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**INVESTIGATION OF COMPONENT FAILURES IN DOWNHOLE
GEOTHERMAL PUMPING SYSTEMS**

Final Report

By
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MASTER

March 15, 1985

Work Performed Under Contract No. AC04-82AL18536

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FINAL REPORT
INVESTIGATION OF COMPONENT FAILURES
IN DOWNHOLE GEOTHERMAL
PUMPING SYSTEMS

March 15, 1985
Contract DE-AC04-82AL18536

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ENGINEERING

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PCF FINAL REPORT

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1.0 INTRODUCTION

Operating experience with downhole geothermal pumps has demonstrated that operating lives of less than one year are very common. In order for liquid-dominated geothermal power systems to be economically viable, one year or longer continuous downhole running times in geothermal wells at temperatures up to 375°F are needed. The effort summarized by this report was directed toward improving the life of electric, downhole submersible pumps. As used herein, "pumps" refer to the assembly comprising the submersible electric motor, motor protector, pumping elements and electric power cable. Pump component refers only to the pumping elements.

Experience with electric downhole submersible pumps showed that intrusion of brine into the motor or cable has been a common failure mode. If the motor and cable can be pressurized to prevent the intrusion of brine, the operating life of the pump can be markedly increased. This report summarizes Barber-Nichols' work during the period of February 1, 1982 through June 30, 1983 under contract number DE-AC04-82AL18536.

This study investigated component failures in electric, downhole submersible pumps which prevented the attainment of one (1) year continuous downhole running times in geothermal wells at temperatures up to 375°F. The following tasks were accomplished:

a. Investigated the feasibility of a pressurized motor to prevent brine intrusion into the motor.

b. Investigated improved pothead and packoff designs for more consistent field installation and improved performance.

c. Investigated brine scale buildup on impeller sleeve bearings and thrust washers.

d. Maintained a record of the performance of electric, downhole submersible pumps operating in wells having temperatures of 300°-F and above.

2.0 PRESSURIZED MOTORS

Operating experience with electric, downhole submersible pumps has shown that geothermal brine intrusion into the cable and/or motor has been the predominant cause of failure. If the brine can be kept out of these components, significant improvement in operating lifetimes is expected. A method of reducing brine intrusion into the motor is to maintain the oil filled motor at a pressure above the local brine pressure.

2.1 OPERATING EXPERIENCE

Barber-Nichols operating experience with electric, downhole submersible pumps at the East Mesa geothermal test facility has

shown that commercially available pumps have an average operating life slightly in excess of 1,200 hours. This experience is discussed in greater detail in Section 5. When a downhole motor was pressurized with an experimental oil pressurizing system, the average lifetime increased to 4,526 hours. The longest operating life was 7,900 hours. This dramatic improvement in operating life is believed to be the result of the motor being maintained above brine pressure by the external oil pressurizing system.

The prototype oil pressurizing system used for our tests at the East Mesa facility was added to an electric submersible Reda pump used to provide geothermal brine for the 500 kW direct contact heat exchanger pilot plant. The pressurizing system schematic is shown in Figure 1, "Downwell Motor Oil Pressurizing System." As shown in the figure, a pipe leads from the downwell motor to the surface mounted oil supply system. As the downhole pressure varied with well production and time, the varying pressure was sensed by the bubble tube pressure measuring equipment and the pressure on the surface adjusted. In this manner, the pressure in the motor was maintained at 7 to 10 psi above the well pressure. Any leakage of oil outward from the motor was then replaced by oil from the surface. When the well pressure was decreased, excessive pressure in the motor was relieved by a relief valve which vented oil from the top of the protector assembly.

A gas pressurized accumulator was incorporated as the

FIGURE 1. DOWN WELL MOTOR OIL PRESSURIZING SYSTEM

FIGURE 2. DOWN WELL MOTOR OIL PRESSURIZING SYSTEM
WITH DOWNHOLE REGULATOR

pressure source rather than a motor-driven pump so that oil pressure was maintained during power outages. A battery power supply provided energy for the control system during power outages. During extremely rapid increases of downhole well pressure (which was possible during electrical power outages), the bubble tube pressure could not keep up with the increase in downhole pressure and the pressure in the motor was maintained above well pressure by a bellows assembly mounted on the bottom of the electric motor. As is further discussed in Section 5.1 of this report, this system operated for 7,900 hours which, at the time, represented a record for electric, downhole submersible pumps operating with 350°-F brine.

2.2 NEED FOR A DOWNHOLE REGULATOR

A disadvantage of this system is encountered with pumps installed at large setting depths in wells with large drawdown. In this situation the column of oil in the oil supply tube between the surface and the motor can result in a static oil pressure inside the motor much greater than the brine pressure on the outside of the motor. The high oil pressure could result in high shaft seal wear rates and premature failure. For installations of this type, a modification to the downhole oil pressurizing system is recommended. Such a system is shown in Figure 2, "Oil Pressurizing System With Downhole Regulator." This system is similar to the previously discussed configuration with the addition of a downhole pressure regulator in the oil

supply tube between the surface and the motor.

The operation of this system is as follows: The oil reservoir on the surface (known as the accumulator vessel) is maintained at constant pressure by regulating the gas pressure from a nitrogen bottle. A nitrogen bottle is used so that oil pressure can be maintained in the event of an electrical power outage. The pressure is selected to maintain the downhole motor oil supply pressure above the brine pressure regardless of operating conditions. This high pressure oil is connected to a downhole pressure regulator which maintains the pressure on the downstream side of the regulator a preset value above ambient well pressure. This regulated oil pressure is then connected to the motor. As the well pressure increases (say during decreased pump flow) this rise in pressure is sensed by the regulator which admits a small additional amount of oil to the motor to maintain the pressure above brine pressure. During operating conditions when the well pressure is reduced (such as during pump start or during increases in pump flow rate), the pressure in the well is reduced and excess pressure in the motor is vented through the downhole relief valve. An expansion bellows assembly mounted below the motor and in communication with the motor provides some "give" in the oil volume to improve control stability. The bellows also maintains the oil pressure slightly above brine pressure in case of oil supply system failure.

