Abstract

A project to estimate well costs in regions of current geothermal activity has been initiated. Costs associated with commonly encountered drilling problems will be included. Activity-based costing techniques will be employed to allow the identification of cost drivers and the evaluation of the economic effects of new technologies and operational procedures on well costs. The sensitivity of well costs to a number of parameters such as rate-of-penetration and daily operating costs will be examined. Additional sensitivity analyses and trade-off studies will evaluate the efficiency of various operational practices and preventive, as well as remedial, actions. These efforts should help provide an understanding of the consumption of resources in geothermal drilling.

Introduction

Carson, Lin, and Livesay published a detailed study of the cost of drilling non-optimal, trouble-free geothermal wells in 1983\(^1\). They began this effort by defining areas of interest and reported costs for eight wells considered representative of the Salton Sea, Heber, West Mesa, Brawley, and Westmorland fields in the Imperial Valley, Roosevelt Hot Springs in Utah, The Geysers in Northern California, and Baca Ranch in Valles Caldera, New Mexico.

They gathered cost information from operators, vendors, drilling contractors, and suppliers working in each area. From these same sources, they obtained information concerning lithology, drilling procedures, and equipment performance. They made time and cost estimates for all phases of a drilling project beginning with site preparation and rig up and continuing through drilling, directional drilling, casing and cement, logging, testing, and completion. Fixed charges were estimated using appropriate price lists, quotations, and invoices, consistent with calculations such as mud volume, mud loss, casing length, etc. Time charges were computed from the charging rates and operational times. Charging rates were estimated from considerations of the equipment and personnel necessary for each operation.

The Carson, Lin, and Livesay study was very useful in identifying costs in geothermal drilling activities in the late 1970s and early 1980s. However, since that time, prices have changed, new technology has come into the industry, and drilling procedures have been modified to reflect improved knowledge and understanding of geothermal resources. The Carson, Lin, and Livesay study is being updated to reflect these changes. It is hoped that the updated study of the costs of geothermal
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drilling will be as informative and useful as the initial effort.

Scope & Approach

In addition to technological and procedural changes, geothermal activity and interest has shifted since the early 1980s. The current effort will include The Geysers, Salton Sea, and Roosevelt Hot Springs from the previous study and expand to new areas of interest that could include Coso, Northern Nevada, Mammoth Lakes, the Cascades, and areas outside the continental United States including Hawaii, Japan, Indonesia, The Philippines, Mexico, Central America, Italy, and New Zealand. It may not be practical to include all of these areas. In particular, if travel to overseas locations is required to collect data, the cost of preparing the well estimates may outweigh the benefits. However, if information about well configurations, procedures, and costs can be obtained without undue expense, overseas locations will be included to help in understanding the current state of geothermal development activities.

In the previous effort, Carson, Lin, and Livesay developed a model of drilling costs and procedures in each region of interest. Drilling operations were broken down into fifteen minute to one-half hour segments. The materials, equipment, and operational procedures were imbedded in the time sequence. A similar approach will be employed in the present effort, but a PC-based cost model is being developed to automate the calculations.

The model will consider all costs associated with drilling a well. The cost-estimation technique will be activity based. The costs of all resources - equipment purchased and leased, services and labor employed, and materials consumed - will be identified with specific activities associated with drilling or prevention/solution of commonly occurring drilling problems. This technique for estimating well costs not only identifies the cost drivers, but also allows assessment of the economic impacts of new technologies and alternative operational procedures on the cost of geothermal wells.

Basic Costs

The general algorithms employed in estimating costs associated with various activities around a drill rig are discussed briefly in the following paragraphs:

**Daily Operating Costs:** These costs include the rig rate, camp expense, drilling supervision, the mud logger, and routine transportation. The costs of tools and services are also included in this category. Tools include nonmag collars, stabilizers and reamers, jars, stand-by fishing tools, shock sub, etc. Services include welders, inspection, waste removal, and a roustabout.

**Water:** Water costs include charges for establishment of on-site storage and delivery mechanisms. During drilling operations, charges will be estimated for general drill-site water usage as well as water used in mud and cement make up.

**Fuel:** Fuel usage will be estimated from rig power consumption during various operations around the rig.

**Mob/Demob:** The initial rig mobilization charges are based on the number of truck-loads needed to transport the rig. Labor costs for rig assembly will be estimated as will location costs including clearing the site, building roads, and putting up a fence. Charges for building the cellar and
establishing the rubble guard will also be included.

