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COMPARISON OF WELL COMPLETIONS USED IN OIL/GAS PRODUCTION AND GEOTHERMAL OPERATIONS: A NEW APPROACH TO TECHNOLOGY TRANSFER

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ABSTRACT

Renewable energy is seen as the future source for meeting the world's growing demand, with geothermal offering a constant and independent supply. Tapping geothermal energy is not always straightforward as deep drilling is required in order to access this high -temperature resource. Geothermal drilling is expensive and is financed by the operator (usually districts or state representatives) with a long period of debt service before costs can be recovered from the energy sale (heat, electricity or a combination of both). It is reported that the success rate for geothermal wildcat wells is only 25-40%, so a reduction in the exploratory drilling costs would be a major incentive for increased exploitation of this resource.

However, drilling costs are only a part of the total well expenditure. Tubulars can double the total well cost , especially when complex well completions are required. Together, drilling and well completions can account for more than half of the capital cost for a geothermal power project.

This paper presents a comparison of different well completions used for oil, gas and geothermal wells. The study identifies ways in which to facilitate a faster technology transfer from the traditional oil and gas arena to the developing geothermal industry. The study provides engineers with a better understanding of geothermal well completion needs and suggests ways to reduce cost.

INTRODUCTION

For a hundred years, deep drilling has been associated with the oil and gas industry. With the advent of Hot Dry Rock (HDR) geothermal exploitation, deep drilling has also become a requirement for geothermal activities. While drilling for hydrocarbons exploitation leads to a fast cash return, thanks to the revenues from the sale of oil and gas, geothermal projects may only break even many years after drilling. Deep heat mining can be "2-5 times greater than oil and gas wells of comparable depths" and can "account for 42% to 95% of total power plant costs" (Augustine *et al*., 2006).

Today's drilling processes for the exploitation of oil and gas have been optimized to affordable drilling costs (dollar per foot), though drilling costs are only part of the total well costs. The tubulars used for the completion of an oil well may double the well's total costs in the case of a complex well design.

The diameter of the last casing string in a geothermal well, often termed the production casing, is commonly 9-5/8 inches (Teodoriu, 2005). Such a large diameter pipe requires a correspondingly larger surface casing and 13-3/8 inches diameter is commonplace in the USA and Japan (Bohm, 2000; Jotaki, 2000; Williamson, 2001). In Europe, most of the wells drilled to depths deeper than 4000 m are completed with surface casing diameters of 18-5/8 inches or greater (Tanzer, 2001).

The large diameter of production casings is a consequence of the amount of fluids (and associated heat) to be pumped from geothermal wells.

GEOTHERMAL RESOURCES

Three main types of geothermal resources exist:

- HDR, which use the very high temperatures found in rocks just a few kilometers below surface. High pressure water is pumped down a well into the hot formation. The injected water travels through fractures in the rock, gets heated up by the rock and travels back to surface via a second well. At surface, the recovered hot water is converted into electricity. Once cooled, the water is injected back into the formation and the cycle is repeated.
- Hydrothermal, which consists of a geothermal reservoir that transfers heat energy upward by vertical circulation of fluids driven by differences in fluid density, corresponding to differences in temperature (NREL, 2006). Hydrothermal resources are the most widely exploited.
- Geo-pressured, which consists of deeply buried reservoirs containing hot brine with dissolved methane under abnormally high pressure (NREL, 2006).

In what follows, the focus will be on HDR, as this is the most challenging resource to be exploited from the point of view of completions.

HDR has three major advantages compared to the other geothermal energy uses: it is considered to be environmentally friendly because there is no contamination of the formation fluids; it has a high rate of success; it is widely applicable as it is not limited to active geothermal zones. On the other hand, the main limitation of HDR is the high drilling and completions costs associated with the greater depths involved. Figure 1 shows the geothermal temperature gradient for selected world regions, with an average of 3°C/100m. As standard electricity generation requires temperatures in excess of 180°C, the depth range for an economic HDR project can be inferred from Figure 1. According to Grimsson (2007), the temperature at depths of 4-5 km can range between 200-300°C in Europe, 300-400°C in the USA and be greater than 500°C in Japan.

