GRANT NUMBER DE-FG07-98ID13654

GEOTHERMAL POWER INITIATIVE/GEOTHERMAL POWER PLANT RESEARCH AND DEVELOPMENT-RUBBER BEARINGS FOR DOWN-HOLE PUMPS

Final Technical Report

Bob Sullivan Mammoth Pacific, L.P.

1. Synopsis of Project Activity

1998	Awarded cost share grant from DOE
1st Qtr 1999	Developed fail safe lubricating system
2nd Qtr 1999	Performed first large scale test with nitrile based bearings. It failed due to material swelling. Failure was blamed on improper tolerance.
3rd Qtr 1999	Material tests were performed with autoclaves and exposure tests to Casa Diablo fluids. Testing of Viton materials began. Alternate bearing designs were developed to limit risk of improper tolerances.
4th Qtr 1999	Site testing indicated a chemical attack on the bearing material caused the test failure and not improper bearing tolerance.
1st Qtr 2000	The assistance of Brookhaven National Laboratory was obtained in evaluating the chemical attack. The National Laboratory also began more elaborate laboratory testing on bearing materials.
2nd Qtr 2000	Testing indicated Viton was an inappropriate material due to degradation in Casa Diablo fluid. Testing of EPDM began.
3rd Qtr 2001	EPDM bearings were installed for another large scale test. Bearings failed again due to swelling. Further testing indicated that larger then expected oil concentrations existed in lubricating water geothermal fluid causing bearing failure.
2002-2003	Searched for and tested several materials that would survive in hot salt and oil solutions. Kalrez®, Viton® ETP 500 and Viton® GF were identified as possible candidates.
2003-2005	Kalrez® has shown superior resistance to downhole conditions at Casa Diablo from among the various materials tested. Viton ETP-500 indicated a life expectancy of 13 years and because it is significantly less expensive then Kalrez ®, it was selected as the bearing material for future testing. Unfortunately during the laboratory testing period Dupont Chemical chose to stop manufacturing this specific formulation and replaced it with Viton ETP 600S. The material is available with six different fillers; three based on zinc oxide and three based on silicon oxide. Samples of all six materials have been obtained and are being tested at the National Laboratory in Brookhaven, New York. This new material's properties as a bearing material and its ability to adhere to a bearings shell must be reviewed, but cost information deemed the material to be too expensive to be economical.

Final Technical Report

Bob Sullivan Mammoth Pacific, L.P.

2. Polymer Bearings Paper List
    a. Surface Analysis of Fluoroelastomer Bearing Exposed to Geothermal Environment, covers information on hydrothermal degradation mechanisms of the Viton elastomers after being exposed for 4 months to geothermal environment. 6/2000
    b. Hydrothermal Oxidation of Fluoroelastomer Bearings after a year-lon Exposure to Geothermal Environments, which was under taken in Program No. 3.5.2 (High-temperature Polymeric Elastomers) aimed at identifying the potential Elastomeric materials for use in bearing systems in down-hole pumps. 3/2001
    c. Post-test results of the Ethylenepropylene-diene-terpolymer (EPDM) Elastomer bearing that was used for 6 months in Mammoth Pacific geothermal power station. 5/2001
    d. Elastomer testing/information –Viton ETP-500/ETP-900, September 2003
    e. Candidate for Elastomer Bearing in Geothermal Down-hole Pumps, Brookhaven

3. Summary of Quarterly Progress Reports

QUARTERLY PROGRESS REPORT FOURTH QUARTER 1998

This quarter's work continued on the project design phase and began the procurement phase. The evaluation of the concept bearing design was completed with the exception of the lubrication system. The bearing design is to insert (vulcanize) high temperature rubber polymer (ZETPOL 2000 with a peroxide cure) bearings into larger inner diameter copies of the bronze bearings manufactured out of carbon steel to increase tensile strength. The material ZETPOL 2000 was chosen for heat resistance. This design allows use of the current lube string and line shaft design. It was determined that the bearing design would allow for both lubricating flow paths envisioned. This allowed an order to be placed for rubber bearings and some of the lube string parts required for the modification of one test pump.

Additional design work and information gathering was undertaken on the lubricating water flow path, control schemes, instrumentation and stuffing box bearing design.

The work proceeded with the remaining technical requirements that were not addressed last quarter. These were as follows:

1. Design should review the required thickness and surface area of rubber bearing to allow for a ten year lifetime, including suitability of a bearing every five feet.