An oil flow meter is provided on the surface to monitor

downhole pump oil pressurizing system performance and a level gauge is provided on the oil accumulator vessel for operator convenience.

This improved downwell pump pressurizing system is suitable for installation in both shallow and deep settings. The downhole pressure regulator is not commercially available and hence, was developed during this program. Additional details of the downhole regulator are discussed in Section 2.3.

2.3 DOWNHOLE REGULATOR DEVELOPMENT

The performance specifications for the downhole regulator assembly are shown in Table 1, Downhole Regulator Specifications. We are unaware of commercially available pressure regulators which meet all the requirements of Table 1. Therefore, B/N's first step to develop the regulator was to procure a commercially available pressure regulator valve. This valve was believed to meet the flow requirements, but not the packaging or metallurgical requirements. This valve was then connected to a commercially available diaphragm-type relief valve to make a "relieving" type pressure regulator which was responsive to both increases and decreases in brine pressure. As the test program confirmed the flow performance of the regulator and identified some material problems, the failed components were replaced with those made of superior materials. The long term plan was to then modify the regulator assembly design to fit

TABLE I
DOWNHOLE REGULATOR SPECIFICATIONS

Temperature	$300^{\circ}\text{F} < T < 450^{\circ}\text{F}$
Oil Flow	$0 < \dot{w} < .25 \text{ gpm}$
Tight shut off required	
Hysteresis	2 psi maximum
ΔP downstream oil - brine	3 to 10 psi
Droop with flow	(TBD)
Brine pressure during operation	$300 < P < 900 \text{ psig}$
Entering oil pressure	$300 < P < 1000 \text{ psig}$
Time constant	1 minute
Materials	Compatible with petroleum based oils and brine containing chloride
Package	Unlimited length, maximum diameter 5"

within a five-inch diameter pipe and construct it from materials compatible with the geothermal environment. Two valves so constructed, were installed in the Barber-Nichols laboratory well casing simulation test rig. Mobil SHC 639 synthetic hydrocarbon oil was pressurized by a hydraulic pump before passing through the regulator valve. The regulator and relief valves and an oil chamber (to simulate the downhole motor and bellows assembly) were located inside a heated, water-filled, pressurized chamber to simulate the downhole environment. The water pressure was cycled to simulate downhole conditions during pump operation. The oil supply pressure to the regulator was maintained at a minimum of 360 psig.

The test rig was operated 24 hours-a-day for six days a week with the "well" pressure cycled between 200 psig and 300 psig. The valves maintained the simulated motor chamber 14 to 35 psi above the simulated brine pressure. The higher oil pressure occurring during higher brine pressure conditions. After six days of operation, the test rig was shut down and the valves inspected. Inspection of the valve components showed no signs of wear or distress.

The valves were reassembled and adjusted and the test rig restarted. After 13 additional days of operation, (19 days total) the phosphor-bronze diaphragm of the relief valve failed. The failure was traced to impurities in the water causing the diaphragm to become brittle and fail during valve

cycling. The bronze diaphragms of both valves were replaced with diaphragms manufactured from 316 stainless steel. It was recognized that 316 stainless steel would probably not be suitable for many well environments because of its susceptibility to chloride stress corrosion cracking. It did represent an expedient replacement for the laboratory testing.

The valves were reassembled and the valve testing continued with 325°-F hot water. The valves were tested for 32 days when the water temperature set point was increased from 325°-F to 380°-F to provide a more severe test of the pressure regulator control and relief valve. The valves maintained the motor cavity pressure 7.7 to 25.3 psi above the simulated well pressure which is slightly higher than desired. The pressures could be changed only by adjusting the valves which were located inside the simulated well which was impossible during the tests. Since this range of pressures would be acceptable for an actual downhole pump, no adjustments were made.

The valves ran for two additional days until the test rig was shut down to inspect the valves and to replace the 316 stainless steel diaphragms with diaphragms made of K-Monel, which is believed to be a suitable material for anticipated geothermal well environments. Inspection of the hardware showed the Teflon seat of the pressure relief valve to be plastically yielding. This deformation was expected to change the valve set point. No modifications were made to the valve at this time to determine

the life of the original soft Teflon seats. The metal-to-metal seats of the pressure regulating valve showed no distress.

The valves were reassembled and installed in the test rig which was operated at 380°-F and the oil supply pressure was set at approximately 300 psig. The simulated motor pressure was maintained three to eight psi above simulated well pressure. The test rig operated continuously for 137 days until the system was shut down because of a pressure relief valve leak. Teardown inspection showed the valve seat area to be partially covered with a black material which prevented the valve from seating tightly. Samples of the black material, new oil and used oil were sent to the Mobil Oil laboratory for analysis. Their analysis showed the used oil sample contained 0.2% water which is not considered excessive for used oil. The used oil sample also contained 30 ppm silicon which is an indicator of wear within the system. The black material removed from the valve seat was primarily composed of nickel and aluminum fines with traces of iron and silicon. Quoting from the Mobil Oil report, "it appears that a pump or other piece of equipment is experiencing wear and the debris is accumulating at the pressure relief valve". During the test program we rebuilt an oil pump which contained an alumina ceramic plunger. Apparently the pump wear material found its way through the test loop and to the relief valve seat where it accumulated, preventing the valve from closing.

