1/32" thick rings were too stiff to create a zero clearance at 1500 psi. At 2.75 hours it was decided to drop the pressure back down to 1500 psi to complete the test.

c. 2.75 hours to 4.0 hours, ΔP=1500 psi

   The test was resumed and run until one gallon of lubricant had leaked past the test seal.

COMPLETED SEAL TESTS

Test ID	Ending Date	Seal Type	No. of Pressure Rings	Back Up Rings	P (psi)	RPM	Duration (Hours)	Chrome Shaft Coating Finish (rms)	Diametral Clearance: Shaft to Back Up Rings
034	2-25-80	*Grafoil*^{R}- Phosphor Bronze	3	Back Up III w/3 ea 1/32" Leaves	1750/ 1500	412	3.48	4-8μ	Flexing Leaves: .001 Back Up Ring : .170
035	3-28-80	*Grafoil*^{R}- Phosphor Bronze	3	Back Up III w/4 ea 1/64" Leaves	1500	412	32.3	4-8μ	Flexing Leaves: .001 Back Up Ring : .170
036	4-03-80	Canted Buna-N	2	9 C Aluminum Bronze	1500	412	-0-	8-12μ	0.008
037	5-20-80	*Grafoil*^{R}- Phosphor Bronze	3	Back Up I SAE 660 Bronze	1500	412	Aborted	4-8μ	0.001

TABLE II

Inspection of the seals after DMT-034 showed a loss of seal material from the *Grafoil*[R] seals. Figure 3 shows a photograph of the Upper (Test) Seal from DMT-034, and Figure 4 shows a photograph of the lower (Dummy) Seal from DMT-034.

Figure 3

DMT-034, Upper (Test) Seal

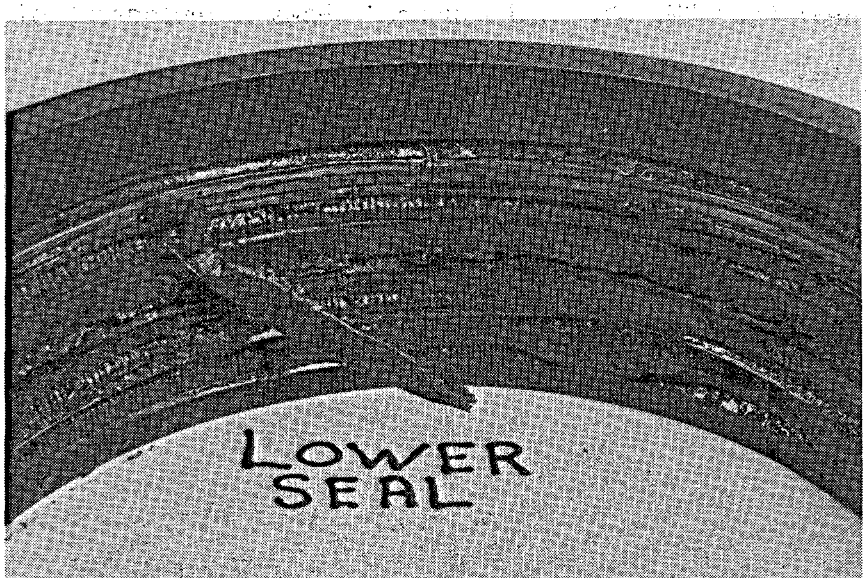


Figure 4

DMT-034, Lower (Dummy) Seal

Based on the experience from DMT-034, it was decided to reduce the thickness of the flexing leaves for DMT-035. DMT-035 tested the *Grafoil*^{R}-Phosphor Bronze seals with four-1/64" thick flexing leaves, and the test lasted 32.3 hours, the second longest running test to date. Some of the observations from this test are as follows:

a. There was a high torque initially, probably due to the wear-in of the flexing leaves. After a couple of hours the torque dropped to below 100 ft.-lb., where it remained during the duration of the test.

b. The seal leaked very slowly (periodically) during the test, and the test was terminated when one gallon of lubricant had leaked past the test seal.

c. Inspection of the seals after the test showed that much less *Grafoil*^{R} had been lost from the seal cavity in DMT-035 than from previous tests with *Grafoil*^{R} seals with Zero Clearance Back Up System I.

d. Inspection of the seal sleeve after the test showed that it had been worn much more than previous tests with *Grafoil*^{R} seals with Zero Clearance Back Up System I. The flexing leaves had worn a groove in the seal sleeve. The upper seal back up leaves had worn a groove 0.014" deep in the seal sleeve, and the lower seal back up leaves had worn a groove 0.004" deep in the seal sleeve.

Figure 5 shows a photograph of the Upper (Test) Seal from DMT-035, and Figure 6 shows a photograph of the lower (Dummy) Seal from DMT-035.

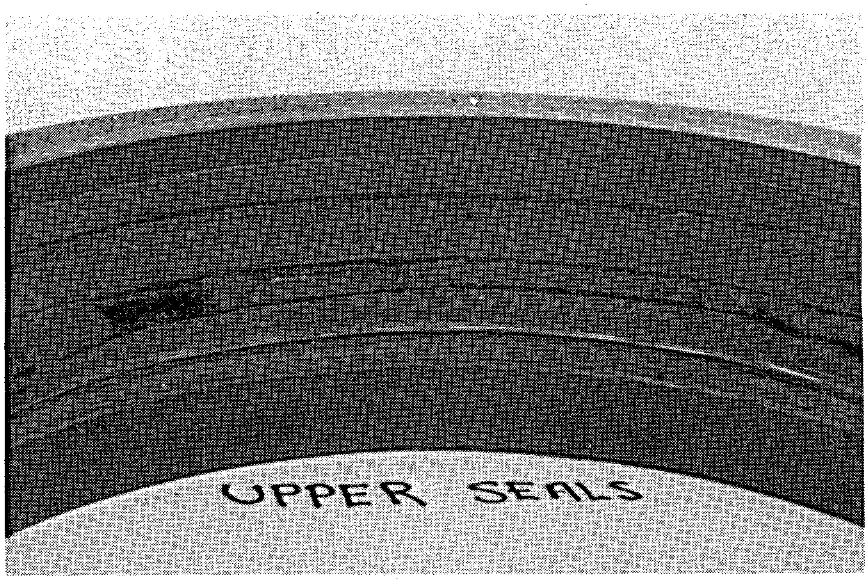


Figure 5

DMT-035, Upper (Test) Seal

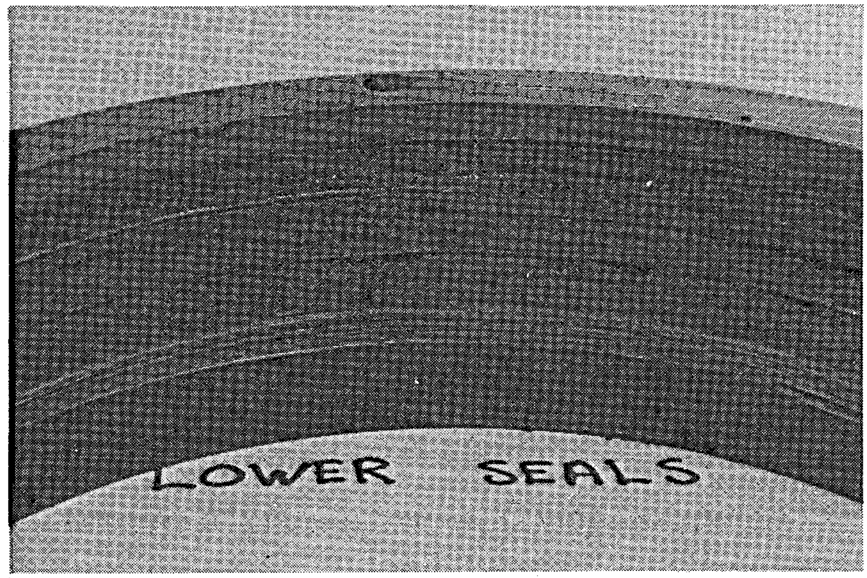


Figure 6

DMT-035, Lower (Dummy) Seal

Grafoil^R with Zero Clearance I

DMT-037 tested the *Grafoil*^{R}-Phosphor Bronze Seal with Zero Clearance Back Up System I. Two attempts were made to run this test and in each attempt a new set of back up rings were machined to a 0.001 inch diametrical clearance with the shaft sleeve. Rotation was attempted after both test set ups, and the Seal Tester was shut down immediately after torques in excess of 500 ft.-lbs. were noted.

DMT-037 was designed to duplicate the test results from DMT-024, the longest seal test to date. Every attempt was made to duplicate the test set up for DMT-024. One conclusion that suggests itself from comparison of DMT-024 and DMT-037 is that the material properties of the back up rings may have been different for the two tests, since the back up rings for each test were machined from different stock pieces of SAE 660 Bronze. Hence, the flexing properties of the lip may have been changed between the two sets of back up rings. This problem may be solved by establishing a flexing tolerance for the lip rather than machining the lip to a certain dimensional tolerance.

Canted - Buna-N

DMT-036 tested the generation II Canted Seal (Buna-N). This new generation seal had a different lip from the first generation seal. This new lip was more flexible and allowed the shaft sleeve to be installed without damaging the lip. This seal would not hold pressure and the test was terminated. Inspection of the seals after the test showed that the outside diameter and height of the seals had degraded and, hence, would not seal properly. Utex Industries was informed of these results and they are working on a new generation Canted seal that could solve the degradation problem.

CONCLUSIONS

1. There may be a limit to the life of non-elastomer seals with Zero Clearance Back Up Systems. The back up system may wear out before the seal wears out.
2. Testing should be performed with Zero Clearance Back Up System III to determine the proper thickness of the leaves for the full scale Bearing-Seal Package tests with lower pressure drops across the seals.
3. Further testing with Back Up System I should be suspended until the system can be evaluated at the next review meeting. Back Up System III should be used in the tests requiring a Zero Clearance Back Up System.
4. The canted seal concept has not been proved or disproved from the testing because of the Buna-N material degradation. High temperature materials are required for this seal to prevent degradation of the material at high temperatures.

FUTURE WORK

Several new seal types have been proposed for testing during the second six month period of Phase IV. These seal types include the hybrid assembly (a combination of elastomer and non-elastomer seals), HTCR (High Temperature Corrosion Resistant) elastomer and the new generation mesh matrix seals. Table III shows the list of proposed seal tests, and a description of each seal type follows. After the completion of these tests, a review meeting will be held to plan the remaining seal tests for the Seal Tester.

PROPOSED SEAL TESTS

Test ID	Seal Type	No. Of Pressure Rings	Back Up Rings	ΔP (psi)	RPM	Finish (rms)
038	Hybrid Assembly "V" Design	3	Zero Clearance SAE 660 Bronze	1500	412	4-8μ
039	Hybrid Assembly "SF" Design	3	SAE 660 Bronze	1500	412	8-12μ
040	HTCR- "SF" Design	3	SAE 660 Bronze	1500	412	8-12μ
041	Mesh Matrix Copper Wire	3	Sintered Graphite	1500	412	4-8μ
042	Mesh Matrix Glass Fiber	3	Sintered Graphite	1500	412	4-8μ
043	Mesh Matrix Carbon Fiber	3	Sintered Graphite	1500	412	4-8μ
044	*Grafoil*®- Horizontal Laminates	3	Zero Clearance SAE 660 Bronze	1500	412	4-8μ
045	Graphite Homogeneous	3	Zero Clearance SAE 660 Bronze	1500	412	4-8μ

TABLE III

Hybrid Assembly - V Design

The Hybrid Assembly - V Design consists of a Top Adapter, three pressure rings and a Zero Clearance Back Up System. The three pressure rings consist of an RD-172 (*Grafoil*^{R}-Phosphor Bronze) ring on top, an RD-239 (HTCR-Homogeneous) ring in the middle, and an RD-172 (*Grafoil*^{R}-Phosphor Bronze) ring on the bottom. The Top Adapter and Zero Clearance Back Up System are made out of SAE 660 Bronze. This seal assembly is shown in Figure 7.

