GEOTHERMAL WELL LOGGING: AN ASSESSMENT OF THE STATE OF THE ART

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ABSTRACT

Geothermal energy is seen as one important component of the nation's effort to achieve energy self-sufficiency. However, wells that are drilled to tap geothermal energy differ in many important respects from the much more numerous oil and gas wells. Geothermal wells are usually hotter, and are often drilled in harder rocks.

Logging geothermal wells poses special problems both in the areas of data gathering and data interpretation. The problems associated with data gathering come about because of the unavailability of cables and tools which can withstand the heat and corrosion encountered in geothermal wells. The problems of data interpretation occur chiefly because geothermal wells are often drilled in unfamiliar formations, and there has not been much experience in logging in such formations, nor has there been much coring and sampling of such wells. Therefore necessary experience and log/core correlations do not exist to allow adequate geothermal well log interpretation.

With the present economic climate, private industry is not now developing the necessary tools and techniques for geothermal well-logging. It is concluded that the attainment of Project Independence goals for geothermal resource development will require government support for the development of geothermal well-logging technology and for the necessary data-gathering activities to facilitate log interpretation.

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INTRODUCTION

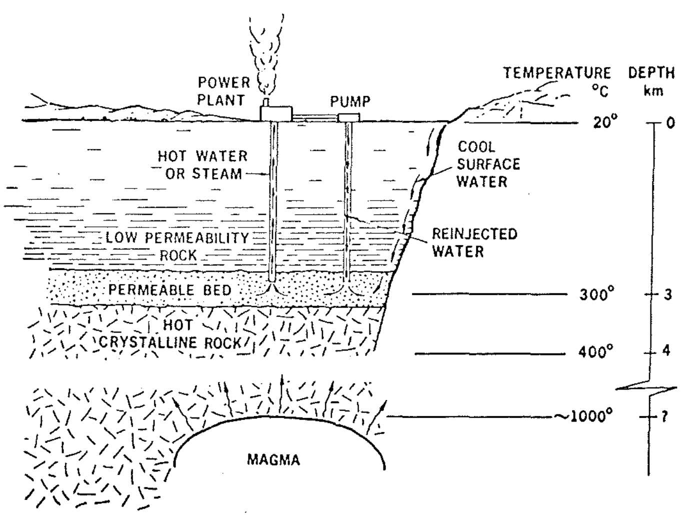
This paper presents part of a study[1] made at the request of Dr. Louis B. Werner and Morris Skalka of the Division of Geothermal Energy, of the United States Energy Research and Development Administration (ERDA). The study was prompted by the concern that with the current high level of activity in the petroleum industry, coupled with the present economic climate, the necessary activities for development of geothermal technology might not occur spontaneously. This paper deals with one small part of the broad area of geothermal technology: the problems associated with the logging of geothermal wells.

We would like to acknowledge the help of the more than eighty people we contacted, who represent more than thirty private and public organizations with various interests in the oil, gas, and geothermal fields.

GEOTHERMAL ENERGY

First, let us consider briefly some general aspects of geothermal energy. Geothermal energy refers to the heat which naturally exists in the earth's interior, and which is believed to result principally from radioactive decay of the elements uranium, potassium, and thorium.

The average or normal geothermal gradient, about 25°C to 30°C per kilometer of depth (70°F to 85°F per mile),* is not now commercially exploitable and probably will not be in the near future. However, regions exist with gradients two or more times this average, generally associated with tectonic-plate boundaries and volcanic activity, and possibly resulting from a near surface instrusion of magma. These higher than normal gradients may occur in conjunction with an aquifer system in which case dry steam (vapor dominated system) or hot water (liquid dominated system) is produced which can be commercially extracted. Lower temperature fluid systems (<150°C/300°F)* have been used for commercial, residential, or agricultural heating purposes (e.g., Klamath Falls, Oregon; Reykjavik, Iceland). Higher temperature fluids are used to supply steam for electrical generating stations. These may have base temperatures as high as 300°C (570°F) for relatively fresh water systems (e.g., Wairakei, New Zealand) and up to 385°C (725°F) for systems with high salinity (e.g., Cerro Prieto, Mexico). Vapor dominated systems (e.g., the Geysers, California; Larderello, Italy) are characterized by initial temperatures near 240°C (465°F). A typical reservoir showing extraction, re-injection, and ground water recharging is shown in Figure 1.



Typical Geothermal Well System
FIGURE 1

Although not presently being commercially exploited, other geothermal systems may provide energy in the future. In areas with above normal geothermal gradients but no aquifer system, it has been proposed (by Los Alamos Scientific Lab and others) to use the energy in the hot dry rock by pumping water down one well and extracting steam from a second well to which a path through the rock has been intentionally fractured. Temperature of the hot rock could run to several hundred degrees Celsius. Large, highly geopressured regions exist along the U.S. Gulf Coast which contain moderately hot (175°C/350°F) waters at high pressure with high dissolved methane content presenting attractive possibilities for energy extraction. In the more distant future are plans for energy extraction using a direct magma tap. In this case, temperatures over 1000°C (1830°F) may be encountered.

