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**TECHNOLOGY ASSESSMENT OF
GEOTHERMAL PUMPING EQUIPMENT**

Final Report, July 1978

**By
Kenneth E. Nichols
Anthony J. Malgieri**

September 1978

Work Performed Under Contract No. EG-77-C-04-4162

MASTER

**Barber-Nichols Engineering Company
Arvada, Colorado**

**U. S. DEPARTMENT OF ENERGY
Geothermal Energy**

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1.0 CONCLUSIONS

1.1 BRINE PRODUCTION

Downhole pumps for producing brine wells represent the largest single pump problem associated with geothermal energy development.

1.2 BRINE TRANSPORT

Brine transport pumps should be installed in the line as close to the wellhead and the discharge of the downhole pump as possible to insure high temperature single phase liquid at inlet. Typical operating conditions for such a pump would be 1,000 gpm of 350°F brine. Pressure rise across the pump would be a constant 100 psi, more or less, and NPSH available would be more than adequate. These are single stage vertical or horizontal centrifugal pumps.

A pump for this duty has not been tested under these conditions, although reinjection pump testing has tended to simulate transport pump operation to some extent. Serious mechanical problems are not anticipated, provided that single phase liquid is provided to this pump, but a transport pump should be procured for field evaluation.

1.3 DIRECT CONTACT HEAT EXCHANGER BRINE FEED

Binary cycles for commercial geothermal power generation may involve a direct contact heat exchanger in which hot brine and the light hydrocarbon turbine working fluid are brought into intimate contact at turbine inlet pressure. Should this type of system be employed commercially, hot brine feed pumps will be required.

The only testing of such a pump reported to date is one of short duration involving a flow rate of only 20 gpm. Pump inlet conditions involved line delivered brine from some distance produced by a free flowing well. This type of system presents difficult inlet conditions to pumping equipment, as evidenced by the problems experienced with the above mentioned installation, and is to be avoided.

Direct contact heat exchangers will not tolerate entrained gases in the brine, as these gases will be "picked up" by the light hydrocarbon vapor and carried thru the turbine to the condenser. Therefore, it becomes necessary for the brine feed pump to be supplied from an insulated vessel installed ahead of it from which entrained gases are vented by dropping the brine pressure to saturation. Resulting precipitates are also removed. This vessel, although providing quality liquid to the brine feed pump, provides this liquid under low NPSH conditions. Unless the vessel can be sufficiently elevated, a horizontal single stage centrifugal pump must be provided ahead of a full scale brine feed pump for boost.

1.4 BRINE REINJECTION

The pumping system installed near Niland, CA. at Imperial Magma #3 (See Section 6.4 Figs. 1,2,3, and 4) is technically sound for brine reinjection. There is a need, however, for more continuous operation using pumps more in the size range likely to be specified for a commercial plant.

1.5 LIGHT HYDROCARBON FEED

Binary cycles for commercial geothermal power generation require light hydrocarbon feed pumps that are two (10MW) to ten (50MW) times larger than high pressure light hydrocarbon process pumps normally supplied by pump manufacturers. No serious problems are anticipated in adapting a boiler feed pump, with a vertical turbine pump as boost, to this duty, but such a pumping system has not been tested.

The test loop shown in Section 6.4 Fig.6 represents a full scale simulation of this geothermal pump application.

1.6 EFFICIENCY IMPROVEMENT

Efficiencies of all brine and light hydrocarbon pumping equipment used in commercial geothermal plants should be in excess of 70%. A good average might be 75%.

Although pump manufacturers consider pumps for these applications to be "custom engineered", available centrifugal pump efficiencies have been compromised in favor of cost in many design areas. If wear ring and impeller schroud clearances were reduced, impellers fabricated rather than cast, volutes precision cast instead of sand cast, hydrodynamic bearings replaced with anti-friction bearings, etc., the average pump efficiency might be increased from 75% to 80%.

Assuming that 30% of the total output energy generated in a 50 MW geothermal plant is consumed in pumping liquids other than condensate and cooling water (See Exhibit Section 6.1), a 5% increase in total pumping efficiency would improve overall plant efficiency by 1.5 to 2.5%, depending upon the type of system used. This improvement is significant, and can probably be justified if the initial cost of these more efficient pumps is not greater than the revenue derived from the sale of 1,500 KW over a two year period, or about \$1,000,000. A 10% average pump efficiency improvement would be worth twice as much.

2.0 PURPOSE AND APPROACH

One purpose of this study is to establish the detailed pumping requirements associated with - drilling, sampling, and testing of geothermal wells; geothermal brine production and transport; brine and organic liquids in the energy conversion process; and the disposal of spent brine. This study will also review available pumping equipment and evaluate its applicability and/or adaptability to these geothermal usages. Specific areas where new or improved pumping equipment or design techniques are needed will be identified, and recommendations for future pump research and development will be described and presented in rank order of priority. Emphasis, in this regard, will be placed upon the following considerations:

1. Where is pump technology lacking?
2. Where should pump research and development be directed in order to close a technology gap?

Information regarding the above has been gathered by conducting interviews with DOE personnel, DOE contractors doing geothermal research, persons associated with geothermal installations, companies engaged in the drilling and completion of geothermal wells, and pump manufacturers. This information is presented in Section 5.0 of this report in a form, which, hopefully, substantially imparts the intent of those interviewed. This information was then correlated and interpreted by the authors so that its meaning could be synthesized in the form of a Summary, and reasoned Conclusions and Recommendations formulated by inclusion of the authors' experience in successfully applying pumping equipment in a variety of services within the Power and Process Industries.

In compliance with the purposes of this Department of Energy contract, as herein set forth, this report is respectfully submitted.

3.0 INTRODUCTION

Although the U.S. geothermal brine resource is substantial, estimated in the Imperial Valley of California alone at 1800 MW output, there are very few commercial operations within the U.S. utilizing geothermal brine for comfort heating, process heating, or for the generation of electrical energy. As a result, experience in this country with pumping equipment in hot geothermal brine service has been gained only on a research level and a very few other limited applications.

Several foreign countries including Mexico, El Salvador, New Zealand, and Turkey have successfully generated power using their higher temperature brine resources, but these commercial plants are supplied from artesian wells and employ flash conversion systems. Problems with pumps and other mechanical equipment caused by temperature, precipitate fouling, and corrosion associated with most geothermal brines are, thereby, avoided. The Country of Iceland utilizes large quantities of geothermal brine for comfort heating, and considerable experience has been gained there in connection with mechanical equipment. Geothermal wells in Iceland, for example, are sometimes pumped using line shaft multistage centrifugal pumps to increase and control production. These Iceland wells are relatively shallow, however, and the brine almost potable and at temperatures less than 300°F. Foreign experience pertinent to this study, then, appears also to be limited.

The Geothermal Division of the Department of Energy is interested in sponsoring research and development aimed at the commercialization of the U.S. geothermal resource on a sufficiently large scale to cause geothermal energy to become a factor in the total energy spectrum. Its current projections call for 3000 MW equivalent on line by 1985 and 20,000 MW by the year 2000. Achieving this goal requires the utilization of geothermal brine at temperatures down to 300°F for power generation and process heat, and at even lower temperatures for comfort heating. Studies sponsored by DOE, and field experience to date, suggest that the realization of this goal requires a thorough assessment of pump technology as it relates to the pumping of geothermal brines.

Geothermal brine reservoirs must be utilized, as steam reservoirs are relatively rare. Brine wells must be drilled and tested using pumps, and those that are not artesian (free flowing) must be pumped. The productivity of all wells capable of producing geothermal brine must be brought to maximum levels, within imposed economic restrictions, which, again, requires pumping.

Geothermal brines at temperatures of 250°F to 500°F are relatively lean sources of energy, while downhole pumps operating in this hostile environment are expensive and subject to premature failure. Hot brine transport pumps will also be needed to deliver the energy laden liquid to the point of usage, while maintaining pressure levels sufficient to prevent loss of entrained gases and precipitation of dissolved solids. Energy conversion from this lean source must be economically maximized, leading to studies of various thermodynamic cycles, including Rankine cycles using organic working fluids that require large feed pumps. Finally, spent brine must be disposed of using re-injection pumps, because of environmental considerations, and, to replenish the depleting geothermal reservoir.

As has previously been stated, the world's geothermal resource has been utilized on only a limited scale. One reason has been the ready availability of fossil fuel energy sources at favorable prices. Another has been the technical problems associated with the extraction, processing, and disposal of geothermal brines. Recent experience has led to the realization that state-of-the-art pump technology in some geothermal brine applications falls short of adequately meeting the commercial requirements of this new industry.

4.0 SUMMARY

About 30 separate interviews were conducted during the course of this study. These interviews revealed that a considerable amount of testing, both in the laboratory and in the field, has been done during the past two years, much of it involving pumps in geothermal brine service. Unfortunately, pump testing in many instances was done incidental to the evaluation of the productivity of a well, or of the feasibility of a process, with insufficient attention being given to proper pump selection and installation. The result, as might be expected under such circumstances, was a rash of pump problems, most of them avoidable.

In some instances, pumps were installed in test loops involving such low flow rates that the installation of positive displacement pumps became necessary. These pumps are, by their nature, high maintenance items when pumping contaminated liquids. In any event, no application exists for pumps of this type in a commercial plant of even the smallest size, due to the high flow rates associated with geothermal brine plants. As a result, brine experience with these pumps is of little real value. The same may be said of the testing at the Bureau of Reclamation's facility at East Mesa of high speed single stage centrifugal pumps manufactured by Sundstrand Corporation. These pumps were applied to brine reinjection, and for brine feed to a direct contact heat exchanger, both at nominal flow rates. These applications, in even a 10 MW geothermal plant, would involve flow rates of at least 1200 gpm per unit, well outside of the range of this pump type.

A multiple error in application has been committed at the facility managed by San Diego Gas and Electric Company at Niland, the East Mesa site of Imperial Magma, and Chevron Resources' facility at Heber, by the use of vertical multistage "turbine" pumps in brine reinjection service. Pumps of this type are normally specified for very low NPSH applications, where more reliable surface mounted horizontal centrifugal pumps cannot be provided with sufficient NPSH by the use of elevated tanks. The pumped liquid must also be "clean", and be capable of properly lubricating the vertical pump's submerged bearings. Field experience to date in pumping geothermal brines with these pumps, in spite of some degree of success reported by both

Magma and Chevron, casts considerable doubt on the desirability of using pumps of this type in this service in a commercial plant.

There have been many problems with downhole pumps, but field testing of the only two pump types available for this service is being pursued aggressively, and at least an interim solution to the downhole pumping problem appears imminent.

No full scale testing of light hydrocarbon or brine feed pumps has been attempted, although these pumps are necessary in binary cycles. Similarly, no full scale tests have been performed on brine transport (pipeline) pumps.

No special pumping problems have been reported in connection with the drilling of geothermal brine wells, although many wells up to 20 inches in diameter and up to 7000 feet in depth have been successfully completed.

With the foregoing general commentary regarding geothermal brine pump testing to date as background, a summary of the information gathered regarding each major geothermal pump application identified is presented.

4.1 DOWNHOLE PUMPS

Based upon interviews conducted in connection with this study, as well as available reference material, initial cost savings of \$5 to \$10 million can be realized by the use of downhole pumps for a 50 MW plant located in the Imperial Valley. This is because of fewer wells being required and less costly gathering systems. This cost saving equates to 10% to 20% of the total estimated cost of such a plant, including both reservoir development and plant cost. Other economic benefits to be derived from the use of these pumps include their capacity for bringing non-free flowing wells into production, the delivery of single phase brine at somewhat higher temperatures to the plant site, and brine flow control for plant operation. Pumps of this type are also needed in testing geothermal brine wells in order to establish the geothermal reservoir's productivity and, thereby, the econometrics of the planned energy system.