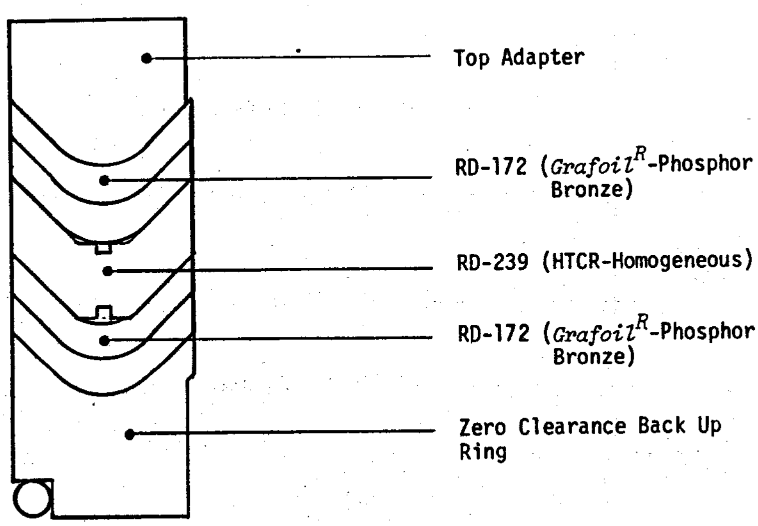


Figure 7

Hybrid Assembly - V Design

Hybrid Assembly - SF Design

The Hybrid Assembly - SF Design consists of a Top Adapter, three pressure rings and a Bottom Adapter. The three pressure rings consist of an RD-241 (HTCR-Fabric) ring on top, an RD-214 (Graphite-Homogeneous) ring in the middle, and an RD-239 (HTCR-Homogeneous) ring on the bottom. The Top and Bottom Adapters are made out of SAE 660 Bronze. This seal assembly is shown in Figure 8.

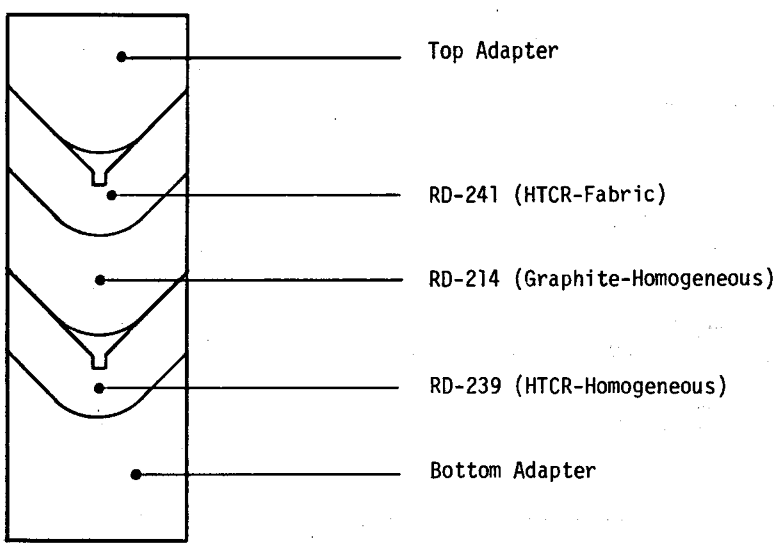


Figure 8

Hybrid Assembly - SF Design

HTCR Fabric - SF Design

The HTCR Fabric - SF Design assembly consists of a Top Adapter, three pressure rings and a Bottom Adapter. The three pressure rings all consist of RD-241 (HTCR-Fabric) rings. The Top and Bottom Adapters are made out of SAE 660 Bronze. This seal assembly is shown in Figure 9.

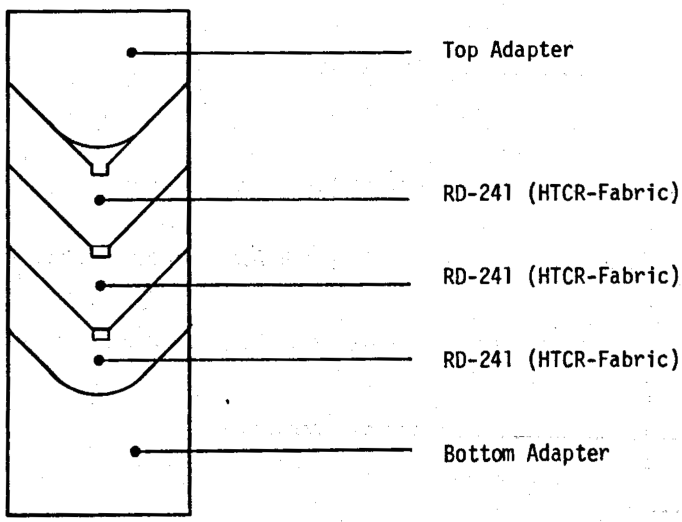


Figure 9

HTCR Fabric - SF Design

Mesh Matrix - Copper Wire

The Mesh Matrix- Copper Wire assembly consists of a Top Adapter, three pressure rings and a Bottom Adapter. The three pressure rings all consist of RD-249 (High Temperature Binder with Copper Wire Reinforcement) rings. The Top and Bottom Adapters are made out of sintered graphite. This seal assembly is shown in Figure 10.

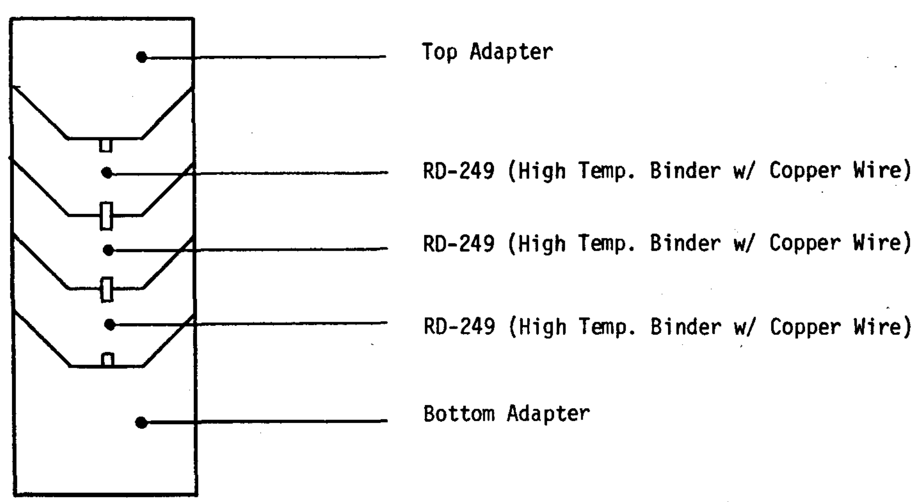


Figure 10

Mesh Matrix - Copper Wire

Mesh Matrix - Glass Fiber

The Mesh Matrix - Glass Fiber assembly consists of a Top Adapter, three pressure rings and a Bottom Adapter. The three pressure rings all consist of RD-250 (High Temperature Binder with Glass Fiber Reinforcement) rings. The Top and Bottom Adapters are made out of sintered graphite. This seal assembly is shown in Figure 11.

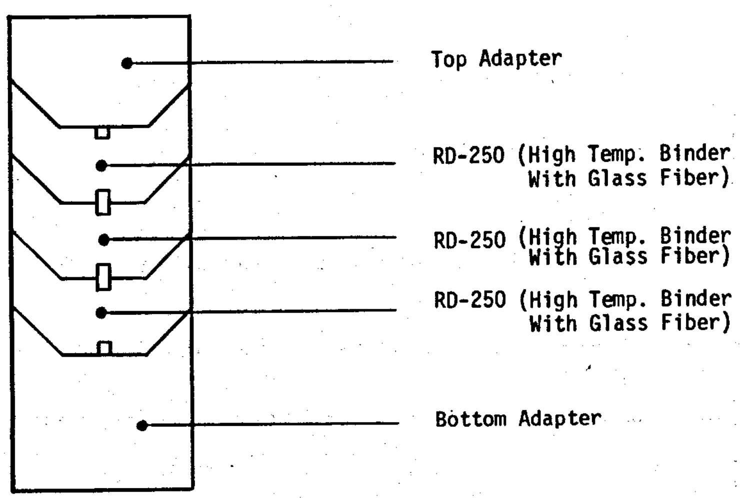


Figure 11

Mesh Matrix - Glass Fiber

Mesh Matrix - Carbon Fiber

The Mesh Matrix-Carbon Fiber assembly consists of a Top Adapter, three pressure rings and a Bottom Adapter. The three pressure rings all consist of RD-251 (High Temperature Binder with Carbon Fiber Reinforcement) rings. The Top and Bottom Adapters are made out of sintered graphite. This seal assembly is shown in Figure 12.

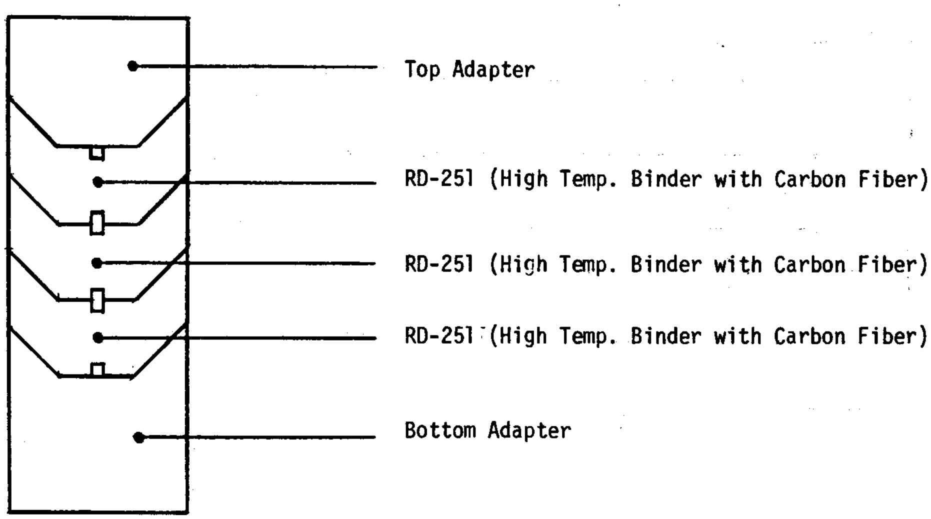


Figure 12

Mesh Matrix - Carbon Fiber

Grafoil[R] (Horizontal Laminates)

The *Grafoil*[R] (Horizontal Laminates) assembly consists of a Top Adapter, three pressure rings and a Zero Clearance Back Up System. The three pressure rings all consist of RD-172 *Grafoil*[R] (Horizontal Laminates)-Phosphor Bronze rings. The Top Adapter and Zero Clearance Back Up System are made out of SAE 660 Bronze. This seal assembly is shown in Figure 13.

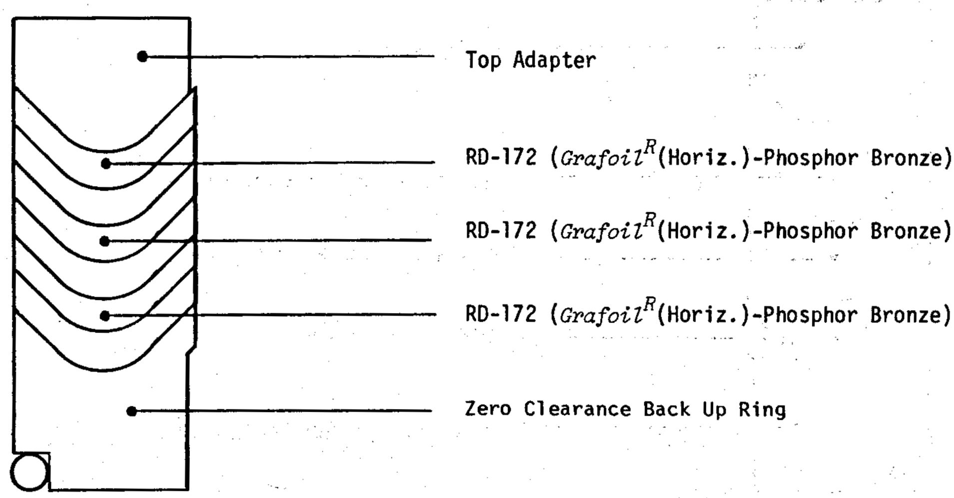


Figure 13

Grafoil[R] (Horizontal Laminates)

Graphite - Homogeneous

The Graphite - Homogeneous assembly consists of a Top Adapter, three pressure rings and a Zero Clearance Back Up System. The three pressure rings all consist of RD-214 (Graphite-Homogeneous) rings. The Top Adapter and Zero Clearance Back Up System are made out of SAE 660 Bronze. This seal assembly is shown in Figure 14.

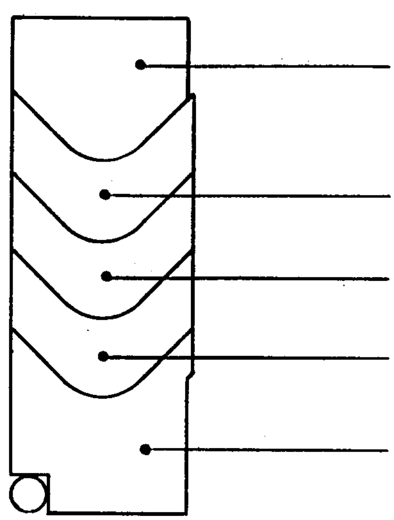


Figure 14

Graphite - Homogeneous

BEARING-SEAL PACKAGE TESTING AND EVALUATION

BEARING-SEAL PACKAGE TEST PROGRAM

Design Criteria

The design criteria for the Bearing-Seal Package Test Facility were first presented in the Phase II Semi-Annual Report (TR77-107). The basic range of test conditions which formed the basis for the design of the test facility are shown in Table IV.

