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REQUIREMENTS FOR DOWNHOLE EQUIPMENT USED
FOR GEOTHERMAL-WELL STIMULATION

GEOTHERMAL-RESERVOIR WELL-
STIMULATION PROGRAM

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I. INTRODUCTION

Geothermal wells, because of the high temperatures and special stimulation requirements, often dictate the need for special downhole equipment which cannot be directly adapted from the oil and gas industry. The intent of this report is to identify the needs for new and improved downhole stimulation equipment for geothermal wells.

For the purpose of this report, downhole equipment can be divided into two categories: (a) downhole logging and survey instruments, and (b) wellbore packoff devices for isolating zones for treatment or testing. Downhole logging and survey instruments fall into three categories, i.e., openhole logging tools, cased-hole logging tools, and Amerada-type survey tools. Openhole logging tools are run primarily for petrophysical evaluation and usually require multiconductor cable. Most standard tools are rated for 350°F (177°C), but some more commonly used logging tools are available for temperatures to 500°F (260°C). Some major logging companies are applying available technology to upgrade more of their logging tools to 400-500°F (204-260°C), but the development is slow because the demand of the geothermal industry at this time does not warrant a high level of effort on their part. High-temperature cased-hole logging tools, including basic production logging tools rated for up to 600°F (315°C), are available from some logging service companies, but more development is needed to improve reliability and to expand the variety of high-temperature tools available. Amerada-type downhole recording instruments are the mainstay of basic pressure and temperature measurements in geothermal wells. These tools are reasonably reliable at temperatures up to 600°F (315°C) and can be operated at a reasonable cost. They do not however, provide the variety of data needed for complete well evaluation.

Wellbore packoff devices commonly used in the oil and gas industry are rated for temperatures of 300-375°F (149-190°C). Improved high-temperature versions of these packers and bridge plugs are becoming increasingly available. These devices are similar to their oil and gas well counterparts but incorporate some design changes and make use of new, high-temperature EPDM elastomer and thermo-plastic elements.

Packoff devices are available in a variety of types to suit the stimulation method, the type of well completion, and the geologic environment. The primary purpose of this downhole equipment is to isolate a particular zone or zones for testing or stimulation. Zone isolation can be very difficult to achieve depending on the formation properties and type of well completion.

Three basic types of completions are used for geothermal wells: (a) openhole; (b) slotted liner* (or casing); and (c) cemented, jet-perforated liner (or casing).¹ These are illustrated schematically

*The term "liner" refers to a pipe which has its top end hung below the surface inside the previous liner or casing string. "Casing" is a pipe which extends to the surface.

in Figure 1. A cemented, jet-perforated completion lends itself well to zone isolation. Zone isolation is feasible with an openhole completion but can be difficult to achieve. A ragged borehole or localized fracture pattern may permit communication around conventional packing elements. In a slotted liner completion isolation of zones is not feasible because of the difficulty of obtaining a seal in the annular space between the slotted liner and the formation face. Packing off inside a cemented liner or casing is the most common and reliable means of zone isolation. Conventional oil and gas well packers and bridge plugs are suitable for lower temperature geothermal wells. A few high-temperature models have been developed for use in hotter wells.

Several well logging companies and equipment manufacturers apply continuing effort to high-temperature tool development. In general, their level of effort is limited to that which can be justified by the foreseeable volume of business in high-temperature wells. DOE-sponsored programs in elastomer development, logging tool components, stimulation, hot dry rock, etc., have accelerated commercial development by making components available and expanding the market for high-temperature equipment.

