Innovative Drilling and Completion Concept for Geothermal Applications

Joachim Oppelt and Jörg Lehr

Baker Hughes

Keywords

Geothermal, cost savings, casing design, monobore, drilling automation, case study, cost elements, low enthalpy

ABSTRACT

The cost of geothermal well construction, especially in areas of low enthalpy, is very often prohibitive to obtaining investors and launching projects. Between 50 and 70 percent of project investments are related to drilling and completing typically two wells. The motivation to reduce drilling expenditure is high. Within a large-scale conceptual and technical investigation, detailed reference case calculations revealed the potential of cost savings for geothermal borehole construction in specific formations of Northern and Southern Germany, which are the most promising geothermal areas in the country.

In South Germany, where Germany has a major hydro-thermal reservoir, the Molasse Basin, cost savings of up to 15%, equivalent to about 2 M EUR per well, can be achieved by applying the monobore casing construction approach. An additional 10% cost savings can be achieved by applying automated closed-loop drilling and reaming systems, which enable an increase of the effective rate of well completion. A third cost-saving potential is based on the strict application of automated wellbore integrity and tool health performance concepts, leading to another saving of 5%. Therefore, a savings of up to 30% of the wellbore construction cost can be realized. The usability of the mono-diameter well design depends upon certain geological conditions. Certain overpressure regimes, for example, limit the application of this alternative casing concept.

In addition to direct cost savings, the mono-diameter design delivers a larger final diameter and enables starting with a smaller surface casing than the standard telescopic well.

1. Introduction

Under a major German government co-funded project, a thorough investigation has been undertaken to develop a concept for a cost-effective wellbore completion process. Three individual sub-areas have been identified to support this goal. Amongst these is the development of a single-diameter wellbore design for geothermal applications. The second component is the wellbore integrity over the entire lifetime of 30 years. Finally, the development of integrated, automated operation processes complements this holistic approach for substantial cost savings in wellbore construction (Fig. 1).

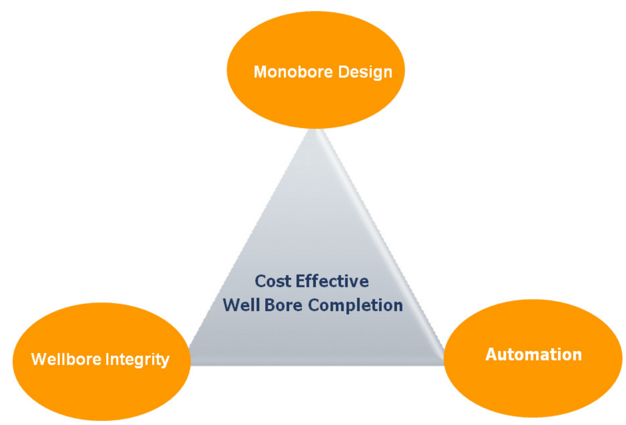

Figure 1. Holistic Approach for Cost Savings in Geothermal Well Construction.

The concept investigated aims at deep wells of up to 4,500 m (15,000 ft) in areas without abnormally high pressure regimes, in Germany and elsewhere. Shallower wells do apply as well. Considering the three approaches in parallel, reference case calculations have been performed on existing gas wells in Northern Germany and potential petro-thermal wells in South Germany, aiming to find the real cost impact potentials through applying the innovative technologies.

2. Potential Cost Savings Through Mono-Diameter Well Design

Although different than the conventional telescopic borehole scheme, which is the standard at present, the mono-diameter borehole construction [1] essentially delivers a single-diameter casing tube (Fig. 2).

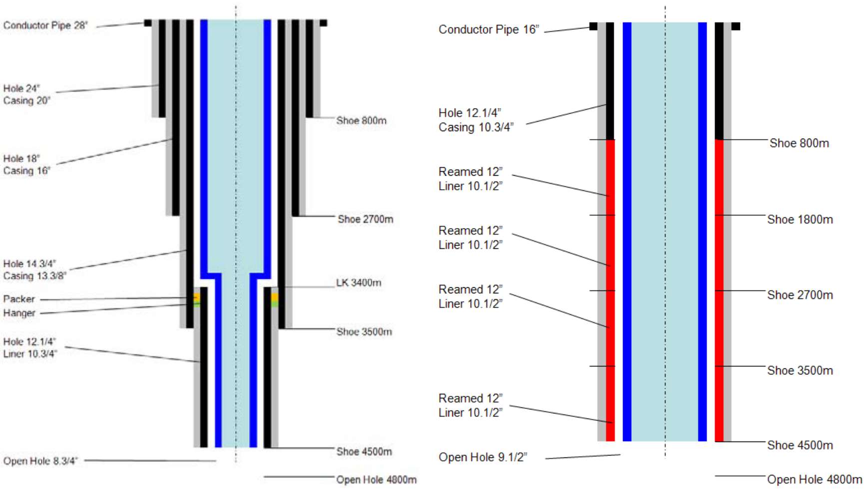

Figure 2. Comparison of Standard and Mono-Diameter Design for Synthetic 4,500 m Deep Petro-thermal Well South Germany.