PARAMETER	RANGE OF TEST CONDITIONS
Pressure	0-5,000 psi
Differential Pressure across Bearing-Seal Package	0-2,000 psi
Pressure Pulsation	0-500 psi
Flow Rate	100-200 GPM
Temperature	32-250° F Circulating 600° F Non-circulating
Rotational Speed	100-1,000 RPM
Dynamic Load	60,000 lbs. ± 60,000 random load at 3 to 10 Hz
Circulating Fluid	Water, Mud, Abrasives

Table IV

Design Parameters for the Bearing-Seal Package Test Facility

In the same report a number of additional design criteria and test requirements were listed:

1) Be able to vary the test conditions over the range indicated in Table IV;

2) Be able to "soak" the Bearing-Seal Package at 500°F for short times and at 350°F for many hours prior to testing;

3) Be able to measure (a) the axial load, (b) axial displacement, (c) torque, (d) RPM, (e) mud pressures, (f) mud temperatures, (g) lubricant temperatures, (h) bearing and seal temperatures, (i) lubricant leak rate, and (j) contamination or deterioration of the lubricant while the test is in progress;

4) Be able to maintain the temperature of the circulating fluid at about 250°F;

5) Be able to easily insert and remove the Bearing-Seal Package from the test vessel;

6) Be able to protect the re-usable Bearing-Seal Package from damage;

7) Be able to adapt the Bearing-Seal Package Test Facility to test full-scale downhole motors.

The following lists some of the design features of the Bearing-Seal Package Test Facility:

1) The pressure vessel has a 2 inch wall thickness and will operate at 5,000 psi.

2) The closures are attached to the pressure vessel by means of Grayloc seal rings and clamps. The Grayloc couplings allow for easy installation of the Bearing-Seal Package into the pressure vessel. These couplings also provide for easy attachment of additional lengths of the pressure vessel to accommodate the testing of full-scale downhole motors.

3) The Bearing-Seal Package Test Facility is fully instrumented to measure the parameters listed in Item 3 above.

4) A dynamic actuator, programmable function generator and servocontroller are used to control the dynamic load.

5) The rotational speed is controlled by a hydraulic drive motor, electrohydraulic flow control valve and servocontroller.

6) The differential pressure across the Bearing-Seal Package is created by replaceable nozzles in the nozzle sub.

7) The controlled soak temperature of the Bearing-Seal Package is provided by a pressurized hot water system.

The hot water system, shown schematically in Figure 15, uses the geothermal vessel equipped with cartridge heaters to heat the water. The water is piped from the geothermal vessel to the Bearing-Seal Package Test Facility. Inside the test facility there is an insulated metal jacket (called the hot water jacket) which surrounds the Bearing-Seal Package. The hot water jacket keeps the Bearing-Seal Package surrounded with hot water and prevents the hot water system from being contaminated by the drilling mud inside the test facility.

An air intensifier is used to pressurize the hot water system. The hot water system must be pressurized to keep the hot water from flashing to steam. The pressure on the inside and outside of the hot water jacket must be balanced to prevent failure of the hot water jacket.

Test Results

Six tests using the hot water system have been run in the Bearing-Seal Package Test Facility. These tests have demonstrated the following:

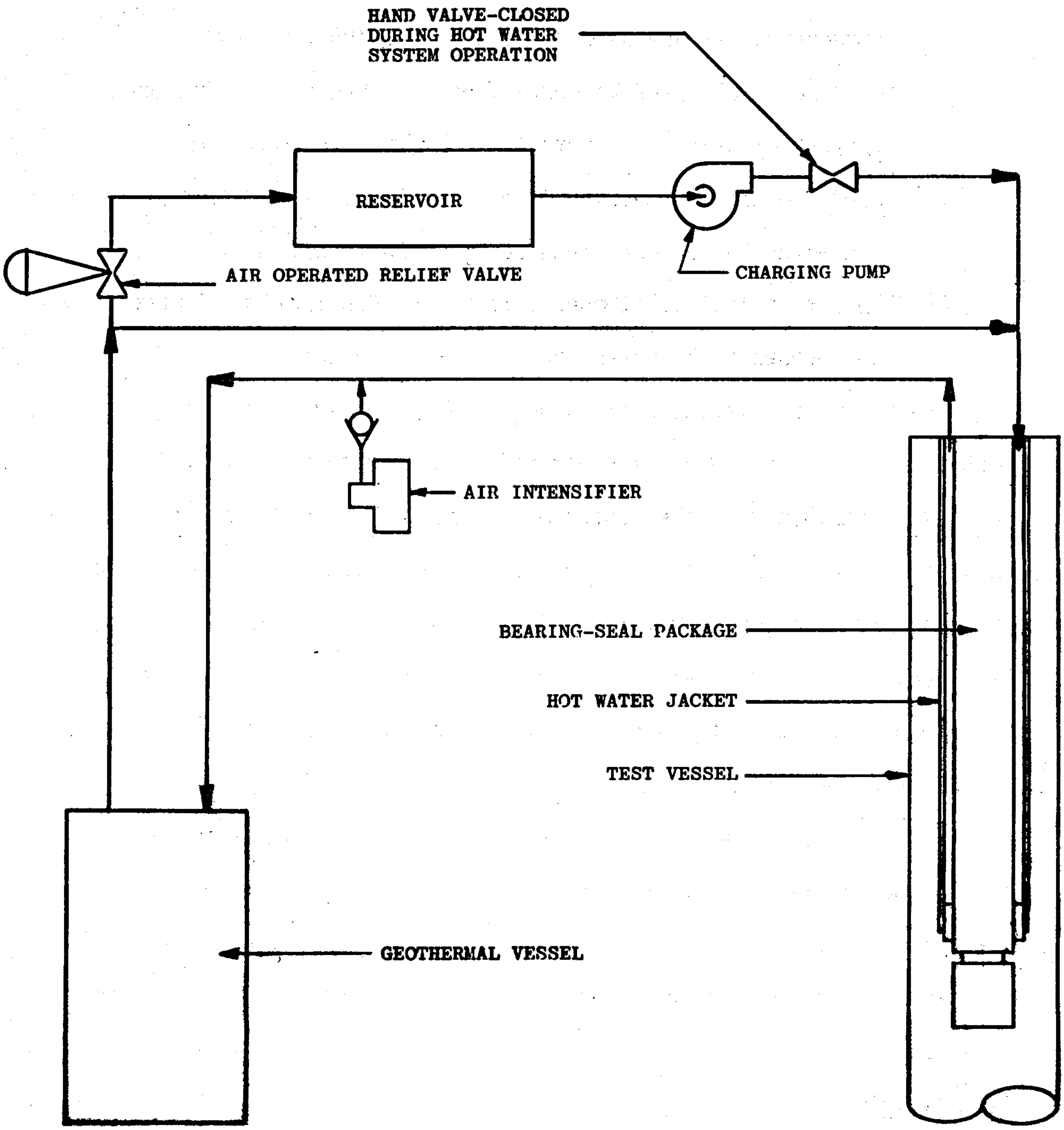


Figure 15

Hot Water System Schematic

1. The torques on the Bearing-Seal Package were relatively low, below 100 ft.-lbs.
2. There may be high temperatures generated in the area of the floating piston in the Bearing-Seal Package.
3. It is difficult for the water in the hot water system to flow without a circulation pump.

Bearing-Seal Package

A new floating piston was designed during this reporting period. The new piston is required because of the high temperatures observed during the tests and the damage that occurs to the floating piston during assembly and disassembly of the Bearing-Seal Package. Figure 16 shows a cross section of the new piston, which is a bidirectional lip seal. It was proposed and manufactured by Utex Industries, and is a one-piece molded seal made out of RD-239 HTCR (High Temperature Corrosion Resistant) elastomer.

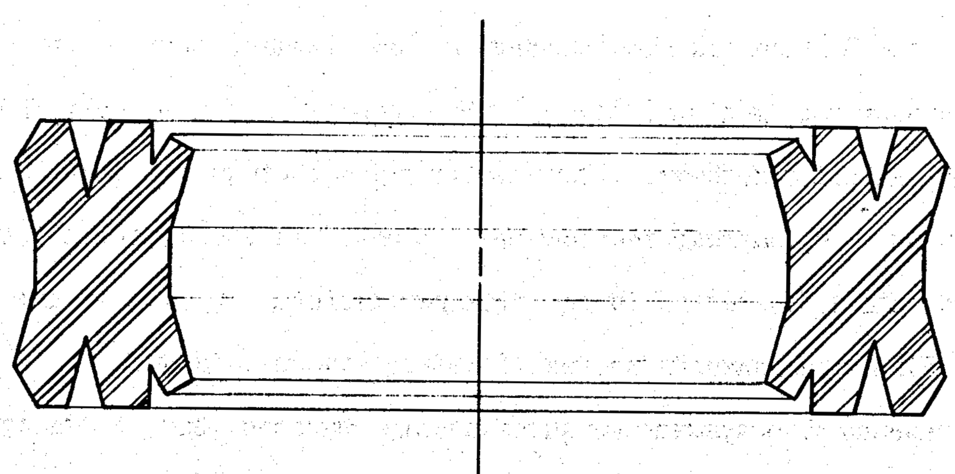


Figure 16

New Floating Piston

Several new floating piston designs were considered before deciding on the bidirectional lip seal. These designs included using *Grafoil*[R] seals and *Variseals*[R] on the inside diameter and "O" rings on the outside diameter. All of these designs were thoroughly evaluated, and Technical Services personnel from Parker Hannifin Corporation, Packing Division, Salt Lake City, were consulted on the designs using "O" rings. They did not recommend using "O" rings on the floating piston because contamination problems from the drilling mud would cause the "O" ring seal to fail. It was decided that the bidirectional lip seal offered the best promise because of the simplicity of construction, easy of installation and the potential problems with the "O" rings on the other designs.

Hot Water System

A reduced flow system was designed and tested during this reporting period in an attempt to maintain the temperature of the Bearing-Seal Package. The system is shown schematically in Figure 17. The fluid flows from the Triplex Mud Pump through a flow divider, part of the fluid flowing through the test facility and the other part of the fluid flowing through the adjustable choke. The fluid flowing through the test facility passes through two nozzles; one nozzle is located in the nozzle sub and the second nozzle is located in the flow restrictor. By varying the nozzle sizes the flow rate through the test facility can be adjusted.

The reduced flow system was successfully operated, but it did not keep the Bearing-Seal Package at the elevated temperature. Following the test of this system, a survey of pump manufacturers was performed to locate a circulating pump for the hot water system. The design

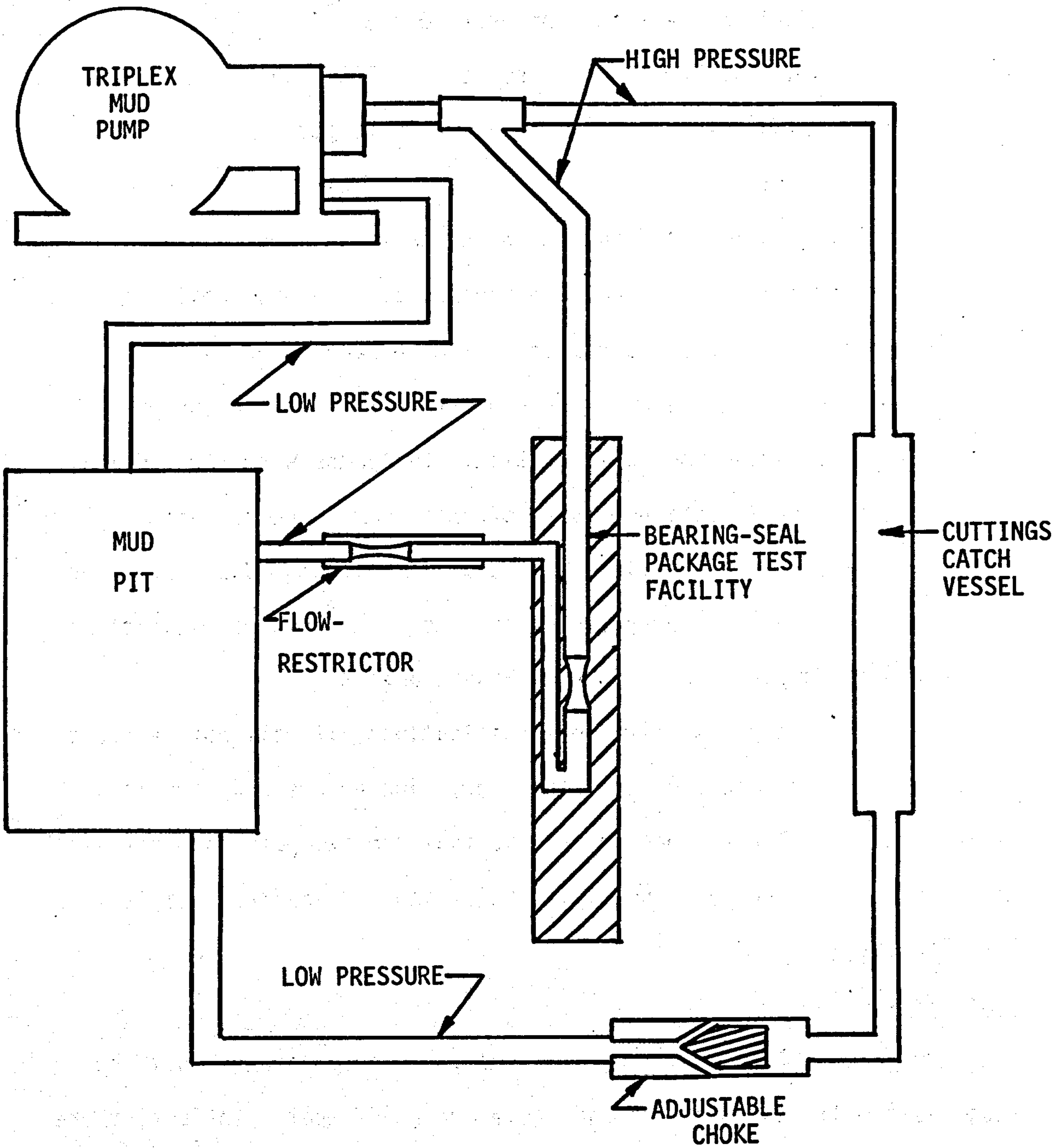


Figure 17

Reduced Flow System

conditions for the pump were:

