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ADVANCED DRILLING SYSTEM FOR DRILLING GEOTHERMAL WELLS - AN ESTIMATE OF COST SAVINGS

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ABSTRACT

An advanced geothermal drilling system (AGDS) has previously been proposed. This system concept is based on the use of a percussion drilling motor and dual wall reverse circulation drill strings. The concept is based on a merger of the deep drilling capabilities of conventional petroleum drilling equipment with mining, water well, and civil engineering drilling technologies.

The use of percussion drilling is introduced to provide significantly increased penetration rates in the harder geothermal reservoir rocks, as compared to roller-cone bits and rotary table drives. The dual wall drillstring provides solutions to lost circulation control (the major problem frequently encountered in geothermal drilling) .

Recent oil and gas literature reports field experience that compares conventional rotary drilling with roller cone bits, directly, with side-by-side drilling using a new hydraulic (mud) percussion drill. These results show a 10 to 15 penetration rate increase for the percussion drill. An example is presented that illustrates the significant time and cost savings that might be afforded by using a percussion drilling technology in a typical geothermal well drilled in the United States. This example results in 35 to 39 days saved from a total of 67 days to drill this 2,930 meter (8,940 ft) typical production well. This corresponds to 52 % to 60 % time savings. When time savings are reflected in only the costs that are time dependent, cost savings of about 27 to 39 % are realized. The example drilled in 1997 at a total cost of US $1.87 million has an estimated savings of about US $600,000. These cost savings are a direct result of an increased rate of penetration (ROP). The world wide average ROP for roller-cone bits ranges from 4 to 5 m/h in geothermal reservoirs. Therefore, the potential of increased ROP with hydraulic percussion drilling can lead to greatly reduced geothermal drilling costs.

The example indicates the clear benefits of an AGDS that can offer increased penetration rates. Because lost circulation averages about 35% lost time, in over one third of all geothermal wells, the cost reductions offered by a system that can help control lost circulation will be enhanced. This AGDS feasibility study is continuing with consideration being focused on the dual-wall reverse circulation drill string performance optimization.

1. INTRODUCTION

This paper reports on the progress of a feasibility study for an advanced geothermal drilling system. The concept originated from a workshop held in April 1993 and was organized by the USA National Academy of Sciences/National Research Council, NAS/NRC (1994). Over the past half-decade this concept has been described and presented at several international technical conferences: Rowley 1993; Rowley 1994; Rowley et al., 1995a; Rowley et al., 1995b; Rowley et al., 1995c; Rowley et al., 1995d; Rowley et al., 1996a; Rowley et al., 1996b; Rowley et al., 1997a; Rowley et al.; 1997b. This sequence charts the course of development of the Advanced Geothermal Drilling System (AGDS) concepts and elements. The purpose of the AGDS is to potentially reduce costs of geothermal drilling significantly from those costs that are incurred with the use of conventional petroleum drilling equipment and procedures.

1.1 Merger of Mining, Water Well, and Civil Engineering Technologies

It has been well established that worldwide application of the presently available oil and gas drilling method produces geothermal drilling costs much greater than oil wells of comparable depth. This is basically due to the low penetration rates in the harder geothermal reservoir rocks, the much higher temperatures encountered for geothermal wells, and that the low reservoir pressures result in many, severe lost circulation zones.

To resolve these limitations the AGDS concept suggests a merger of technologies that are well established in the harder rocks found in typical mining, water well, and civil engineering drilling projects. Therefore, the use of a hydraulic or air/nitrogen driven percussion hammer and application of a larger diameter dual-wall (concentric pipe) drillstring were adopted.

The many technical papers presented, reviewed, and published over the past half decade have provided a thorough evaluation of the AGDS concept. In addition an international team of drilling engineers has been formed to provide critical, detailed reviews and guidance for this AGDS feasibility study.