The monobore construction leads to a significant reduction in material costs. The reduced expenditure for the cost-intensive casing materials, the minimized quantity of drilling fluid to be used and the sufficiency of a smaller drilling rig should be seen as fundamental cost-saving opportunities, see Figs. 3, 4, and 5. Fig. 3 shows the total wellbore construction cost for a synthetic petro-thermal well in South Germany, when a standard design is used. Accordingly, the cost distribution for the same well requirements based on the mono-diameter approach is represented in Fig. 4.

Apart from the obvious cost savings, the case comparison also includes some cost-adding initiatives such as the under-reaming operation, reaming drill bits, required logging, expansion and cementation service, and the slightly extended time period needed to construct the wellbore (Fig. 5).

Taking all considerations together, the total savings calculated in this synthetic case study are approximately 15%, if the alternative mono-diameter design is applied instead of the conventional telescopic design. The exact savings amount obviously depends on several parameters, but additional variance discussions and sensitivity analyses provided a large confidence that the approximation is realistic.

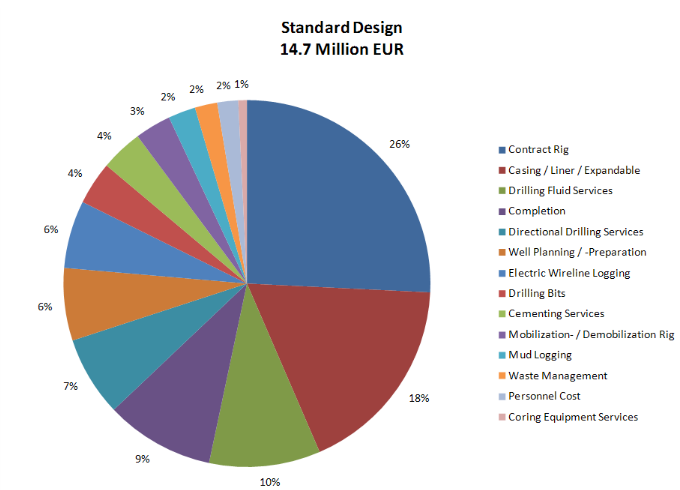

Figure 3. Total Wellbore Construction Cost Distribution for the Standard Design.

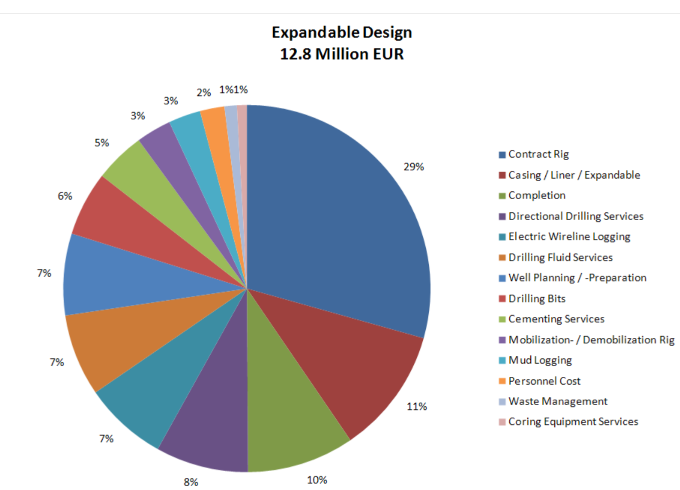

Figure 4. Total Wellbore Construction Cost Distribution for the Monobore Design.

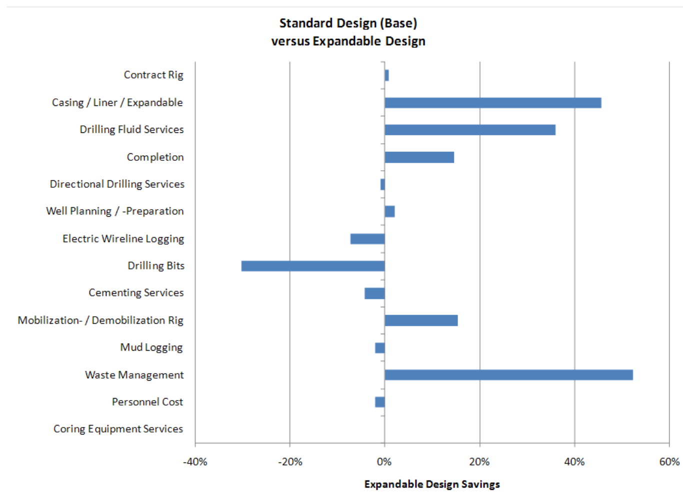

Figure 5. Additional Spending vs. Cost Savings.