II. DOWNHOLE EQUIPMENT FOR PRE- AND POST-STIMULATION ANALYSES

A. Mechanical Downhole Recording Instruments

Downhole pressure and temperature data in geothermal wells are most often acquired using mechanical downhole recording instruments. This eliminates the need for the sophisticated downhole electronics necessary to transmit data to the surface. These Amerada-type instruments are lowered into the well on a single strand steel wireline called measuring line or "slick line". These are analog devices and the pressure or temperature is recorded mechanically with a stylus on a time-drive chart which is driven by a spring-wound clock. High-temperature versions of these temperature and pressure tools perform satisfactorily at temperatures up to about 600°F² (315°C) and are commercially available from Kuster Company of Long Beach and Geophysical Research Corporation of Tulsa. Experience has shown that reasonably accurate data can be obtained from these instruments if they are run and maintained properly and calibrated frequently. However, these instruments have some important limitations:

1. There is no surface readout. It is not possible to detect a downhole malfunction in the equipment until it is brought back to the surface.
2. The instruments do not supply a continuous survey. A 10-20 minute stop is required at each survey point in order for the pressure or temperature element to reach equilibrium and provide an indentifiable mark on the chart.

3. Downhole logging time with these tools is limited by their spring-wound chart drive (a clock) to about 48 hours. Longer duration clocks are available, but their reliability in high-temperature wells is poor.
4. The published accuracy is $\pm 0.2\%$ of full scale which is less than that attainable with electronic devices, but adequate for most well evaluation work.

Some mechanical modifications can be made to Amerada-type instruments which increase their reliability at high-temperature. These modification techniques were developed by Sandia Laboratories.³

B. Electric Line Logging Tools

1. Openhole Logging Tools

Geothermal reservoirs are analyzed in part by geologists and reservoir engineers using petrophysical information obtained from openhole logs. Petrophysical logs fall into the categories of spontaneous potential, gamma ray, resistivity, caliper, neutron porosity, density, sonic, and special devices such as the 4-arm dipmeter and acoustic borehole televiewer. Failures in logging runs in geothermal wells are caused primarily by exceeding the temperature limitations of the cable or electrical components of the logging tools. Most standard tools are rated for 300-350°F (149-177°C). These tools, are, of necessity, used in all but the hottest of wells. However, extensive cooling by circulation is required before the logging starts, logging time is short, and tool failures are common. Even within the nominal temperature ratings of the tools, reliability is markedly reduced near the upper limits. Temperature ratings of a representative group of openhole logging tools are listed in Table 1.

Most, but not all, openhole logging tools are available from certain service companies in high-temperature versions rated for 400-500°F (204-260°C). However, there is a need for: (a) a wider variety of high-temperature tools; (b) tools capable of withstanding higher temperatures (>500°F); and (c) tools capable of withstanding high temperatures for extended periods of time. The near-term temperature rating goal of the Department of Energy/Division of Geothermal Energy (DOE/DGE) Geothermal Logging Instrumentation Development Program is 527°F (275°C).⁴ The DOE/DGE has sponsored research to improve the temperature ratings and time-in-the-hole capabilities of these primary logging tools. Under this program Sandia Laboratories and its subcontractors have developed electronic logging tool components rated at or above 527°F and at least two commercial logging companies are in the process of developing tools using the new components. Multiconductor logging cable rated for 600°F (315°C) is available commercially, but none is in use by logging service companies, primarily because of the high cost of the cable and the limited need for it.

One recent development is the "hot-hole" acoustic televiewer log. This sonar device provides a surface "picture" of the borehole showing fracture patterns and other hole irregularities. This tool was patented by Mobil Oil Corporation and was originally built by Simplec Manufacturing, Inc. of Dallas, for low temperature applications. In cooperation with Simplec, the USGS developed a high-temperature version of the televiewer which has operated successfully in a 502°F (261°C) wellbore.⁵ More recently, in cooperation with Simplec, a new version of the tool has been constructed at Sandia Laboratories which is rated for 527°F (275°C).⁶ It is not yet commercially available, but has been licensed to at least one service company.

Primarily because of budget constraints, the responsibility for further development of hot-hole petrophysical logging tools lies with the service companies. High-temperature electronic and mechanical components have been made available, but logging tool development is a long and costly program and service companies must give it a priority commensurate with the foreseeable volume of business from the geothermal industry.

2. Cased-Hole Logging Tools

Data for the determination of flow distribution patterns in multizone geothermal production intervals (or injection intervals) can be obtained by downhole flow meters (spinner tools) and continuous temperature measurements. These tools traverse the borehole while the well is producing. The changes in temperature, and the spinner tool response to fluid-flow velocity, indicate not only the producing intervals but also the magnitude of flow rate from each.