Two types of commercially available downhole pumps have been tested to date by Chevron, E G and G, Republic, and Imperial Magma. These are the lineshaft type of vertical multistage centrifugal pump, and the deep well submersible motor multistage centrifugal pump. Pump settings to date have been from 500 to 900 feet, and flows from 100 to 600 gpm of brines at temperatures from 300°F to 356°F. Standard designs of both pump types are limited to pumped liquid temperatures in the order of 250°F, and, as a result, have proven not to be sufficiently reliable in geothermal brine service in the Imperial Valley.

Line shaft pumps are said to have been applied successfully at depths to 1800 feet in pumping cool potable water, although it is generally acknowledged that the reliability of line shaft bearings comes into question at depths exceeding 800 feet - even under ideal pumping conditions. At nominal temperatures "compliant" elastomer bearings are used that are lubricated with the pumped liquid. Bearings may either be exposed to the pumped liquid, or enclosed and lubricated from a separate source at the wellhead. When temperatures exceed that tolerated by compliant bearings (200°F.), rigid teflon journal type radial bearings have been used successfully. Teflon has the characteristic of "slipperyness", a quality that is particularly valuable in instances where boundary lubrication conditions exist, as is the case with line shaft bearings lubed with hot water. Unfortunately, testing to date in geothermal brine wells at East Mesa having downhole temperatures between 335°F and 356°F has suggested that teflon loses sufficient bearing strength at

these temperature levels to preclude its use as a bearing material. This, if true, poses a formidable problem in that the only reasonable alternative now appears to be oil lubricated bronze journals. This design approach results in lube oil being introduced into the brine stream. Unless the introduction of 1 or 2 gal. per week of lube oil into a 500 to 1500 gpm stream of hot brine can be tolerated by the process, the use of line shaft pumps at these temperatures and depths is probably not feasible. Although it is likely that this contaminant condition can be tolerated, deep wells must be extra straight, and pump shaft sections assembled with great care to minimize shaft misalignment for reliable pump operation at these extreme depths.

Deep well submersibles have also experienced difficulties in geothermal brine wells because of temperature. Test results to date, however, appear promising, at least for brines at temperatures less than 360°F. A successful run of 8000 hours in a Raft River geothermal brine well pumping brine at 300°F, although encouraging, is far from conclusive in terms of reliable operation at East Mesa and Heber. More recent tests in a Republic well at East Mesa, although plagued with difficulties, exposed problem areas that appear to lend themselves to solution. Problems were largely confined to the motor protector assembly. This assembly contains the shaft seal that prevents the pumped liquid from entering the motor cavity, while, at the same time, venting said cavity. This assembly also transmits pump pressure thru a fine orifice to a thrust balancing drum that maintains thrust on the main thrust bearing in the upward direction and at acceptable levels over most of the pump's operating range. The shaft seal permitted trace amounts of brine to enter the motor oil during these tests, contributing to the deterioration of the stator winding potting compound, and the thrust balance orifice clogged with solids causing thrust bearing overload and attendant overheating of its babbitt faced shoes during off-design operation.

Pumps of the submersible type are preferred for deep wells because they are less expensive to purchase and install, and less sensitive to both deviating wells and the poor assembly conditions that normally exist at the wellhead. Byron Jackson, which manufactures both line

shaft pumps and submersibles considers well depths of 150 feet as the cost breakover point.

It is reasonable to assume that one or both of these pump types can be brought to the point of being commercially useful in brine wells at temperatures to 360°F during the next 12 months as long as there continues to be economic incentive for brine producers and pump manufacturers to cooperate in achieving this objective.

4.2 BRINE REINJECTION PUMPS

Experience with pumps in geothermal brine reinjection service has been extensive and has established that there can be problems.

The low NPSH available to these pumps suggests the need for a line fed vertical multistage centrifugal (turbine) pump. This approach was taken at the experimental loop facility managed by San Diego Gas and Electric Co. at Niland. Pump problems developed almost immediately. Entrained gases, principally CO₂, are released by the brine at this point in the process, and this release, coupled with reduced temperatures (185°F±), results in precipitation of carbonates and silicates. These precipitates clogged the pump in low velocity areas, and plated pump surfaces in high velocity areas. Bearings, for example, being lubricated by the pumped liquid, plated with precipitate. This Peerless pump is said to be operating reasonably well since the configuration was changed to permit bearings to be lubed by lube water from an external source. Clogging, however, remains a problem.

A similar arrangement exists at Imperial Magma's site at East Mesa, except that brine from the well is not reduced in temperature or pressure before reinjection, and is allowed to pass thru a "sand separator" tank before entering the Floway vertical turbine pump. This pump was said to be operating satisfactorily, but true reinjection pump inlet conditions are not being simulated.

Chevron also has a reinjection system that includes a Peerless vertical turbine pump and reports good experience to date. No details have been provided regarding this installation.

Imperial Magma at Niland has had good experience with a system that involves a clarifier unit ahead of the reinjection pump that removes precipitates. The "clean" liquid is then transferred to a storage tank that provides flooded suction to a horizontal single stage centrifugal pump that charges the inlet of the horizontal multistage centrifugal injection pump. This is the system that is most likely to be used commercially, as it is technically sound from a pumping standpoint and has the added advantage of removing solids that have already plugged the injection well supplied by the reinjection pump previously discussed and located at the SDG & E managed facility nearby.

Other reported reinjection pump experience included testing of a Moyno undulating screw type pump at Niland by personnel with Lawrence Livermore Laboratories, and a Sundstrand high speed single stage pump and Gaso plunger type pumps at the Bureau of Reclamation's facility at East Mesa. The Moyno pump, a positive displacement pump that is capable of pumping heavy chemical slurries, including cement, acted reasonably well except for wear of pumping elements and attendant performance deterioration. The Sundstrand pump suffered some inlet cavitation damage, because it was pumping against too low a back pressure, and experienced a pump shaft seal failure that allowed brine to enter its step-up gearbox. This pump should have been fitted with a double shaft seal with buffer fluid sub-system to prevent this kind of catastrophic failure, and a flow control, but neither was specified.

Experience with Gaso triplex plunger pumps at the Bureau of Reclamation's East Mesa facility has been excellent during 6000 hours of operation in reinjection service. However, field experience with positive displacement pumps, as well as high speed centrifugal pumps of the Sundyne class, becomes somewhat academic for purposes of this study, as the flow rate required by even a 10 MW commercial plant would be well outside of the range of these pumps (approximately 1200 gpm per pump).

4.3 BRINE TRANSPORT PUMP

This is a pump that would be used to take brine from the wellhead and deliver it to the plant site.

If a downhole pump is used to produce the well, it would be more efficient and more reliable to size the downhole pump to deliver liquid only to the wellhead above its vapor pressure, and make up gathering system losses with a separate surface mounted low head rise centrifugal transport pump. This pump would be handling the same liquid as the downhole pump, namely, single phase liquid at downhole temperature.

There are any number of manufacturers of horizontal split case centrifugals that can cope with inlet pressures in the 150 to 350 psi range at temperatures to 500°F, and develop 100 psi, more or less. Flow rates would be the same as for the downhole pump, ranging from 500 to 2000 gpm. In-line overhung impeller single stage centrifugals are also available for this duty, and are less expensive to install. In either case, these pumps have outboard oil lubricated bearings, and can be provided with double mechanical pump shaft seals lubed with filtered and cooled brine from the line, or fresh water, if it is available.

Problems with transport pumps can be expected if two phase liquid is allowed to enter these pumps. This can occur if the transport pump is located too far from the wellhead, or if the well is not pumped and is "free flowing". In these instances, a vented and elevated settling tank with blowdown must be installed ahead of the transport pump for reliable operation.

Interviews conducted during this study did not identify any field experience with a brine transport pump as herein defined.

4.4 LIGHT HYDROCARBON FEED

Light hydrocarbons having specific gravities in the 0.4 to 0.6 range have been pumped successfully for many years in petroleum refineries under the inlet conditions and TDH's required by geothermal binary cycles.

The accepted refinery approach is to use pit mounted vertical multistage centrifugal (turbine) pumps, as these products are vessel stored near grade as boiling liquids, and available NPSH is normally low. Bearings in these pumps are lubricated by these light hydrocarbons, which, at temperatures up to 100°F, have sufficient lubricity. Shaft seals are double mechanical seals flushed with pump discharge liquid throttled in pressure, and sometimes cooled, to prevent flashing across shaft seal faces.

A more expensive alternative approach is the use of a horizontal multistage barrel type centrifugal pump, with or without a single stage centrifugal boost pump ahead of it. The need for this boost is dictated entirely by available NPSH. Bearings, in this instance, would be outboard and oil lubricated. Shaft seals would be designed in the same manner as the vertical pump described above.

The total flow rate required for a 50 MW binary cycle geothermal plant would be in the order of 20,000 gpm. With four pumps in parallel being used, to provide redundancy and match driver size limitations, each pump would deliver about 5000 gpm at 2500 feet of TDH and require about 1500 input horsepower. Pumps much larger than those normally used in refineries would, therefore, be involved.

United Centrifugal Pump and Byron Jackson, personnel of both companies having been interviewed during the course of this study, see no problem in applying their extensive experience with high pressure process pumps delivering light hydrocarbons at flows to 500 gpm to their larger boiler feed pump line for application in geothermal binary cycles.

As a measure of confidence in meeting the requirements of this application, United supplied an isobutane feed pump for a test loop at the Niland facility managed by SDG &E, and Johnston Pump Co. its pit mounted vertical turbine pump boost.

These pumps were installed in the loop, but have operated only on water as of this writing. Since the 50 MW plant design for the Niland area has been changed from a binary cycle to a double flash system, these pumps will probably not be tested on isobutane unless funding is provided by DOE, or a producer planning a binary cycle plant.

These pumps, when installed in light hydrocarbon service, should not be enclosed. They should be mounted outdoors, as there is always the possibility of leakage of these highly flammable liquids that flash to high density gas upon reaching atmospheric pressure. There should also be no open flames or depressions that can trap the heavy gas in the immediate area. The fact that geothermal plants do not require open fired boilers, greatly reduces the safety hazard associated with handling these liquids.

4.5 DIRECT CONTACT HEAT EXCHANGER BRINE FEED

Only Occidental Research Co. reported field experience with a pump in this service.

Occidental had some problems with a Sundstrand LMV-311 high speed centrifugal pump in a test loop at the Bureau of Reclamation's facility at East Mesa. This pump was called upon to deliver only 20 gpm, but at a realistic 625 psi. Unfortunately, the pump was fed directly from a free flowing production well some distance from the pump, so that the brine contained precipitates and released gases. Occidental now realizes that a vented elevated tank with blowdown is needed ahead of this feed pump, unless a down-hole pump is used to pump the well and liquid above its vapor pressure can be delivered to pump inlet.

The Sundstrand pump, although not capable of being applied in even a 10 MW commercial plant because of flow limitations (1200 gpm per pump being required), was fitted properly for this application. It had a double pump shaft seal configuration with separately supplied buffer fluid, and flow control to protect against insufficient back pressure. For the flow and pressure required for these tests, this pump was a good choice and performed satisfactorily in spite of difficult inlet conditions.