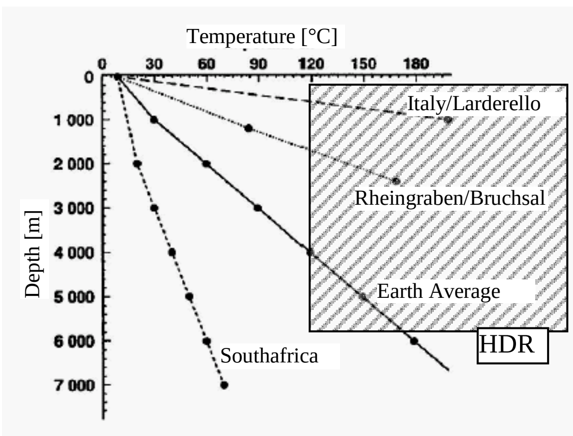

Fig. 1. The Earth's temperature gradient, modified after Rogge(2004)

The HDR concept was originally conceived during the first oil crisis in the 1970's by atomic physicists and researchers from the Los Alamos Scientific Laboratory, New Mexico. The idea was to use the inexhaustible and widely available deep geothermal potential for electricity generation. At that time, the HDR systems were defined as "Man-Made-Geothermal-Systems" (MAGES). Figure 2 illustrates the HDR concept. Tenzer (2001) noted that, "this concept rarely agrees with present day systems for the use of geothermal energy and had been termed as <far future technology> even by sustaining geothermal pragmatists".

NCDPPEA (2006) presented an economic comparison between the costs of HDR and hydrothermal projects, as shown in Figure 3. The author suggested that the point of minimum costs for a typical HDR project is likely to be encountered later than for a typical hydrothermal project. At some point in time, the cost curves intersect, indicating that, from that point onwards, it becomes less expensive to develop HDR resources than the remaining low-quality/low-enthalpy hydrothermal resources. The same author also estimated that the minimum cost for a typical HDR can be approximately twice that for a hydrothermal project and it will occur after 15 to 20 years.

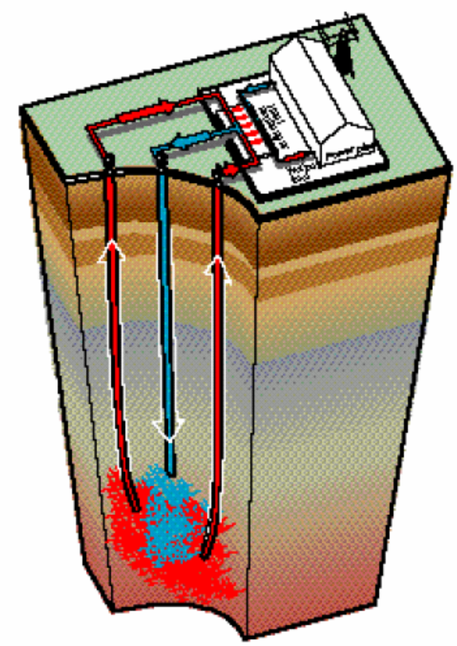

Fig. 2. Schematic of a Hot Dry Rock process, after Duchane (1993)

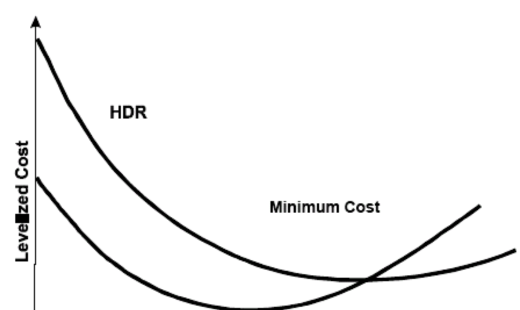

Fig. 3. Hypothetical minimum cost curves for hydrothermal and HDR projects, after NCDPPEA (2006)

As shown in Figure 4, the costs involved with HDR technology are significant due to the need for two wells, usually deviated. Hydraulic fracturing is required to ensure a maximum contact area between heat transport substance (water) and heated formation. The completions of HDR wells are extremely demanding, due to the great depths involved, the high pressure imposed on the well during fracturing operations, the need for an intermediate casing to touch the target, the high temperature at depth and the large temperature variations along the well.