2. Design should review required clearance of rubber bearing to that of line shaft and the resulting clearance after thermal growth of all members.
3. Design should review changes to natural resonance of the line shaft due to changes in bearing clearances or rigidity.
4. Design should review any significant changes in starting or running torque and resulting effects on motor.

These issues were addressed one by one with both Johnston Pump and Palmer Products.

As discussed in the last quarterly report, there are pros and cons for competing lubricating water flow paths. A flow path from pump discharge up through the lube string is the option that is most seriously being pursued. The decision is being delayed while more input is being gathered from industry experts.

A basic control scheme has been developed. This includes a flow meter of the annubar type to measure lubrication water flow. The flow indication will provide input into protective logic to shutdown the pump in the event of a loss of lubricating water flow to prevent bearing damage. Additionally, an allowance for automatically reversing flow, to top down, in the event of a pump trip is being studied. This will ensure lubricating flow during pump spin down.

To adopt a bottom up flow path, a method of returning the water back to the well at depth is required. This is most likely going to be a capillary tube from the surface through the annulus to a sufficient depth to prevent flashing and resultant scaling of the tube. The size of the tube should be sufficient for the required flow rate, but small enough to prevent excessive flashing at the throttle point. This sizing requirement is being worked on currently.

The pump stuffing box bearing is currently a pressed in bronze bearing. This will have to be converted to rubber. This bearing is currently being designed.

Work proceeds to complete the design phase. The procurement of parts has begun and will continue as outstanding design questions are answered.

QUARTERLY PROGRESS REPORT FIRST QUARTER 1999

This quarter’s work continued on the project design phase and the procurement phase. The evaluation of the lubrication system was completed. The instrumentation requirements, control scheme and stuffing box bearing design were developed.

Lubricating Flow Path

A lubricating flow path from the pump discharge up through the lube string was decided on. This was based on the following reasons:

Because of bearing clearance a large amount of flow may be required to ensure the lube string remains “packed” or at a high enough pressure to ensure water does not flash and cause scaling or interfere with proper lubrication of the bearing. This flow rate may not be achievable due to restrictions on the size of entry ports and overloading the seal cooling system. In a top down design, this can be mitigated by installing an orifice at the bottom of the lube string, allowing a smaller flow rate to maintain sufficient pressure in the lube string. This orifice would be most likely a standard steel bearing. The disadvantage to this design is the likely hood of bearing wear and resulting increasing flow rates.
There is no envisioned way air initially trapped in the lube string during installation can be removed. This may interfere with bearing lubrication. A bottom up system will naturally vent all the air from the lube string.
Current technology utilizes a bottom up system for low temperature water wells.

The return tubing was selected based on the calculated pressure drop to limit throttling at the surface. Excessive throttling will possibly cause flashing and scale precipitate. The tubing will extend approximately to 400 feet. The tubing end will be inserted into a steel guide welded to the last pump column to protect it during installation. It will be banded to the pump column every 10 feet.

<u>System Schematic and Control Scheme</u>

A piping and instrument schematic has been developed and is attached (Drawing No. 20144-1-D-3210A). The motive force of the lubricating water is from the pump discharge. Lubricating water flows out of the stuffing box at VALVE 3 and VALVE 4, through flow meter, FT-116A and a throttle valve set to maintain approximately 5 gpm. The flow continues through electrically operated valve C2 and finally into the well annular area through 5/8”. A lubricating flow path from VALVE 1, VALVE 5 and VALVE 6 is provided for pump startup and pump trip conditions. In this situation the lubrication flow is reversed from the brine production header (which is normally pressurized) into the stuffing box and down the lube string. A flow sight glass is provided for flow indication during both normal and startup conditions. When the pump is started and develops head at the surface, VALVE 5 is shut and VALVE 2 is opened, allowing normal flow.

An overriding design concern has been the fact that the bearing material is very susceptible to damage if allowed to run dry. During controlled startup conditions flow can be ensured through the alternate flow path, but during unplanned pump trips the pump typically back spins up to one minute as the pump discharge column unloads of water back through the pump impellers. At this time, bearings above normal annulus water level will become dry. To prevent this situation Control valves C1 and C2 have been added to automatically reverse lubricating flow down the lube string to ensure bearings are continually wetted. C1 is a fail open design on a loss of power and C2 is a fail close design. They will be powered from auxiliary contacts on the motor relay. These contacts will be opened when the MR relay is de-energized, which is the condition during a pump trip or shutdown. This automatically sets up a reverse flow path, the same as during pump startup.