4.6 PUMPS USED IN WELL DRILLING

Based upon only one interview, that with Dr. Bob Rex of Republic Geothermal, Inc. and Republic Drilling Company, there are no pump problems that are uniquely associated with drilling geothermal wells.

4.7 EFFICIENCY IMPROVEMENT

Reference material has indicated that 10% to 15% of the power generated in a geothermal plant is consumed in driving pumps, whereas only 3% to 4% is so used in a conventional power plant. This geothermal pumping power does not include downhole pumps and transport pumps needed to deliver brine to the plant site. With geothermal plant overall efficiencies in the order of 10% to 15%, the efficiency level at which pumping is accomplished becomes important.

Exhibit 6.1 of this report shows that pump efficiencies greater than 70%, particularly for the higher horsepower units, can be achieved by proper pump selection and system design. Downhole turbo pumps would not be that efficient without further development.

There are, no doubt, possibilities for increasing the efficiency of conventional pumping equipment to some degree, at the penalty of a higher initial cost. In geothermal applications, however, this cost premium might be justified on the basis of improved overall system performance.

5.0 INTERVIEW REPORTS

5.1 U.S. Department of Energy
Geothermal Division
20 Massachusetts Avenue, NW
Washington, D.C. 20545
Telephone: (202) 376-4912
Person Interviewed: Clifton Carwile
Date of Interview: October 14, 1977

The new DOE organization was described. Various divisions of other government agencies have been consolidated to form DOE, including the Federal Energy Administration (FEA), the Energy Research and Development Administration (ERDA), the Federal Power Commission (FPC), Mining Research, etc.

The only geothermal pump development sponsored by DOE was through downhole pump contracts let to Sperry, Sundstrand, and Lear Motors in 1975 and 1976. Pumps were designed and built to produce 1000 gpm at a pressure rise of 485 psi. Only the Sperry pump was tested in a geothermal well. Reports were written by these contractors. Kobe of Los Angeles has also built a downhole multistage turbo pump. John Erikson of Kobe should be contacted. No further testing of downhole pumps will be done this fiscal year.

Peerless and Johnston build line shaft pumps for brine, and should be contacted.

There are no commercial plants in the U.S. using brine. The Geysers field north of San Francisco is owned by Union Oil and Magma Power and is rare in that it produces natural steam. Condensate from Pacific Gas and Electric's plants located in this field is disposed of by gravity feed, so that reinjection pumps are not required. For information regarding this field, contact Del Pyle at the Union Oil Research Center at Brea, California. The phone number is (714) 528-7201.

There is an experimental brine reinjection project at Niland (contact Mr. Gil Lombard of San Diego Gas and Electric Co. at (714) 348-2223). There is also another experimental project at Raft River, Idaho where Jay Kuntz may be contacted for information.

Chevron Oil of San Francisco has wells at Heber, California.

The U.S. Navy is drilling an exploratory well at Coso (China Lake), California. Drilling is to be done entirely with mud. Bill Glass of Big Chief Drilling Company, Oklahoma City, OK should be contacted. George Kemnitz of Laughlin Drilling Company of Farmington, New Mexico has also had some experience drilling geothermal wells using mud to the formation, then air. The major manufacturers of mud pumps for drilling wells are Continental-Emsco and Halliburton.

Republic Geothermal is now pumping a well at East Mesa. Contact Bob Rex.

Jim Kuwada at Rogers Engineering in San Francisco is also a good contact, particularly in connection with foreign projects (Iceland, Turkey, El Salvador, etc.).

The Elliott Company of Jeannette, PA, and General Electric-San Jose, are involved in geothermal plant design. Fluor-Pioneer of Chicago has also done some system studies.

There is very little free oxygen in geothermal brine, permitting the use of carbon steels.

5.2 United Centrifugal Pumps

1132 North 7th Street

San Jose, California 95112

Telephone: (408) 298-0123

Persons Interviewed: Harry C. Booth, President

Robert R. Ross, V.P.- Chief Engineer

Jack Miller, V.P.

Robert L. Lendahl - Sales Manager

Date of First Interview: November 16, 1977

United manufactures a complete line of horizontal centrifugal pumps for process and pipeline applications, including the larger horizontal split case and barrel type multistage units. Although hundreds of these pumps have been applied in waterflood service, which often involves brines, the company has not yet been approached regarding reinjection of geothermal brines.

Bearings of these pumps are outboard and are oil lubricated. A variety of shaft seal configurations are available, including designs which provide for flush with tap water or filtered and cooled process fluid. Pumps also can be provided in a variety of metallurgies, such as cast iron, cast steel, 316 stainless steel, ductile Ni-Resist, etc.

Flows and pressures for geothermal brine reinjection are ideal for these pumps.

United would like to see pump specifications for commercial plants now in the planning stage.

5.3 United Centrifugal Pumps
1132 North 7th Street
San Jose, California 95112
Telephone: (408) 298-0123

Persons Interviewed: Robert R. Ross-V.P., Chief Engineer
Jack Miller-V.P.
Mark Bell- Metallurgist

Date of Second Interview: June 8, 1978

The purpose of this visit was to expose United's management to typical pumping requirements for centrifugal pumps in geothermal brine service, and in light hydrocarbon feed service for binary cycles.

Pumps for 10 MW and 50 MW geothermal power plants were discussed. United has not had any direct experience in pumping "geothermal" brines. They would be willing to quote pumps for these applications, however, based upon their prior experience in related applications - principally brine reinjection in oil field secondary recovery operations and the pumping of a variety of other liquids at temperatures to 500°F. United's only reservation relates to corrosion.

Mr. Ross found it difficult to believe that carbon steel internals would stand up to medium and heavy brines over the long term, and would be reluctant to quote such a pump. Stainless steel 316, stellite faced, is normally specified for shafting and impellers. Ductile Ni-Resist is normally employed for impeller wear rings, rather than bronze, if chloride concentrations are high.

The pumps discussed are as follows:

<u>Item</u>	<u>Liquid</u>	<u>Nominal Temp.-°F</u>	<u>10 MW and 50 MW Flows - GPM</u>	<u>TDH - Ft.</u>	<u>NPSH - Ft.</u>
1.	Brine	375	1000 to 2000	250	10+
2.	Brine	375	5000 and 25,000	1500	10+
3.	Isobutane	150	5000 and 25,000	3000	10+
4.	Brine	180	5000 and 25,000	2000(max.)	10+

The transport pump (Item 1) is fed by a vertical downhole pump. The brine feed pump (Item 2), used only in a direct contact heat exchanger system, would be fed by either the downhole or the transport pump. Three pumps may be used, each rated at one half of the above flows. The iso-butane feed pump (Item 3) would be fed by either a vertical or horizontal boost pump capable of picking up boiling liquid from an elevated tank (2 to 3 ft. NPSH). Three pumps at one half total capacity would probably also be used in this application. Item 4 is the reinjection pump, which, again, could be three pumps each at half total capacity supplied from an elevated tank (clarifier).

Messers Ross and Miller stated that pumps for the above commercial size plants would have sufficiently large passages to minimize solids clogging. The smaller the pump, the greater the problem. High velocity areas are normally plated by dissolved salts, whereas precipitates tend to deposit in low velocity areas.

United reinjection pumps, each delivering flows up to 20,000 gpm, were said to have operated successfully for ARAMCO in a Saudi Arabia waterflood. Brine temperature is 180°F, and the brine contains 230,000 mg/liter of dissolved solids. These are 22 inch cast steel pumps (ASTM A-216 WCB) with 316SS internals. One of these large pumps would accommodate a complete 50 MW reinjection system involving Niland brine, if a separate single stage boost pump were provided to provide sufficient NPSH and a 10,000 HP driver was possible.

Many light hydrocarbon pumps, with total delivered heads up to 3300 feet, have also been supplied, but these pumps deliver flows of less than 1000 gpm. A pump was furnished to San Diego Gas and Electric's test facility at Niland for a flow rate of 4250 gpm, but this pump has only been run on water to date.

Messers Ross and Miller do not see any problems associated with furnishing light hydrocarbon feed pumps delivering flows in the 2000 to 12,500 gpm range. A proven boiler feed pump would be adapted for this application. The shaft seal configuration would be the same as that used successfully on lower capacity pumps. Mr. Miller recommended that these pumps not be enclosed, although the absence of an open fire in a geothermal power plant greatly minimizes the potential danger posed by shaft seal leakage.

5.4 Pacific Pumps Division
Dresser Industries, Inc.
5715 Bickett Street
Huntington Park, California 90255
Telephone: (213) 588-2201

Person Interviewed: J. Arthur Lundquist

Date of Interview: November 21, 1977

Pacific is interested in furnishing pumps for geothermal application. Some experience has been gained with pumps at the Geysers. Pacific has also built a downhole pump with assistance from Barber-Nichols, but this pump has not been tested.

5.5 Lawrence Berkeley Laboratory
One Cyclotron Road
Berkeley, California 94720
Telephone: (415) 843-2740

Person Interviewed: Jack Angevine

Date of Interview: November 9, 1977

The pump for reinjection of spent brine is a major problem. No one has pumped economically in this application. The Bureau of Reclamation bought a centrifugal pump from Sundstrand's Fluid Handling Division, which was backed up by two horizontal plunger pumps manufactured by Gaso of Shreveport, Louisiana. There were problems with these pumps. Tom Lindemuth of Bechtel and Bill Oswald of Sundstrand - Los Angeles may know the details. San Diego Gas and Electric's test site at Niland has also installed a reinjection pump. Bob Lacy has had nothing but problems with this pump. Contact him at (714) 232-4252.

Brine feed pumps are needed for systems using direct heat exchange. Contact DSS Engineers of Florida about this. Ed Wahl of Occidental Research in Los Angeles has had some experience with a Sundstrand pump used for brine feed.

Downhole pumps of the line shaft type have also had many problems. Magma Power sent Harry Falk to Iceland to learn what modifications had to be made to these pumps to get them to work properly. Republic Geothermal has had some operating experience with Peerless line shaft pumps. There have been a number of bearing failures. Contact Jim Barkman about details.

Lawrence Livermore Laboratory is currently working mostly on a total flow turbine system and corrosion studies. See Ken Mirk, Mechanical Engineering Supervisor. Lawrence Berkeley Laboratory has a Well Testing Group, and is concentrating on studies relating to the geology of geothermal wells. Ron Schroeder should be contacted there.

5.6 Rogers Engineering Company, Inc.
111 Pine Street
San Francisco, California 94111
Telephone: (415) 986-6546

Person Interviewed: James T. Kuwada, V.P.

Date of Interview: November 15, 1977

There are many pump problems, but private industry is not interested in developing pumps using government funds as they want to retain proprietary rights. Sperry-Vickers, Lear, and Sundstrand have done some development on downhole pumps at flows to 1000 gpm to be used in 9-5/8 inch casings. These pumps are single stage and operate between 9000 and 18,000 rpm. The necessity for operating at these speeds is surprising. Downhole pump impellers should be tested in a loop before getting into a full scale test.

Mr. Kuwada did not believe that Barber-Nichols could get the Sperry-Vickers downhole pump started. This pump probably started because it was tested in an artesian well. What about more typical wells? Kuwada saw the proposals made to NSF by Sperry, Lear, and Sundstrand. Milestones should have been set up for these, and for future pump developments.

Sperry asked Kuwada to compare its pump with a line shaft pump. The Sperry pump requires a packing between it and the well casing. The packer can stick to the casing, and you can't get the pump out. The line shaft pump has its own discharge pipe, and doesn't need a packer.

