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GEOTHERMAL DRILLING PROBLEMS AND THEIR IMPACT ON COST

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Charles C. Carson
Sandia National Laboratories

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ABSTRACT

The Circum-Pacific region is the focus for much of the current geothermal energy activity. Geothermal resources are typically exploited using conventional petroleum or water well drilling techniques. However, the uniqueness of the geothermal resource often causes problems. This paper discusses the impact such problems have on the costs of accessing geothermal reservoirs.

Historical data are presented that demonstrate the significance of unexpected problems. In extreme cases, trouble costs are the largest component of well costs or severe troubles can lead to abandonment of a hole. Drilling experiences from U.S. geothermal areas are used to analyze the frequency and severity of various problems. In addition, average trouble costs are estimated based on this analysis and the relationship between trouble and depth is discussed.

The most frequent drilling and completion problem in geothermal wells is lost circulation. This is especially true for resources in underpressured, fractured formations. Serious loss of circulation can occur during drilling--because of this, the producing portions of many wells are drilled with air or aerated drilling fluid and the

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resulting corrosion/erosion problems are tolerated--but it can also affect the cementing of well casing. Problems in bonding the casing to the formation result from many other causes as well, and are common in geothermal wells. Good bonds are essential because of the possibility of casing collapse due to thermal cycling during the life of the well. Several other problems are identified and their impacts are quantified and discussed.

INTRODUCTION

Sandia National Laboratories manages the United States Department of Energy's Geothermal Technology Development Program. (1) This program is directed toward developing new technologies for drilling and completing geothermal wells and combatting the problems inherent in geothermal drilling. It has focused on technologies appropriate for accessing high temperature resources for production of electricity. The problems of high temperature wells are generally more severe than those found in the shallower, cooler wells drilled for the direct use of geothermal fluids.

Most high enthalpy hydrothermal resources are located at the edges of the tectonic plates or in regions of recent volcanism where abnormally large geothermal temperature gradients exist. (2) As a result, the Circum-Pacific region is the focus for much geothermal development. Approximately 81% of the 1981 geothermal electrical generating capacity was in the Circum-Pacific countries, and it is estimated that 85% of the 1985 capacity will be. (3) Producing countries include the U.S., Philippines, New Zealand, Mexico, Japan and El Salvador.

Drilling for geothermal resources generally utilizes current petroleum drilling technology and equipment, but several characteristics of geothermal resources cause problems with current technology--problems that significantly increase the time and money required. For example, geothermal drilling--at least successful geothermal drilling--is into very hot formations (>200°C). Drilling is most often through hard rocks rather than through the softer, sedimentary rocks of petroleum bearing formations. Geothermal drilling is frequently in regions with highly corrosive formation fluids and often is in areas that are underpressured--or sub-hydrostatically pressured--due to high temperatures and mountainous terrain. Each of these natural characteristics of geothermal resources causes difficulties for the adapted petroleum drilling technology.

COMMON GEOTHERMAL DRILLING PROBLEMS

Lost Circulation

The most frequent problem in geothermal drilling is loss of circulation of the drilling fluid due to the highly fractured formations found in many reservoirs. Fractures are common because 1) hard rock formations in seismicly active regions tend to be fractured; 2) higher-than-normal thermal gradients are often due to convective flow of groundwater through fracture systems; and 3) required flow rates in commercially attractive hydrothermal wells (10,000 to 30,000 barrels/day) dictate flow from fractures. Thus, good geothermal wells are often those that intersect major fracture systems; and the best well may be the one that encounters the most severe lost circulation problem.

In addition to being expensive to combat, lost circulation can lead to other problems. Drilling without returns can leave formation pressures unbalanced, which can allow the hole wall to fall in. This can cause stuck pipe, twist offs, or loss of the hole. Flow of the drilling fluid with cuttings into the formation can damage the formation permeability and reduce well productivity. Lost circulation that occurs during the cementing of the well can cause incomplete cement jobs that can, in turn, lead to premature casing failure.

Lost circulation is not unique to geothermal resources. It also occurs in oil and gas drilling, but there the losses are often due to matrix permeability rather than flow into fractures. The solution techniques for the two types of loss are generally quite different, and, in addition, the high temperatures of geothermal wells severely degrade conventional lost circulation materials. As a result, what is a minor problem for petroleum drilling is a major problem in geothermal. There have been geothermal wells with such severe lost circulation problems that drilling had to be abandoned. More often, lost circulation is an expensive headache that must be solved during both drilling and completion activities. (4,5)