**Drilling Time:** Drilling time will be based on the estimated rate-of-penetration in each area. Tripping time to change the bit and at each casing point will be estimated separately from drilling time; and time to change the bottom-hole assembly (BHA) will be included explicitly in the estimates.

**Directional Drilling:** Costs included in directional drilling are for a directional supervisor, rental charges for a motor (PDM) and measurement-while-drilling (MWD) unit, and for needed tools including bent subs, mills, whipstocks, mini-whipstocks, bridge plugs, stabilizers, reamers, and other BHA equipment.

**Mud Costs:** The basic mud costs are dependent on bottom-hole temperature. Consideration will be made for special mud formulations where necessary. In addition to increasing hole volume, mud consumption includes filtration losses - modeled as equivalent to a 45-cc loss in a 30-minute filtrate test - and flow losses over the mud cleaning equipment.

**Air Drilling and Aerated Mud:** Air drilling charges include both mobilization and rental costs for the compressors and rotating head, soap and other additives, and fuel usage by the compressors while drilling.

**Bits and Tools:** This is primarily the cost of downhole equipment including bits, stabilizers, roller reamers, and redress of stabilizers and roller reamers.

**Logging:** Logging costs are modeled as including mud conditioning, equipment rental and mobilization, wireline charges, and crew charges for labor, mobilization, food, and lodging.

**Casing:** Casing costs are dependent on size, weight, and grade. Additional costs for handling, transportation, and delivery will be estimated. Estimated costs for the casing crew allow for labor, mobilization, food, and lodging.

**Cement:** In addition to material costs for cement, silica, and other additives, the costs of cementing include equipment mobilization, handling, transportation, and delivery charges, and the cost of float equipment (shoes, collars, and centralizers). Estimated costs for the cementing crew include labor, mobilization, food, and lodging.

**Wellhead and Valves:** This includes the costs of expansion spools, valves, and the production tree as well as the cost of installation time.

**Drilling Problems**

Because drilling is seldom trouble-free, realistic cost prediction needs to account for potential drilling problems. The costs associated with drilling problems are often estimated either as a percentage of the expected total well cost or as a fixed add-on based on experience. While these approaches are often sufficient for well cost prediction, they do not lend themselves readily to analysis in search of ways to reduce or mitigate trouble costs.

From an analytic viewpoint, the following two pieces of information are necessary to assess the cost of drilling problems:
Pierce, Bomber, and Livesay

1. The cost and time associated with remedial action, given that a particular problem has occurred, and

2. The frequency of problem occurrence.

A number of actions may be taken to work any particular problem. It is not possible to develop cost estimates for all conceivable approaches, but the following paragraphs give an indication of the algorithms to be developed for estimating the cost of some corrective actions for a number of common problems in geothermal drilling operations.

Lost Circulation: Lost circulation is probably the most widespread and costly problem associated with geothermal drilling. The times and costs associated with methods for combating lost circulation, including the use of lost-circulation materials and the use of both standard and foam cement plugs, will be estimated.

Stuck Pipe: As a preventive action, the cost of placing jars in the drill string will be evaluated. Once the pipe is stuck, possible remedial actions to be evaluated include 1) working the pipe, and 2) backing off, setting a cement plug, and sidetracking. The costs associated with each of these actions will be estimated.

Deviation Control: There are at least three actions possible to control well direction and the cost of each will be estimated. The first action would be to adjust the BHA. If this is unsuccessful, another approach would be to bring a directional service on site and make a correctional run using a motor and MWD unit. And finally, if the deviation is too great, it may be necessary to place a cement plug prior to making the correctional run.

Lost Tools or Drilling Assemblies: Estimates of the costs and times associated with two alternatives are being developed for equipment lost in the hole: 1) fish for the lost material and 2) set a cement plug and sidetrack around the lost materials.

Cement Failure: There are both preventive and corrective actions that can be taken for cement failure. Preventive actions to be evaluated include the use of stage collars and special cement formulations. Corrective actions include top jobs and casing perforation followed by cement squeeze.