The modified pressure regulator was tested for 3,200 total

hours. With proper modification and additional development, these components can be packaged in a manner suitable for installation with a downhole submersible pump.

3.0 IMPROVED POTHEAD AND PACKOFF CONFIGURATIONS

Barber-Nichols experience with downhole pump installations has shown that cable end terminations have a high rate of field failures. The electrical cable termination at the motor is known as the pothead while the termination at the surface-mounted wellhead is called the packoff.

The present pothead provided by Reda incorporates an elastomer seal to prevent the entrance of brine into the motor cavity. This seal must be compatible with both hot oil and hot water. In general, high temperature (approximately 350°-F capability) elastomers which are excellent for use with hydrocarbon oils are not compatible with hot water and vice versa. Hence the elastomer incorporated in the present pothead configuration is a compromise. A metal hermetic sheath surrounding the electrical conductors would eliminate the need for the elastomeric seal.

Our first step toward producing an improved pothead and cable configuration was to determine the commercially available cable insulating material that could be incorporated in a metal sheath. Communication with wire manufacturers determined that a

Teflon-insulated copper conductor most met our goals. However at elevated temperatures, a Teflon-insulated copper wire is not capable of supporting its own weight for lengths greater than approximately 800 feet. It is necessary to support the wire by means other than local clamping of the Teflon insulation because the Teflon can "cold flow" away from the clamping pressure. Numerous techniques and potential vendors were evaluated in this regard.

It was learned that Halpen Engineering Company has a technique whereby Teflon-insulated instrument cables are covered with alloy 625 welded sheaths. This technique can conceivably be extended to power cables which are much larger than the instrument cables. However, costly new tooling is required to accommodate the larger wire size. As part of this concept, the three sheathed wires would be joined to the motor with a special pothead. The sheath would be protected from abrasion and other mechanical damage by a wrap of galvanized steel armor similar to that presently applied to downhole pump power cables.

Because the metal sheaths are not drawn tightly against the electrical insulation, there is a small discontinuous annulus between the Teflon and the sheath. This annulus may be pressurized with either gas or liquid to prevent ingress of brine. If oil is used to pressurize the annulus, it could also be used to pressurize the motor cavity by simply admitting oil to the motor through the pothead. For installation having deep setting depths

and large well drawdowns, the column of oil inside the cable would develop excessive pressure in the motor and a pressure-tight pothead along with a downhole regulator system is required. A conceptual design of the improved pothead configuration for a shallow setting depth is shown in Barber-Nichols drawing PCF-001, Concept-Cable Feedthrough. The assembly of the insulated conductor in the metallic sheath is known as the MSC. The MSC enters a standard Swagelok tube fitting made by Crawford Fitting Company wherein the sheath is terminated. The Swagelok connector forms a metal-to-metal barrier between the geothermal brine and the oil. The insulated electrical conductor continues through a metal tube to the pothead connector which interfaces with the motor head. This configuration provides good sealing of the brine and oil while being suitable for existing motor pothead configurations. This concept is suitable for installation where the motor may be pressurized directly through the MSC. The concept is also amenable to deep setting pumps where the motor is pressurized through a separate oil supply line. Pressurized oil would then backup through MSC to provide an oil-filled cable to a level above the water level in the well. The oil level will be maintained above the water level because of the lower specific gravity of the oil. The sheath could be made of Monel, alloy 625 or alloy AL 29-4.

4.0 PUMP SCALE ACCUMULATIONS

Many geothermal brines have the potential to form calcium carbonate scale on pump parts. If scale is formed inside pump impellers, sleeve bearings or thrust washers, the pump operating torque may become excessive and result in reduced output or electrical overloads.

Two methods of eliminating this scale may be incorporated into pump programs. The first technique (and is the one utilized by Barber-Nichols) is to set the pump deep enough in the well to prevent the CO_2 gas from coming out of solution and the subsequent formation of calcium carbonate scale. For example, during the 7,900 hours operation of a Reda pump, the motor current showed a slight decrease due to impeller wear rather than an increase that would be caused by scale buildup and subsequent rubbing. Hence, it is concluded that maintaining adequate pump suction pressure through submergence is an effective technique to prevent scale formation.

If scale formation cannot be prevented by adequate submergence then it may be removed or prevented by chemical treatment. A common technique is to dissolve the carbonate scale with acid. Often inhibited muriatic acid is used. Citric acid is less aggressive and hence, is recommended. However, great care must be exercised when it is used in hotwells because its aggressiveness in dissolving scale and attacking pump parts is

greatly increased at elevated temperatures. What may be a suitable inhibitor at room temperatures may be completely inadequate at the temperatures encountered in a hot geothermal well.

It is preferable to add the acid through the production tube of a shutdown pump rather than adding it to the annulus formed between the production tube and the well casing. The quantity of carbonate scale in the annulus is difficult to estimate and hence, it is difficult to determine how much acid is required. The brine in the production tube has been pressurized preventing the evolution of carbon dioxide, therefore the amount of scale on the production tube wall would be expected to be minimal. If the acid is added to the well annulus, it may simply flow down past the pump and clean the well casing while not removing the pump internal scale.

Acidizing the pump through the production tube requires modification of the standard installation. Pumps normally incorporate a check valve between the pump discharge and the production tube. If the pump is to be acidized through the production tube, this check valve should not be installed at the pump but at the wellhead. Barber-Nichols operating experience with REDA 80 hp downhole pumps since November 1979 has shown these check valves not to be required in artesian wells.

An alternative to acidizing scaled pumps would be to add

small amounts of anti-scalant chemicals such as those produced by Pfizer to the continuously operating pump. This chemical treatment procedure would also serve to protect downstream equipment from calcium carbonate or silica scaling.