A common solution has been to use low density drilling fluids. For example, in The Geysers field in California the production interval (roughly the bottom half of the well) is drilled using air as the drilling fluid. In the Baca field in New Mexico, mist drilling was commonly used to assure returns. Unfortunately, these "solutions" merely postpone lost circulation to the cementing phase of completion and introduce other problems. In air drilling the velocities required to lift cuttings are so high that erosion of drill pipe and casing becomes a problem. In both air and mist drilling, the introduction of oxygen to a hot, highly corrosive environment greatly speeds corrosion of the steel tubulars, and so extensive and expensive anti-corrosion steps must be taken. (6)

Cement Displacement

In addition to the problem of cementing casing through a lost circulation zone, another cementing problem often arises in geothermal drilling--getting complete displacement by cement of the drilling mud between the casing and the formation. This problem also occurs in oil and gas drilling. However, it is more frequent in geothermal areas because of the tendency of drilling fluids to degrade or gel at high temperatures and thus be more difficult to displace. In addition, this problem is more serious in geothermal wells since repeated starting and stopping of production can cause casing to fail due to thermal cycling in sections unsupported by cement. Similarly, thermal expansion of water trapped in an undisplaced pocket of mud can exert enough pressure to buckle the casing. (7)

Other Problems

The high temperatures encountered in geothermal drilling can degrade the performance of many parts of conventional drilling systems. Examples include logging tools, seals and lubricants, muds and other fluids, and downhole tools and bits. Extensive effort has recently gone into developing high-temperature-capable ging tools that can operate accurately in most geothermal environments. (8) Similarly, research has been carried out in developing and testing materials and designs for high temperature seals and lubricants, (9) and special high temperature muds have been formulated and fielded for use in geothermal wells. (10) Many tools have been developed specifically for high temperature applications; an example is the geothermal turbodrill developed for the U.S. Hot Dry Rock Program. (11) Often, high temperatures affect completed wells through shorter lifetimes, higher costs, and reduced capabilities.

Other severe problems stem from corrosion and corrosion-caused failures of tools and tubulars. Geothermal brines are typically quite corrosive, and even if aerated fluids are not used in drilling, corrosion rates for downhole equipment can be excessive. Corrosion increases well cost through the cost and time associated with use of corrosion inhibiting chemicals, as well as through the costs of damaged equipment.

DRILLING TROUBLE HISTORY

The study of geothermal drilling problems has focused on U.S. drilling areas and has relied on statistics from the U.S. drilling experience. Experiences from other countries have been considered as well, and a major reference for them is from an international conference held in Albuquerque, New Mexico, in January 1981. (12)

The International Experience

Mexico has one of the most active geothermal drilling programs in the world. Drilling experience at Cerro Prieto, the major geothermal area, is summarized in Reference 13. The frequently mentioned problems include lost circulation, casing failure (due to thermal stresses and embrittlement), temperature-caused mechanical and logging problems, and cave-ins. The general condition of slow advance is summarized by the observation that "the problems of drilling hotter zones greatly increase drilling times and costs." The problems of casing failure were addressed in a companion document (14) which pointed out that scaling, casing break and casing collapse were most common. The report said that of the causes for casing failure, "the most frequent is failure in the cementing operation."

The New Zealand experience is summarized in Reference 15, which discusses problems in lost circulation, cementing, hardware difficulties, and casing failures. Although this paper gives no cost impact statistics, it points out that "any improvement in techniques and materials which will effectively seal loss zones will result in very significant savings in rig, personnel and material costs." The European experience in geothermal drilling has been quite varied; but, in general, the problems have been identical to those of the U.S., Mexico, and New Zealand. (16,17,18,19)

General Impacts of Trouble

Trouble history in the U.S. was used in two analyses: a study of the general effect of trouble, and a study of the frequency and severity of specific problems.

Geothermal wells tend to cost considerably more than do similar wells drilled for oil and gas--2 to 4 times more on the average. (20) Based on total drilling time data, trouble was identified as one of the causes for this cost difference. Figure 1 presents total drilling time for 123 wells at The Geysers. Similar data have been compiled for wells at the Baca resource and for wells in the Imperial Valley, California, area. If trouble were not a major factor in drilling time, wells drilled to similar depths in any one region would require similar amounts of time to drill. The uncertainties of drilling and the variability of drilling rates would cause dispersion around the average or expected drilling time. However, actual data show very great dispersion that dominates the drilling time-depth relationship. This result is true for the other areas as well.

Another result common to all three areas was the lack of a "learning" effect. Neither the average drilling time nor the wide dispersion of times reduced with experience. Some of the most recent wells considered required the greatest amounts of time.

The analysis of drilling time data indicates that drilling problems cause at least a part of the wide dispersion and that encountering extreme, unplanned-for problems can occupy a significant portion of the time required to drill a geothermal well. (21)

Frequency and Severity of Problems

To study the frequency and severity of specific troubles, it was valuable to look at drilling histories for wells in different areas. The best source of trouble data was found to be the reports that summarize the daily activities in the drilling of wells. These reports, available through the governmental units responsible for many geothermal areas, are not well suited to analyses of problems. They do not include all problems--only those significant enough to be reported in a brief daily summary. They do not explain problems or solutions in detail, and they generally do not describe the times and costs necessary to solve the encountered problems. However, the reports are available and there are enough records for two areas, The Geysers and the Baca, to draw significant conclusions about problems.