As additional protection for the event flow fails for unknown reasons, the flow meter (FT-116A) provides a 4-20 ma output which will be used to trip the pump if flow falls below a safe point. An orifice is installed as a bypass around C2 to ensure a small amount of lubricating water flow in the event C2 fails shut and the pump fails to trip.

Pump Modification

To provide the motive force for lubricating water flow the pump has been modified. The combination bearing will be grooved to allow pump discharge to travel up the lube string. Additionally, a new bearing will be inserted to block annular discharge ports. This prevents lubricating water from escaping to the annular cavity. The new bearing will be grooved also. An attached drawing shows the design of the pump's discharge case and last stage.

Pump Stuffing Box

Two polymer bearings were manufactured for the pump stuffing box. These have larger inner diameters to accept the shaft sleeve. They are in a bronze shell that is pressed into the stuffing box.

Procurement

This quarters procurement consisted of the polymer bearings, miscellaneous pump parts (gaskets and o-rings, centralizers, tension nipple etc.), tubing for water return and some consulting fees.

Next Quarter

Tentatively, the bearings are scheduled to be installed and testing to begin in May.

The design of the bearings and lubricating system is essentially complete. The procurement of parts is nearly complete. Installation and testing is scheduled to begin next quarter.

QUARTERLY PROGRESS REPORT SECOND QUARTER 1999

We performed the installation phase, beginning on the May 24th. This consisted of removing the pump and lube string on production well 24C-32 and re-installing new lube string, shafting, pump and rubber bearings. We completed installation on the 26th and started the pump up. The pump ran approximately 2 minutes and had to be shutdown due to vibration and high running current on the motor. Prior to the start we were experiencing difficulty turning the pump by hand and had spent several hours investigating. Our best conclusion, which is a consensus amongst all the people that were here, including Johnston Pump, Palmer Products and INEL, was that the bearing tolerance were too tight and thermal growth that we experienced was not what we anticipated. The pump acted normally at lower temperatures, but became much more difficult to turn as it was heated to normal operating temperatures. Bearing tests prior to this indicated a .002 -.003 " growth inwards by the rubber. The bearing was then oversized by this amount in relation to the original bronze bearings. So even though the problem seems clear the reason for it does not.

As was originally planned for in the solicitation, the pump was removed on June 9th and a normally designed pump was installed with normal bronze bearings. The removed rubber bearings showed significant expansion and extrusion of the rubber. The bearings were analyzed and found that the durameter was "bone" hard. If the bearings had been attacked chemically the durameter would have been softer. If the bearings had swelled from absorbing water they would have again had a softer durameter. This seems to coincide with the theory that the problem was improper original tolerances. If the line shaft was rubbing due to tight clearances, the rubber would heat causing expansion in turn causing more heat and more expansion etc. As the octagon opening began to swell shut, fluid flow would be cut off. The rubber was heated to the point that it re-set, explaining the expansion and extrusion we found upon removal.

INEL assisted us in checking the thermal growth patterns and tensile effects on the lube string to ensure this had not caused the loss of clearance. Their calculations showed what we had expected. A report is being prepared for their work.

We have submerged two bearings in a section of our hot brine system to ensure there is no chemical attack, this test has been ongoing for one week now. Results show no attack or degradation at all.

Financially, the project is under budget by approximately $24,000(federal share). According to the original scope, it is also over with the exception of some more testing and reporting with insignificant costs.

Initial testing indicates with some confidence that failure was due to improper bearing tolerances, which can be corrected quite easily.

Final Technical Report

Bob Sullivan Mammoth Pacific, L.P.

QUARTERLY PROGRESS REPORT THIRD QUARTER 1999

This quarter's work involved investigation into the expansion and extrusion of the rubber bearings that occurred during the initial test. Two bearings were submerged in a section of our hot brine system to verify no chemical attack. After one week there was no attack or degradation at all, but after six weeks the bearings exhibited the same expansion and extrusion of the rubber that was evident during the pump test. This shows a reaction with the brine that is transforming the rubber. The original test only subjected the bearings to approximately two days submergence in hot brine, but expansion and extrusion occurred, while over seven days were required during the static test. This indicates another influence involved such as friction or pressure.