Barber-Nichols' experience with brine pump seizing after removal from the well may be of interest. During removal and subsequent disassembly of geothermal brine pumps at the East Mesa geothermal test facility, it was common for the pump to turn freely upon initial removal. Upon exposure to air the pumps would bind and become difficult or impossible to rotate by hand. This phenomenon was observed even when the pump was flooded with water or Diesel fuel. It is believed that scale did build up on impellers and bearings during normal pump operation, but this scale did not significantly effect pump performance. Upon exposure to air, this scale was chemically altered causing it to expand and thereby causing the rotating elements to bind. The nature of the chemical change is unknown, but is believed to be caused by the carbon dioxide or oxygen in the air acting on the carbonate scales.

5.0 PUMP PERFORMANCE RECORD

Operating experience with electric, downhole submersible pumps is summarized in this section. Barber-Nichols' experience at the East Mesa geothermal test facility is discussed first.

5.1 BARBER-NICHOLS EXPERIENCE

The configuration of the pump discussed below consists of a multistage vertical REDA pump connected to a three-phase, 80 hp motor through a protector which contains the shaft seals required to isolate the motor from the hot brine. The pump provides between 175 and 235 gpm of 350°-F geothermal brine. Power is provided to the downhole motor by means of an armored cable which consists of copper conductors individually wrapped with aramid fabric, EPDM rubber and lead. The three wires are then wrapped together with a galvanized steel armor to make a flat cable which contains no splices between the pothead and packoff. A quarter-inch diameter carbon steel bubble tube was located slightly above the pump suction to measure the downhole pressure at the pump inlet.

Barber-Nichols experience is summarized in Table II. The table summarizes the installation number for identification, installation date, failure and removal dates, well number, pump inlet setting depth, geothermal brine temperature, and a brief description of the run and failure. Additional information about the installations and failures is found below.

Build #1, Well 8-1

This pump was installed on 7/21/79, but was not started until 8/14/79 because the remainder of the facility was not

TABLE II
BARBER-NICHOLS DOWNHOLE PUMP EXPERIENCE

Well No.	Build No.	Installation Date (Start Date)	Failure Date (Removal Date)	Setting Depth (Feet)	Operating Time (Hours)	Surface Temp. (°F)	Comments
8-1	1	7/21/79 (8/14/79)	9/25/79 (10/24/79)	620	315	333	Motor burned out Wellhead incipient failure
8-1	2	11/16/79 (11/17/79)	5/05/80 (5/19/80)	620	4052	333	Motor contained ½ gallon water leak path unknown
8-1	3	6/25/80 (6/26/80)	8/26/80 (9/22/80)	620	1481	333	Packoff failure
6-2	1	8/21/80 (8/22/80)	8/26/80 (9/17/80)	762	100	350	Packoff failure
6-2	2	9/18/80 (9/18/80)	12/18/80 (1/15/81)	731	2184	350	Same unit as 6-2 Build #1. Sus- pected incipient cable failure
6-2	3	1/16/81 (1/17/81)	1/31/81 (2/03/81)	762	336	350	Packoff failure & leaking wellhead
6-2	3	2/06/81 (2/06/81)	2/06/81 (2/09/81)	731	½	350	Leaking wellhead
6-2	3	2/10/81 (2/10/81)	2/11/82 (2/17/81)	700	4½	350	Pot head crack
6-2	4	3/17/81 (3/18/81)	6/27/81 (7/24/81)	729	2352	350	Wet cable. Wet mot. Suspected pothead water leak
6-2	5	9/04/81 (9/08/81)	9/14/81 (9/22/81)	739	136	350	B/N oil pressur- izing system. Oil supply tube failure. Pot head O-ring shaved
6-2	6	10/23/81	9/22/82	615	7900	350	B/N oil pressur- izing system. Sand wore out pump elements
6-2	7	10/6/82 (10/07/82)	1/04/83 5/25/83	615	1152	350	B/N oil pressur- izing system. Damaged well casin caused pump to be- come stuck

ready. This pump was manually shut down on 8/22/79 after operating for eight days. While attempting to restart the pump on 9/25/79, the pump shut down due to overload. While the pump was still downwell, a meggar indicated a short circuit from a phase conductor to ground. The pump was removed from the well on 10/24/79. The motor and oil smelled burned. A total of two pints of water were removed from the motor and protector and there was evidence of brine leakage across the shaft seal located in the protector. Subsequent inspection showed the unit failed due to motor burnout which occurred in a stator winding slot. In addition, a lead wire between the pothead and stator winding had melted.

Inspection of the well head showed the RTV rubber used to seal around the production tube was decomposed.

Build #2, Well 8-1

This pump was installed 11/16/79 and started 11/17/79. It operated almost continuously until 5/05/80 when the pump shut down automatically due to overload. The cable and motor were megged and showed 100 K resistance phase-to-ground. A restart was attempted, but the pump shut down because of overload. A second meggar reading showed 0 ohms phase-to-ground. When removed from the well on 5/19/80 significant carbonate buildup was discovered on the pump inlet screen. The motor and protector turned freely, but the pump showed resistance to turning. The

motor contained about 1/2 gallon of water. The resistance between the conductors and motor case was 8K ohms, which indicated a wet dielectric. The pothead megged at 20M ohms. All but one shaft seal in the protector were in excellent condition and all were still sealing. The protector and motor bearings were in good condition, but the pump bearings and wear rings contained some scale. The motor resistance was deteriorating and it was felt it would have been a short time before motor arcing and burnout would occur, even with a dry motor.