3. Technical Implications of a Mono-Diameter Well Design

A mono-diameter well design requires the process of reaming a hole section below a first casing to a larger diameter, running a tubular casing in place of this enlarged section of hole, and expanding the tube in place. Providing a secure connection between the first upper casing and the lower set of expanded new casing presents a technical challenge that is under consideration in this ongoing research program.

Another challenge originates from the need to connect several individual sections of casing on the surface before being run into the hole. This is normally done through threaded connections. The lifetime and reliability of the expandable connections of a monobore wellbore design, however, are still a challenge. Available expandable threads used for liner expansion applications seemed unable to deliver sufficient sealing over time, and they are too expensive to gain the 15% out of the wellbore construction related cost savings. A new casing welding technology is, therefore, the subject of research and development in this ongoing project.

Feasibility studies on automated welding technologies, together with research from the Leibniz University Hannover, revealed that the magnetic impelled-arc butt welding (MIAB) technology has the highest potential for a successful application on expandable tubulars. The technology is well known from the automotive industry, were MIAB welding is used to connect drive shafts and torsion beam axles.

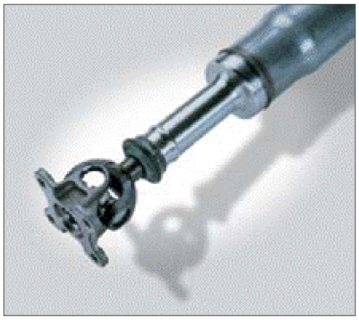

Figure 6. MIAB Welded Automotive Drive Shaft (KUKA AG).

Basic advantages of this technology are:

- Short welding times (5 -30 sec)
- Very good reproducibility
- High level of automation
- No welding filler metal necessary
- Many combinations of materials can be welded
- High welding quality

The main process steps of this technology are:

- Tubular are aligned and brought into contact
- Initiation of the welding current
- An arc is generated by movement between the faces of the components
- The magnetic field is perpendicular to the arc
- The welding arc rotates between the joint surfaces (Lorentz force)
- The melted faces are pressed together and the components are welded
- Machining of the offset dimension if required

The main challenges to apply this technology on the rig floor are:

- The wall thickness of the oil field tubular
- Pollution shielding and hot permit approval
- Heat treatment of the welding seam to regain formability of the material after welding
- Alignment of the tubular while connecting

Manipulation of the beam trajectory on the surface of the tubular is required to heat the surfaces of the tubular equally. The approach to connecting a thick wall tubular is to manipulate the trajectory of the beam by a magnetic field acting on the beam from the inner side of the tubular in a radial direction. Pollution shielding and hot permit approval will be achieved by sealing the welding area with a shield gas provided in a process chamber. The process chamber (Fig. 8) isolates the welding zone from the environment (preventing flying sparks), floods the chamber with inert, forming gas (stabilizing the arc) and prevents scaling at the weld seam surface for optimal weld quality and expandability.

The technology can be used to connect liners and casing tubulars, as well as coil tubing tubulars, for tube extension or repair purposes.