Downhole pumps must deliver liquid to the surface above its vapor pressure to maintain single phase flow. Vapor pressure is a function of temperature.

500°F	1500 psi well head pressure
600°F	2000 psi well head pressure

Well head pressures on a gas well are 3000 to 6000 psi, and even higher, but temperatures are lower. Producers are worried about the cement bond in geothermal wells that holds the casing in the hole.

The question is whether the well is bore limited or reservoir limited. Wells are rated according to their productivity index, calculated by dividing the well's output in gpm by the drawdown in psi required to produce that flow.

Johnston and Peerless make irrigation pumps. When using these line shaft pumps in geothermal wells it is necessary to compensate for temperature. It is very expensive to change one of these pumps. Harry Falk of Magma Power says that the Icelanders have a benign brine, but they still enclose bearings. They had to open the bearing clearances because of temperature. These adjustments increase the cost of the pump, but the pump can be made to work. You have to jog these pumps before running them to get the hot liquid up along the shaft to stabilize temperatures. Line shaft pumps are limited to 1000 feet, but 800 feet is better.

Wells are normally 3000 to 7000 feet in depth, but the brine normally comes to within a short distance of the surface. A good producing well on pump may draw down 1000 feet. This can cause problems if the well is drawn down to the flash point of the liquid or to the entrained gas evolution pressure.

Kuwada has seen a well in Turkey that will free flow 1,200,000 lbs/hr. of brine until it throttles itself back to about half this flow due to calcite deposition. Its bottom hole temperature is about 400°F. Divide by 500 to convert this flow to gpm.

5.7 Johnston Pump Company
1775 East Allen Avenue
Glendora, California 91740
Telephone: (714) 599-2351

Persons Interviewed: Herman A.J. Greutink, V.P.
Robert Trout

Date of Interview: November 17, 1977

Four approaches to downhole pumping of wells have been investigated:

- 1) Hydraulic turbine drive - Sundstrand
- 2) Steam turbine drive - Sperry-Vickers
- 3) High frequency electric motor drive - LMC
- 4) Line shaft drive - Peerless, Johnston, Floway,
Layne and Bowler

All of these designs require either separate discharge piping going down to the pump or a packer between the pump and the well casing. The line shaft approach has the advantage of requiring the smallest well casing for a given capacity. ERDA has made studies of well diameter versus cost.

Total dissolved solids (TDS) at Heber is 15,000; seawater is 30,000; Niland is 100,000 plus. East Mesa has a TDS of only 2,500. Raft River and Roosevelt Hot Springs are also low in TDS.

Downhole pumps are needed with binary systems to keep solids and gases in solution.

Line shaft pumps can have bearings enclosed in a tube and lubricated with oil or pure water from the surface, or bearings exposed to the hot brine.

Starting of a line shaft pump must be done properly. The bearings have to be flushed before starting. Then the pump is jogged and adjusted to compensate for expansion. Johnston believes that temperature compensation can be done automatically.

Johnston has many brine applications down to 1000 feet. The Oregon Institute of Technology at Klamath Falls is heated with geothermal wells at 190°F. Graphite bearings have been used in an Idaho well.

Ken Nichols of Barber-Nichols Engineering Company discussed a specific application needed for a test binary system at East Mesa.

Temperature	340°F to 360°F
Flow	300 gpm
TDH	250 psi (est.)
Depth of Setting	650 feet (est.)

The well to be used is artesian and free flows 80 to 100 gpm. The well casing is 7-5/8 inches in diameter.

Greutink estimated that the pump would have 12 stages. Thirty 20 foot lengths of line shaft would be needed, which, for standard construction, would cost \$300 per length, or \$9,000. This would be an enclosed bearing design. Cast iron bowls, bronze impellers, and 1-1/4 inch carbon steel shafting would be standard construction. The bearing cover tubing would also be carbon steel. The 12 stage pump in standard construction would cost \$1,000 and the motor \$2,000. For geothermal brine application, Johnston would need help on the metallurgy, and on the bearing design. Bearings would be special (not rubber). This special pump could cost \$20,000, instead of the \$10,000 estimated for the standard pump less motor. Cast iron bowls work well in seawater, and may be compatible with geothermal brine.

5.8 Sundstrand Corporation
Fluid Handling Division
1485 West 64th Avenue
Arvada, Colorado
Telephone: (303) 425-0800

Person Interviewed: Ed Gravelle

Date of Interview: February 22, 1978

Hasan Onal designed a downhole pump, the details of which are outlined in a report written by Gravelle in June, 1976. The work was originally contracted for by NSF, with the contract later being assigned to ERDA. The pump was tested in the laboratory, but was not field tested. It was designed for a TDH of 770 feet at 1000 gpm. According to Gravelle, this head would not have been sufficient to prevent flashing of the brine at the surface in a typical geothermal well. Well draw down at 1000 gpm can be up to 1000 feet, and the brine must be delivered to the surface under a head of at least 300 feet to prevent flashing. This was not known at the time the contract was awarded.

Gravelle has confidence in the Sundstrand design approach, and feels that a follow-on contract should be awarded by DOE. He has been told that DOE wants to gain a better understanding of the reservoir engineering associated with geothermal resources before continuing downhole pump development.

Gravelle had no knowledge of Sundstrand pumps being used for brine reinjection or transport as reported by others. He suggested that Bill Oswald, Sundstrand's Los Angeles Service Representative be contacted at (213) 724-4105.

5.9 Republic Geothermal, Inc.
11823 East Slauson Avenue
Suite 1
Santa Fe Springs, California 90670
Telephone: (213) 945-3661

Persons Interviewed: Dr. Robert W. Rex, Pres.
Dr. James H. Barkman, V.P.

Date of First Interview: November 17, 1977

The first "wet steam" commercial plant rated at 48 MW net will go on line early in 1980. This plant will be built under the DOE Loan Guarantee Program.

Well productivity indexes at East Mesa are excellent. Production averages 70,000 BPD per well (2042 gpm). Republic is currently using a Peerless line shaft pump, but is also talking to Johnston and Vickers.

Republic's field is expected to involve 10 to 12 producing wells. Cost estimates indicate a saving of \$4 to \$6 million in the gathering system alone by using downhole pumps.

Two phase	\$12,000,000
Single phase	\$ 6,000,000

Downhole pumps also protect gathering systems against scaling.

Republic is about to order two 12 inch downhole pumps from Peerless, each to flow 2000 gpm. Magma Power will also order some of these pumps for test in this same field.

Republic has been running 1100 gpm Peerless pumps (12 inch). Differential expansion ruined the cast iron impellers. The grooves in the graphite impregnated teflon bearings plugged when the filtered lube water flashed. This pump was similar in design to pumps used successfully in Iceland.

"Mac" McCabe talked Peerless into building 12 inch pumps for Republic and Magma. Peerless will try capton polyimide bearings impregnated with moly-disulfide. This material is stable up to 500°F. These pumps will be set at depths of 750 to 1000 feet. Peerless is the only company that offers such a pump.

Republic is looking at wells cased with 16 inch casings for the first 2000 feet, and then 11-3/4 inch casings for 3000 feet to the formation. These larger wells cost only 30% more than 7 to 9 inch wells; \$650,000 versus \$500,000.

Reservoirs at medium temperatures and below will require downhole pumps.

Republic has had some experience with reinjection of spent brine using Peerless line shaft pumps. Flow rates were up to 4000 BPD (117gpm) at 400 psi and 200°F. These pumps were diesel engine powered. Line shaft pumps have too large a downward thrust for electric motor bearings. A right angle gearbox is needed. Hasan Onal's all titanium mixed flow pump has also been used for brine reinjection. A titanium pump can be run at super-cavitating conditions without damage.

East Mesa brine is not very severe. The temperature of this brine is 350°F. Thermodynamically speaking, there is no advantage in a binary system above 300°F. There are many pumps needed in a binary system that are not needed in a flash system.

The "hot dry rock" technology could have great potential. E.J. Walsh at Bechtel believes that there is a least 90,000 square miles of accessible "hot rock" in the U.S.. Water injection into these formations requires 5000 to 10,000 psi in a pulse mode to get the flow through the formation, and to keep the formation open.

The DOE should buy a Sperry-Vickers pump and make it available to Republic for field testing. This unit should not be a prototype, however. DOE should spend more to commercialize this pump. Republic has a need for 20 to 30 of these pumps through 1980 to provide brine for just one 50 MW. plant. Over the next 12 years 800 MW will be installed at East Mesa and another 800 MW at Heber. This amounts to a market for downhole pumps of at least \$50 million in this one area.

5.10 Republic Geothermal, Inc.
11823 East Slauson Avenue
Suite 1
Santa Fe Springs, California 90670
Telephone: (213) 945-3661

Persons Interviewed: Robert V. Verity - Staff Engineer
Michael J. Walker - Mgr. Facilities

Date of Second Interview: June 9, 1978

The primary purpose of this visit was to review the results of recent tests with a Reda deep well submersible pump in a Republic brine well located in the East Mesa field.

The deep well submersible pump was first developed early in this century by a Russian immigrant named Aramais Arutonoff. He is the founder of the Reda Pump Company of Bartlesville, Oklahoma, now a division of TRW. These pumps are multistage centrifugals driven by special high slenderness ratio hermetically sealed electric motors running in oil. They were first applied in pumping petroleum from wells having productivity indexes outside the range of "sucker rod" powered check valve pumps, and beyond the practical depth of line shaft pumps. In more recent times, thousands of these pumps have also been applied in oil field secondary recovery operations where they pump a mixture of oil and brine with entrained sand at flows up to several hundred gallons per minute and at total delivered heads to several thousand feet. Oil field applications, however, do not require the pump's downhole electrical components to operate above 275°F, and submersible motors and power cable assemblies are designed accordingly. Material selection, then, is similar in practice to that followed in designing electrical components for general industrial usage (ambient + 80°C temperature rise).

There are currently three manufacturers of these pumps - Reda and Byron Jackson of the U.S.A., and Klein, Schanzlin and Becker (KSB) of West Germany. To date, only Reda is sufficiently interested in pumping geothermal brine to devote the time and money necessary to assess the effect on its equipment of operation in ambients up to 350°F, and two pumps have been furnished to Republic for field evaluation.

Three runs were made in a 9 inch well at East Mesa in recent months using two different motor configurations. The pump furnished has 12 stages, and the setting depth was 600 feet. Anticipated steady state flow was 30,000 BPD (875 gpm), but the well proved capable of delivering continuously only 583 gpm. The downhole temperature of this well is 335°F.

The pump furnished for the first run was driven by two 240 HP motors in series powered thru an EPDM cable (ethylene-propylene) previously tested at Reda at 400°F. The run lasted 4 days. The reason for shutdown was a twisted off drive shaft. A faulty starter control at the surface resulted in numerous abortive attempts to restart the motors following this failure, repeated surge currents damaging the cable and motor windings.

The pump furnished for the second run employed three 160 HP motors in series. The purpose of this change was said to have been improved heat transfer between the motor windings and the 335°F brine. The first run with this configuration was only of 15 minutes duration because of arcing over of the leads of the main power cable at the well head. This arcing was attributed to a poor splice. A second run with this same unit ended after 15 days with a second cable failure, this time at the packing gland on the motor housing. Brine was seen to have entered the motor oil upon disassembly, which was assumed to have been the primary cause of visible damage to the motor winding insulating varnish and insipient failure of the main thrust bearing. The power cable also showed significant discoloration, the red colored elastomeric filler having turned black.