Maximum Operating Temperature	=	500°F
Maximum Operating Pressure	=	5000 psi
Flow Rate	=	10 gpm
Fluid	=	Water

The Thomas Register was used to obtain the names of pump manufacturers to contact. In addition, the chemical process, oil and gas, boiler and nuclear industries were all consulted for pump recommendations.

The extreme temperature and pressure requirements for the pump eliminated most pumps from consideration. Two pumps were located that would meet the specifications. Both of these pumps are magnetically driven and have no shaft seals. One pump is manufactured by Autoclave Engineers, Inc., Erie, Pennsylvania, and the other pump is manufactured by The Kontro Company, Inc., Orange, Massachusetts.

Although both pumps meet the specifications, it will not be practical to use either pump because both carry very high prices and very long delivery times. The reason for this is that the two pumps are not stock items and would have to be specially built for the Bearing-Seal Package Test Facility.

Test Matrix

From the seal testing program it has been demonstrated that the test seals will generate a considerable amount of heat. In fact, there are times when the heat generated by the test seals is sufficient to keep the Seal Tester at the 250°F temperature without the heater system operating.

Since it is not practical to continue the test matrix with the hot water system as designed, the hot water system will be eliminated from the test facility. The Bearing-Seal Package will then be tested using the self-generating heat of the seals and other flow modifications to establish baseline data. The test matrix will then continue with adjustments made for the hot water system elimination.

FULL SCALE MOTOR TEST PROGRAM

Downhole Motors

Arrangements have been made with Dyna Drill and Eastman Whipstock to use their motors in the full scale motor tests. These two companies have provided valuable support in the design of the interconnecting parts for the Bearing-Seal Package, machining the connecting motor threads on these parts and in making arrangements to provide motors for the tests.

Dynamometer

The dynamometer system is required to load the downhole motors and turbines during the full scale motor tests. The system will be mounted at the bottom of the test vessel and the motors and turbines will be connected to the dynamometer by a splined cross-over shaft. It should be noted that when the test vessel is completely assembled, the components of the dynamometer which are attached to the vessel base will be completely inaccessible. This factor dictated that the system must be very reliable and have minimal maintenance requirements.

The dynamometer is shown schematically in Figure 18. The system selected is a hydraulic type and operates in the following manner. A large hydraulic pump is attached to the base of the vessel. This fixed displacement pump is driven by the motor or turbine being tested. High pressure piping is plumbed up to the main working level where the monitoring components are located. These components consist of a flow meter, a pressure transducer and housing, and a remote operated relief valve. The pump generates flow and pressure by pumping against the

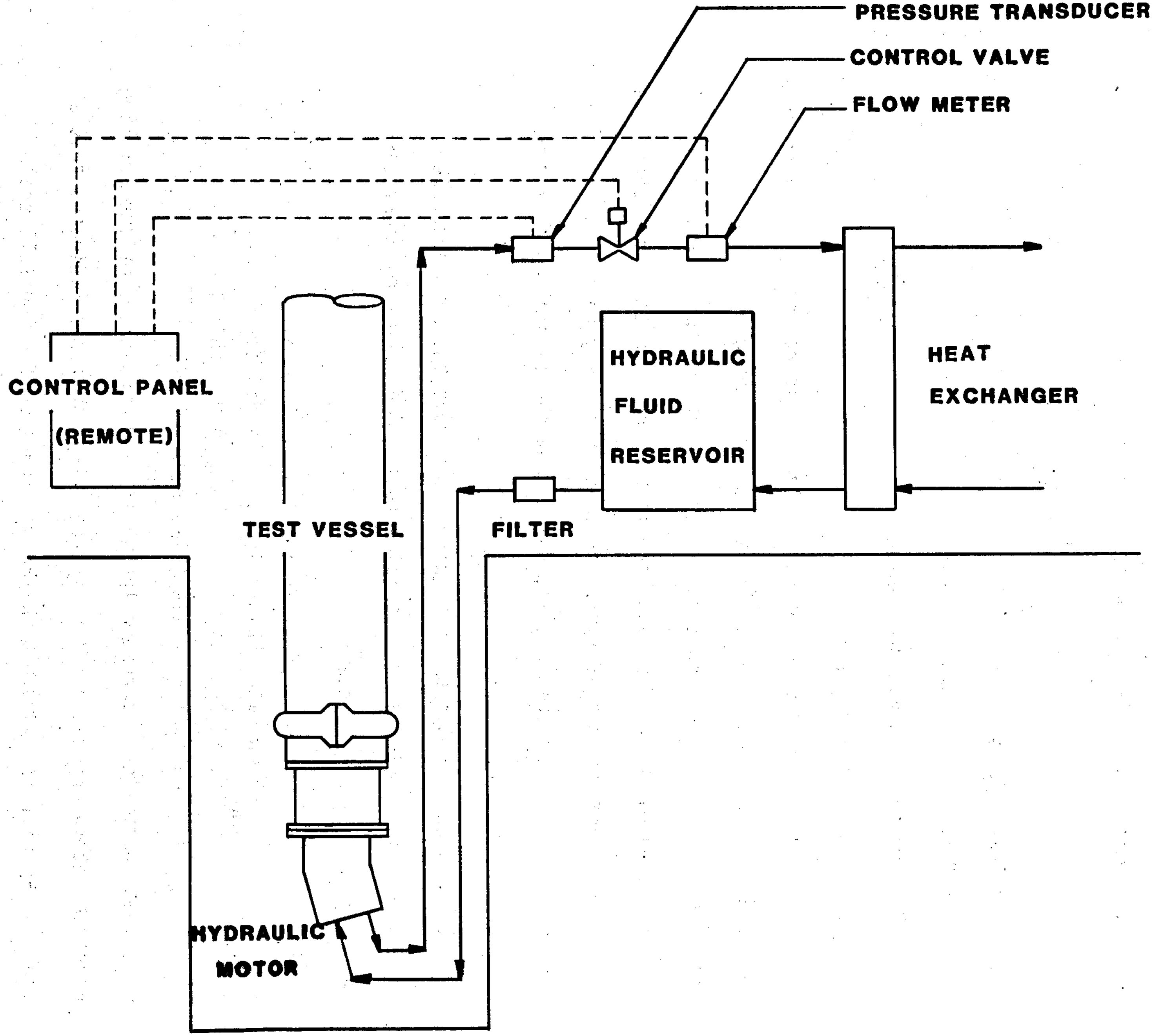


Figure 18
Dynamometer System

relief valve. Thus, with the pressure and flow rate known, the output power is determined by the following equation:

$$F = \frac{Q(P)}{1714} Np$$

where F = Power (horsepower)

Q = Flow rate (gallons per minute)

P = Pressure (pounds per square inch)

Np = Pump efficiency (97%)

After passing through the relief valve, the oil is cooled by a filter to tube and shell heat exchanger. It is then sent through a remove any contaminants, and then stored in a 300 gallon reservoir. The flow then enters the suction line to the pump and the cycle continues. The major advantage to this system is that it is very reliable; all components except the pump are accessible and the technology is known.

Mud Cooling System

The mud cooling system is required to remove the heat generated during the full scale motor or turbine test. The following parameters were used to size the system:

Pressure Drop (Maximum)	= 5500 psi
Flow Rate (Maximum)	= 360 gpm
Fluid Density	= 9.5 lb/gal
Maximum Particle (Diameter)	= 0.025 in.

These parameters represent the worst case condition for the Drilling Research Laboratory mud handling system. This analysis indicated that a cooling capacity of 1,000,000 BUT/Hr was required for the full scale motor and turbine test.

The mud cooling system is shown schematically in Figure 19. The main components of the system are the heat exchangers, cooling tower and cooling water circulating pump. The most critical component of the system is the heat exchanger, since it has to be able to handle the abrasive slurry without clogging or erosion problems. The type selected was a plate and frame heat exchanger. The plate and frame system operates by passing the hot fluid mud between two thin stainless steel plates and on the outside of the two plates, and cooling water is circulated in the opposite direction. Thus, every other space between the plates contains either cooling water or drilling mud. The unit has nearly 210 square feet of heat transfer area which consists of 64 stainless steel plates. The frame can accommodate 200 plates and thus triple the present heat transfer capacity as required.

To remove the heat from the water a cooling tower was purchased. The tower is approximately 8 feet high and nine-1/2 feet long. The all plastic construction will maximize life and minimize maintenance. The cooling water is circulated at a flow rate of 450 gpm.

Referring to the flow diagram in Figure 19, the operation of the mud cooling system is as follows. The mud is stored in a reservoir or mud pit. From this pit, the mud is pumped to the Triplex Mud Pump by a charging pump. The Triplex pump then pumps the mud to the Bearing-Seal Package Test Facility through the nozzle sub and out the test facility. The mud is then pumped through the heat exchanger and back to the mud pit. The cooling system will provide the Drilling Research Laboratory mud handling system with the capability of operating continuously for extended periods of time with minimal temperature increase.