The statistics obtained from the drilling records are reported elsewhere. (22) The general conclusions were that for both regions, lost circulation was by far the most common problem, occurring severely enough in roughly half the wells to be noted on the drilling record. Other frequently cited problems included stuck pipe, twist offs, and cementing problems. The frequency of references to cementing problems was surprising since most symptoms don't occur until long after the drilling phase. Roughly 90% of the wells encountered severe enough problems to be noted on the drilling record. An interesting feature of the drilling statistics is their consistency between the two different resource areas--one a proven commercial, dry steam resource, and the other a currently sub-commercial, hot water resource. In addition, the similarity between the U.S. history and the international experience is obvious.

THE IMPACT OF DRILLING TROUBLES ON COST

The costs of baseline, trouble-free wells have been studied extensively. (23,24) These were analyzed by considering the sequence of operations required to make a well and then determining times and costs for each operation. Some of the results are shown in Table 1, in which costs and times are listed by function for three U.S. areas.

A problem, such as lost circulation, increases well cost in two ways: its solution requires time, which increases cost, and it imposes a direct cost for materials or special tools. For example, each instance of lost circulation recorded in the drilling records for the Baca and The Geysers cost an average of 2-1/4 days. Furthermore, for each occurrence there were costs for lost circulation materials or cement, make-up mud, etc. From the baseline cost analysis it is possible to determine an average cost increase for each day of trouble delay. For the U.S. regions considered, a day of delay will increase total well cost by one to two percent, depending on the region. (Roughly $15,000 per day for a $1,000,000 well.)

The fifty Geysers wells for which drilling records were reviewed had an average total trouble delay of between 9-1/2 and 10 days. Thus, the total impact of the troubles cited in daily drilling records is an average increase in well cost of at least 15%. This result was common for the Baca region as well. Accounting for the troubles that are not noted on the records increases this estimate of the average trouble cost to roughly 25%. The source and cost of this additional trouble is greatly dependent on the region. For example, it has been shown that for the Baca, the costs of combatting drill pipe corrosion alone can be as high as 10% of the baseline well cost. (25)

POST-DRILLING PROBLEMS

Troubles that commonly arise during well completion or production can also greatly increase the costs of accessing the geothermal resource. These problems can best be analyzed by considering, not the initial cost of a well, but its effective cost--the total cost of the well divided by its total production. An analytical model for computing effective well cost has been developed (26,27,28) and used to study the impacts of common problems, including insufficient well flow, rapid scale buildup, significant flow declines, and premature casing collapse.

The problem of not achieving sufficient flow is common in geothermal drilling, and its impact is obvious. If one well in four in a field does not produce sufficient flow for production, well costs are effectively increased by 33%. This hypothetical case is similar to the situation in the Baca field. Many wells there produced insufficient flow, even after stimulation attempts and even though neighboring wells were good producers.

The impact of rapid scale buildup is more difficult to quantify. Scaling of wells is a major problem in many Imperial Valley areas, as well as in other areas of the world. Analysis has shown that if descaling is a fairly cheap ($25,000 to $30,000) but effective process that is required once per year, reduced flow and scale removal increase the effective well cost by about 30%.

If flow into a well declines over the life of the well, the effective well cost increases. For example, well cost is increased by 25% if productivity declines at a rate such that, if left unchecked, the well flow would decrease to 50% of its initial value in 20 years.

Finally, if casing collapses irreparably early in the life of a well, perhaps due to an incomplete cement job, the effective cost of the well is increased. This is especially true if the failure occurs during the first ten years. For example, a failure after five years increases effective well cost by approximately 40%.

SUMMARY

Geothermal resources generally occur in areas that present problems to conventional drilling technology. These problems are much the same for geothermal areas throughout the Circum-Pacific region and the world. The most frequent drilling problems are those caused by loss of circulation of the drilling fluids. The second most common problem seems to be achieving complete cement bonding of casing to the formation. These and the other major problems increase well cost by an average of roughly 25%.

Accessing the geothermal resource also introduces common drilling-related production problems. Their incidence seems to be much more reservoir dependent than that of the drilling problems, but their potential cost impacts are as great or greater and must not be overlooked.

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Table 1. Costs of Trouble-Free Wells

Activity	Cost ($1000) Geysers	Baca	Brawley
Site Prep/Rig Up	93	98	62
Drilling/Reaming	317	255	109
Tripping	100	64	13
Casing	210	236	184
Cementing	110	108	62
Completion	70	81	58
Other	253	233	131
Total	1153	1075	619

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