There are at least three other production logging tools which augment and aid interpretation of the basic temperature and spinner logs. The caliper log is important for proper interpretation of the spinner log because the local borehole diameter measurement is needed to calculate flow rate from the spinner log fluid velocity measurement. A magnetic casing collar locator, when run in conjunction with production logging tools, is useful in establishing an accurate depth reference for the logs with respect to the casing and formation. The third tool is a combination gamma-ray detector and multiple-shot R/A tracer injector. This tool augments the spinner in that it reliably indicates the direction of flow in any section of the wellbore and can measure fluid velocities below the threshold of sensitivity of the spinner. Low-temperature versions of this tool are available from some logging companies. A high-temperature, single-shot version has been built by LANL⁷ using technology that could be applied to a multiple-shot injector. The same tool can be used to detect flow behind the casing in an injection well.

The main impetus for commercial production logging tool development has been the high level of oil company activity in thermal recovery of high viscosity oil. Table 2 lists the current temperature ratings of a representative group of cased-hole logging tools available to the industry. High-temperature spinner, temperature, gamma ray, caliper, and collar locator tools are available from some logging companies for temperatures up to 550°F (288°C). Poor reliability is still a problem with these production logging tools at temperatures near their service rating. Spinner and caliper tools are especially troublesome. They sometimes fail to operate, or the data is erroneous, and expensive backup runs are needed to corroborate the data. The high-temperature environment is the primary problem, affecting both the electronics and static and dynamic seals.

Commercially available high-temperature tools are not designed to withstand long periods of exposure at high-temperatures. The high-temperature capability of these Dewar flask tools is owed to the "thermos bottle" effect by which the electrical components are insulated to protect them from the high temperature, albeit for a limited time. The high-temperature single-conductor logging cable currently in use by the logging service companies has an intermittent rating of 550°F (288°C) and a continuous duty rating of 500°F (260°C). As with the logging tools themselves, temperatures near the rating of the cable and extended time in the hole both work to reduce the reliability of the cable. A 600°F (315°C) (intermittent service rating) single-conductor cable is available commercially, but is not in use by any logging companies, primarily because of its high cost.

Industry and DOE/DGE-sponsored programs at Sandia Laboratories, Los Alamos National Laboratory (LANL), et al, have improved some existing tools and developed new components and some complete tools capable of functioning in severe geothermal environments.^{2, 3, 8} Current developments include: (a) hot-hole electronics (527°F capability) which can be incorporated in production logging tools to provide the ability to function in the high-temperature environment for extended periods of time; (b) high-temperature cable heads, seals, and other mechanical components; and (c) high-temperature pressure transducers to be utilized in development of a high-temperature surface recording downhole pressure logging tool (as yet unavailable in the industry). Budget cuts have forced a curtailment of these development programs, but some work is continuing at a low funding level to bring these developments to the point of commercial application.⁶ Several other cased-hole logging tools exist which are useful in stimulation-related work. The acoustic cement bond log, multifinger casing caliper, and electronic casing inspection log are useful for evaluating the condition of cement and casing, both important factors in selecting an interval for stimulation.

The borehole noise survey augments other production logs by detecting the sounds of fluid flow into the wellbore, behind casing, etc. Commercial development of hot-hole versions of these tools has been slow because of limited demand by the geothermal industry. However, a 500°F (260°C) cement bond log is available and a 400°F (204°C) electronic casing inspection tool and multifinger electro-mechanical casing caliper are newly available (Table 2).

III. DOWNHOLE TOOLS USED FOR ZONE ISOLATION

A. General

Virtually all methods of packing off in casing or openhole require elastomers or other flexible sealing elements. The temperature limits of conventional elastomers restrict their capability for most geothermal applications. However, since in many cases there is no readily available substitute for conventional elastomeric packoff equipment, operational techniques are used to cool the wellbore so that the equipment will work. This is time consuming and adversely affects the downhole mechanical equipment lifetime. This temperature cycling of the wellbore can be detrimental to the steel casing and especially damaging to the cement sheath. Also, if the well cannot be kept cool, the elastomer packoff can fail. If this occurs during a large stimulation job, several hundred thousands of dollars can be wasted.