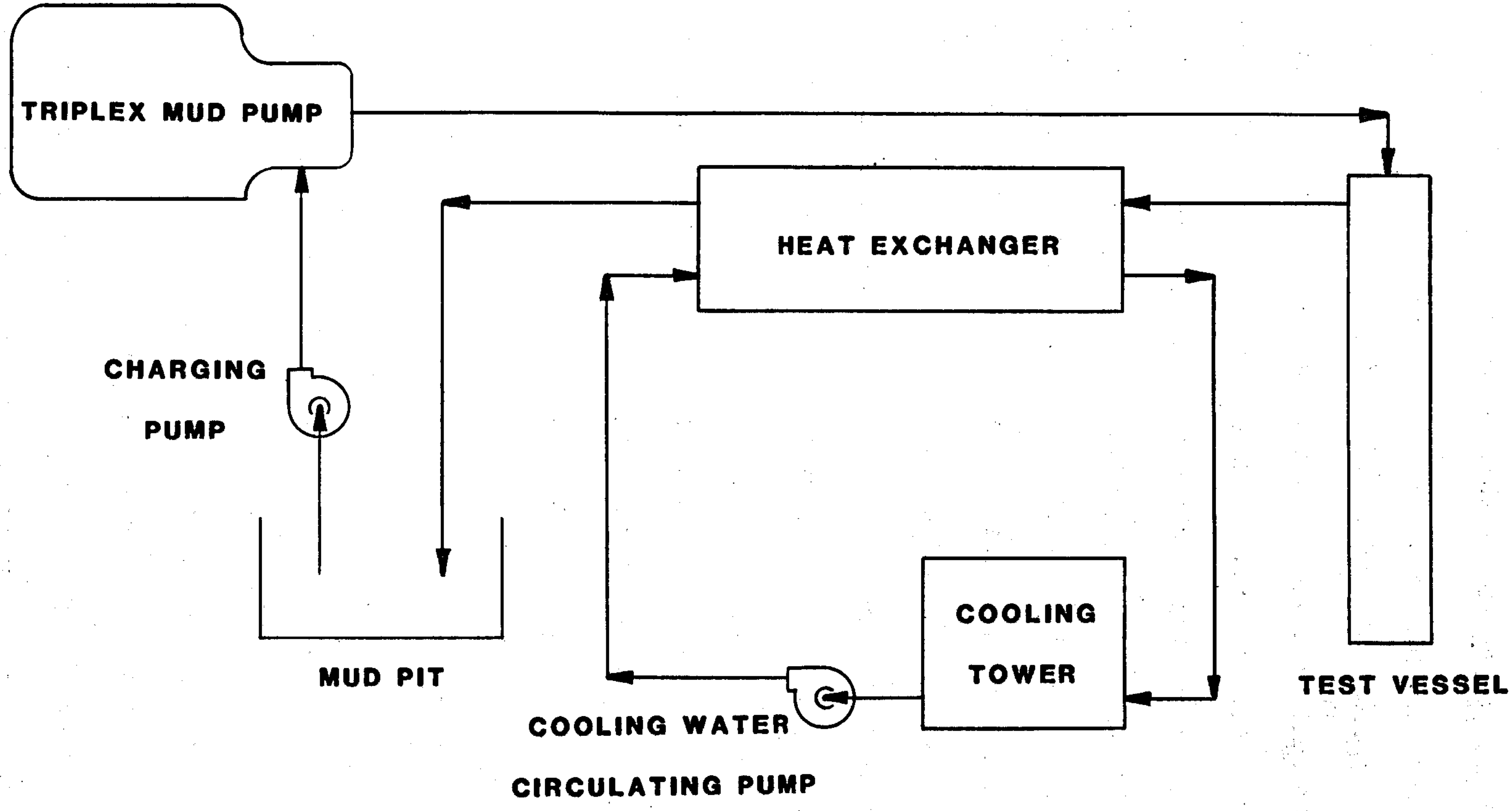


Figure 19
Mud Cooling System

LUBRICANT TESTING AND EVALUATION

LUBRICANT TESTING AND EVALUATION

Lubricant Test Results

Candidate high temperature lubricants are tested in the Terra Tek High Temperature Lubricant Tester which was described in the Phase II-Final Report (TR78-28). The machine was a statically loaded wear block which contacts a rotating ring that is partially submerged in the test lubricant. The tester is similar to the Alpha Model LFW-1 Friction and Wear Testing Machine described in ASTM Standard D2714-68, "Standard Method for Calibration and Operation of the Alpha Model LFW-1 Friction and Wear Testing Machine."

Results of tests on twenty three candidate high temperature lubricants were reported in the Phase III-Part 2 Semi-Annual Report (TR79-38). Pacer PLX-014, a synthetic oil developed by Pacer Lubricants, Inc., was found to be superior to any other sample tested. Based on these screening tests, Pacer PLX-014 was selected as the candidate lubricant for testing in the Bearing-Seal Package.

Since the initial lubricant screening tests, Pacer Lubricants has submitted several new lubricant samples for testing in the Terra Tek High Temperature Lubricant Tester. These new samples aimed at optimizing the PLX-014 formulation which was the best lubricant sample tested in the initial screening tests. The following describes the new lubricant samples tested and gives the qualitative results of the tests:

I. PLX-022

a. Description: Similar to PLX-014, but with an additional anti-wear agent.

b. Compatible with Elastomers: No

c. Results: Good - Comparable to PLX-014

II. PLX-023

a. Description: More viscous version of PLX-022
b. Compatible with Elastomers: No
c. Results: Good - Comparable to PLX-014

III. PLX-024

a. Description: More viscous version of PLX-014
b. Compatible with Elastomers: Yes
c. Results: Good - Comparable to PLX-014

IV. PLX-025

a. Description: PLX-014 with Teflon swelling agent
b. Compatible with Elastomers: Yes
c. Results: Poor lead-carrying ability

V. PLX-030

a. Description: Similar to PLX-022 with additives to improve lubrication below 135°C
b. Compatible with Elastomers: No
c. Results: Lubricant caused seizing and test terminated

VI. PLX-031

a. Description: Same as PLX-030
b. Compatible with Elastomers: No
c. Results: Lubricant caused seizing and test terminated

VII. PLX-042 (1)

a. Description: Similar to PLX-014 with an additional EP additive. Both PLX-014 and PLX-042 contain suspended graphite
b. Compatible with Elastomers: Yes

PLX-043 (2)

a. Description: Contains no solids and is a blend of two oils having different viscosities
b. Compatible with Elastomers: Yes

PLX-044 (3)

a. Description: Contains no solids and uses one base oil having a viscosity similar to PLX-043
b. Compatible with Elastomers: Yes

PLX-045 (4)

a. Description: Contains no solids and uses very high viscosity base oils
b. Compatible with Elastomers: Yes

PLX-046 (5)

a. Description: Contains no solids and uses very high viscosity base oils
b. Compatible with Elastomers: Yes

Results: PLX-042 to PLX-046 were designed to evaluate the effect of molecular weight and suspended solids on the load bearing ability of very high viscosity synthetic hydrocarbon oils. The conclusions from these tests were:

a. Suspended solids are not necessary
b. Higher molecular weights has a slight beneficial effect.

VIII. PLX-014XG

a. Description: PLX-014 without suspended graphite
b. Compatible with Elastomers: Yes
c. Results: Good - comparable to PLX-014, but not exceeding the results of PLX-014

The testing of these lubricant samples was performed under the project "Improved Seals and Lubricants for Geothermal Rock Bits," Sandia Contract No. 13-8783. These lubricant test results will be published in the next report for this project. The main conclusion that can be drawn for the Downhole Motor Project from these tests is that Pacer PLX-014 is still the best candidate lubricant for use in the Bearing-Seal Package.

PROGRAM STATUS, PLANS AND SCHEDULE

PROGRAM STATUS, PLANS AND SCHEDULE

Seal Testing and Evaluation

Thirty-seven seal tests have been completed in the DHM Seal Test Machine. During this reporting period the second longest test to date (33.1 hours) was completed with a set of three *Grafoil*^{R}-Phosphor Bronze seals with Zero Clearance Back Up System III (four-1/64" thick flexing leaves). Additional testing with this back up system will be performed in the second six month period of Phase IV.

During the second six month period of Phase IV, testing will be performed on new seal types. Some of these seal types are:

a. Hybrid Assembly

b. HTCR (High Temperature Corrosion Resistant) Elastomer

c. New Mesh Matrices

d. *Grafoil*^{R}-Horizontal Laminates

e. Graphite-Homogeneous

All of the seals listed in the proposed seal tests in Table III have been received and testing is in progress. At the completion of these tests a review meeting will be held at Terra Tek to evaluate the test results and plan for the future seal testing in Phase IV.

Bearing-Seal Package Testing and Evaluation

Testing will be performed in the Bearing-Seal Package Test Facility without the hot water system to establish baseline data for the heat generation of the seals in the Bearing-Seal Package. These test results will be evaluated at a review meeting at Terra Tek, the test matrix will be reviewed and the testing started. The number of tests that will be performed will remain the same as that listed in the Phase IV Proposal.

The design for the mud cooling system and dynamometer have been completed and all materials have been received. Installation of these two systems in the Drilling Research Laboratory is in progress.

Lubricant Testing and Evaluation

The main lubricant testing program has been completed. New candidate high temperature lubricants will be tested as they are received.

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November 11-12, 1976	Geothermal Projects Review Meeting Terra Tek, Salt Lake City.
July 19-20, 1977	Geothermal Well Technology Program Review Meeting, Albuquerque, New Mexico
September 7, 1977	Geothermal Drill Bit Program and Downhole Motor Program Review Meeting, Terra Tek, Salt Lake City.
February 7, 1978	Sandia/Terra Tek/Maurer Engineering DOE/DGE Project Review Meeting, Terra Tek, Salt Lake City.
June 11, 1978	Seal Test Review Meeting, Terra Tek, Salt Lake City.
June 20-22, 1978	Geothermal Drilling and Completion Contractor Review Meeting, Washington, D.C.
March 22, 1979	Sandia/Terra Tek/Maurer Engineering Downhole Motor Project Review Meeting, Terra Tek, Salt Lake City.
December 11-13, 1979	Geothermal Drilling and Completion Contractor Review Meeting, Washington, D.C.
January 28, 1980	Sandia/Terra Tek/Maurer Engineering Downhole Motor Project Review Meeting, Terra Tek, Salt Lake City.