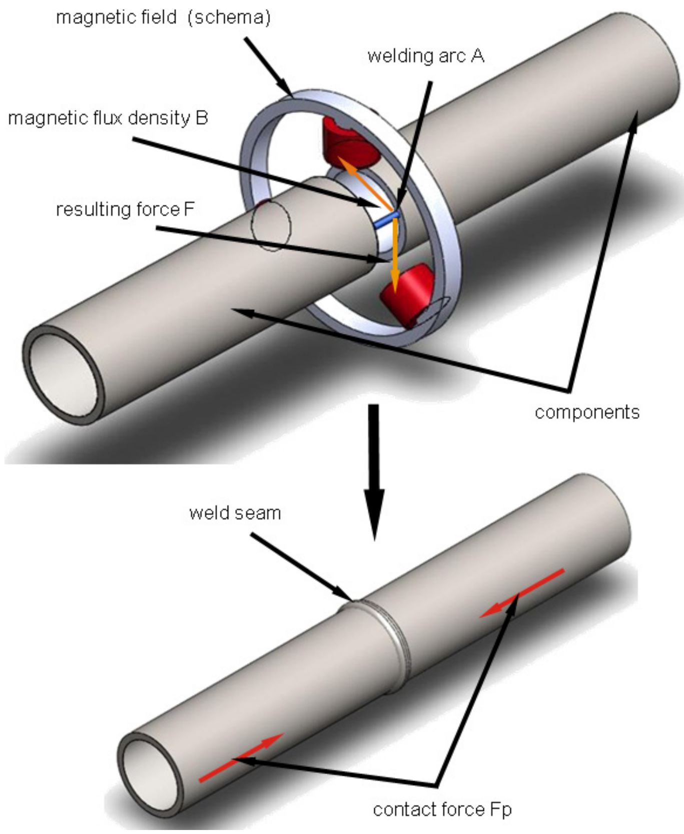

Figure 7. Principle of MIAB Welding Process (Leibniz University Hannover).

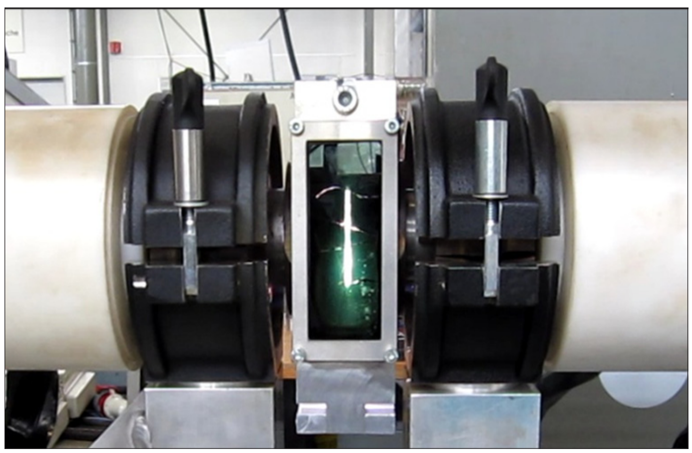

Figure 8. MIAB Experimental Process Chamber Leibniz University.

4. Further Improved Cost Efficiency Through Automated Processes

The mono-diameter drilling and completion approach delivers a measurable reduction in cost, as compared to the standard procedure. However, the extend of the reduction accomplished with this alternative casing scheme, by itself, is believed to be insufficient in overcoming the economic constraints of geothermal energy production in low-enthalpy areas. Consequently, opportunities for additional cost savings were identified. These are basically related to providing major automated functionality to the wellbore construction process in two ways:

- Drilling process automation to maximize the rate of penetration
- Automatic measures to better control the integrity of the borehole and the equipment used, in other words, reduction of the non-productive time (NPT)

Drilling Process Automation

The monobore approach requires an innovative drilling concept to produce the desired wellbore design. This concept is based on automated, directional pilot hole drilling, incorporating controlled calibration, and reaming of the final monobore borehole diameter (Fig. 9).

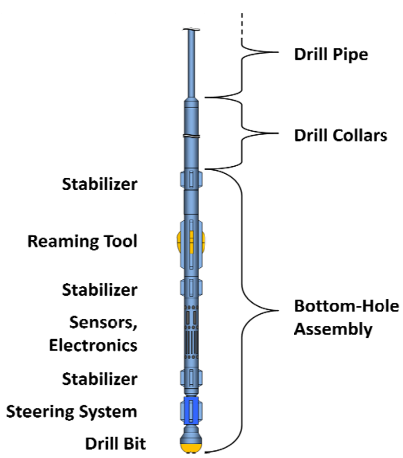

Figure 9. Monobore Drilling BHA [3].

The pilot hole drilling tool includes an appropriate rock-destruction method for formations under a high compression state. A reaming tool that runs behind the pilot tool has already been evaluated, developed and used in various formations. The formation must be drilled and reamed so that the energy to remove the appropriate volume to final monobore diameter is minimal, while maintaining the stability of unprotected sections of the wellbore.

Drilling automation will optimize the operating parameter adjustment, such as weight-on-bit, RPM, and flow rate, for the pilot drilling and reaming tool. It will also provide downhole pressure adjustment in real time, with the goal of maximizing the rate of penetration (ROP) and minimizing energy consumption, while protecting and stabilizing the formation. A closed-loop control expert system approach (Fig. 10) must be utilized to gain an additional ~10% cost savings out of the improved drilling performance. A 50% improvement in ROP provides a 10% reduction in total wellbore construction cost as shown in Fig. 4, based on the synthetic case study.