Build #3, Well 8-1

This pump was installed 6/25/80 in well 8-1. On 8/26/80 this pump shut down automatically because of an electrical overload. Inspection of the cable during removal showed water between the lead and the EPDM insulation in two of the conductors below the packoff. Subsequent testing of the pump and cable below the packoff indicated they were still good (the cable megged between 1 and 1500 meggaohms), but one phase was deteriorating and failure was expected to occur shortly. A teardown of the packoff showed the water circulation barrier was not in place. This barrier prevents the natural circulation of hot water into the packoff area. Its need was identified in the GPTF portable pump test rig tests. Furthermore, there was plastic tape on one phase conductor and fiberglass tape on all three. There was no water in the protector, but there was some

water in the motor indicating the shaft seals were working properly, and there was a leak path directly between the motor and well. This was the last installation in well 8-1.

Build #1, Well 6-1

This pump was installed 8/21/80 and started 8/22/80. This represents the first installation in higher temperature well 6-2. This pump shut down automatically on 8/20/80 due to an electrical overload. During removal, we cut the cable just below the packoff. The measured resistance between the phase wires and ground in the packoff showed two phases shorted to ground. Measured resistance of downhole cable and motor was 20M ohm phase to ground, indicating the electrical failure occurred in the packoff. When the packoff was disassembled, it was discovered the water circulation barrier in the packoff extension was missing and the lead sheath had been removed from the cable near mid-packoff. The edge of the lead sheath had cut through the rubber insulation and into the conductors, shorting them to ground. The packoff was repaired with the pump in-well.

Build #2, Well 6-2

This build uses the pump which was installed in build #1 in well 6-2 with the repaired packoff. It was started 9/18/80. This pump was manually shut down on 12/18/80 upon completion of the 500 kW plant testing at which time a meggar check showed 150K

ohms between conductors and ground. Before removal on 1/15/81 it was megged at 500K ohms. There was no water in the protector and one pint of water in the motor. Motor oil was yellow-white and foamy with no burned smell. It was believed that this unit was failing because of a short in the cable.

Build #3, Well 6-2

This pump was installed 1/16/81 and started the next day. This pump shut down automatically on 1/31/81 due to underload. At this time it megged at 70K ohms phase to ground, which is inconsistent with the underload shutdown. On February 2, 1981, brine leakage was observed around the coupling welded into the wellhead flange. A new coupling was welded to the wellhead flange the next day. The pump was lifted one production tube joint and a new packoff was made using lubricant to help seat the sealing blocks.

The pump was restarted on 2/6/81. After one half-hour of operation, a leak was observed at the wellhead coupling. The weld had failed due to poor weld penetration in the coupling. During the subsequent repair work, the cable was accidentally damaged and the pump was raised 30 feet to provide enough cable to remake the packoff.

The pump was started on 2/9/81 and was left pumping overnight at about 200 gpm. The next morning, while changing the

flow control valves, the pump flow increased and the pump shut down on overload. The motor and cable were megged at 3K ohms and the pump was pulled on 2/10/81. The packoff was okay. A crack was found in the solder joint between the pothead and the cable armor. About one gallon was water and was drained from the motor. The motor thrust bearing was scored and one of its tilting pads was jammed. The motor head and stator were found to be rusty. The water had apparently leaked into the motor through a void in the pothead casting.

Build #4, Well 6-2

This pump was installed 3/17/81 and started the following day. The pump shut down on 6/27/81 due to a power outage. The pumped was megged at 50K ohms after sitting idle over the weekend. No restart was attempted. The pump was removed on 7/24/81. After removal, the protector and pump turned smoothly but the motor turned roughly and one pint of water was drained from the motor. The motor had a broken lead wire which may have been broken during the removal of the pothead. An oil sample taken from the motor showed many particles suspended in the oil, including particles that appeared to be rust, dirt, and pieces of electrical insulation. Teardown inspection showed the motor thrust washers had been overheated and were cracked and crumbly. The motor shaft was blue near the motor rotors. The cable was wet its full length, but still passed a 20K volt high potential test. The pothead cable armor joint was damaged. It

was concluded that the failure of this pump was caused by water entering the cable and motor through the pothead.

Build #5, Well 6-2

REDA pump #5 was the first installation to use the B/N motor oil pressurization system. This consisted of a surface-mounted oil supply system connected to the motor by an oil line, as discussed in Section 2.0. The pump was installed on 9/04/81 and started on 9/08/81 after the Labor Day weekend.

The pump was shut down on 9/14/81 to perform maintenance on the electrical supply system. At this time it was observed that the motor pressurizing system was out of oil. Additionally there was an electrical short from the phase conductors to ground in the cable and/or motor. During removal on 9/22/81, the packoff was found to be okay. Inspection revealed that the 304 stainless steel oil line had broken below the wellhead due to stress corrosion cracking. Additionally the O-ring seal between the pothead and motor had been shaved during installation and two of the tubular connectors on the end of the motor lead wires were loose. They had been improperly installed at the factory. Motor resistance was found to be 70 to 80M ohms, indicating the stator was still intact and could be dried out. Three quarts of water were drained from the motor and the pump was difficult to turn by hand. An oil sample taken from the protector contained water.