Reda promised to furnish a new pump for continued testing on or about mid-October 1978. This pump will be sized for an 11 inch well casing and will be set at a depth of 950 feet. Expected flow is 60,000 BPD (1750 gpm). The pump will deliver brine at the wellhead at 50 psi or more above vapor pressure (175 psi). Two motors, each rated at 240 HP, will be employed. One or more of the following design changes will be incorporated -

1. A higher temperature oil in the motor.
2. A higher capacity thrust bearing.

3. A higher temperature varnish on the motor windings.
4. An improved cable packoff assembly.
5. An improved thrust balance pothead.

This upgraded pump will be installed in another well in this same field cased with 11 inch casing that is known to be capable of producing 1750 gpm at a pump setting of 950 feet. Its downhole temperature is 350°F. This well will be refurbished prior to pumping. A new 11 inch well will also be put on this pump. The productivity will be established prior to installing the Reda to be sure that the pump, when installed, can operate somewhere near its design point.

Although two other known attempts to pump geothermal wells using Reda submersibles were unsuccessful, this series of tests appears to show promise.

Republic personnel interviewed look upon this test program with reserved optimism. Reda personnel, on the other hand, are said to be highly confident of ultimate success.

Testing of Peerless type line shaft pumps at Republic, which began in August of 1977, have not yet resulted in a design configuration suitable for commercial use. Continuous runs in the range of 27 to 39 days were achieved, but this performance falls far short of the 12 month MTBF objective. Taking into consideration the trend towards greater setting depths (1000 from 600 feet) and its negative effect upon line shaft pump reliability, initial cost, and replacement (tripping) cost, the prospect of a deep well submersible pump on wire line having enclosed motors and a power cable capable of surviving a 360°F environment is understandably appealing. Whether or not this can be accomplished without the complexities of surface cooling of the motors remains to be seen.

Republic would like to have a \$100,000 contract from DOE to offset a portion of its cost in continuing these tests. A test report would be furnished under this contract.

5.11 Peerless Pump Company
1200 Sycamore Street
Montbello, California 90640
Telephone: (213) 726-1232

Person Interviewed: George Crabtree

Date of Interview: November 17, 1977

Peerless has sold about 20 line shaft pumps for pumping geothermal brine. The maximum practical depth on brine is 1000 feet, although Peerless has gone to 1800 feet on fresh water. They have gotten good runs up to 5 months duration on 325°F water. Peerless also sold some pumps to Chevron for the Geysers project in 1959, but these were not line shaft pumps.

Problems with line shaft pumps largely involve bearings. Experience has shown that copper base alloy bearings cause plating out of some salts which fills the bearing clearances. Teflon bearings have been tried, but do not work. Neoprene takes a permanent set and is useful only for static seals. Bearing problems have occurred even though bearings are enclosed and lubricated with filtered brine from the surface.

Low pressure areas within the pump causes carbonate precipitation. Entrained CO₂ lowers the pH and keeps carbonates from forming. When the pressure is lowered, the CO₂ comes out of solution and a toothpaste-like precipitation is formed. Temperature reduction of the brine results in the precipitation of silicates.

Cast iron bowls and impellers are standard in line shaft pumps and appear to work well in geothermal brine.

Iceland's geothermal wells produce water that is almost potable and much cooler than either East Mesa or Heber. Somebody there is importing Floway pumps and modifying bearing clearances to compensate for the temperature.

Peerless can oil lubricate line shaft bearings, either gravity feed or by pressurization, but customers do not want oil in the brine.

Vertical centrifugal pumps can also be used for reinjection. Flash type systems produce spent brine at only 5 to 15 psia, difficult inlet conditions for a surface pump. Vertical pumps do not employ shrouded impellers with wear rings, thereby avoiding potential problems of plugging of clearance with precipitates.

Line shaft pumps normally run at 1750 rpm. A 6 inch pump will develop 300 gpm at this speed, and 450 gpm at 3460 rpm. The slower speed pump has a bearing every 10 feet, whereas the higher speed pump is designed with a bearing every 3 feet 4 inches. Bearing spacing is determined by critical speed considerations. The 1750 rpm pump, for a setting at 600 feet, would have 28 stages and would sell for about \$50,000. Its efficiency would be about 70%. Pressure at the surface would be about 50 psi above vapor pressure. Shafting would be AISI 416 heat treated to 220 Brinell and ground to a 32 rms finish. Bearing material, clearances, and method of lubrication is still a question. Len Elliott at Chevron-San Francisco wants to do some research and development on bearings.

Republic Geothermal estimates that it will purchase 1000 downhole pumps for the Imperial Valley by 1985.

5.12 Bechtel National, Inc.
P.O. Box 3965
San Francisco, California 94119
Telephone: (415) 768-6786

Persons Interviewed: Alex Renton
Jerome W. Hankin

Date of First Interview: November 11, 1977

Al Rogers should be interviewed, as he is in charge of component field testing for DOE at East Mesa. Al Cooper of Chevron in San Francisco also has experience in pumping geothermal brines.

Terry Walsh is manager of new technology for Bechtel. Robert Greider was formerly with Chevron doing studies on geothermal economics, but is now with:

International Energy Corporation
600 South Cherry
Denver, CO 80222
(303) 773-6703

Certain power cycles, including binary systems, require a downhole pump. Organic fluid pumps are available for use in these binary systems. There is a 10 MW binary system now under construction at East Mesa (see Tom Hinrichs of Magma Power (714) 743-7008). Some people say that the cross-over point between binary and flash systems is between 300 and 350°F. There is some question about generating power from geothermal brine that is below 300°F. Idaho National Engineering Laboratory (INEL) is doing testing in connection with a dual boiling binary cycle at Raft River.

Some wells in the Imperial Valley are at temperatures of 700°F. This temperature level is ideal for flash systems. New Zealand, Japan, Mexico, El Salvador, etc. are using flash systems.

Most problems at Geysers are due to corrosion caused by the H₂S in the steam.

Renton would like to see some good downhole pumps. Pumps have been designed for certain temperature and flows. These temperatures and flows are too low. Each well costs \$300,000 to \$600,000. Economic studies have been done on well casing size versus flow, and free flow versus pumping. Pump economics would be more favorable if pumps were designed to produce higher flows of higher temperature liquid.

Reinjection pumps operate at 180°F more or less and flows can be 2000 gpm for each producing well. Inlet pressures range from 2 psia to 15 psia, and discharge pressures are in the order of 300 to 400 psi. Vertical pumps installed in a pit are needed because of the low available NPSH. Bearings and shaft seals can be a problem on reinjection pumps. Shaft seals must be flushed with pure water. Instrumentation passages, pressure gages, etc. become plugged with precipitates (carbonates, etc.). Other internal surfaces become coated with scale. There can also be corrosion problems if air becomes entrained in the brine. George Tardiff at Lawrence Livermore Labs, (415) 447-1100, Extension 7883, should be visited. He is Geothermal Project Chemist. George can refer you to Paul Needham of the Bureau of Mines, who has also had experience with brine scaling and corrosion.

There could also be problems with vacuum pumps needed to extract non-condensable gases from the system.

5.13 Bechtel National, Inc.
50 Beale Street
P.O. Box 3965
San Francisco, California 94119
Telephone: (415) 768-4081

Persons Interviewed: Thomas Lindemuth
Jerome Hankin
Alex Renton
Carlos Figueroa
Malcolm Weekes

Date of Second Interview: June 7, 1978

Mr. Lindemuth was in charge of the Bureau of Reclamation test facility at East Mesa for more than one year. Ninety percent of all mechanical failures during the period were pump failures. Test programs were largely aimed at desalinization plants at the time. Most of these pump applications involved very low NPSH ie: in the order of 2 to 3 feet. Liquid temperatures ranged only up to 300°F. Shaft seal failures were frequent, but they did not try double mechanical seals with flush. In-line centrifugals in brine transfer service pumped liquid at 100 to 175°F. These pumps used packings as shaft seals, which were allowed to leak. Pump casings were stainless steel.

Occidental Research tested its direct contact heat exchange system at this East Mesa facility. Interview Fred Baucher of Occidental regarding these tests. A direct heat exchange system requires large hot brine feed pumps.

Corrosion effects of geothermal brine are not well understood. Carbon steel vessels and pipe work well, because the brine scales and protects the metal. Carbon steel pumps, however, did experience significant corrosion. NiAl Bronze, on the other hand, worked well.

The last pump tests run at this facility while Lindemuth was Project Manager involved a Sundstrand 14,000 rpm pump with flow control and bypass on reinjection service. This pump was fed from an elevated tank with a gas blanket on the liquid. The pump inducer showed cavitation damage. A single mechanical seal without flush was used in this pump, and several seal failures were experienced. One such failure allowed brine to enter the gearbox, resulting in its total destruction. Testing was completed

in January of 1977 after the Sundstrand pump had been replaced with two Gaso plunger pumps. Contact Mr. Suemoto at the East Mesa facility for more recent test results.

Magma Power is now under construction with a 12 MW binary plant at East Mesa, and Rogers Engineering is designing a 10 MW single stage flash plant for Union Oil at Brawley.

Fluor-Pioneer of Chicago has designed a 50 MW plant for SDG &E.

Electric Power Research Institute of Palo Alto, CA. should also be contacted. They have a Mobile Test Laboratory for testing brine chemistry. See Vasel Roberts.

Gil Lombard's Brine Reinjection Pump Report on ERDA Contract No. E (04-3) - 1137 might also prove useful.

5.14 Phillips Petroleum Company
P.O. Box 858
Milford, Utah 84751
Telephone: (801) 387-2879

Person Interviewed: Ron Forrest, Geologist

Date of Interview: March 10, 1978

Phillips Petroleum has leased the government owned geothermal reservoir at nearby Roosevelt Hot Springs. A previous interview suggested that this facility had installed some brine reinjection pumps. According to Forrest, there is currently only one production well and one reinjection well in this field, and spent brine disposal is accomplished without the use of pumps.

The production well is cased with 13 inch casings and can produce up to 1,200,000 lbs/hr of brine at 506°F containing only 8000 parts per million of dissolved solids. This well was drilled about two years ago. The reinjection well is 1.4 miles from the production well. There is a 10-3/4 inch pipeline connecting the two. The production well is at an elevation that is 271 feet higher than that of the reinjection well.

Phillips is working with the Jet Propulsion Laboratory of Cal Tech in designing a 1 MW plant based upon a flash system using 430°F steam.

5.15 San Diego Gas and Electric Company
Niland Facility
P.O. Box 840
Calipatria, California 92233
Telephone: (714) 232-4252, Ext. 2061

Person Interviewed: Bill Jacobson, Project Manager

Date of First Interview: March 10, 1978

San Diego Gas and Electric manages a test facility here for component testing. The original plan was to construct a 50 MW power plant here based upon an isobutane binary cycle. A pump test loop has been built to evaluate the performance of the low pressure isobutane boost and the main isobutane feed pumps for this 50 MW plant.

According to a design study of this plant done by Bechtel, San Francisco under an ERDA contract, the total isobutane flow rate would be 5,370,000 lbs/hr (about 20,000 gpm). The low pressure boost pump would add about 150 feet of head to this liquid stream to charge the main feed pump, which adds an additional 2180 feet of head.

It appears that this facility has selected a Johnston vertical boost pump and a United 4 stage horizontal split case main feed pump for evaluation. The flow rate for these pumps is 4250 gpm, or about 1/4 of the flow rate needed for a 50 MW plant.