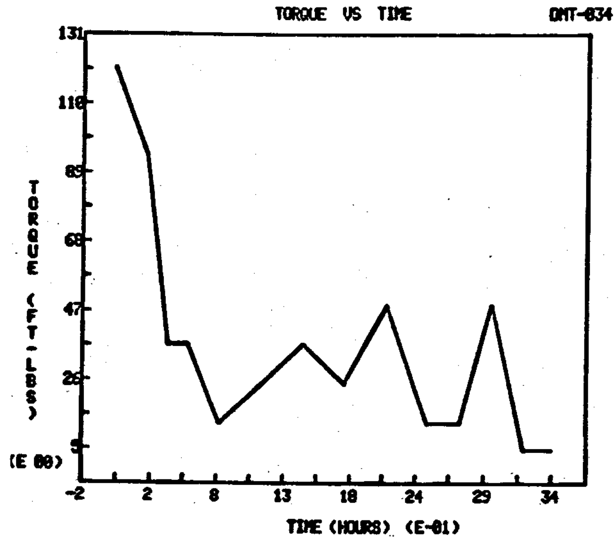
APPENDIX A

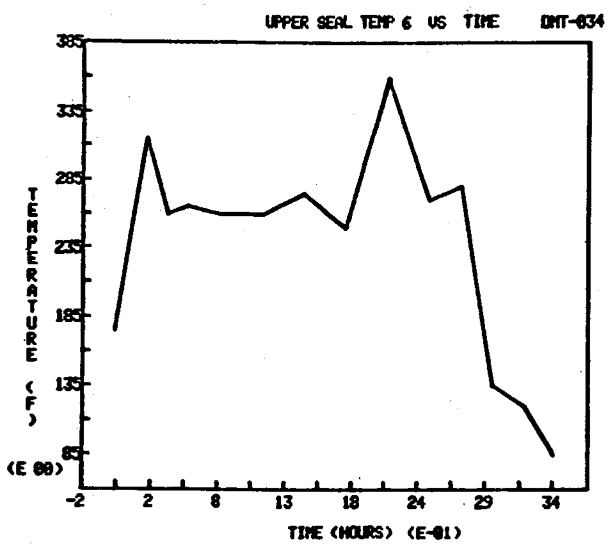
SEAL TEST RESULTS

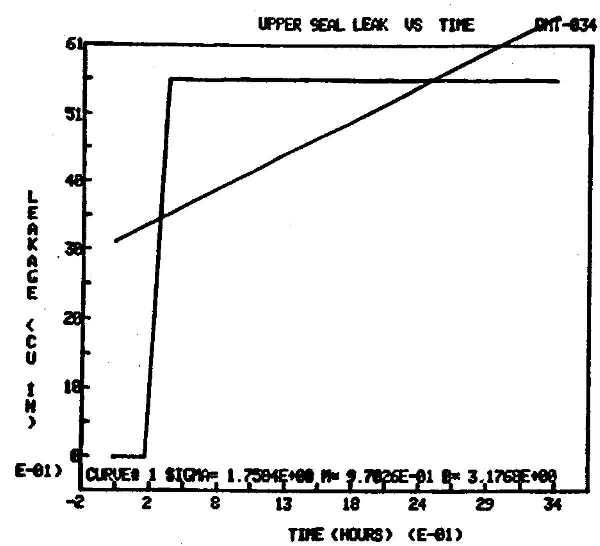
DMT - 034

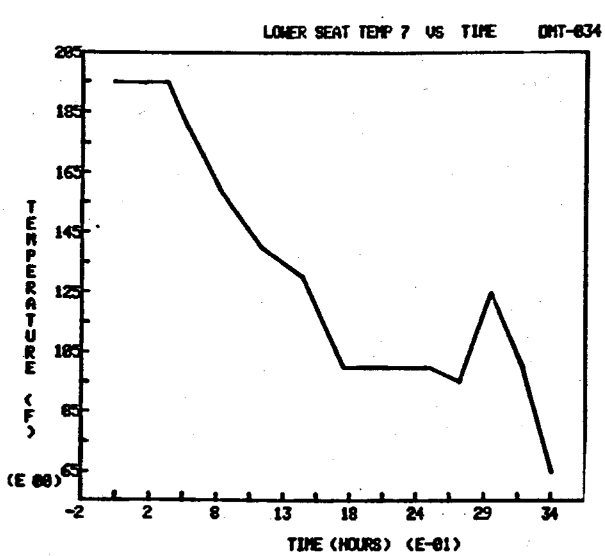
TEST ID: DMT-034

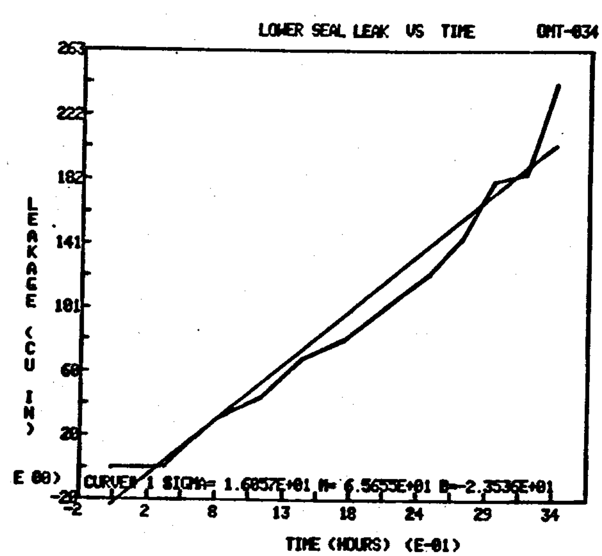
POINT	TIME	TORQUE	UPPER SEAL TEMP6 (F)	LOWER SEAL TEMP7 (F)	UPPER SEAL LEAK CU IN	UPPER SEAL LEAK RATE CU IN/HR	LOWER SEAL LEAK CU IN	LOWER SEAL LEAK RATE CU IN/HR	2 UPPER VESSEL	3 MID VESSEL	4 MID VESSEL	5 LOWER VESSEL
1	0.00	121.	175.	195.	0.0	0.0	250.0	0.0	250.	265.	255.	230.
2	0.25	95.	315.	195.	0.0	0.0	240.0	0.0	240.	265.	300.	315.
3	0.42	37.	260.	195.	5.6	33.1	230.0	6.6	230.	260.	255.	250.
4	0.58	37.	265.	180.	5.6	0.0	200.0	77.3	200.	240.	235.	250.
5	0.83	13.	260.	160.	5.6	0.0	205.0	72.0	205.	235.	245.	255.
6	1.17	25.	260.	140.	5.6	0.0	225.0	39.7	225.	260.	265.	270.
7	1.50	37.	275.	130.	5.6	0.0	220.0	75.0	220.	255.	260.	270.
8	1.83	25.	250.	100.	5.6	0.0	215.0	37.5	215.	250.	255.	270.
9	2.17	49.	360.	100.	5.6	0.0	210.0	62.9	210.	250.	260.	270.
10	2.50	13.	270.	100.	5.6	0.0	210.0	61.4	210.	250.	260.	275.
11	2.75	13.	280.	95.	5.6	0.0	210.0	90.0	210.	250.	260.	270.
12	3.00	49.	135.	125.	5.6	0.0	230.0	144.0	230.	250.	250.	210.
13	3.25	5.	120.	100.	5.6	0.0	250.0	18.0	250.	265.	220.	205.
14	3.48	5.	85.	65.	5.6	0.0	235.0	244.6	235.	255.	220.	205.

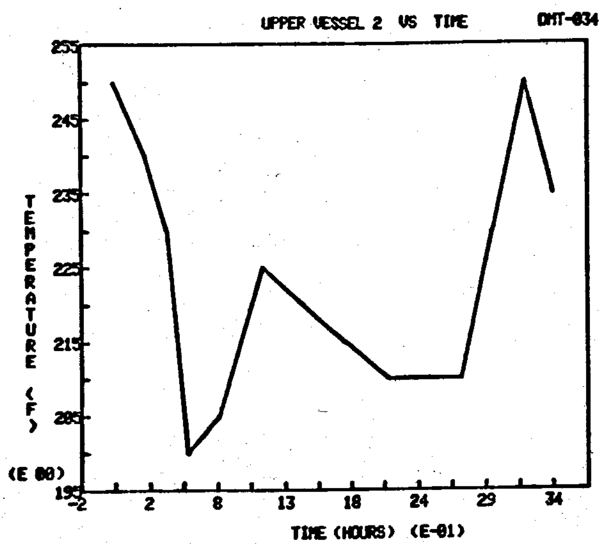

TORQUE VS TIME
DMT-034
TORQUE (FT-LBS)
(E 00)
131
110
89
68
47
26
5
-2
2
8
13
18
24
29
34
TIME (HOURS) (E-01)

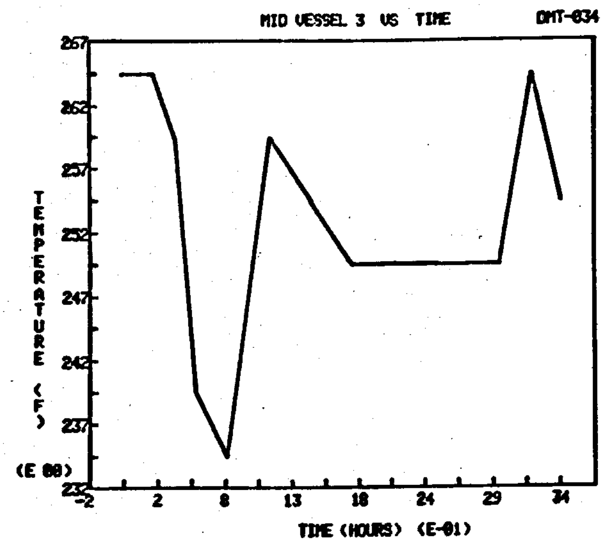

UPPER SEAL TEMP 6 VS TIME
DMT-034
TEMPERATURE (F)
(E 00)
385
335
285
235
185
135
85
-2
2
8
13
18
24
29
34
TIME (HOURS) (E-01)

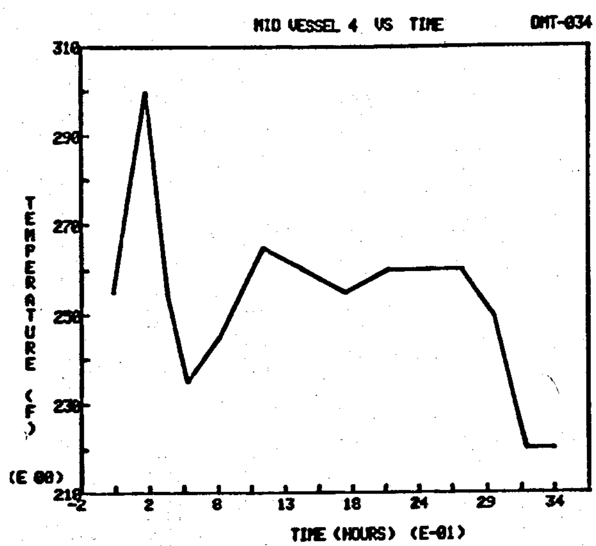

UPPER SEAL LEAK VS TIME
DMT-034
LEAKAGE (CU IN)
E-01)
61
51
40
30
20
10
0
CURVE# 1 SIGMA= 1.7584E+00 M= 9.7026E-01 B= 3.1768E+00
-2
2
8
13
18
24
29
34
TIME (HOURS) (E-01)


LOWER SEAT TEMP 7 VS TIME
DMT-034
TEMPERATURE (F)
(E 00)
205
185
165
145
125
105
85
65
-2
2
8
13
18
24
29
34
TIME (HOURS) (E-01)


LOWER SEAL LEAK VS TIME
DMT-034
LEAKAGE (CU IN)
E 00)
263
222
182
141
101
60
20
-20
CURVE# 1 SIGMA= 1.6057E+01 M= 6.5655E+01 B=-2.3536E+01
-2
2
8
13
18
24
29
34
TIME (HOURS) (E-01)


UPPER VESSEL 2 VS TIME
DMT-034
TEMPERATURE (F)
(E 00)
255
245
235
225
215
205
195
-2
2
8
13
18
24
29
34
TIME (HOURS) (E-01)


MID VESSEL 3 VS TIME
DMT-034
TEMPERATURE (F)
(E 00)
267
262
257
252
247
242
237
232
-2
2
8
13
18
24
29
34
TIME (HOURS) (E-01)


MID VESSEL 4 VS TIME
DMT-034
TEMPERATURE (F)
(E 00)
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290
270
250
230
210
-2
2
8
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18
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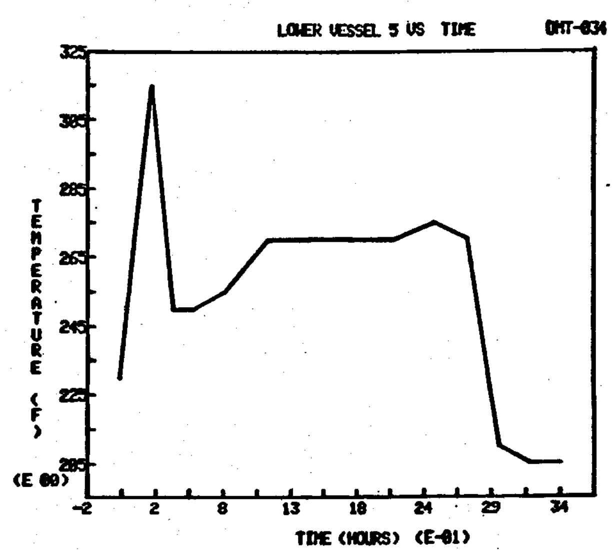
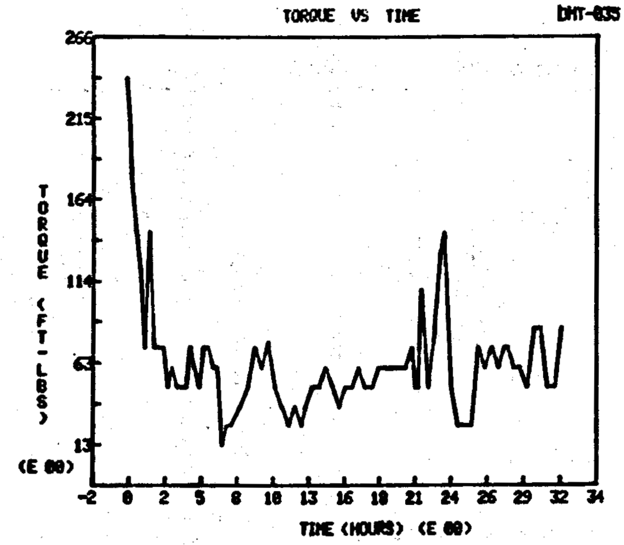
29
34
TIME (HOURS) (E-01)

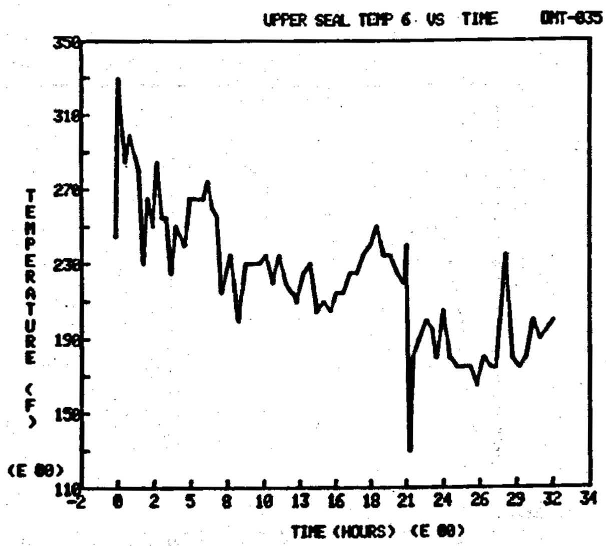

LOWER VESSEL 5 VS TIME
DMT-034
TEMPERATURE (F)
(E 00)
325
305
285
265
245
225
205
-2
2
8
13
18
24
29
34
TIME (HOURS) (E-01)

