Budgeting and Risk Assessment for Deep Geothermal Wells

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Abstract

To date, cost planning and time schedule forecasting for the well construction process of deep geothermal wells drilled in the South German Molasse Basin have been based on a deterministic approach. This means the estimate has been based on a historic average time and uncertainties have been taken into account by adding a contingency factor. This approach is simple and fast but it does not consider the variability of the estimate and therefore its application is limited. In this article we present an approach of probabilistic well construction modelling which can provide risk assessment for geothermal wells to investors, insurance companies and decision makers. This aids proper budgeting and the calculation of insurance premiums. Moreover, the modeled technical limit or best historic performance can be used as a technical performance reference. Probabilistic modelling also allows a sensitivity analysis to identify the key driving forces of well construction costs. Therefore, optimization strategies can be steered into the right direction.

Introduction

Hydrothermal energy has been used in the South German Molasse Basin for decades to supply spas with warm water. However, geothermal development has also targeted district heating and power generation on a larger scale over the last ten years. Depending on the temperature and production rates, the thermal energy is used for power generation coupled with heating or, in case of lower temperatures, for heating only. A typical

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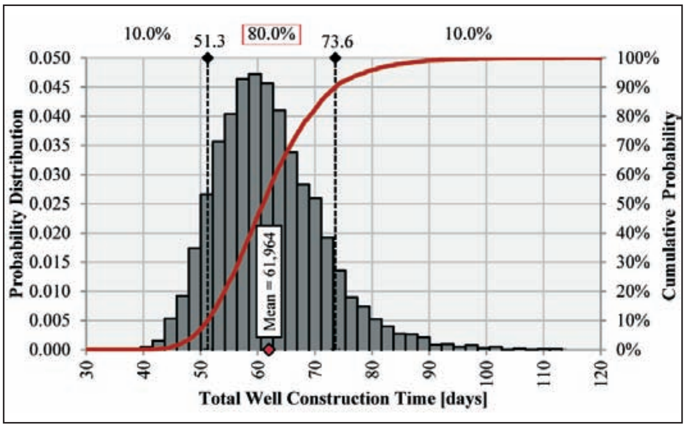

Fig. 1 Example of a probability distribution and cumulative probability of the total well construction time

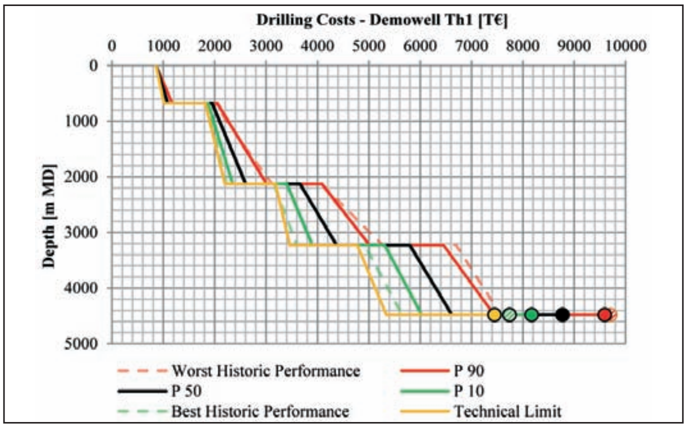

Fig. 2 Drilling costs vs. Depth curve of an example well

well doublet, used for a coupled system, can support 5–50 MW for direct use (heating) and has an electrical capacity of approx. 5 MW. [1]

The geology in the South German Molasse Basin is generally well known. However, drilling down to the reservoir can be challenging and drilling performance has been unsteady in the past. To counter this, rotary steerable systems have been applied in recently drilled wells (cf. [2]) and a lot of effort has been put into well designs, which considers the lessons learned. These measures have led to a significant decrease in well delivery time and costs. However, the variability is still high and there is great potential for improved performance and saving costs.

To date, cost planning and time schedule forecasting for the well construction process have been based on historical performance data of offset wells, whereas outstandingly strong or weak performance has been rejected and an average estimated time for the main operations has been summed up to the total well delivery time. By multiplying the times with the respective costs and adding the fixed costs, total well costs have been identified. Uncertainties have been taken into account by adding a contingency factor whose value has been based on the engineer's subjective degree of optimism.

This deterministic approach has the advantage of being simple, fast and easy to communicate. However, it does not give any idea about the uncertainty of that estimate, which limits its application: For example, the estimated time schedule was used for both, budget planning and as technical reference for the drilling contractor. But from the engineer's point of view it was too conservative and provided no incentive for the well construction team. On the other hand, if drilling problems occurred, costs could increase rapidly and the forecast was too optimistic. Now, rather than one case, one could estimate two or more cases (e. g. best-case, business-case or worst-case) again with the same deterministic method (scenario based approach). However, it does not deliver the probability of each case and quantitative risk assessment is still not possible.

In this article we present a different approach for time and cost estimates which is based on a probabilistic well construction model. This approach allows the simulation of a time schedule forecast and the well delivery costs on a statistical basis. It allows risk assessment by yielding a distribution of expected values, the probability of a certain value and the range of outcomes.