According to Jacobson, the test loop at Niland has been operated successfully on water, but tests on isobutane have not yet begun. He is not expecting any mechanical problems with these pumps in this loop, as light hydrocarbons have been pumped at these flow rates and pressures in petroleum refineries for many years. He feels, however, that a full scale geothermal plant could benefit from larger pumps of this type than are commonly used in refineries, and that power plant safety requirements may place more stringent limitations on shaft seal leakage than would be necessary in a refinery.

In addition to the organic liquid test loop previously described, SDG & E has been operating a 9 stage vertical Peerless pump in brine reinjection service for several months. Jacobson deferred to Art Wilbur of DOE-Oakland for details of the reinjection pump experience gained here, as it is all documented in bi-monthly reports submitted to this DOE office. He did, however, volunteer the information that the pump is installed in a pit 18 feet in depth to provide sufficient NPSH, and that the liquid is near its vapor pressure. There has been some cavitation damage, but mainly the problem has been scale buildup in the lines, bearings, bowls, and instrumentation.

5.16 San Diego Gas and Electric Company
Niland Facility
P.O. Box 840
Calipatria, California 92233
Telephone: (714) 232-4252

Persons Interviewed: Arthur R. Ellis - Info. Supervisor
David Newell - Project Engineer

Date of Second Interview: June 12, 1978

Brine well downhole temperatures at Niland are between 500 and 600°F. Originally, a binary system was planned for this area because of entrained gases released by a flash system, but 98 percent of this gas proved to be carbon dioxide. Carbon dioxide release not being environmentally objectionable, a two stage flash system will be constructed on this site.

A brine reinjection pump is being evaluated at this facility. It is a Peerless 9 stage vertical turbine pump that takes flashed brine at 220°F under boiling conditions and delivers it into the reinjection system at pressures from 0 to 600 psi. Design flow is 1600 gpm, but the pump is normally operated at 500 gpm. This vertical pit mounted pump was selected because of the low NPSH available.

The interstage bearings of the first pump installed were lubricated with the pumped liquid. Bearings plated with dissolved solids and siezed after a few hours of operation. The pump was then converted to a design that permitted these bearings to be lubricated from an external source of acidized condensate. The pump can now operate successfully for periods of 1000 to 1500 hours before spiders and bowls clog with precipitates.

Mr. Newell feels that a better approach to the brine reinjection problem would have been two surface pumps in series, a single stage centrifugal to cope with the low NPSH, and a multistage centrifugal to develop the necessary pressure. In any case, an upstream clarifier unit is needed ahead of the reinjection pump, and will be installed by year end.

5.17 U.S. Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, California
Telephone: (415) 273-7943

Person Interviewed: Tony Adduci

Date of Interview: March 10, 1978

This interview was made to obtain additional information regarding the field test experience gained at Niland with the Peerless reinjection pump. The pump has been operated off and on for several months. Precipitation of silicates has clogged the pump, and the reinjection well approximately one mile distant. The well has been acidized at least once, and settling tanks and a clarifier (centrifuge) has been added at the well head. It is believed that the pump is of standard construction (cast iron and bronze), and that the problems experienced to date have not been corrosion related. Pump discharge pressures were originally in the 300 to 350 psi range at flow rates of 1000 to 2000 gpm, but are now about 600 psi.

Adduci agreed to mail a set of the bi-monthly reports submitted to this DOE office by the Niland test site to Barber-Nichols Engineering Co. for use in connection with this study. Included are details of the reinjection pump installation, and a description of the pump problems encountered to date.

5.18 Lawrence Livermore Laboratories
P.O. Box 808
Livermore, California 94550
Telephone: (415) 422-3967

Person Interviewed: Andy Lundberg (M.S. L-220)

Date of First Interview: March 10, 1978

This government laboratory also has a test facility at Niland, and various types of brine reinjection pumps have been tested there during the past two years. Frank Locke should be contacted at Niland (714) 348-2220 for details regarding the results of this earlier testing.

At the present time, liquid is being drawn from the reinjection line and stored in an elevated tank. This tank provides flooded suction to a Moyno pump manufactured using materials specified by Livermore as being compatible. The temperature of the liquid is 100°C. This pump has operated successfully, but its maximum capacity is only 20,000 lbs/hr. The total flow rate to be reinjected is 800,000 lbs/hr. The Moyno pump is an undulating screw type pump and is not available for applications involving high flows and pressure.

5.19 Lawrence Livermore Laboratory
University of California
P.O. Box 808
Livermore, California 94550
Telephone: (415) 422-6268

Persons Interviewed: George Tardiff - Supervisor
Haskell Weiss - Mech. Engineer
Frank Locke - Test Engineer
Daniel McBride - Metallurgist

Date of Second Interview: June 8, 1978

The purpose of this visit was to obtain details regarding testing of an undulating screw type pump for brine reinjection.

Lawrence Livermore's test facility adjoins the SDG & E facility at Niland. Its pump test loop receives brine from the same production well, and injects brine into the same disposal well as the SDG & E loop.

The pump tested was a Robbins and Myers Model 6P10. It delivered 60 gpm at 450 rpm of brine that had previously been flashed. The temperature of this brine was 185°F and its specific gravity 1.13. Brine was taken by the pump from an open tank and discharged into the line at pressures up to 450 psi. The rotor of the pump was chrome plated tool steel, and the stator had been molded from a Buna-N elastomer.

After 1000 hours of operation, abrasion and corrosion had damaged the chrome plating on the rotor causing the pump to lose capacity.

The test pump is one of the largest manufactured by Robbins and Myers, and, although the design is useful in pumping highly viscous liquids and slurries, approximately 70 such pumps in parallel would be needed to dispose of the waste brine from even a 10 MW plant.

Livermore's experience with the corrosion of geother-

mal brines was also discussed. Hastalloy C or B is best for corrosion resistance, but low grade stainless and corrosion resistant steels are not much better than carbon steels. High silicon cast irons are also acceptable, but not sufficiently ductile for casings. Copper base alloys and Monel are not recommended because of the high concentration of chlorides present. Brine that has been exposed to air is much more corrosive. Brine taken from storage tanks and holding ponds by reinjection pumps is more likely to cause corrosion problems than the brine seen by downhole and transport pumps.

5.20 Shell Oil Company
P.O. Box 100
Deer Park, Texas 77536
Telephone: (713) 476-6374

Person Interviewed: Dennis Tiede

Date of Interview: March 13, 1978

Butane and propane are produced and pumped in Shell Oil refineries. Isopentane is no longer separated out of the LPG stream.

API type single stage centrifugals with overhung impellers are used for low pressure service. Vertical turbine pumps (multistage centrifugals) are used to pump these liquified gases from storage at ambient temperature and pressures up to 500 psi. These pumps are used because of the low available NPSH. Arrangements are also used whereby a vertical turbine pump is used to charge a horizontal split case multistage centrifugal that delivers the liquid into a pipeline at 500 psi. This latter arrangement is more reliable, but also more expensive.

The highest flow rates that Tiede was aware of are about 700 gpm. For a 20,000 gpm flow rate (a 50 MW geothermal plant) Shell would normally use 3 pumps in parallel, each with a capacity of 10,000 gpm. One pump would be on standby. Tiede suggested that the manufacturers of large boiler feed pumps and pipeline pumps be contacted, as process pumps are not available in this capacity range. These larger pumps can probably be modified for LPG service.

Proper shaft seal design is important to minimize leakage. Shell uses Borg-Warner "U" type or Crane 8B mechanical seals. These seals are carbon faced running on tungsten carbide. Viton A is the elastomer. Shaft seals normally see suction pressure, although, to be sure that the liquid at the seal face is well above vapor pressure, and to provide cooling, liquid is sometimes tapped from the second or third pump stage and piped to the "stuffing box" through a throttle valve used to regulate pressure.

OSHA regulations regarding leakage of toxic liquids from pump seals are becoming more and more stringent. However, LPG's are not, as yet, considered toxic.

5.21 Sundstrand Corporation
Fluid Handling Division
1436 Goodrich Boulevard
Los Angeles, California 90022
Telephone: (213) 724-4105

Person Interviewed: Bill Oswald

Date of Interview: March 13, 1978

Sundstrand sold an LMV-311 high speed centrifugal pump to the Bureau of Reclamation for testing in the East Mesa field. The pump was to deliver 200 gpm of hot brine at pressures up to 500 psi to a reinjection well. To provide adequate NPSH, the pump was fed from a storage tank 10 feet in diameter and 30 feet tall that was set 6 to 8 feet above the pump. Initial reinjection pressure was only 50 psi, so that the pump was running on the cutoff portion of its characteristic. Somehow, brine leaked into the gearbox and the pump was returned to the factory for repair. The pump was re-installed and Oswald believes that it subsequently operated successfully. Two Gaso plunger pumps were purchased in the interim, but Oswald did not know anything about the Bureau's experience with these plunger pumps. He suggested that the following contact be made:

Ken Mathias
Bureau of Reclamation
P.O. Box 427
Boulder City, Nevada 89005
(702) 293-2161

Two pumps were also sold to Occidental Research of LaVerne, CA. One was an LMV-322 to feed isobutane at 24 gpm and 500 psi. The other was an LMV-311 to be used for brine feed at 20 gpm and 625 psi. This pump was furnished with 316SS internals and a cast steel case. A double shaft seal configuration was provided, and the pump seals were lubricated and cooled with fresh water supplied by a separate Sundstrand pump (Sunflo). Oswald did not know anything about Occidental's experience with these pumps except that they had been shipped February 26, 1976. He suggested the following contact:

Ed Wahl
Occidental Research Corp.
1855 Carrion Road
La Verne, CA. 91750
(714) 593-7421

5.21a Bureau of Reclamation
P.O. Box 427
Boulder City, Nevada 89005
Telephone: (702) 293-2161

Person Interviewed: Ken Mathias

Date of Interview: July 20, 1978

Mr. Mathias reported on the Bureau's experience with plunger pumps manufactured by Gaso of Shreveport, Louisiana in brine reinjection service at the East Mesa test facility.

The reinjection system at this location consists of a settling pond with a sand filter at its outlet thru which the spent brine passes prior to entering one or more of three single stage centrifugal boost pumps that deliver the liquid a distance of $1\frac{1}{2}$ miles, thru a bag type filter and into a large storage tank. The stored brine, then, is free of sand and precipitates, and is at ambient temperature. This storage tank provides flooded suction, and is fitted with a float valve and pneumatic control that starts and stops the two Gaso pumps.

The Gaso triplex pumps, Model 354 A, are installed in parallel. They have carbon steel heads and ceramic plungers. Rated flow is 225 gpm at 360 rpm. Maximum developed pressure is 800 psi. Drivers are 125 HP electric motors. These pumps have operated successfully in this service at rated flow, and at discharge pressures in the 400 to 500 psi range, for approximately 6000 hours. The only problem experienced to date has been breakage of inlet valve studs, a problem considered unrelated to this application. These studs have since been redesigned, and the breakage problem has not recurred.

These pumps were recently disassembled for inspection, and were found to be in excellent condition.

5.22 Occidental Research Corporation
1855 Carrion Road
La Verne, California 91750
Telephone: (714) 593-7421

Person Interviewed: Fred Baucher

Date of Interview: March 13, 1978

Ed Wahl is no longer with Occidental. Baucher reported that the Sundstrand isobutane pumps were used in tests related to a direct contact heat exchanger. The DOE contract under which this work was being done has now been completed. This pump operated without problems.