Wellbore Construction Automation

Reducing non-productive time in constructing a well is seen as another major opportunity to reduce well construction costs. The approach taken here is based on the concept of automating the drilling process, as shown in Fig. 10. This has a dual effect. First , any incidents caused by insufficient wellbore integrity are minimized. At the same time, due to the much-improved control of operating conditions, the health of the drilling BHA can be maximized. Fewer "hole problems" and improved service reliability can contribute considerably to improved economics. Conservative calculations indicate that the higher level of automation applied will deliver another 5% savings in wellbore construction costs. This approach is based on the assumption that NPT can be reduced to 50% of what is occurring today, due to the introduction of automated control processes.

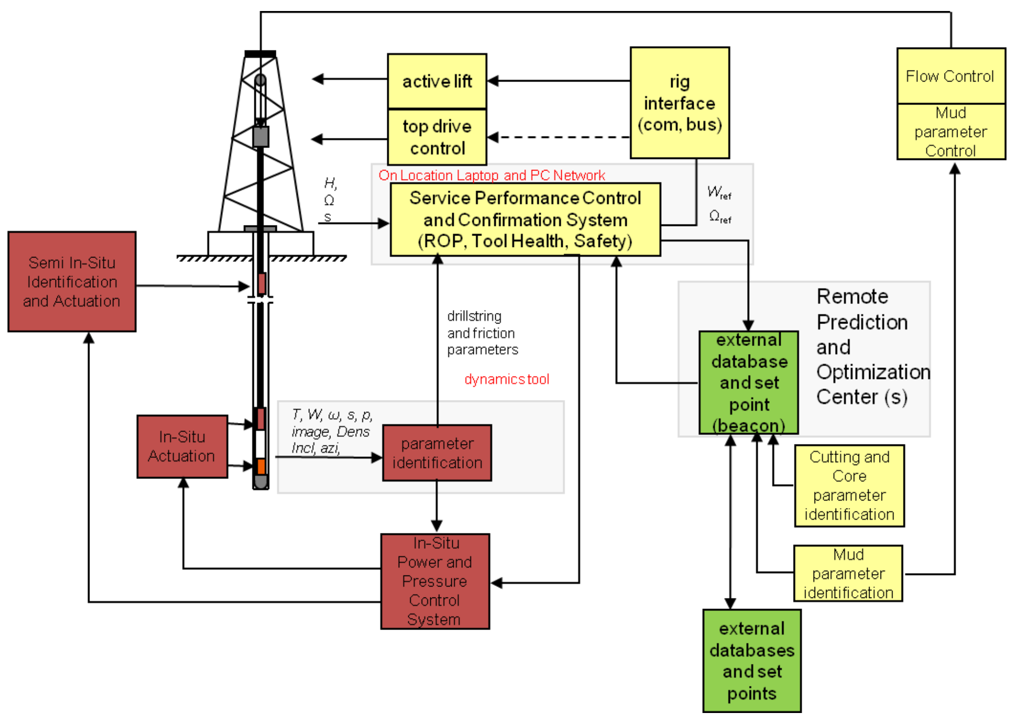

Figure 10. Closed-Loop Drilling Control Expert System.

5. Summary

In general, technology development tends to improve functionality, to provide enhanced value to the customer. However, often such added functionality adds to the complexity of systems, which causes higher operating costs. However, geothermal well construction requires cost-competitive methods, even more than the drilling for oil and gas, because in geothermal the energy content of a specific volume is much smaller, while the exploration risk is even higher. The approach described here has started with a thorough benchmark activity of existing technology and processes, and utilizes three components: Mono-diameter casing (sections), highly automated drilling and completion processes and enhanced wellbore stability. Detailed case studies have shown that the size of potential gains vary greatly, depending on the actual formation situation at a given location. Critical elements of the new casing construction concept, advanced automation features and safer wellbore integrity services have been identified, and several of these are under development.

6. Acknowledgements

The authors wish to express their thanks to Baker Hughes for giving permission to perform the work and to publish the results presented herewith. In addition, the authors appreciate the financial support of the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU) as well as their related agencies for several of the activities described in this paper. Many discussions were held with representatives of various industry and external firms as well as research institutes.

7. References

[1] FKZ 0325073, Konzept, Entwicklung, Fertigung, und Test eines innovativen und kostengünstigen Geothermie-Verrohrungssystems, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), 2009-2013.

[2] WO2011062991, Apparatus and Method for Multi-Layer Wellbore Construction.

[3] B. Meyer-Heye, Zum Einfluss von Räumwerkzeugen auf die Dynamik von Tiefbohrgestängen, Aachen, 2011, ISBN 978-3-8322-9897-5.