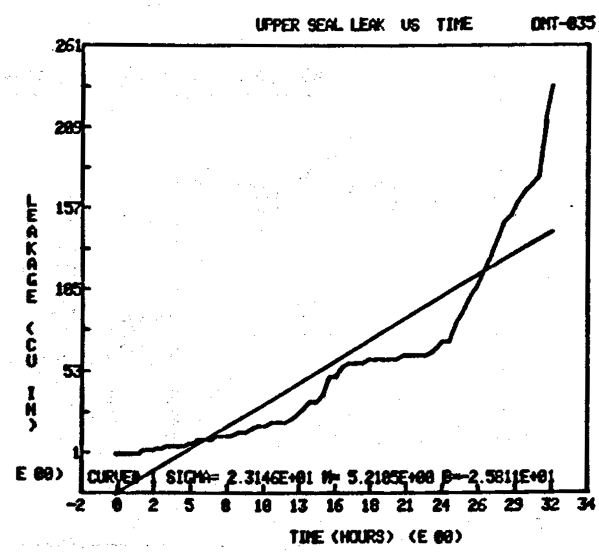
DMT - 035

TEST ID: DMT-035

POINT	TIME	TORQUE	UPPER SEAL TEMP6 (F)	LOWER SEAL TEMP7 (F)	UPPER SEAL LEAK CU IN	UPPER SEAL LEAK RATE CU IN/HR	LOWER SEAL LEAK CU IN	LOWER SEAL LEAK RATE CU IN/HR	2 UPPER VESSEL	3 MID VESSEL	4 MID VESSEL	5 LOWER VESSEL
1	0.00	241.	245.	0.	0.0	0.0	255.0	0.0	255.	260.	280.	225.
2	0.17	217.	330.	0.	0.0	0.0	240.0	0.0	240.	265.	280.	235.
3	0.33	181.	315.	0.	0.0	0.0	230.0	0.0	230.	265.	275.	240.
4	0.67	145.	285.	0.	0.0	0.0	215.0	0.0	215.	250.	265.	250.
5	1.00	121.	300.	0.	0.0	0.0	225.0	0.0	225.	250.	265.	260.
6	1.33	73.	290.	0.	0.0	0.0	230.0	0.0	230.	250.	265.	270.
7	1.67	145.	280.	0.	0.0	0.0	230.0	0.0	230.	250.	260.	275.
8	2.00	73.	230.	0.	2.3	6.8	230.0	6.8	230.	250.	260.	275.
9	2.33	73.	265.	0.	2.3	0.0	230.0	13.6	230.	250.	260.	280.
10	2.67	73.	250.	0.	2.3	0.0	235.0	0.0	235.	250.	260.	280.
11	3.00	49.	285.	0.	3.4	3.4	235.0	6.8	235.	250.	260.	280.
12	3.33	61.	255.	0.	3.4	0.0	230.0	6.8	230.	250.	260.	275.
13	3.67	49.	255.	0.	4.5	3.3	235.0	6.6	235.	250.	260.	275.
14	4.03	49.	225.	0.	4.5	0.0	235.0	12.5	235.	250.	260.	270.
15	4.37	49.	250.	0.	4.5	0.0	235.0	72.8	235.	250.	260.	275.
16	4.70	73.	245.	0.	4.5	0.0	235.0	6.8	235.	250.	260.	270.
17	5.03	61.	240.	0.	4.5	0.0	240.0	6.8	240.	250.	255.	270.
18	5.37	49.	265.	0.	6.8	6.6	240.0	26.5	240.	270.	265.	275.
19	5.70	73.	265.	0.	6.8	0.0	240.0	34.1	240.	250.	265.	275.
20	6.03	73.	265.	0.	9.0	6.8	240.0	27.3	240.	250.	265.	275.
21	6.37	61.	265.	0.	9.0	0.0	240.0	26.5	240.	255.	265.	275.
22	6.70	61.	275.	0.	9.0	0.0	235.0	6.8	235.	250.	265.	270.
23	7.03	13.	260.	0.	9.0	0.0	240.0	0.0	240.	255.	260.	265.
24	7.37	25.	255.	0.	11.3	6.6	240.0	0.0	240.	250.	260.	265.
25	7.73	25.	215.	0.	11.3	0.0	240.0	0.0	240.	250.	260.	265.
26	8.40	37.	235.	0.	11.3	0.0	225.0	36.9	225.	250.	265.	265.
27	8.98	49.	200.	0.	13.5	3.9	245.0	23.3	245.	245.	250.	275.
28	9.48	73.	230.	0.	13.5	0.0	240.0	13.5	240.	250.	265.	270.
29	9.98	61.	230.	0.	15.8	4.5	235.0	0.0	235.	250.	280.	285.
30	10.48	77.	230.	0.	18.0	4.5	235.0	0.0	235.	250.	260.	260.
31	10.98	49.	235.	0.	18.0	0.0	240.0	4.5	240.	255.	260.	260.
32	11.48	37.	220.	0.	20.3	4.5	245.0	9.0	245.	255.	270.	270.
33	11.98	25.	235.	0.	20.3	0.0	240.0	4.5	240.	255.	265.	285.
34	12.48	37.	220.	0.	20.3	0.0	240.0	0.0	240.	255.	265.	285.
35	12.98	25.	215.	0.	22.5	4.5	240.0	4.5	240.	255.	260.	285.
36	13.27	37.	210.	0.	24.8	7.8	250.0	7.8	250.	255.	265.	300.
37	13.77	49.	225.	0.	29.3	9.0	240.0	0.0	240.	255.	260.	295.
38	14.27	49.	230.	0.	33.8	9.0	240.0	4.5	240.	255.	265.	300.
39	14.77	61.	205.	0.	33.8	0.0	240.0	0.0	240.	255.	260.	280.
40	15.27	49.	210.	0.	38.3	9.0	245.0	0.0	245.	255.	255.	300.
41	15.77	37.	205.	0.	49.5	22.5	245.0	0.0	245.	255.	265.	305.
42	16.27	49.	215.	0.	49.5	0.0	245.0	0.0	245.	255.	265.	305.
43	16.77	49.	215.	0.	56.3	13.5	245.0	0.0	245.	255.	265.	300.
44	17.27	61.	225.	0.	58.5	4.5	250.0	0.0	250.	255.	265.	320.
45	17.77	49.	225.	0.	58.5	0.0	240.0	4.5	240.	255.	265.	300.
46	18.27	49.	235.	0.	58.5	0.0	240.0	0.0	240.	260.	270.	305.
47	18.77	61.	240.	0.	60.8	4.5	240.0	0.0	240.	255.	270.	300.
48	19.27	61.	250.	0.	60.8	0.0	240.0	4.5	240.	255.	270.	300.
49	19.77	61.	235.	0.	60.8	0.0	240.0	0.0	240.	255.	265.	300.
50	20.27	61.	235.	0.	60.8	0.0	240.0	0.0	240.	255.	265.	305.
51	20.77	61.	225.	0.	60.8	0.0	240.0	0.0	240.	255.	265.	305.
52	21.27	73.	220.	0.	63.0	4.5	240.0	4.5	240.	255.	265.	305.
53	21.52	49.	240.	0.	63.0	0.0	240.0	0.0	240.	260.	265.	310.
54	21.73	49.	130.	0.	63.0	0.0	190.0	0.0	190.	215.	170.	160.
55	21.95	109.	180.	0.	63.0	0.0	200.0	0.0	200.	245.	215.	185.
56	22.45	49.	190.	0.	63.0	0.0	235.0	0.0	235.	255.	210.	175.
57	22.95	85.	200.	0.	63.0	0.0	230.0	0.0	230.	265.	220.	180.
58	23.43	133.	195.	0.	65.3	4.7	230.0	0.0	230.	260.	210.	195.
59	23.68	145.	180.	0.	67.5	9.0	230.0	0.0	230.	240.	230.	195.
60	24.18	49.	205.	0.	72.0	9.0	215.0	4.5	215.	240.	215.	200.
61	24.68	25.	180.	0.	72.0	0.0	240.0	0.0	240.	265.	220.	200.
62	25.18	25.	175.	0.	83.3	22.5	230.0	4.5	230.	260.	225.	185.
63	25.68	25.	175.	0.	90.0	13.5	230.0	4.5	230.	260.	225.	200.
64	26.18	73.	175.	0.	99.0	18.0	215.0	4.5	215.	250.	195.	195.
65	26.68	61.	165.	0.	105.8	13.5	225.0	0.0	225.	245.	215.	195.
66	27.18	73.	180.	0.	114.8	18.0	220.0	0.0	220.	250.	220.	195.
67	27.68	61.	175.	0.	123.8	18.0	225.0	0.0	225.	250.	210.	180.
68	28.07	73.	175.	0.	132.8	23.1	220.0	0.0	220.	250.	215.	190.
69	28.35	73.	200.	0.	139.5	24.1	225.0	0.0	225.	255.	220.	195.
70	28.77	61.	235.	0.	148.5	21.4	250.0	10.7	250.	265.	265.	240.
71	29.27	61.	180.	0.	153.0	9.0	225.0	9.0	225.	260.	215.	215.
72	29.77	49.	175.	0.	162.0	18.0	230.0	13.5	230.	275.	215.	195.
73	30.27	85.	180.	0.	168.8	13.5	230.0	9.0	230.	275.	215.	200.
74	30.77	85.	200.	0.	173.3	9.0	230.0	9.0	230.	275.	220.	200.
75	31.27	49.	190.	0.	177.8	9.0	230.0	18.0	230.	275.	220.	200.
76	31.77	49.	195.	0.	213.8	72.0	230.0	4.5	230.	275.	210.	200.
77	32.27	85.	200.	0.	236.3	45.0	235.0	4.5	235.	275.	220.	200.



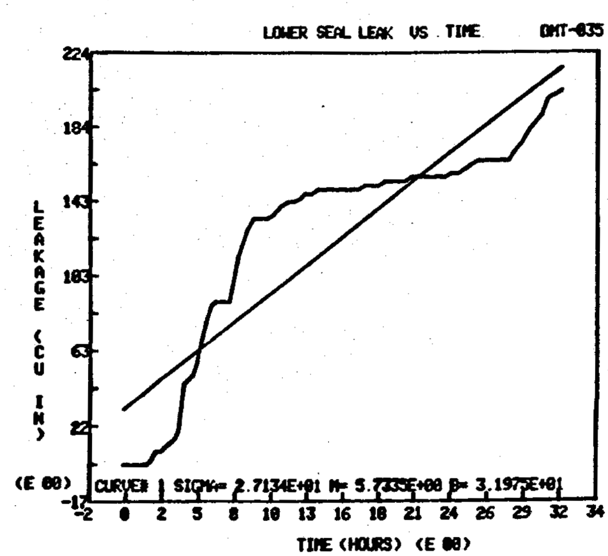


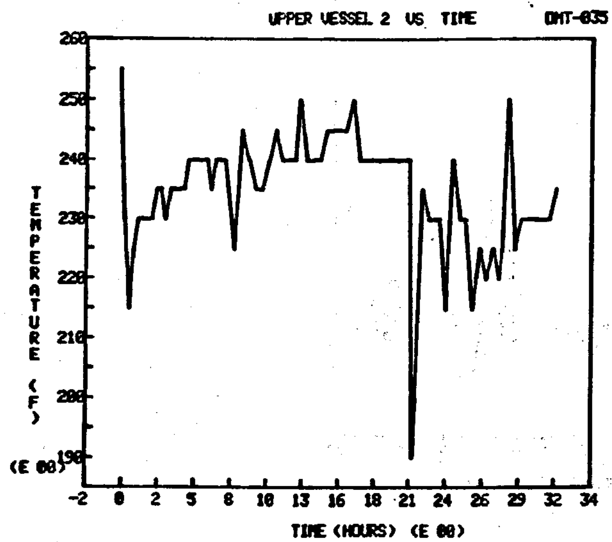


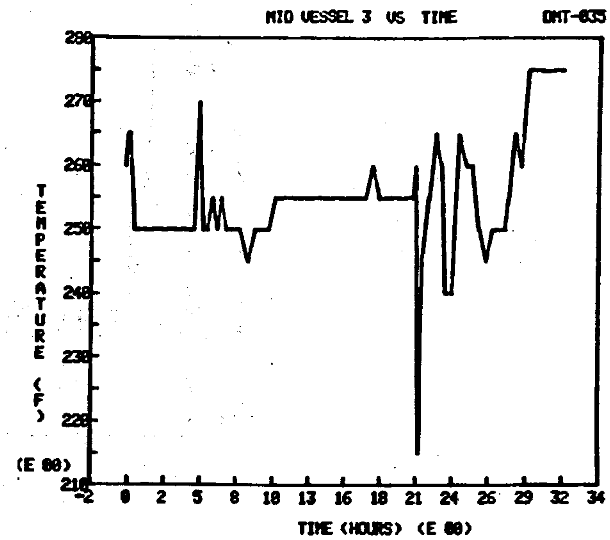
Signal From Thermocouple

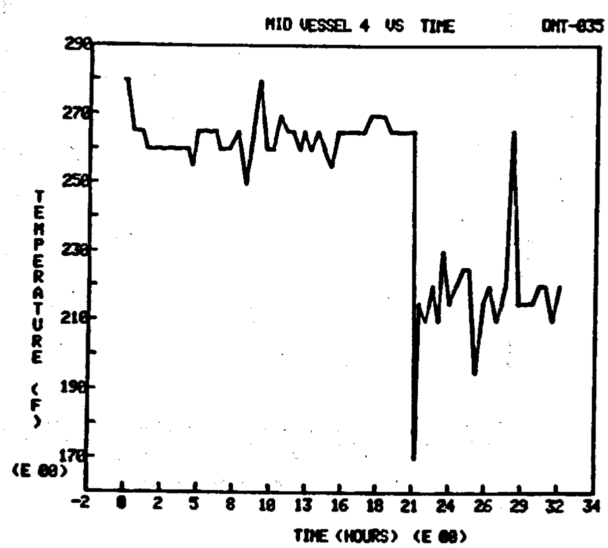
No. 7 Was Lost During

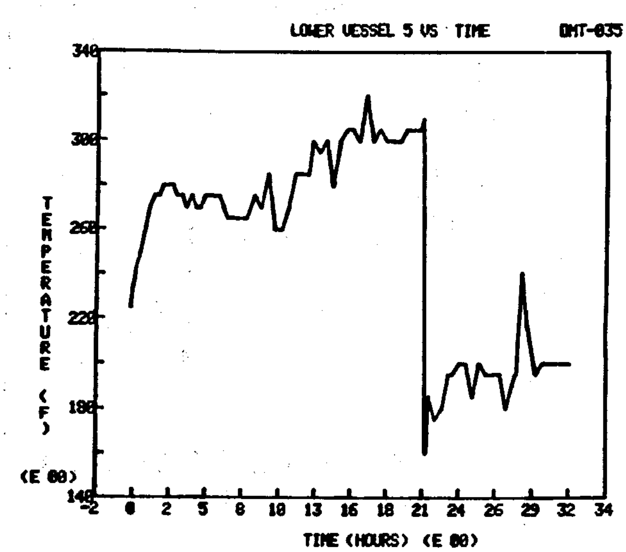
The Test.