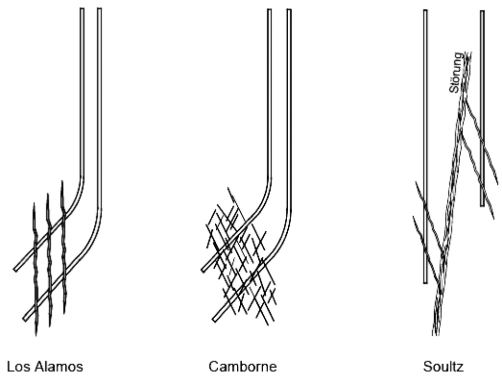

Fig. 4. The need for two wells (usually deviated) and hydraulic fracturing in HDR projects, after Tenzer (2001)

GEOTHERMAL WELLS CLASSIFICATION

It is difficult to classify geothermal wells, as most of the existing geothermal projects are custom-designed to accommodate the local geothermal conditions. However, a classification may be attempted on the basis of the type of geothermal energy resources. It has been suggested that geothermal resources should be classified by temperature (Dickson and Fanelli, 1990) or in a way that reflects their ability to do thermodynamic work (Lee, 2001).

COMPARISON OF COMPLETIONS USED IN OIL/GAS PRODUCERS AND GEOTHERMAL WELLS

The authors have chosen the following criteria to perform a comparison of well completions used in oil/gas wells and in geothermal wells:

- Wellhead and surface equipment are excluded.
- Tubulars, connections, and well integrity factors are accounted for.
- Three typical well completions are assumed, representative of an HDR producing well, a deep gas well and a heavy oil producer, respectively.

The large diameter of production casings in geothermal wells is a consequence of the amount of fluids to be pumped and the associated high enthalpy. Large, high flow rate electrical submersible pumps must be accommodated in HDR wells to recover the hot water from the reservoir.
Figure 5 reports a typical completions diagram for a HDR producing well, based on the analysis of several HDR projects. The setting depth of the 9 5/8" casing is calculated so that the downhole pump is completely submerged at maximum flow rate. This depth may vary depending on the characteristics of the specific geothermal rock.

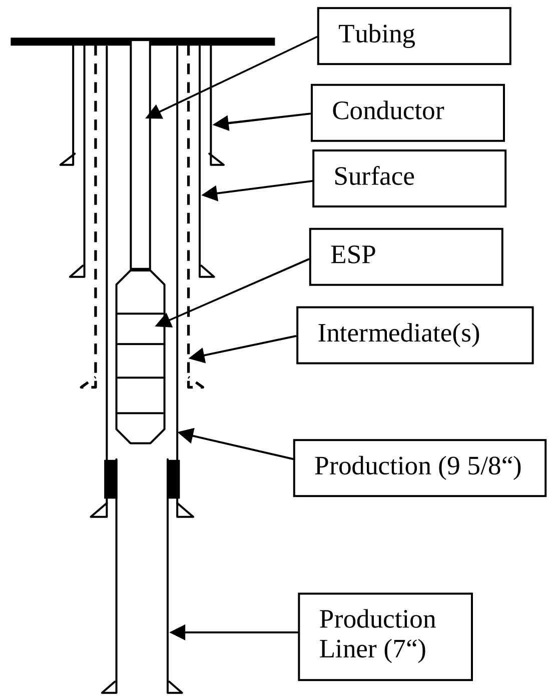

Fig. 5. Completion schematic for a typical HDR well.

The main challenges for this type of completions are: the quality and long-term behavior of the cement, the selection of the appropriate casing hanger (able to withstand high temperatures) and the evaluation of thermally-induced loads. Casing fatigue and cement integrity are the key issues for HDR wells.

Figure 6 shows the completion of a typical gas well from onshore Germany, where a 7" production casing is used to ensure good downhole accessibility and high well productivity. The first difference between the HDR well and the gas well and is that, in the latter, the completion may have the same diameter from bottomhole to surface. The gas well uses production tubing string to transport the reservoir fluids to surface, so the casing string is not in direct contact with the reservoir fluids, nor is it directly exposed to the reservoir pressure. Generally, completion fluids containing corrosion inhibitors are placed into the annulus between tubing and casing to protect the tubulars.
It should be noted that the conventional gas well completion illustrated in Figure 6 is not representative of a High-Pressure-High-Temperature (HPHT) gas well, where completions can be five to ten times more expensive.