DOE-sponsored work by L'Garde, Inc. has established that most retrievable elastomeric packoff tools commonly available to the oil and gas industry have an operating temperature limit of about 350°F (177°C).⁹ L'Garde has developed an EPDM elastomer suitable for casing packers which is applicable at temperatures in excess of 575°F (302°C). Only Otis Engineering, Inc. at this time, is known to offer commercially a casing packer with the Y-267 EPDM elastomer elements developed by L'Garde. This packer has performed well in two stimulation experiments to date with no special procedures for cooling the wells.

Dresser Industries has developed a packer using a thermo-plastic packing element. Laboratory results indicate that this material will withstand geothermal well temperatures up to 750°F. Otis and Baker Packers Division of Baker International Corp. also offer thermo-plastic elements on their steam packers intended primarily for use in steam enhanced oil recovery projects. These companies claim a temperature rating equal to Dresser's. Within their temperature limitations, however, elastomers are superior to thermo-plastics for use in service tools and inflatable packers. Elastomers provide the capability for releasing and resetting the tools without round tripping for redressing as is the case with thermo-plastic equipped tools. The service tools referred to are packers, bridge plugs, hydraulic jars, etc., which are normally used in stimulation, cementing, drilling, and workovers.

In openhole completions, even an ideal elastomer or thermo-plastic element cannot be relied upon totally for an adequate seal. In the openhole, ragged or enlarged borehole walls often exist which are not suitable for a packer to seat on properly. Also, natural fractures in the formation or failure of the borehole wall allow leakage around the packer or allow it to slip. In lieu of these packoffs, cement or sand plugs can be used to exclude lower sections of the wellbore. To block off upper zones, a liner can be run and cemented above the zone to be stimulated allowing the use of a casing packer or a stab-in seal device to pack off inside the liner.

High-temperature inflatable packers are available from Lynes, Inc. which offer the possibility of packing off above a selected zone in openhole. As described above, however, effective isolation is often not achieved because of borehole irregularities or natural fractures in the reservoir rock (Figure 2). Available inflatable packer elements are on the order of 5 feet long. An exceptionally long inflatable element, perhaps on the order of 100 feet long, may provide the isolation needed for hydraulic fracturing. However, even short inflatable packers can be troublesome to recover from openhole, and such a long element would pose an unacceptable risk unless some novel recovery features were incorporated in the design. Significant incentive exists to develop methods to pack off in openhole since the alternative, a cemented liner, costs on the order of \$200,000.

B. Packers and Bridge Plugs

There are several types of packers and bridge plugs with potential applications in stimulation. These can be classified as:

1. Openhole - Inflatable
2. Openhole - Compression
3. Cased-hole - Permanent
4. Cased-hole - Retreivable

The Hot Dry Rock Program has been actively trying to develop an adequate openhole packer. However, only few successes have been realized in the numerous attempts of fracturing formations by isolation with openhole packers. Lynes, Inc. has an inflatable packer ready for field testing at the Hot Dry Rock Project which has a high-temperature (550°F) EPDM elastomer element. Another openhole packer developed for the Hot Dry Rock Project is a hydraulically-set compression-type by Dresser-Guiberson having a thermo-plastic element with a wire-reinforced asbestos covering. This packer has not yet been field tested.

Cased-hole permanent packers (also called drillable packers) are common in oil and gas wells and find some use in low-to-moderate temper-

ature geothermal wells. The packer can be run and set with either electric logging cable, tubing, or drillpipe. After being set, a workstring with a seal assembly can be run into the hole and "stabbed" into the seal bore of the packer (Figure 3).