Build #6, Well 6-2

This installation also incorporated the downwell oil pressurizing system. The pump was installed 10/23/81 and started the same day. It ran for approximately 7900 hours until it was removed October 4, 1982. This 7900 hours represents a significant improvement in pump operating time. During the run, pump head and flow degraded continuously as summarized in Figure 3. The performance decreased to a point where the pump could not supply the 500 kW pilot plant needs. Upon removal of the pump and inspection at the Reda Bartlesville facility, it was found that the pump impellers had literally worn out because of small amounts of sand in the well. The sand had worn the impeller thrust balancing seals allowing the impellers to bottom out and rub against their stators, thereby causing additional wear. The motor insulation was in excellent condition and the meggar showed 2000+ megohms phase-to-ground. During the run, the resistance between the cable and motor to ground had decreased as shown in Figure 4. The electrical cable was in the process of failing and if the pump had not worn out the cable would have been the failure mode. The motor and protector were reusable with all motor and protector internals being in good condition. Trace amounts of water were found in the motor and protector during the disassembly. There had been some intrusion of brine into the oil pressure tube. The path of the oil leak is not known, but is suspected to be the threaded joints of the oil supply pipe. The brine removed the phosphorous additives from the lubricating

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FIGURE 3. REDA PUMP NO 6 - EAST MESA WELL 6-2
MOTOR AND CABLE MEGGAR READINGS

9670

FIGURE 4. DEGRADATION OF REDA
PUMP PERFORMANCE WITH TIME

90%

oil. This phosphorous combined with calcium in the brine to produce calcium phosphate which precipitated out of the liquid. Much calcium phosphate was found upstream of the five micron downhole oil filter. This combination of phosphorous in the oil and calcium in the brine is also suspected to be the reason for the relief valve plugging often found in used downhole geothermal protectors.

An operational problem was plugging of the bubble tubes. Inspection of the bubble tube after 7900 hours of operation showed the lower end to be plugged with a white scale. It is believed that the dry nitrogen gas used for the bubble tube caused the brine inside the bubble tube to be slowly evaporated leaving behind a calcium carbonate deposit.

Build #7, Well 6-2

This pump was installed 10/6/82 and started 10/7/82. It ran until 11/24/82 when it was shut down because the brine was no longer required. During inspection on 1/4/83 a meggar showed 12K ohms phase-to-ground and the pump was not restarted. During the attempt to pull the unit on 2/8/83, we discovered the production tube was stuck in the well. A stretch test of the production tube showed it to be stuck approximately 340 feet below the wellhead. It was believed the tube was restrained by scale or a damaged well casing. At the time, it appeared that scale was the more likely cause because the well had been produced by flowing

100 gpm of brine from the annulus for 60 hours. Sufficient kill fluid was pumped into the well to fill the annulus. The fluid did not flow out the top of the well indicating there was still an opening past the pump.

On 4/18/83, 500 gallons of inhibited 10% acetic acid was pumped into the well annulus. The workover rig pulled and twisted the production tube to loosen it. A total of 240 feet of production tube was removed. On 4/20/83, another 500 gallons of acetic acid was added, but no additional tubing was removable. The well annulus was filled with fresh water while the workover rig was used on another well. On 4/25/83, 1500 gallons of 30% inhibited acetic acid was added to the well. However, the workover rig was still not able to remove the pump. On 5/29/83, a set of jars were used to "hammer" the equipment out of well. The pump component was full of sand and broken pump pieces. There were two gallons of water in the motor and the pothead was cracked. The motor, protector or pump did not turn freely. The motor windings were shorted to the motor case. After the pump was removed from the well, a logging tool would not go below 315 feet.

5.2 OPERATING EXPERIENCE OF OTHERS

The best documentation of the operating experience with electric downhole submersible pumps available in the public domain was prepared for the Electric Power Research Institute

under project #RP195-8 by Peter F. Ellis and P.F. Greene of Radian Corporation, Austin, Texas under the direction of EPRI project manager Evan Hughes. With EPRI and Radian's kind permission, the operating experience of the other geothermal pumps is summarized in Table III of this report. The information enclosed is from the draft copy of the EPRI report.

There is one other pump installation included in our study. Because of the dramatic success of the Barber-Nichols oil pressurized system, REDA designed and assembled an oil pressurizing system for a 300 hp submersible pump in well 44-7 at the Magma site. The oil supply system was a proprietary design called POSILIFE. Considerable difficulty was encountered during the installation of this prototype system. After the pump had been installed, the resistance between phase conductors and ground was 150 megohms. The pump suction setting depth was 1388.5 feet. The pump operated for approximately two weeks and shut down due to an electrical overload. The pump was pulled and shipped to Bartlesville, Oklahoma for a teardown inspection witnessed by Barber-Nichols engineers. The pump and protector were in good condition and could be reused. The tandem motors were wet with water, but it would be possible to dry them out and they also could be reused. The cable had been mechanically abused either during the installation or removal. The pothead had blown up (literally) and approximately one-half of it was missing. It is hypothesized that water got into the pothead area. The resulting short circuit caused a spark and some of the water