Geothermal energy is seen as one important component of the nation's effort to achieve energy self-sufficiency. The Project Independence Report[2] predicts the generation of from 7,000 to 15,000 megawatts of electricity from geothermal sources by 1985, on the basis of their accelerated development scenario. A recent Report from Jet Propulsion Laboratory[3] establishes a tentative goal for the utilization of geothermal energy of 30,000 to 30,000 megawatts electrical by 1985, a utilization level that will save one million barrels of oil per day. Generation of electricity at this rate will require drilling an average of about 1000 wells per year over the next 10 years.

It is notable that the product sought from geothermal wells is heat itself rather than a product which can be burned to produce heat. The geothermal heat, whether in the form of steam or hot water, cannot be practically transported long distances.

Of course, geothermal heat can be used to generate electricity, which is easily transportable. Although transforming the heat energy into electrical energy does solve the transportation problem, there arises the new problem of insuring that adequate geothermal energy will be available at a site before large capital investments are made in a conversion plant, which must be near the energy source. The investors must be reasonably sure that there will be available at a site before large capital investments are made in a conversion plant, which must be near the energy available at a fixed site for a sufficient time to justify the large investment required. The necessity for a large capital investment at the site of the energy source makes reservoir engineering for geothermal fields extremely important. It is clear that the development of geothermal reservoir engineering, which requires downhole well-logging as a source of information, is of paramount importance among the activities necessary for the efficient utilization of the geothermal energy resource.

Geothermal wells differ from oil or gas wells in many important respects. Geothermal wells are usually hotter, and often they are drilled in harder rocks. Most oil wells are drilled in sedimentary formations, whereas many geothermal wells are drilled in igneous or metamorphic formations. These harder rocks often are fractured, and many of the formations are under-pressured. This combination of high temperatures and

*Temperature conversions are rounded to the nearest five degrees.

hard, fractured, and unfamiliar rock types causes a great number of problems in the drilling, logging, and completion of geothermal wells. Typical problems are crooked holes, the loss of drilling fluid in fractured or underpressured formations, and failure of drilling fluids and drilling and logging tools because of the elevated temperatures. Additionally, there are often problems of corrosion caused by naturally occurring gases such as hydrogen sulfide, as well as saline formation fluids.

As a resource geothermal energy has been slow to be exploited. There are only a few areas in the United States where geothermal energy is used at all, and only one (the Geysers in California) where significant electrical power is generated. However, at the Geysers several hundred megawatts are now being produced, with more in the planning stage. Commercial interest in geothermal energy is increasing rapidly. In recognition of this, the United States government has designated certain Known Geothermal Resource Areas (KGRA's). Within these KGRA's leases must be obtained on the basis of competitive bids.

The recent upsurge in geothermal activity and interest are indicated by recent leasing and wildcatting activities. In January 1974 there were 2,456 applications for non-competitive Federal geothermal leases filed in 11 western states; in 1974 competitive KGRA sales were conducted which totaled more than $4,400,000 and included bids from $10.16 to $3,287.00 per acre; geothermal wildcats (outside of the Geysers KGRA) numbered 16 in 1972, 22 in 1973, and 31 in the first half of 1974.[4]

GEOTHERMAL WELL-LOGGING AND ASSOCIATED PROBLEMS

Well-logging has developed over the past decades into a mature technology, principally in support of, and supported by, the oil industry. The existence of large economic incentives and keen competition has led to the establishment of strong programs in research and development. These have resulted in an industry that makes intensive use of advanced technology to further the state of the art in well-logging for the oil industry.

Unfortunately, there have been almost no economic incentives for the development of well-logging in support of geothermal development. The number of geothermal wells drilled (and logged) to date has been insignificant compared to the more than 25,000 wells drilled for oil and gas per year in the United States. As a result, in those areas where geothermal well-logging and oil well-logging requirements differ, the state of the art in geothermal well-logging is relatively primitive.

The problems of obtaining needed information on geothermal wells by logging may be grouped into two broad areas: data gathering and data interpretation. It is obvious that these two are somewhat interrelated. Without data there can be no interpretation, but the interpretation and analysis methods used have a bearing on the measurements required. Each of these areas presents unique problems that are discussed below.

Data Gathering

The single major obstacle to data gathering appears to be lack of sufficient high temperature capability. Equipment and techniques for working at temperatures up to 175°C (350°F) are highly developed and such operations may be described as routine when logging in familiar formations. When well temperatures exceed this limit, a number of problems are encountered. Many of the tools are not made in high temperature versions and so the variety of measurements that may be taken is limited. Logging hot wells requires special high temperature 260°C (500°F) rated cable that is more costly and not widely available. Those high temperature "hostile environment" tools that are available exist only in small quantities and may be difficult to obtain on short notice. The field engineers and technicians in general have had little experience with the high temperature equipment and procedures and so are more prone to make errors. The equipment itself is seldom, if ever, tested at its absolute temperature limit, because life at the high temperature extreme is severely limited. Hence, frequent breakdowns may be expected. As a result of equipment time/temperature limitations, logging may need to be rushed, leading to additional problems.