For moderate (less than 375°F) temperature geothermal wells, the wireline-set packoffs are generally applicable. However, at higher temperatures, the elastomer seals often fail. In addition, the explosives used to set the packer often fail to effect a high order detonation and the packer does not set properly. Often the well must be cooled prior to effectively setting this type of packer. The permanent packers run on a workstring are identical to those run on logging cable except that the setting mechanism is different. That is, a mechanical setting device is used instead of an explosive. A design feature of drillable permanent packers which is especially advantageous for geothermal wells is the use of expandable metal backup rings above and below the packing element, which expand to contact the casing wall upon setting. These backups significantly reduce element extrusion, a common cause of failure at high temperatures and high differential pressures.

The retrievable-type, cased-hole packer is widely used with all types of stimulation and workover methods. Conventional retrievable packers frequently fail to maintain a seal in high-temperature wells and are often difficult to retrieve because the rubber elements bond to the well casing. A few packers are now available with high-temperature elements and special design features which overcome these problems. Extrusion and ultimate failure of elements due to temperature and high differential pressure can be controlled with the use of expandable metal backup rings such as those used on permanent packers. Their use on retrievable packers is being developed by Halliburton Services, Otis, and perhaps other service companies. The Otis packer referred to above is equipped with such backups.

C. Other Techniques for Zone Isolation

There are other zone isolation methods besides packers. The most common types are; (a) the sand (or cement) plug, and (b) a cemented liner with a polished bore receptacle at the top (Figure 4). The polished bore receptacle, primarily used in oil and gas wells, is also applicable to geothermal well work. The seal should be competent in high-temperature applications because close tolerances can be maintained between the two sealing surfaces, greatly reducing extrusion problems.

The major disadvantage of using a cemented liner for zone isolation is that all of the upper zones which are blocked off by the liner are eliminated from the completion interval.

IV. REQUIREMENTS FOR A NEW ZONE ISOLATION SYSTEM

An economical packoff method applicable to openhole and slotted liner geothermal well completions would enhance the feasibility of stimulation in many geothermal wells and would be applicable to hot dry rock. The ideal packoff method should:

1. Seal within a rugose geothermal openhole wellbore
2. Withstand high temperatures
3. Be impervious to the geothermal brine
4. Be usable in a slotted liner completion
5. Prevent bypass through the formation around the packer by using a sealing material injected into the formation and/or by packing off over a sufficiently long interval.

The capability of zone isolation in a slotted liner/openhole annulus would be of great benefit to the geothermal industry but will be very difficult to accomplish. No such packoff techniques presently exist. The difficulty arises because of the inaccessibility of the annular area between the slotted steel casing and the formation face. Attempts to use cement plugs alone have generally not succeeded in isolating particular zones in geothermal wells.

For zone isolation in the openhole, a suitable packoff system must be able to seal not only along the wellbore face but must also seal any fractures in the area near the wellbore (Figure 5).

For a packoff method applicable to both slotted liner and openhole completions, a viscous sealing material which can; (a) fill in the annular area between slotted liner and openhole, and (b) penetrate the fractures in the vicinity of the wellbore is required. This being the case, the high bottomhole temperatures can be used to advantage. Setting time for the sealing material would be accelerated by the high-temperature environment, thus reducing waiting time for the rig and support equipment. The packoff system described above is depicted schematically in Figure 5.

V. RECOMMENDATIONS

Continued improvements in downhole equipment will enhance the technical and economic feasibility of geothermal well stimulation. The required equipment includes both logging equipment and the downhole hardware needed to perform the stimulation job on a well. It is recommended that the DOE/DGE support the following activities:

1. Continued R&D activities on openhole and cased-hole logging tools,
2. Commercialization of recent developments in logging instrumentation such as a high-temperature (527°F) electronics and high-temperature/high-resolution pressure transducers,
3. A new program to develop zone isolation systems that are applicable to both openhole and slotted liner completions.