TABLE III

GEOTHERMAL PUMPING EXPERIENCE SUMMARY: ELECTRIC SUBMERSIBLES

	Well Identification	Radiation Pump Ident. No.	Pump System Failure Experienced?	Pumping Assy. Data					Modifications to Previous Pump Assys., Comments, Etc.	Operating Data					Operation and Failure Summary	Improvements Identified, Etc.	I.D. No.	
				Pump Model	"Seal Section" Model	Motor(s) Series	Motor(s) No. HP	Cable Description		TDS (ppm)	Approx. TKS (ppm)	Setting Depth (ft)	Production Temp. (°F)	Date Installed				Endurance (Rotating Hours)
Reft River 5 MW Binary Power Plant (Operator: GAG)	RRGE-1	R-1-RR	Distressed	4-N1500			2 160			1560	900	620	284	11-20-75	112	Pump did not fail: pulled because production too great for well. Water intrusion into motor reported.		R-1
	RRGE-3	R-2-RR	Yes	8-M675			2 160	1/7 Reda lead 64F cable	Motor thrust bearing material changed to high temp. babbitt.	4130	2270	773	300	6-7-77	1358	Failure caused by cable short on well collar grating. Water intrusion into motor reported. 19 start-ups.		R-2
	RRGP-5	R-3-RR	Distressed	8-M675			2 160		Pump assy. R-2-RR with new motor and cable.	1267	890	1000	268	3-10-79	568	Pump did not fail: pulled for well fracture. Bearings in pump, bearings in motors, and cable elec. resistance reported "bad". 25 starts.		R-3
	RRGP-5	R-4-RR	Yes	8-M675			2 160		Refurbished R-3-RR pumping assy.	1267	890	1098	268	12-14-79	85	Pump tripped on overcurrent from downhole short. Burnt motor, damaged cable, dry protector, gutted pump reported (sand production).		R-4
	RRGE-1	R-5-RR	Yes	14-N1050			3 200			1560	900	2020	284	8-13-80	942	Accidental elec. malfunction causing downhole short is reported failure cause.		R-5
	RRGP-5	R-6-RR	Yes	8-M675			2 160			1267	890	1153	268	8-14-80	61	Failure reported to be caused by downhole short. Excessive pump wear due to sand production reported.		R-6
	RRGP-5	R-7-RR	Yes	8-M675			2 160			1267	890	1098	268		0	Water intrusion into motor.		R-7
	RRGE-1	R-8-RR	Yes	12-N1050			2 340			1560	900	1978	284	10-22-80	4	Downhole elec. short reported. No cause given.		R-8
Republic Geothermal's East Mesa Testhole	78-30	R-9-EH	Yes	12-N1050	950/738 Type 66		2 240	#1 Reda red 63R cable (EPDM)			1100	1203	328	2-24-78	~200	Thrust brg. seizure in protector assy., likely due to operating pump out of recommended range. Motor winding deterioration reported.		R-9
	16-29	R-10-EH	Yes	12-N1050	950/738 Type 66		3 160	#1 Reda red 63R cable (EPDM)			1100	1318	322	3-19-78	~336	Cable failure where cable had been squeezed at peckoff during previous test. Inspection revealed motor winding deterioration, some water intrusion, badly worn pump thrust brgs.	Apparently modified motor insulation material.	R-10
"Portable" Geothermal Pump Test Facility, On Site in Bartlesville, Oklahoma	NA	R-11-TF	Yes	27-6220			1 80		Build No. 1.			NA	Not reported	1-31-79	2.75	Elec. failure: all three legs of power open. Cause not reported. 4 starts.		R-11
	NA	R-12-TF	Yes	27-6220			1 80		Build No. 2.			NA	340	3-5-79	215	System overload failure: cause not given. Pump underwent 4 shallow thermal cycles; 5 starts.		R-12
	NA	R-13-TF	No	27-6220			1 80		Build No. 3.			NA	340-365	4-9-79	74	No reported failure: pump pulled to repair packer. 3 shallow and 1 deep thermal cycle, 5 starts.		R-13
	NA	R-14-TF	No	27-6220			1 80		Build No. 4.			NA	340-375	5-2-79	609	No apparent failure: pump pulled because test completed. 10 shallow and 3 deep thermal cycles, 15 starts. Inspections not reported.		R-14

NA = Not applicable.

1. P = Reda, RR = Reft River, EH = East Mesa, TF = Test Facility.

TABLE III

GEOTHERMAL PUMPING EXPERIENCE SUMMARY: ELECTRIC SUBMERSIBLES (Con't.)

	Well Identification	Radian Pump Ident. No.	Pump System Failure Experienced?	Pumping Assy. Data					Operating Data					Operation and Failure Summary	Improvements Identified, Etc.	I.D. No.		
				Pump Model	"Seal Section" Model	Motor(s) Series	Motor(s) No. HP	Cable Description	Modifications to Previous Pump Assys., Comments, Etc.	TDS (ppm)	Approx. TDS (ppm)	Setting Depth (ft)	Production Temp. (°F)				Date Installed	Endurance (Rotating Hours)
Rafé River 3 No Binery Power Plant (Operator: Edde)	RRGE-1	C-1-RR	Yes	10-JB1300	675/HSCP	725	1 400 1 250	#1 CL/B1 (EPDM)		1560	900	2021	284	9-9-79	114	Pumping environment caused hardening of bushing in lower end of pump, causing vibration, seal failure, water intrusion, motor burn.	Changed bushing mat'l. & insulation mat'l. on motor leads.	C-1
	RRGE-2	C-2-RR	Yes	11-JA1100	675/HSCP	725	1 400 1 100	#1 CL/B1		1267	800	1860	~280	9-21-79	0	Unit pulled to replace bushing mat'l. as per C-1-RR experience. Unit mugged bad due to damaged cable. Start not attempted.		C-2
	RRGE-3	C-3-RR	No	12-1A600	675/HSCP	725	1 250	#1 CL/B1		4130	2270	1110	~300	9-26-79	0	Unit pulled to replace bushing as per C-1-RR experience. Start not attempted.		C-3
	RRGE-1	C-4-RR	Yes	10-JB1300	675/HSCP	725	1 400 1 250	#1 CL/B1	C-1-RR with modified bushing mat'l. and motor lead insulation mat'l.	1560	900	2021	~284	4-9-80	0	Unit tested bad prior to start-up due to motor short. Inspection showed rotor and ring damage due to galled sleeve/brg. upper mech. seal cracked.	Increased quality control & inspection of mechanical seals.	C-4
	RRGE-1	C-5-RR	Yes	10-JB1300	675/HSCP	725	1 400 1 250	#1 CL/B1	C-4-RR with new 400 HP motor to replace the one shorted.	1560	900	2021	284	4-11-80	8.5	Cable burn 500' below surface. Mechanical damage during installation suspected.		C-5
	RRGE-3	C-6-RR	Yes	12-1A600	675/HSCP	725	1 250	#1 CL/B1	C-4-RR with modified bushing mat'l. & motor lead insulation mat'l.	4130	2270	1042	300	4-13-80	815	Carbon thrust runner cracked, causing thrust brg. vibration, seal leak, motor burn. Seal section shaft also worn.	Improved Q.C. and inspection of seals.	C-6
	RRGE-2	C-7-RR	Yes	11-JA1100	675/HSCP	725	1 400 1 100	#1 CL/B1	C-2-RR with modified bushing mat'l. & motor lead insulation mat'l.	1267	800	1884	280	4-23-80	0.25	Stator epoxy particles deposited into rotating motor members causing excessive wear and motor burn.		C-7
	RRGE-2	C-8-RR	Yes	11-JA1100	675/HSCP	725	1 400 1 100	#1 CL/B1		1267	800	1884	280	5-6-80	0.25	Same failure mode as C-7-RR.	Developed technique to remove excess epoxy prior to motor assy.	C-8
"Portable" Geothermal Pump Test Facility On Site at Claremore, Oklahoma	NA	C-9-TF	Yes	2-JA1100		725	1 100		Build No. 1.			NA	300	3-25-80	36	Water intrusion into motor through pothead seal.		C-9
	NA	C-10-TF	Yes	2-JA1100		725	1 100		Build No. 2.			NA	300	4-30-80	470	Water intrusion into motor.		C-10
	NA	C-11-TF	Yes	2-JA1100		725	1 100		Build No. 3.			NA	300	10-6-80	3	Radial bearing seized due to clearance problems related to thermal expansion.		C-11
	NA	C-12-TF	Yes	2-JA1100		725	1 100		Build No. 4.			NA	300-325	11-11-80	134	Water intrusion into motor through pothead.		C-12
	NA	C-13-TF	Yes	2-JA1100		725	1 100		Build No. 5.			NA	300	1-29-81	93	Burn in the pothead insulation block due to inadequate mat'l.	Changed to a different, proprietary insulating mat'l.	C-13
	NA	C-14-TF	Yes	2-JA-1100		725	1 100		Build No. 6.			NA	300-325	2-81	911	Water intrusion into motor and seal section.		C-14
	NA	C-15-TF	No	2-JA-1100		725	1 100		Build No. 7.			NA	350	5-15-81	29	Pump removed to repair test rig immersion heater. No failure reported.		C-15
	NA	C-16-TF	Yes	2-JA-1100		725	1 100		Build No. 8			NA	350-375	5-23-81	124	Motor thrust bearing failure due to lack of lubricity of motor oil at elevated (375°F) temperature.	Selected an (undisclosed) synthetic oil for future use.	C-16