Literature Review

In the oil & gas industry probabilistic techniques for time and cost planning of wells are well established. Its use started as an improvement on deterministic approaches by splitting up the well construction process in smaller operations, defining how their duration and costs depend on input variables and simulating an estimate for a new well by combining the operations again whilst applying actual design parameters.

For example, Thorogood [3] described "a mathematical model for analyzing drilling performance and estimating well times" in the North Sea. Shilling and Lowe [4] published a paper about the development of an "automatic cost estimating and tracking system" in the Gulf of Mexico.

Although this approach might result in a more accurate prediction it does not show the uncertainty in the planned well construction costs and time. Therefore probabilistic estimations are necessary and there are several papers on this topic: Murtha [5], Williamson et al. [6] and Akins et al. [7] refresh concisely the theoretical background of probabilistic techniques. They proposed the use of a Monte Carlo simulation for well planning and explained its strengths, weaknesses and the pitfalls. Examples for practical studies are Peterson et al. [8], Peterson et al. [9], Kitchel et al. [10], Zoller et al. [11], Hariharan et al. [12], and Adams et al. [13]. The ideas and methods described in these papers provide the theoretical basis of our work.

Methodology

The aim is to model the Total Well Construction Time of one single well and to generate a distribution function with a Monte Carlo simulation.

Therefore the first step is to define the model. The Total Well Construction Time can be broken down into sequential steps. The processes defined are: Drilling Hole, Logging, Conditioning Tripping, Running Casing or Running Liner, Cementing, WOC/BOP and Drilling Cement/Shoe. Repeatedly connecting these seven processes for each section describes the typical well construction process without any gaps.

The process Drilling Hole is a function of following input variables:

- ROP [m/h] (Rate of penetration). ROP is measured only when the bit is rotated at bottom and mud is circulated
- DFT [h/100 m] (Drilling Flat Time). DFT is the time consumed for all operations except drilling during the drilling process, normalized to 100 m
- Casing Setting Depths and the resulting section lengths.

After defining the model is has to be fed with real values. Therefore, the duration of these processes and input variables were gathered from rig sensor records and morning reports of offset wells. Then a distribution function was assigned to every input variable by fitting a theoretical distribution to the respective data set (parametric fit). Learning trends over time were implemented by assigning a correlation coefficient between the well number and the respective input variable. Especially ROP shows a significant improvement over time. Moreover, correlations between input variables are to be considered. This means that if two variables are related to each other, the sampling of a relatively high value for one input variable should lead to a high value (or low value in case of negative correlation) for the second variable. Based on the model described above a Monte Carlo simulation can be run. Figure 1 shows the resulting probability distribution of the total well construction time of a simulated future example well.

A further step is to model drilling costs based on the time model. The total time-dependent costs can be determined by multiplying the time-dependent costs of each process with the respective process duration. The time-independent costs are summarized and assigned to the respective section (e. g. casing, mud materials, etc.). The cost inputs can be handled either as probability distributions or fixed values depending on the phase of the project. For example, if the project is already in a phase where tender offers are available or contracts are in place, costs should be considered as fixed values.

Results

The model results can be transferred to a time vs. depth curve and cost vs. depth curve. Figure 2 shows a cost vs. depth diagram for an example well. There are six different curves on the diagram:

Firstly, the "historic technical limit": It is the sum of the best historic process duration of all wells. Therefore, for each process (e. g. Drilling Hole), the minimum value of the offset data is gathered and stacked together. So this curve is a mixture of processes from different wells.

Then, the "best historic performance" curve is displayed, which is based on the data of the well with the best overall outcome (normalized to the modeled casing setting depths). This well does not necessarily have the best performance in all sections. Only the overall outcome was the best.

The next three curves are the modeled P10, P50 and P90 values as a function of depth. From the spread between these curves, the risk involved is indicated.

Finally, the "worst historic performance" is displayed. It is, in analogy of the "best historic performance", based on the data of the well with the worst overall outcome (normalized to the modeled casing setting depths).

The time-independent costs of each section are displayed at the respective casing setting depths together with the time-dependent costs of the flat time processes (processes which do not add depth). The costs before spud are displayed at a depth of 0 m and represent the costs for the rig site and rig up. Then the section costs are added up until the final depth is reached. Then costs for completion and testing are added.

With the presented approach of well construction modelling, decision makers can evaluate the risk involved in the well construction process. Uncertainties are acknowledged and the variety of expected outcomes can be communicated more effectively. The awareness of risks and opportunities is improved.

Moreover, the normalized technical limit or best historic performance can be used as a technical performance goal, which is separated from the drilling time used for budget planning. This is the foundation for performance improvement. It can also be easily assessed how good the current performance is compared to other wells. This is essential for effective performance management.

Building a probabilistic model also stimulates the analysis of offset data and the actual operational time and cost data. It also gives the opportunity to perform a sensitivity analysis. Based on the results of the sensitivity analysis, the key driving forces can be identified. Therefore, optimization strategies can be steered into the right direction.

Nomenclature

ROP	Rate of Penetration
DFT	Drilling Flat Time
FIT	Formation Integrity Test
BOP	Blow Out Preventer
WOC	Wait on Cement

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