UPPER VESSEL 2 VS TIME
DMT-035
TEMPERATURE (F)
(E 00)
260
250
240
230
220
210
200
190
-2 0 2 5 8 10 13 16 18 21 24 26 29 32 34
TIME (HOURS) (E 00)


MID VESSEL 3 VS TIME
DMT-035
TEMPERATURE (F)
(E 00)
280
270
260
250
240
230
220
210
-2 0 2 5 8 10 13 16 18 21 24 26 29 32 34
TIME (HOURS) (E 00)


MID VESSEL 4 VS TIME
DMT-035
TEMPERATURE (F)
(E 00)
290
270
250
230
210
190
170
-2 0 2 5 8 10 13 16 18 21 24 26 29 32 34
TIME (HOURS) (E 00)


LOWER VESSEL 5 VS TIME
DMT-035
TEMPERATURE (F)
(E 00)
340
300
260
220
180
140
-2 0 2 5 8 10 13 16 18 21 24 26 29 32 34
TIME (HOURS) (E 00)

APPENDIX B

Semi-Annual Progress Report

on

IMPROVEMENT OF DOWNHOLE DRILLING MOTOR BEARINGS AND SEALS

Sandia Contract No. 46-3054

by

Jeff L. Barnwell

submitted to

SANDIA LABORATORIES
Geothermal Drilling and Completion
Technology Development Program
Albuquerque, New Mexico 87185

Attention: Mr. John Finger

May 1980

TR80-15

Maurer Engineering contracted to participate in the rotary seal and bearing-package development program. The following tasks were laid out in the work statement:

Task I - Manufacture Motor Interface Parts

The parts required to adapt the Bearing-Seal Package to commercial downhole motors will be manufactured by Maurer Engineering. The manufacturing will include materials selection, construction, and heat treatment of parts to make the Bearing-Seal Package with the motors.

Task II - Design and Manaufacture an Improved Floating Piston

The Bearing-Seal Package uses a floating piston, exposed on one side to mud pressure and on the other side to the bearing lubricant, to maintain pressure on the bearing lubricant. To do this more reliably, a new floating piston will be designed and manufactured.

Task III - Design and Manufacture Improved Redundant Seals

Results from the initial tests with redundant seals will be evaluated, and improved redundant seals will be designed and manufactured for use in the seal tester or in the DOE Bearing-Seal Package.

Task IV - Design and Manufacture Improved Rotary Seals

Design and manufacture improved Grafoil rotary seals based on the results of previous seal tests and on the use of the seals in the Maurer geothermal turbodrills in the LASL Hot Dry Rock experiment.

Task V - Bearing-Seal Package Testing Evaluation

Assist Terra Tek personnel in post-mortem examinations of worn parts in Bearing-Seal Package and in redesigning any parts which may fail.

Task VI - Assist Terra Tek in Conducting and Evaluating Full-Scale Motor Tests

Assist Terra Tek in designing and conducting full-scale tests in the Downhole Motor Test Facility.

At the time of this reporting, the work which has been completed is reviewed below:

Task I - The four interface parts (Nos. 79-71, 79-72, 79-73, 79-74) were manufactured in Houston. Then, parts which required such work were sent to the respective positive displacement motor manufacturers to have proprietary threads machined on them. As of this date, all of these parts have been received at Terra Tek. These parts, along with a set of assembly drawings (Nos. 79-67, 79-68), will allow the use of both Dyna-Drill and Eastman-Whipstock motors with the Bearing-Seal Package.

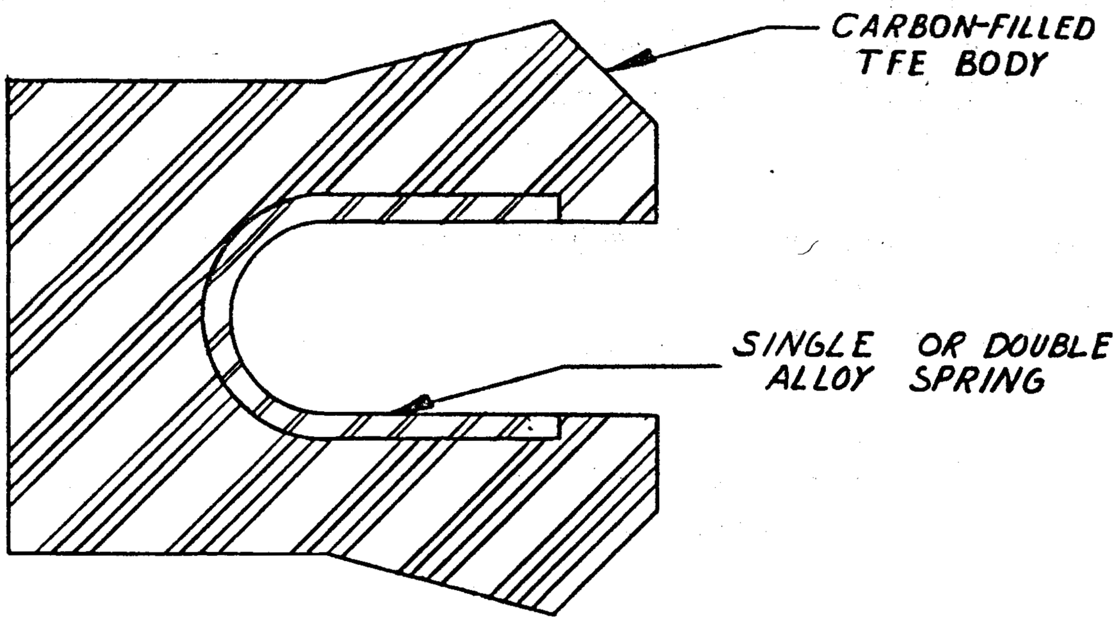
Task II - Using information gained from LASL and Sandia sponsored motor tests, a new floating piston (No. 80-80) was designed and manufactured. The new concept incorporates the use of a Ryton body. Besides lower friction and less chance of seizure, this material weighs far less than bronze, thus preventing any opening of the seals by dynamic inertia "whipping." Also, the new piston uses the Variseal® seal design. A cross section of the Variseal® is shown in Attachment 1.

Task III - The first redundant seal assembly (Nos. 79-444, 79-445, 79-446, 79-447, 79-453, 79-454, PI-256) was manufactured and sent to Terra Tek during this period. Several other conceptual designs have been completed. After the feasibility of each design has been evaluated, a final choice will be detailed and manufactured.

Task IV - MEI personnel have been involved in both the evaluation of test results and design of new seal concepts. The Variseal® design was used to come up with an assembly for the lower seal of the Bearing-Seal Package. Also, Variseals® and housings necessary to test them in the seal tester were supplied (Nos. 80-83, 80-84) to Terra-Tek.

Task V - MEI personnel assisted in replacing the mesh springs in the Bearing Pack with the newer Belleville springs. Most of the work under this task will be performed after the Bearing Package/Motor System becomes operational.

Task VI - The work under this task will be performed as the Bearing Package/Motor System becomes operational.



VARISEAL CROSS-SECTION

APPENDIX C

SUMMARY OF PROGRAM RESULTS

Phase I Major Accomplishments

(1) Gathered background information to determine current needs of industry and establish a range of conditions needed to simulate geothermal conditions -

- A meeting was conducted with downhole motor experts at Rice University.
- Jeddy Nixon presented his experiences in downhole motor development at a review meeting at Terra Tek, Inc.
- John Jeter was consulted on the Bearing-Seal Package design and the DHM Seal Test Machine.
- Industry contacts and correspondence were established.
- Information from the Geothermal Bit Program such as downhole geothermal temperatures, rock formations, and drilling problems was used to establish design limits of the seal and bearing test equipment.

(2) Determine the state-of-the-art in motor development and the feasibility of new motor concepts -

- Maurer Engineering conducted a patent search on downhole motors and reported the results in the Semi-Annual (TR76-59) and Final (TR77-29) reports.
- Maurer Engineering presented a review of the economic incentives for geothermal downhole motor development.

(3) Performed the preliminary design of the Bearing-Seal Package -

- The Bearing-Seal Package design was described in the Semi-Annual (TR76-59) and Final (TR77-29) reports.

(4) Candidate high temperature seals were identified -

- A description of the candidate seals was presented in the Semi-Annual (TR76-59) and Final (TR77-29) reports.
- Bearing application was presented in the Semi-Annual (TR76-59) and Final (TR77-29) reports.

(5) Design and fabrication of the DHM Seal Test Machine was completed -

- Preliminary concepts and evolution of the final design were presented in the Semi-Annual (TR76-59) report.
- John Jeter was consulted on the design of the DHM Seal Test Machine.
- Detailed design and fabrication of the DHM Seal Test Machine was completed.

(6) Conceptual design of the Bearing-Seal Package Test Facility was completed

Phase II Major Accomplishments

(1) Seal Testing and Evaluation -

- Debugging tests on the DHM Seal Test Machine were completed.
- The first evaluation tests on the baseline seals were completed.
- Contacts were established with major seal manufacturers.
- Candidate seals for future testing were obtained.

(2) Bearing-Seal Package Testing and Evaluation -

- Preliminary design of the Bearing-Seal Package Test Facility was completed
- Fabrication of the Bearing-Seal Package was completed.

(3) Lubricant Testing and Evaluation -

- The Terra Tek High Temperature Lubricant Tester was made operational

Phase III Part 1 Major Accomplishments

(1) Seal Testing and Evaluation -

- Baseline tests on a standard industry seal were completed.
- Several of the new candidate seal types were tested.
- Additional high temperature candidate seal types were tested.
- The DHM Seal Test Machine underwent several modifications to improve ease of handling and for more reliable operation.

(2) Bearing-Seal Package Testing and Evaluation -

- A design to solve the fluid erosion problem was completed and successfully tested.
- Final design of the Bearing-Seal Package Test Facility was completed. Fabrication of parts was started.
- Machining of the Grayloc connections in the pressure vessel tubes was completed.
- Design and fabrication of the pressure vessel holding fixture was completed.
- The Dynamic Actuator was received and modifications for the Bearing-Seal Package Test Facility were started.
- The 100-HP hydraulic power supply to drive the dynamic actuator and Bearing-Seal Package was designed and purchased.

(3) Lubricant Testing and Evaluation -

- Wear rings and blocks for the Terra Tek High Temperature Lubricant Tester were obtained.
- A survey of downhole motor manufacturers was made to obtain lubricant recommendations. The candidate lubricant matrix was revised.

Phase III Part 2 Major Accomplishments

(1) Seal Testing and Evaluation -

- Second and third generation seals were obtained and some of these seal types tested.

- New seal back up system designs were completed and tested.

(2) Bearing-Seal Package Testing and Evaluation -

- Bearing-Seal Package Test Facility was completely assembled and debugging was started.

- The hot water system was completed and operated. Three tests were performed.

- The electronics from the DHM Seal Test Machine system were interfaced with the Bearing-Seal Package Test Facility.

(3) Lubricant Testing and Evaluation -

- Initial screening of candidate high temperature lubricants was completed in the Terra Tek High Temperature Lubricant Tester.

- The candidate lubricant was selected for testing in the Bearing-Seal Package.

Phase IV Major Accomplishments

(1) Seal Testing and Evaluation

- Second generation canted seals were tested

- Flexing leaves back up system was tested

(2) Bearing-Seal Package Testing and Evaluation -

- The dynamometer and mud cooling system were designed, parts received, and assembly is progressing.

- Three tests run to operate hot water system and measure breakout torques of Bearing-Seal Package.

(3) Lubricant Testing and Evaluation

- Several new lubricant samples were tested in the Terra Tek High Temperature Lubricant Tester

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1100	C. D. Broyles
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