NA = Not applicable.

1. C = Centriflts, RR = Rafé River, TF = Test Facility.

* EDWARDS HYDROSTATIC HEAD.

TABLE III

GEOTHERMAL PUMPING EXPERIENCE SUMMARY: ELECTRIC SUBMERSIBLES

	Well Identification	Radian Pump Ident. No.	Pump System Failure Experienced?	Pumping Assy. Data						Operating Data						Operation and Failure Summary	Improvements Identified, Etc.	I.D. No.
				Pump Model	"Seal Section" Model	Motor(s) Series	Motor(s)	Cable Description	Modifications to Previous Pump Assys., Comments, Etc.	TDS (ppm)	Approx. TDS (ppm)	Setting Depth (ft)	Production Temp. (°F)	Date Installed	Endurance (Rotating Hours)			
Portable Geothermal Pump Test Facility On Site at Oklahoma City, Oklahoma	NA	K-1-TF	No	18-68MD			1 60		Build No. 1.	NA	NA	NA	300	7-1-81	147.5	No failure reported. Pump assy. removed for inspection. No results given.		K-1
	NA	K-2-TF	Yes	18-68MD			1 60		Build No. 2	NA	NA	NA	350	7-16-81	125	Motor burn. No cause given.		K-2
	NA	K-3-TF	Yes	18-68MD			1 60		Build No. 3.	NA	NA	NA	300	8-1-81	600	Unit pulled once for inspection after ~300 hrs. running. Failure apparently was burned motor caused by leaking seals.	Changed elastomer composition.	K-3
	NA	K-4-TF	Yes	18-68MD			1 60		Build No. 4.	NA	NA	NA	350	10-6-81	2160	Unit pulled for motor/seal inspection. Seals replaced--apparent imminent failure.		K-4
	NA	K-5-TF	Yes	18-68MD			1 60		Build No. 5.	NA	NA	NA	350	1-21-82	1990	Apparently pulled for inspection, with leaking seals revealed.	Changed elastomer composition.	K-5
	NA	K-6-TF	No	18-68MD			1 60		Build No. 6.	NA	NA	NA	350	4-28-82	1650	Unit pulled because operators thought motor problems surfaced. Inspection revealed motor OK; problem with test rig.		K-6
	NA	K-7-TF	Yes	18-68MD			1 60		Build No. 7.	NA	NA	NA	350	9-17-82	120	Motor failure due to too soft thrust bearing runner.	Changed thrust runner mat'l.	K-7
	NA	K-8-TF	No	18-68MD			1 60		Build No. 8.	NA	NA	NA	350	11-4-82	Running as of 11-9-82			K-8

NA = Not applicable.

TF = Test Facility.

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by Peter Ellis and P.F. Greene of Radian Corp.

flashed into steam, resulting in catastrophic failure. The ends of the copper wires had been melted into round balls.

APPROVED		DATE		BARBER-NICHOLS ENGINEERING	
DWN	B.N.	5-25-83	TITLE		
CHK			CONCEPT: CABLE FEED-THRU		
PRJ	101	525-83			
SIZE		CODE IDENT NO.	DRAWING NO.		
C		57377	PCF-001		
SCALE		1/1	WT	ACT. CALC	SHEET 1 OF