The rubber manufacturer does not yet understand the mechanism of the rubber's transformation. Because of this, work proceeds on several other fronts. Two bearings were manufactured out of a viton based rubber versus a nitrile based rubber. These were submerged in a section of our hot brine system for testing. The test has been ongoing for 8 days now.

Alternate bearing designs have been developed and evaluated, including modified hex, modified octagon and partial arc (cross sections are attached). These allow more lubricating flow and less contact than the standard hex design. This will allow less critical tolerances for heat expansion. A prototype partial arc design has been manufactured.

Work has progressed on a silicon based bearing impregnated with graphite. The material, trade name AFLAS, has excellent heat properties, but poor resistance to tearing. Impregnating with graphite will make it a more suitable candidate for a bearing material.

A silicone coating applied to the bearing immediately after milling to fill the natural pores has been discussed as a way to prevent entry of brine into the material.

In summary, testing will continue until the transformation is understood and/or a more suitable bearing material or manufacturing process is selected. The material will be statically tested successfully and at that time another pump will be modified and tested.

Attached are several reports:

INEEL assisted us in checking the thermal growth patterns and tensile effects on the lube string to ensure this had not caused the loss of clearance. A report is attached.

Palmer Products issued two reports after the initial test. These are attached.

Barham consulting, who witnessed the initial test issued a report based on his observations. The report is attached.

QUARTERLY PROGRESS REPORT FOURTH QUARTER 1999

This quarter's work continued testing of the viton based rubber bearing. Two bearings are submerged in a section of our hot brine system to verify no chemical attack. The test began on November 19, 1999. The test consists of two viton bearings, one screwed into a lube tube section and one with a section of shaft installed. To date the bearings have exhibited no negative effects. On November 30, 1999, another test began with the nitrile based rubber to attempt to better quantify the expansion and extrusion of the rubber. This bearing stopped expanding in approximately 3 weeks. It is currently still submerged and eventually a percentage of expansion will be calculated. All three bearings are inspected once a week. If the testing of the viton base material continues to be successful, a pump modification can be tentatively scheduled for this spring/summer.

QUARTERLY PROGRESS REPORT FIRST QUARTER 2000

This quarter's work continued testing of the viton and nitrile based rubber bearing. Three bearings are submerged in a section of our hot brine system in an attempt to verify no chemical attack on the viton and quantify the effects on the nitrile.
The viton test began on November 19, 1999. The test consists of two viton bearings, one screwed into a lube tube section and one with a section of shaft installed. To date the bearings have exhibited no negative effects.
The nitrile test began on November 30, 1999 to attempt to better quantify the expansion and extrusion of the rubber. This bearing stopped expanding in approximately 3 weeks. It is currently still submerged and eventually a percentage of expansion will be calculated. All three bearings are inspected once a week.

On March 20, 2000 two of the test bearings (one nitrile and one viton) were cut in half. One half of each type was reinstalled to continue testing and the other halves were sent to Brookhaven National Laboratories for testing and evaluation by Dr. Toshifumi Sugama. Dr. Sugama is going to attempt to verify that there have been no negative effects on the viton material and explain the hardening and expansion of the nitrile material.

The proposed prototype design of a semi-arc bearing is being manufactured by Palmer Industries. When the prototype becomes available, Idaho National Engineering Laboratories will assist us by checking the thermal growth patterns and tensile effects of the lube string to ensure that bearing clearances are correct.

If the testing of the viton base material continues to be successful, a pump modification can be tentatively scheduled for this spring/summer.

QUARTERLY PROGRESS REPORT SECOND QUARTER 2000

This quarter's work continued testing of the viton and nitrile based rubber bearing. Bearings are submerged in a section of our hot brine system in an attempt to quantify the effects of the brine on various materials.

A report was received detailing Dr. Toshifumi Sugama of Brookhaven National Laboratories investigation of the exposed nitrile bearings. The report is attached. Briefly, Dr. Sugama has found significant hydrothermal degradation of the nitrile rubber over a short time period making nitrile an unacceptable choice for down-hole production pump bearings.

The exposure of the original viton bearing has continued to nearly 12 months compared to the sample Dr. Sugama analyzed at 4 months. An estimation of life span will be obtained by analyzing this sample at the one year mark which will occur in November 2000. We began testing an Ethylene-propylene-diene terpolymer (EPDM) bearing on September 21, 2000.

The projects direction continues along three main paths: 1) Obtaining an estimate of viton life span , 2) Testing EPDM and 3) Testing other possible materials. A report can be expected from Dr. Sugama in the first quarter of 2001. If the report indicated an acceptable life-span for the viton, a production pump can be modified prior to summer of 2001.