The brine feed pump used in these tests also operated reasonably well. NPSH problems were experienced because this pump was fed directly from a free flowing production well. If and when this test program is resumed, the brine well would feed a vented tank elevated above the pump. This tank would provide flooded suction and allow released gases to vent to the atmosphere and solids to settle before the liquid enters the pump. This should eliminate the problems encountered previously.

5.23 E G and G Idaho, Inc.
P.O. Box 1625
Idaho Falls, Idaho 83401
Telephone: (218) 645-2244

Person Interviewed: Raymond Gould - Site Superintendent

Date of Interview: June 28, 1978

This location is E G and G's geothermal brine resource at Raft River, Idaho.

A Reda deep well submersible was first tested in one of these wells in 1974. The pump was a standard Model N 1500 pump (1500 gpm at design). A few problems were experienced in this relatively light (1400 to 2700 TDS) brine having a downhole temperature of only 300°F. The most important problem was the entry of small quantities of brine into the motor. This pump has since been rebuilt, and is going back into service soon on a new well.

Another Reda pump, Model N 1050, has just been removed after about 8000 hours of trouble free service in another well. It was just shipped back to the factory for disassembly and inspection. This pump delivered 600 to 880 gpm of 300°F brine at a setting of 800 feet in a well cased with 13 inch casing, but with 200 feet of 20 inch casing at the top. Clarence Dunbar of Reda should be contacted after this pump has been inspected.

About 3 months ago, testing began on a Peerless line shaft pump in still another well. All of these wells are 4000 to 7000 feet in depth. This 15 stage pump is driven by an electric motor with a high capacity thrust bearing. It pumps from a depth of 800 feet, and delivers about 700 gpm. The line shaft bearings are enclosed, and the bearing material is graphite impregnated teflon. These bearings are lubricated by filtered and cooled process water at sufficient pressure to prevent flashing in the bearing column. About 30 days of operation has been accumulated to date without problems.

Mr. Gould stated that thrust bearings in both the Reda pump and on the electric motor shaft driving the Peerless unit tolerate up-thrust more than down-thrust. It is important that these pumps be hydraulically balanced so that the thrust is up, even under off-design conditions.

Gould also feels that Magma and Republic may be allowing the lube water for the line shaft unit bearings to flash in the column by not keeping the column pressurized sufficiently. Dissolved solids will not plate out unless the brine flashes. He considers that proper field assembly and installation, proper start-up and shut-down procedures, and proper well completion, are essential to reliable line shaft operation. Flanges for the pump sections must be square, etc., and the well must be straight. If the line shaft bearings experience excessive misalignment, they will become overloaded and will fail. This is particularly true with bearings lubed with hot water.

The submersible pump is less expensive than the line shaft type. Availability is also much better - 24 hours for Reda, and 52 weeks for Peerless.

On or about August 1, 1978 a contract will be let by E G and G for the construction of a 5 MW binary plant at Raft River with a 14 month completion schedule.

5.24 Imperial Magma Company
East Mesa, California 92233
Telephone: (714) 356-4635

Persons Interviewed: Robert Brassfield
John Featherstone

Date of Interview: June 12, 1978

Imperial Magma is a subsidiary of Magma Power Company and is responsible for developing the Company's geothermal resources.

A reinjection pump is being tested near Imperial Magma well No. 3 in the Niland area. Spent brine at a temperature of 180°F is put through a clarifier unit that removes a slimy green precipitate. The treated liquid is then sent to an open storage tank on grade that floods the inlet of a single stage double entry centrifugal pump. This pump pressurizes the inlet of a multistage centrifugal pump that is capable of developing discharge pressures up to 600 psi. Both pumps have outboard oil lubricated journal bearings. Shaft seals are stuffing boxes with teflon packings. These packings are exposed to the process fluid at suction pressure, and glands are not tightened to a zero leaking condition. This practice increases the life of the packings by providing some lubrication and cooling.

This system design, although much more expensive than the system at the SDG & E managed facility nearby, is technically sound and is reported to be working well. Photos of these units are presented in Section 6.4.

Imperial has also tested several configurations of Peerless line shaft pumps in its well at East Mesa. Currently, a 13 stage Model 12 LP pump, set at a depth of 865 feet, is being evaluated.

This is a diesel driven 12 inch pump designed to deliver up to 1000 gpm of brine. The brine temperature in this well is 356°F. The pressure of the brine at the well head is now maintained at 300 psi, as entrained gases were

"breaking out" at 265 psi. This pump has bronze line shaft bearings, as bronze proved to be superior to teflon in a previous test in which several types of bearings were installed in the same pump. The bearings are enclosed, and are lubricated and cooled by pumping filtered and chemically treated "canal water" down the shaft enclosure with a small positive displacement pump. The lubricant flow is 2 to 3 gpm. This pump had run almost continuously from May 10, 1978 to the date of this visit (33 days). It had been shut down after 20 days of operation to replace the packing at the well head that contains the lube water. Early on the morning of this visit (June 12) the pump was again shut down, apparently for the same reason.

The downhole test pump delivers liquid to a sand separator that is also the supply tank for a 21 stage Floway vertical pump. This pump reinjects the hot brine at pressures up to 500 psi. This pump was said to be operating successfully, although shaft bearings are exposed to hot brine.

5.25 Magma Power Company
631 South Witmer Street
Los Angeles, California 90017
Telephone: (213) 483-5542

Persons Interviewed: Edwin (Skee) Zajac - V.P.
Lester Brassfield - Production Supervisor
Norman Hodgson - Field Supervisor

Date of Interview: June 12, 1978

Magma's first experience with pumping a brine well dates back about 3 years when Mr. Zajac used a Peerless line shaft pump to pump a well at Brady Hot Springs, Nevada. The flow was 100 gpm, and the pump was set at 500 feet. The brine temperature was 325°F, and the pump delivered brine to the surface at a pressure of 135 psi. Total dissolved solids at this site was only 3200 mg/liter. This pump had enclosed teflon bearings lubed by filtered brine from the well. This pump ran continuously for 5 months (4000 hrs.) without damage.

During the past year Magma has been attempting to duplicate its Nevada experience at East Mesa. Several Peerless pumps have been tested, with the life of these pumps in this service having been established at only 25 to 35 days of continuous operation. Problems have centered around line shaft bearing failures. Successful line shaft pump experience in Iceland has been studied. Various bearing materials have been tried, and bearing and pump clearances adjusted to compensate for temperature. The pumping conditions in this field are more severe than the Nevada field conditions. TDS is 11,000, and brine temperatures 335 to 360°F. Setting depths were 600 feet, and have now been increased to 900 feet to increase production. Flows were originally 500 gpm, and are now moving toward 1000 gpm. All of these pumps had enclosed bearings lubed with filtered water at moderate temperatures, as was true in the successful Nevada test.

Downhole pump testing continues at East Mesa in an effort to develop a reliable 1000 gpm line shaft pump so that 5 production wells can supply the 10 MW plant being constructed on this site by Magma. This plant is scheduled to be put into operation in October of this year, so that

time is of the essence.

Mr. Zajac believes that the shaft bearing problems are largely caused by precipitates from the lube water that plug the bearing passages. A secondary cause is the possibility of a "kink" in the well casing of the well in which recent pumps have been tested. Bearings in the 12 inch pump now being evaluated are bronze, and lube water is chemically treated and filtered canal water. This pump has run for 33 days, but was shut down for maintenance at the time of this visit (June 12). A similar pump had been tested on two previous occasions in these wells, each experiencing bearing column fouling from carbonate and sulfate deposition with attendant line shaft bearing failures after 25 to 35 days of continuous operation. Most of the problems, according to Mr. Zajac, were in the top 80 feet of shafting.

5.26 TRW Reda Pump
P.O. Box 1181
Bartlesville, Oklahoma 74003
Telephone: (918) 661-2576

Persons Interviewed: Richard O'Neil - Sales Engineer
Clarence Dunbar - Geothermal Engineer

Date of Interview: June 28, 1978

Following, is a discussion of the Reda deep well submersible pump testing in a Republic Geothermal, Inc. brine well at East Mesa.

The Reda pump tested was a standard unit with K-Monel shafting, Ni-Resist impellers and diffusers, and a carbon steel housing. Journal bearings are used only at the top and bottom of the pump shaft. These bearings are bronze lubricated by the process fluid.

The motors and power cable were also of standard construction. The power cable was armoured and insulated with EPDM ("Reda Red"), an elastomer lab tested at 500°F.

A pump was tested in a well that was expected to produce a continuous flow of 35,000 BPD (1021 gpm) at a given depth setting. It soon became necessary to lower the pump, which required a field splice and "re-wrap" of the power cable. Even at the higher depth setting, the well was capable of only 19,000 BPD continuous flow (554 gpm). The same condition existed in a second well in which the same pump was tested, although with different motors.

Several problem areas were revealed during these tests.

1. Field splicing, particularly the re-wrap, of the power cable in higher temperature environments must be done with greater care.

2. The automatic thrust balancing feature of the pump, which involves a fine orifice, proved unreliable because of solids contamination. The pump had been balanced for thrust at a flow rate of 35,000 BPD, and this device failed

to properly compensate for off-design operation. The result was excessive downthrust. A higher capacity thrust bearing would not require the use of this device.

3. A babbit faced tilting pad thrust bearing cannot be used at these temperatures. A higher capacity bronze bearing is being investigated.

4. The varnish used to "pot" the stator windings of the motor deteriorated (flaking). This seems to have been caused by the small amount of brine entering the motor oil, coupled with the higher temperature. A new varnish is being investigated.

5. A high temperature synthetic oil will be used in the motor,

6. Improved static and dynamic seals will be used in the motor protector assembly. The standard design permits small amounts of oil leakage into the process and small amounts of process fluid leakage into the oil during heating and cooling upon startup and shutdown. This does not result in problems if the process fluid is heavier than oil and is not miscible with the oil. It merely settles to the bottom of the motor housing. Geothermal brine applications appear to require a more sophisticated design approach in sealing the motor.

Mr. O'Neil stated that at no time during the Republic tests were the motors not operational. There was also no evidence of cable insulation breakdown. The thrust bearing did not actually fail, but the babbit facing appeared to have experienced some melting due to excessive loads and temperatures. The pump showed no evidence of radial bearing problems. Neither was there plating of precipitates nor precipitate deposition in low velocity areas. The pump has a bronze journal bearing only at the top and bottom of the shaft. There are also "fiber thrust pads" ahead of and behind each impeller. All of these bearing surfaces were in good condition after the final 29 day run.

Reda has many oil field pump applications at downhole temperatures up to 250°F . There are also brine applications in Arkansas at downhole temperatures of 220°F. The oil in the motors will normally be at a temperature between 50 and 80°F above that of the process fluid when flow rates are high. In a 360°F brine application, motor and protector assembly components must be designed to withstand 425°F. Reda believes this to be within the present state of the art for such components.

5.27 Chevron Resources Company
P.O. Box 3722
San Francisco, California 94119
Telephone: (415) 894-5990

Person Interviewed: L.T. Elliott - Design Engineer

Date of Interview: June 7, 1978

Chevron has a geothermal brine resource at Heber, California. The Company has used one of its wells at this location to test a Peerless line shaft pump, a Reda deep well submersible pump, and the Sperry steam turbine driven prototype pump. Brine temperature in this well is 360°F.