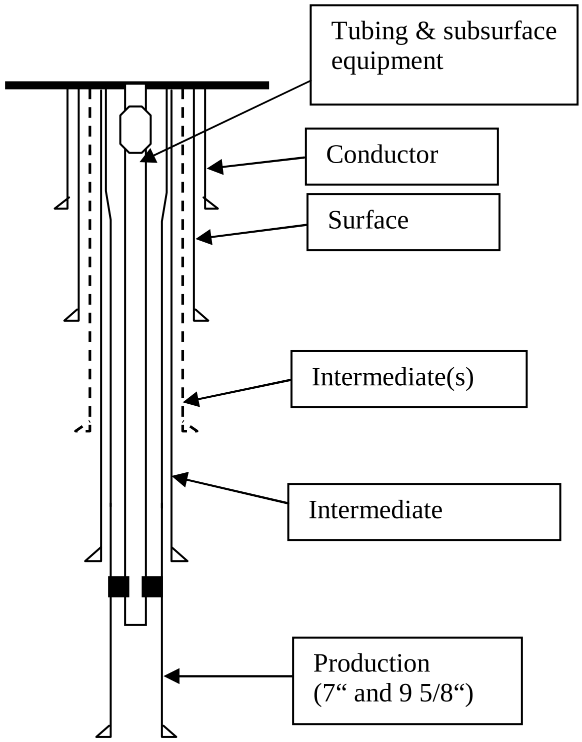

Fig. 6. Completion schematic for a typical gas well.

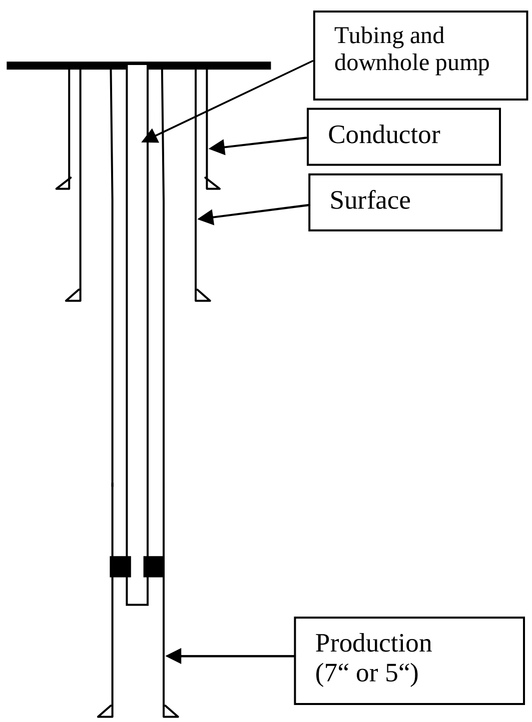

Fig. 7. Completions schematic for a heavy oil producer.

Figure 7 shows a typical completion diagram for a heavy oil producer. The main feature of heavy oil completions is the need for casing string pre-tension, which limits the effects of axial compressive forces due to thermal expansion. Despite many reports (Brunetti and Mezzeti, 1970; Elis, 1979; Allen 2000) of casing failures for high temperature applications, the importance of casing fatigue analysis for these wells is still not widely recognized.

The production of heavy oils is usually compounded by the corresponding injection of steam, which is used to reduce the in-situ oil viscosity, thus making the oil more mobile. Steam injection increases the temperature of the reservoir fluids to be produced, which may represent an operational constraint from the completions point of view.

As heavy oil reservoirs tend to be found at relatively shallow depths, the completions for heavy oil wells have different requirements from those for deep hydrocarbon wells.

Table 1 shows a selection of well completions parameters for the three well completions types that have been discussed above.

Table 1. Key completions parameters for a HDR well, a gas well and a heavy oil well.