QUARTERLY PROGRESS REPORT THIRD QUARTER 2000

This quarter's work continued testing of the viton and nitrile based rubber bearing. Bearings are submerged in a section of our hot brine system in an attempt to quantify the effects of the brine on various materials.

A report was received detailing Dr. Toshifumi Sugama of Brookhaven National Laboratories investigation of the exposed nitrile bearings. The report is attached. Briefly, Dr. Sugama has found significant hydrothermal degradation of the nitrile rubber over a short time period making nitrile an unacceptable choice for down-hole production pump bearings.

The exposure of the original viton bearing has continued to nearly 12 months compared to the sample Dr. Sugama analyzed at 4 months. An estimation of life span will be obtained by analyzing this sample at the one year mark which will occur in November 2000. We began testing an Ethylene-propylene-diene terpolymer (EPDM) bearing on September 21, 2000.

The projects direction continues along three main paths: 1) Obtaining an estimate of viton life span , 2) Testing EPDM and 3) Testing other possible materials. A report can be expected from Dr. Sugama in the first quarter of 2001. If the report indicated an acceptable life-span for the viton, a production pump can be modified prior to summer of 2001.

QUARTERLY PROGRESS REPORT FOURTH QUARTER 2000

This quarter's work continued testing of the viton and nitrile based rubber bearing. Bearings are submerged in a section of our hot brine system in an attempt to quantify the effects of the brine on various materials.

The exposure of the original viton bearing has continued to 14 months. Dr. Sugama analyzed a sample at 4 months of exposure. The Ethylene-propylene-diene terpolymer (EPDM) bearing has been exposed for four months. Samples of both materials were sent to Dr. Sugama on December 4, 2001. Initial visual observations showed a lack degradation for both samples. Dr. Sugama has estimated a report in March. The object of the report will be to estimate the life span of the viton and investigate any degradation of the EPDM.

The projects direction continues along three main paths: 1) Obtaining an estimate of viton life span , 2) Testing EPDM and 3) Testing other possible materials.

QUARTERLY PROGRESS REPORT FIRST QUARTER 2001

A request for project extension was submitted this quarter which is attached.

This quarter's work continued testing of the viton, nitrile and Ethylene-propylene-diene terpolymer (EPDM) based rubber bearings. Bearings are submerged in a section of our hot brine system in an attempt to quantify the effects of the brine on various materials.

The exposure of the original viton bearing has continued to 14 months. Dr. Sugama analyzed a sample at 4 months of exposure and at 12 months and concluded that a 4 year lifetime could be achieved. This report is attached also. The Ethylene-propylene-diene terpolymer (EPDM) bearing has been exposed for six months. A samples of the EPDM was sent to Dr. Sugama in early April. Initial visual observations showed no degradation.
Depending on the results of Dr. Sugama's analysis of the EPDM, it seems likely that EPDM will be chosen as the bearing material for pump modification.

Final Technical Report

Bob Sullivan Mammoth Pacific, L.P.

QUARTERLY PROGRESS REPORT SECOND QUARTER 2001

This quarter's work continued testing of the viton, nitrile and Ethylene-propylene-diene terpolymer (EPDM) based rubber bearings. Bearings are submerged in a section of our hot brine system in an attempt to quantify the effects of the brine on various materials.

Dr. Sugama completed his analysis of the Ethylene-propylene-diene terpolymer (EPDM). The report is attached. Insignificant degradation was observed. Based on this report, EPDM was selected as the bearing material. Test results of the first bearing test were reviewed and final bearing tolerances were chosen by Palmer Industries. Production runs on prototype bearings were started to test the manufacturing process.

A full scale test was scheduled for September or October time frame. EPDM bearings were procured. Bearings were installed in a pump, but immediately degraded. Discussions and further testing by Dr. Toshifuma Sugama determined that higher concentrations of oil then expected caused degradation of the EPDM bearings. The oil caused almost immediate swelling and loss of interference of the installed bearings.

QUARTERLY PROGRESS REPORT SECOND QUARTER 2002

This quarter's work included searching and testing several materials that would survive in hot salt and oil solutions. Kalrez®, Viton® ETP and Viton® GF were identified as possible candidates. Dr. Toshifumi Sugama documented testing of these polymers in the attached report "Candidate for Elastomer Bearing in Geothermal Down-Hole Pumps.