The insulation in the power cable and in the motors broke down during testing on the Reda pump. This was in 1974. Reda personnel were not interested in cooperating with Chevron in developing a pump for geothermal brine service at that time, so the program was abandoned.

The Peerless pump tested was an open bearing design with the bearings completely exposed to the process liquid. This testing was also unsuccessful because of line shaft bearing failures.

The Sperry pump testing indicated that the pump needed a great deal of further development.

The availability of a good downhole pump is important to geothermal development. None exists at the present time.

A special Peerless pump is to be tested at Heber again late this year. The pump will have enclosed bronze bearings, and the L/D ratio of these bearings will be 2, rather than the 4 being tested by others. A bearing will be located every 5 feet along the line shaft. Pump bowls will also be modified for greater axial clearance. Teflon does not have sufficient strength to serve as a bearing at these temperatures. Line shaft misalignment is probably also contributing to the bearing problem, but there is no compliant bearing material that will perform at temperatures of 300°F and up. The viscosity of water at 325°F is only one tenth of what it is at room temperature, making it a very poor lubricant.

Mr. Elliott would like to use a high temperature oil recommended by Chevron at Richmond, California to lube the shaft bearings of the new Peerless test pump, but the process engineers at Chevron are opposed to the idea. Oil in the brine may foul heat exchangers and could damage the formation when reinjected. The question is whether or not 2 gallons per week of synthetic lubricant in a 600 gpm brine stream can be expected to cause significant problems. This matter will be considered further before testing of this new pump begins.

Johnston Pump Company's line shaft pumps have successfully pumped geothermal brine for comfort heating at the Oregon Institute of Technology at Klamath Falls, Oregon, but the brine is very light, and at a temperature of only 190°F. This application relates to successful line shaft pump experience in Iceland.

Chevron has tested a Peerless vertical multistage centrifugal (turbine) pump at Heber on brine reinjection service with good results.

5.28 Byron Jackson Pump Division
Borg Warner Corporation
P.O. Box 2017
Terminal Annex
Los Angeles, California 90051
Telephone: (213) 587-6171

Persons Interviewed: Eric Fiske - Chief Engineer
Arthur Meares - Industry Mgr. Nuclear
Robert Yam - Mgr. Applications & Est.

Date of Interview: June 9, 1978

The purpose of this visit was to expose Byron Jackson personnel to typical pumping requirements for centrifugal pumps in geothermal brine service, and in hydrocarbon feed service in binary cycles.

B-J manufactures a full line of centrifugal pumps, vertical and horizontal, for all industrial applications.

Downhole pumps and surface pumps for both 10 MW and 50 MW plants were discussed. B-J has not had any experience in pumping geothermal brines. Its brine experience is limited to the pumping of seawater for desalinization plants, and in oil field secondary recovery operations.

Company personnel appear to be ultra-conservative regarding new applications. Mr. John Deloss - Industry Mgr. Power, although not present at this meeting, had apparently indicated previously that the geothermal pump market was five years in the future.

Conversation centered around the downhole pump problem, as all present considered that all surface pumping requirements could be handled from prior experience with minimal development effort if systems were designed for pump reliability rather than for minimum cost. Good system design should include cool and clean flush water for shaft seals, elevated tanks and/or boost pumps to provide adequate NPSH, clarifiers ahead of pumps to remove precipitates, etc.

B-J is one of three manufacturers in the world that can supply a deep well submersible pump for an 11 inch well that can deliver brine at flows to 2000 gpm from a depth of 1000 feet. B-J has done this for ARAMCO, but the temperature

of the oil-brine mixture was only 210°F. The cost of this pump was said to be approximately \$200,000. With brine at a temperature of 350 to 400°F, a surface cooling system for the motors would be necessary. B-J would consider a study contract from DOE in which a cooled motor pump would be designed specifically for geothermal brine service. The value of this contract should be about \$60,000, and a design report would be furnished.

Mr. Yam stated that B-J, having available both line shaft and submersible pumps, will not quote line shaft pumps for setting depths greater than 150 feet even when pumping cool clean water. Beyond this depth, submersibles are less expensive, and more reliable. Tolerance buildups cause misalignment and attendant bearing failures in line shaft pumps as the length increases. Mr. Fiske said that 325°F was well beyond the temperature limit established by B-J for both its line shaft and submersible pumps.

Mr. Yam estimated that a 10,000 gpm multistage centrifugal pump for hot brine (direct contact heat exchange or reinjection), or isobutane feed (binary cycle) with a TDH of 2500 feet would cost about \$300,000 less driver. Normally, three of these pumps would be purchased for each service - two operating at capacity and one stand by. This flow rate relates to a 50 MW plant. Double seals would be used by B-J in the brine pumps, and a tandem seal arrangement in the isobutane pumps.

6.1 TYPICAL GEOTHERMAL PUMP SPECIFICATIONS (50MW PLANT)

APPLICATION	METALLURGY	SUCTION PSI	DIS- CHARGE PSI	GPM	TEMP-°F	FLUID	PUMP TYPE	PUMP EFFICIENCY %	INPUT HORSE- POWER
1. BRINE PRODUCTION (DOWNHOLE)	CARBON STEEL (Ni-Resist Trim)	50- 100	400- 800	500- 2000	300- 400	BRINE SINGLE PHASE	CENTRIFUGAL VERTICAL MULTISTAGE OR HIGH SPEED SINGLE STAGE	60-75	150- 1200 (Each pump)
2. BRINE WELL TESTING	SAME AS FOR BRINE PRODUCTION								
3. BRINE FEED (DIRECT CONTACT HEAT EX- CHANGE CYCLE ONLY)	CARBON STEEL (SS Trim)	150- 350	400- 600	22,500	250- 350	BRINE SINGLE PHASE	HORIZONTAL CENTRIFUGAL MULTISTAGE	75-85	1000- 1875 (See note 1)
4. BRINE REINJECTION a. Boost b. Main	CARBON OR STAINLESS STEEL	2-15 PSIA	20-50	20,000- 25,000	180- 220	BRINE TWO PHASE	HORIZONTAL CENTRIFUGAL	75-85	75-225 (See note 1) 0-3250 (See note 1)
		20-50	0-800				SINGLE STAGE MULTISTAGE		
5. BRINE TRANSPORT	CARBON STEEL (SS Trim)	150- 350	250- 450	500- 2000	300- 400	BRINE SINGLE PHASE	HORIZONTAL CENTRIFUGAL SINGLE STAGE	65-75	40-200 (Each pump)
6. LIGHT HYDROCARBON FEED (BINARY CYCLE ONLY)	CARBON STEEL	15-20 PSIA	400- 600	20,000- 25,000	100- 150	Isobutane, Isopentane, Propane, etc.	VERTICAL MULTISTAGE CENTRIFUGAL (See note 2)	65-75	1750- 3125 (See note 1)

Note 1. Each for four pumps.

Note 2. Preferred alternative is horizontal multistage centrifugal
boosted by single stage centrifugal similar to arrangement per
Item 4

EXHIBITS

6.1 (CON'T)

ESTIMATED PUMPING HORSEPOWER - 50MW PLANT

<u>PUMP APPLICATION</u>	<u>EST. LIQUID SP.GR.</u>	<u>EST. TOTAL FLOW-GPM</u>	<u>EST. PRESSURE RISE-PSI</u>	<u>INPUT HP @ 75% EFF.</u>	<u>INPUT HP @ 80% EFF</u>
1. DOWNHOLE	1.05	25,000	500	10,210	9,572
2. TRANSPORT	1.05	25,000	100	2,042	1,914
3. BRINE FEED	1.05	25,000	450	9,189	8,615
4. HYDROCARBON FEED	0.52	25,000	600	6,068	5,688
5. REINJECTION	1.10	25,000	600	<u>12,835</u>	<u>12,033</u>
TOTALS				40,344	37,822
				Δ HP 2522	

SUMMARY

<u>System Type</u>	<u>H.P. At 75% Eff.</u>	<u>H.P. At 80% Eff.</u>	<u>Avg. H.P. As % Total Plant Output</u>
Flash System (1+2+5)	25,087	23,519	27
Simple Brine System (1+2+5)	25,087	23,519	27
Binary (1+2+4+5)	31,155	29,207	31
Binary With Direct Contact H.E. (1+2+3+4+5)	40,344	37,822	37
Binary With Direct Contact H.E. And 80% Brine Pressure Recovery (1+2+3+4+5-0.8X3)	32,993	30,930	32

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6.3 OTHER INTERVIEW CANDIDATES SUGGESTED

1. Del Pyle - Union Oil Research Center
Brea, CA.
(714) 528-7201
2. Fluor-Pioneer; Chicago, ILL.
3. Procon, Inc.; Des Plaines, ILL.
4. Ben Holt Company; Pasadena, CA.
(213) 684-2541
5. Bill Suratt - DSS Engineers, Inc.
Ft. Lauderdale, Florida
(305) 792-6660
6. David Howell - Republic Drilling Co.
Santa Fe Springs, CA.
7. Floway Pump Co.; Fresno, CA.
8. Robert Grieder - International Energy Corp.
Denver, CO.
(303) 773-6703
9. Worthington Pump U.S.A.; Harrison, N.J.
(201) 484-1234
10. Ingersoll Rand Co.; Phillipsburg, N.J.
(201) 859-7931
11. Bingham-Willamette Co.; Portland, Oregon
(503) 226-5393
12. David Elliott - Jet Propulsion Laboratories
Pasadena, CA.
(213) 354-4321 Ext. 3486
13. Paul Needham - U.S. Bureau of Mines
14. Sus Suemoto - Bureau of Reclamation Test Facility
East Mesa, CA.

15. Al Rogers - Bechtel National, Inc.
San Francisco, CA.
16. Bill Glass - Big Chief Drilling Co.
Oklahoma City, OK.
17. George Kemnitz - Laughlin Drilling Co.
Farmington, N.M.
18. Thomas Hinrichs - Imperial Magma Co.
Escondido, CA.
(714) 743-7008
19. John Erikson - Kobe Pump Co.
Los Angeles, CA.
20. Al Cooper - Chevron Resources, Inc.
San Francisco, CA.
21. Vasel Roberts - EPRI
San Jose, CA.
22. Gil Lombard - SDG & E
Niland, CA.
(714) 232-4252
23. Ray Collins - Imperial Magma Co.
East Mesa, CA.
(714) 356-4635

Fig. 1

A single stage centrifugal boost pump in brine reinjection service. This pump feeds from a clarifier unit and charges the inlet of a high pressure centrifugal pump - Imperial Magma #3 at Niland, California

Fig. 2

Close-up of above brine reinjection boost pump

Fig. 3
A multistage centrifugal pump in brine reinjection
service - Imperial Magma #3 at Niland, California

Fig. 4
Close-up of above reinjection pump

Fig. 5
A Peerless 9
stage vertical
turbine pump on
brine reinjection
service at the
SDG & E Experimental
Loop Facility at
Niland, California

Fig. 6
A Johnston ver-
tical turbine boost
pump charging a
United multistage
centrifugal iso-
butane feed pump
at the SDG & E
Experimental Loop
Facility at Niland,
California

Fig. 7

A 21 stage Floway vertical turbine pump in brine reinjection service with Imperial Magma at East Mesa, California

Fig. 8

A 12 inch deep well
Peerless line shaft
multistage centrifugal
pump producing a brine
well with Imperial
Magma at East Mesa,
California

Fig. 9

The bearing water
lube system for the
line shaft pump pictured
above

6.5 SYSTEM SCHEMATICS

7.0 BIBLIOGRAPHY

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