The preceding problems are encountered when logging holes up to 260°C. Presently no logging equipment (with the exception of a very few special purpose tools) exists which has a claimed capability for use at temperatures greater than 260°C. The method now in use for really hot holes involves cooling the hole by circulation of cooled fluid for a period of time before logging. This requires additional costly rig time and entails risks to the borehole, as well as masking important temperature relationships within the borehole. Even with cooling, logging often involves sacrifice of some equipment, and often the results are disappointing.

Many concerned with geothermal logging have expressed the opinion that the cable limitations now present the most serious obstacle to high temperature logging. Little incentive to develop high temperature tools exists, if cables are not available on which to run them. Well temperatures slightly over 370°C (700°F) have been measured (with maximum reading mercury thermometers), which implies an eventual goal of 400°C (750°F) for equipment (perhaps higher to support hot dry rock and magma projects). For the near future, a temperature capability of about 345°C (650°F) would be adequate for most geothermal requirements and appears to be within the present state of the art for cable technology.

The major service companies are presently working to extend the temperature limits of logging tools to 260°C (500°F) to allow logging in those few hot holes encountered in oil and gas wells. There appears to be little, if any, intention to extend capability beyond this limit. Government incentives to industry will be required to assure near-term development of logging tools with capability beyond 260°C. Unfortunately, those companies best able to carry out such programs are hesitant to participate in government funded development, because of lack of protection of proprietary information.

Corrosion has always been a problem in the oil and gas industry, but in addition to the normal causes of corrosion, geothermal wells also present new conditions imposed by high temperature and hot geothermal brines. The geothermal development at Cerro Prieto in Mexico has experienced extreme difficulties because of the unexpected types of corrosion caused by geothermal brines.

Data Interpretation

The general problem of data interpretation includes all those factors which are involved with the use of logs, including specifying measurements to be made, deriving well parameters from the measurements, and applying the parameters to derive useful information for resource development and utilization.

Reservoir models figure in data interpretation in two ways: first, the specification of measurements to be made is determined by requirements of the various models, and second, the results of the measurements are used as specific inputs to the models. In the petroleum industry, exploitation is guided by such models, which allow optimization of production while minimizing environmental impact. Reservoir models are particularly important for geothermal exploitation because of the large on-site capital investment required. For the petroleum industry, reservoir modeling is highly developed and the parameters needed from field measurements are well defined. Geothermal reservoir models are not so well developed. While some of the same techniques will certainly apply, geothermal reservoir models may require the determination of different parameters. Hence, modeling of the different geothermal reservoir types is needed in order to define those parameters that must be obtained through well logging for efficient resource development.

A second problem associated with data interpretation has to do with the unfamiliar lithologies in which the wells often are drilled. These unfamiliar lithologies produce unfamiliar responses from the logging tools. This disadvantage shows up in at least two ways. First, because the responses of the tools are different from those the logging crew normally sees, there are often malfunctions in a tool that go undetected while the logging run is being made. Again, this is a problem of inexperience, because malfunctions that occur in the logging of oil or gas wells are often immediately detected when the logging crew recognizes a peculiar tool response. The second problem imposed by the unfamiliar lithologies is that interpretation of the logs after they are run is supported neither by the experience of those who are doing the interpretation nor by well-developed theoretical models of tool responses. Temperature can play a part here also in that the formation parameters themselves are sometimes a function of temperature, often affecting the interpretation model.

Because so little logging and coring has been done in geothermal wells, very little information is available to allow correlation of logs with subsurface characteristics. The development of effective log interpretation techniques will require that an extensive program of coring and logging be undertaken so that future geothermal well logs can be understood.

CONCLUSIONS

The following are major conclusions of this study:

1. Geothermal measurement requirements are not well defined due to lack of reservoir models and to log interpretation problems in unfamiliar formations.

2. Logging problems differ with geothermal well type.

3. Attempts to log geothermal wells to date often have met with marginal success.

4. Geothermal wells usually exhibit temperatures higher than normally encountered (~175°C/350°F) in oil and gas wells.

5. Maximum claimed temperature capability of well-logging equipment is presently about 260°C (500°F). Many geothermal wells are hotter than that.

6. Special corrosion problems may be encountered in geothermal wells resulting from high temperature and the varied natures of geothermal fluids.

7. Large-scale geothermal well-logging, such as is implied by Project Independence goals, should be done by private industry.

8. There is insufficient economic incentive at present for private industry to provide adequate geothermal logging capability.

9. Government support of geothermal well-logging technology will be required to meet the goals for geothermal resource development contained in the Project Independence report. This support can buy lead time for the process of eventual industrial development, as well as promote advances in near-term logging capability.

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