VI. REFERENCES

1. Nicholson, Robert W., Raft River: Mechanical Design and Operations, Proceedings of the Geothermal Reservoir Well Stimulation Symposium, San Francisco, CA, February 7, 1980, p. 155.
2. Mathews, Mark, et al, "High-temperature Logging for Basic Development of HDR Reservoirs," Geothermal Resources Council, Transactions, Vol. 5, October 1981, p. 299.
3. Veneruso, A. F. and Stoller, H. M., "High-temperature Instrumentation Development and Commercialization for Geothermal Applications," Geothermal Resources Council, Transactions, Vol. 3, Sept. 1979, p. 745.
4. Veneruso, A. F. (editor) Minutes Geothermal Logging Instrumentation Development Program Steering Committee Meeting, January 15-16, 1981.
5. Keys, W. Scott, The Application of the Acoustic Televiewer to the Characterization of Hydraulic Fractures in Geothermal Wells, Proceedings of the Geothermal Reservoir Well Stimulation Symposium, San Francisco, CA, February 7, 1980, p. 176.
6. Kelsey, James R., Sandia Laboratories, May 1982, personal communication.
7. Hot Dry Rock Geothermal Energy Development Program, Annual Report for F.Y. 1979, LA-8280-HDR, p. 165.

8. Haney, J., et al, A Review of LBL Geothermal Well Testing Equipment, Geothermal Resources Council, Transactions, vol. 3, Sept. 1979, p. 287.
9. Hirasuna, A. R., and Stephens, C. A., Geothermal Packers and Packer Elastomers, Geothermal Resources Council, Transactions, vol. 5, October 1981, p. 243.

FIGURE 1

TYPES OF GEOTHERMAL WELL COMPLETIONS

RGI E1215

FIGURE 2

CONCEPT OF OPENHOLE INFLATABLE PACKER

FIGURE 3

PERMANENT DRILLABLE CASING PACKER

FIGURE 4

ZONE ISOLATION WITH LINER AND SAND PLUG

FIGURE 5

GEO THERMAL OPENHOLE PACKOFF

The idea for this packoff system was originally proposed by
Dr. R. W. Nicholson in a technical report dated October 1, 1979.

TABLE 1

TEMPERATURE LIMITATIONS OF SOME COMMERCIAL OPENHOLE LOGGING TOOLS

	<u>Dresser-Atlas</u>	<u>Gearhart</u>	<u>Schlumberger</u>
Resistivity	400	350	500
Gamma Ray	400	400	500
Sonic	400	350	500
Density	400	400	400
Neutron	400	350	350-400
Caliper (4-arm)	400	350	500
Dipmeter	350	350	400
Cable (Multiconductor)	450	400	450

TABLE 2

TEMPERATURE LIMITATIONS OF SOME COMMERCIAL CASED-HOLE LOGGING TOOLS

	<u>Dresser-Atlas</u>	<u>Gearhart</u>	<u>Geophysical Research Corp.</u>	<u>Kuster Co.</u>	<u>N. I. McCullough Triangle</u>	<u>Otis Engineering</u>	<u>Schlumberger</u>	<u>United Wireline</u>
Temperature	550	600	600 ⁴	600 ⁴	550	-	500,600 ²	550
Pressure	-	-	600 ⁴	600 ⁴	-	-	350	-
Flow (spinner)	550	600	-	350 ⁴	300	-	500 ²	550
Magnetic Casing Collar Locator	550	500	-	-	550	-	500	350
Gamma Ray	550	400	-	-	550 ¹	-	500	-
R/A Tracer Injector (Multi-shot)	-	350	-	-	250	-	350	-
Electro-Mechanical Caliper (2, 3, 4-arm)	550 (3-arm)	-	-	-	- ²	-	500 (4-arm)	-
Electro-Mechanical Caliper (Multi-arm for casing inspection)	-	325	-	-	400	-	-	-
Mechanical Caliper (self-contained, downhole recording)	-	-	-	-	-	600 ⁴	-	-
Borehole Sound Survey	-	350	-	-	-	-	350	-
Cement Bond Log	350	350	-	-	350	-	500	-
Casing Inspection & Electronic Caliper	-	-	-	-	400	-	-	-
Cable (single- conductor)	550 ³	550 ³	-	-	550 ³	-	550 ³	550 ³

1 Noncalibrated type for logging R/A tracers.

2 Under development. Expected to be available in the near future.

3 Intermittent rating; continuous duty rating is 500°F.

4 Tools have self-contained recorders and are run on nonelectric wireline or cable.