Parameter	**HDR**	**Gas**	**Heavy oil**
Temperature [^{0}C]	80 - 250	60 - 150	60 – 350*
Depth [m]	1000–5000 (or more)	3000-6000	300-1200
Production Casing OD [in]	9-5/8” and 7” liner	9-5/8” with crossover to 7”	5” or 7”
Connection type	API Buttress	Premium	API Long/Buttress

**The high temperature values correspond to the injected steam in thermal oil recovery processes.*

TECHNOLOGY TRANSFER

Based on the above comparison, is it possible for the oil and gas industry’s expertise in well completions to be directly transferred to the geothermal energy sector? The following text suggests where the lessons learnt from oil and gas completions can help in the frontier areas of new geothermal wells completions.

A major issue related to geothermal wells completions is that of the high temperatures encountered. In general, the required increased resistance of casing strings to high temperature can be achieved by carefully selecting high-strength steels and by increasing the wall thickness of the pipe. However, both solutions tend to increase well costs. Materials that are more resistant to high temperatures (especially for the seals of downhole packers) can be selected based on the experience gained from producing wells over the past sixty years or so of heavy oil production activities.

Heavy oil wells require similar casing design to that of geothermal wells, though heavy oil wells tend to be shallower than HDR wells. Pre-tensioning of the casing string (usually adopted for heavy oil wells) is inappropriate for deep wells, due to the additional loads involved. Information on the resistance of tubular connections under axial compression/tension is also available from heavy oil wells production history. It has been found (Brunetti and Mezzeti 1970) that API LTC (Long Thread Coupling) connections are unsuitable for high compression/tension loads. All projects having API LTC connections have reported connection failure during or after exposure to high temperatures. A better connection is the API Buttress, though it has limited resistance to leaks of gas and liquidas at very low pressure. The Premium connection can offer an excellent resistance to axial loads versus leak resistance, but the high cost of these connections may impair the economics of marginal geothermal projects. In this case, looking at alternative technology, such as casing drilling connections, may help. Casing drilling connections are designed to withstand high axial compressive loads and torque. These connections could be used in geothermal wells, if their resistance to high temperature can be proved.

HDR wells are usually deviated to extend the contact area between injected water and hot formation. The experience gained within the oil and gas industry with respect to directional wells completions is readily transferable to improve the drilling and completing HDR wells.

A common requirement of all geothermal projects is a long operational life of its wells. The projected producing life of oil wells rarely exceeds fifteen to twenty years. Some new gas wells are designed for twenty five to thirty five years. Underground storage wells are designed with an operational life time that may exceed thirty five years. However, most HDR projects require a minimum operational life time of fifty years to become economic. In the case of high oil prices, shorter operational life times can become economic, as the electricity price also increases.

The long-term integrity of geothermal wells is a critical issue, not only because of the shortage of experience in this field, but also because testing a well's integrity takes time. Casing and cement fatigue are two examples of the geothermal well design challenge. While casing fatigue has been already investigated by several researchers (Teodoriu, 2005), cement fatigue remains a less explored area.
The use of intelligent well completions to continuously monitor casing stresses and deformations, the temperature along the well and the downhole pressure may become a standard practice for geothermal wells. This information gathered via may prove fundamental towards the optimization of future geothermal projects.

Finally, the major challenge faced by the design of geothermal wells is the cost. Higher well costs will impair the economics of a geothermal project. An underestimation of the well costs at an early stage may lead to the project being abandoned at a later date. On the other hand, the implementation of cheap completion solutions may lead to high maintenance costs in the future. A case study was presented (Brunetti and Mezzeti 1970), where 86% of the total casing failures were found to occur at the couplings. The major cause of the connection failures was found to be due to the "compressive stress during heating cycles". As the authors reported, "much damage was noticed in 9-5/8" and 13-¾" casings used in geothermal drilling, necessitating expensive restoration of the well." The connections that referred to were API LTC type. Most of the newer geothermal well completions employ API Buttress or proprietary connections.

CONCLUSIONS

Geothermal energy offers a constant and independent supply. Tapping geothermal energy is not always straightforward as deep drilling is required in order to access this high -temperature resource. Together, drilling and well completions can account for more than half of the capital cost for a geothermal power project. However, the lessons learnt from oil and gas completions can help in the frontier areas of new geothermal wells completions, both from the technical and the economic point of view. This paper presented a comparison of different well completions used for oil, gas and geothermal wells. It identified ways in which to facilitate a faster technology transfer from the traditional oil and gas arena to the developing geothermal industry.

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