Collapsed Casing: There are no approaches that are certain to repair collapsed casing; however, there are a couple of strategies for remedial action that can be attempted. Depending on the severity of the problem, one approach is to attempt to force casing rollers through the collapsed section. Another approach is to use a casing mill to cut the collapsed section and follow the mill with a cement plug. After drilling the plug, a casing patch or liner may be placed over the damaged area. When the length of the damaged section is specified, the costs associated with each of these approaches can be estimated.

Corrosion: All or nearly all methods to fight corrosion involve preventive actions such as the use of polymer-cement-lined pipe, exotic metals, non-metallic materials, and special cement formulations. These costs can be estimated.

Temperature: One characteristic that sets geothermal drilling apart from oil and gas drilling, and causes a number of problems in materials and procedures, are the high temperatures encountered. The costs incurred due to high temperatures generally
manifest themselves as special materials or procedures. These increased costs, particularly for cement, drilling muds, and logging procedures and equipment, will be assessed.

Once the costs associated with the remedial actions have been estimated, the only additional information needed is the expected frequency of each problem. The operators, vendors, drilling contractors, and suppliers working in each region should be able to provide insight in this area.

**Reports**

The classification of costs through the development of representative wells will identify the major costs and cost drivers in each area. It is planned to report the costs estimated in each region in the following formats:

**Sequential Operations List:** a list of the sequence of operations from initial drill site activity to rig down and site clean up. The information will include depth, time, activity, and cost. The estimated cost will be separated into materials costs, service charges, and rig and drill-site costs. Cumulative costs will be given as depth and time increase.

**List of Basic Costs:** a table giving the basis for the cost estimate. Included will be the rig rate, a breakdown of the site charges, bit costs, casing costs, and the basis for each service charge (hourly rate, unit material charges, etc.).

**Well Configuration:** a table or graphical output identifying casing sizes, weights, grades, and depths.

**Pareto Diagrams and/or Pie Charts:** Pareto diagrams and/or pie charts will be employed to illustrate the relative magnitude of the estimated costs of the various functions and operations.

**Chart of Accounts:** the total estimated well cost by account. This will detail the costs of the materials consumed and list the estimated charges for service contracts during the drilling operations.

**Graphical Displays:** A number of graphical displays are planned including depth vs. time, cost vs. depth, and cost vs. time.

**Sensitivity Analysis & Trade-off Studies**

Once the initial cost estimates have been developed, there are a number of possible sensitivity analyses and trade-off studies that can be performed. These will include at least some, if not all, of the following:

1. Examination of the sensitivity of well costs to variations in parameters such as rate-of-penetration (ROP) and daily operating costs. These analyses could be summarized with charts of cost as a function of the appropriate variable, as in Figure 1,

![Figure 1: Drilling Interval Costs](image-url)
or as spider charts showing the relative effect of several variables. Figure 1 was developed from the costs associated with a single drilling interval\(^2\). Similar analyses will be performed over the entire well.

2. Estimation of the performance requirements necessary to offset the cost of a drilling tool such as a mud motor.

3. Examination of the cost of various operational practices such as the use of contingency strings of casing and possible savings from reduced casing sizes.

4. Comparison of the investment necessary to avoid drilling problems with the cost of remedial action once the problems have occurred.

5. Comparison of the cost of maintaining a service on stand-by to the cost of calling for the service only when needed. For example, under what conditions and frequency of occurrence could maintenance of cementing capability on-site for lost circulation be justified?

Some of the studies in the above list are expected to result in estimating some frequency of occurrence for a phenomenon below which one action would be the most economical and above which another action would be better. For example, whether or not it is economical to allow for a contingent string of casing depends on how often the string is needed. Below some frequency of occurrence of drilling problems, it would be economic to design the casing without allowance for an extra string while realizing that this would occasionally result in failure to reach the desired depth.

Conclusions

A project to update the Carson, Lin, and Livesay cost study has been initiated. This effort will estimate well costs in regions of current geothermal activity. Costs associated with both normal drilling activities and commonly encountered drilling problems will be estimated. Activity-based costing techniques will be employed to allow the identification of cost drivers and the evaluation of the economic effects of new technologies and operational procedures on well costs. In addition to estimating well costs, the sensitivity of these costs to a number of parameters such as rate-of-penetration and daily operating costs will be examined. Further sensitivity analyses and trade-off studies will evaluate the efficiency of various operational practices and preventive, as well as remedial, actions. These efforts should help provide an understanding of the consumption of resources in geothermal drilling.

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