The current phase of the AGDS development is focused on a fluid flow, heat transfer, and pressure loss analysis for the dual-wall drillstring configuration. The purposes of such analysis is to determine the optimum concentric pipe diameter ratios to minimize pressure drop (lower mud pump power) effectiveness of cooling of bottom hole assemblies (BHA) and to evaluate the use of the flow analysis between the borehole wall and the other pipe to control lost circulation. Such an optimization was previously established for a dual-wall drillstring using air/nitrogen (Rowley et al., 1996c).

1.2 Drilling Advances

Recently, two new basic drilling advances have been reported that are directly relevant to this AGDS concept. They provide support for the viability of this concept. The first is the report of field tests of roller-cone bits and a percussion hydraulic hammer (Schoemakers 1997). This drilling performance comparison indicates that the percussion drilling method can easily yield 10 to 15 times increased ROP in deep hard rock drilling.

The second sets forth the extensive field drilling results for casing-drilling (Tessari et al., 1999 and Tessari et al., 1999a). This is a definitive demonstration that the concept of drilling with casing (without a conventional drillstring) can be realized. The field trials in Canada have shown deviated and directional drilling including horizontal drilling.

1.3 Cost Savings Example

This paper concludes with a brief examination and estimate of the possible cost savings by use of an AGDS for drilling a commercial geothermal well in the USA. The data for this drilling analysis are taken from field records. An advanced hydraulic percussion hammer is conservatively assumed to provide improved ROP of from 5 to 10 times those obtained by the roller-cone bits used to drill the example well in 1997. Large cost savings from this performance gain are estimated from 27 to 39 percent. The analysis includes only those savings related to the time saved in drilling the 17 1/2 inch and 12 1/4 inch hole sections that comprised the major sections of this example well. No advantage was taken for additional time savings possible by use of the dual-wall drillstring to control lost circulation.

2. CONCEPT

The AGDS concept has been described in detail as noted above, however a summary technical description is warranted. It should be remembered that this concept is a merger of previously applied drilling hardware and methods. Only slight modifications were suggested to adapt to geothermal well drilling applications.

2.1 Overall Concept

The schematic sketch in Fig. 1 illustrates the major components of the AGDS. A deep well, 4,000 meter depth capacity, and a large diameter, 12-1/4 inch production hole, drill diameter is intended.

The schematic of a typical dual-wall (concentric-pipe) drillstring is shown in Fig. 2. The type of casing couplings and thread geometry are set forth in the class of joints designated as Integral Joint Couplings (IJC) and are extensively used on premium casings (Bethke et al., 1994). These are the same structural couplings used for the casing-drilling system mentioned above.

2.2 BHA and Percussion Drill

The sketch in Fig. 3 indicates a concept for the appropriate BHA for the AGDS. It has a dual-wall flow interchange element, an indexing motor, orienting and bent subcomponents, and a hydraulic (mud) hammer. Several hydraulic hammers are currently under development (Pixton et al., 1995 and Bui 1989).

The basic configuration of one hydraulic hammer under development is shown in Fig. 4. This design features a central, parallel flow path and a unique valving system (Hall et al., 1995).

2.3 Use of Air/Nitrogen

Geothermal well drilling often encounters pressure sensitive fractured reservoir rocks; this is particularly true for steam dominated reservoirs. Such situations are usually drilled underbalanced. One example is The Geysers in California USA (the largest steam field thus far developed). Therefore the analysis of a dual-wall drillstring using air/nitrogen was conducted and results of an optimization calculation is shown in Fig. 5.

It seems very possible that a similar optimization can be found for liquid drilling fluid (mud) drilling. A range of ratios of pipe diameters should be found to minimize the pumping power requirements and flow conditions that can provide the most effective cooling of the BHA components. The modeling of a dual-wall drillstring should also explore the optimum fluid flow conditions for the borehole-to-outer pipe annulus. That is to define ranges of conditions that would enhance lost circulation control and promote borehole stability.

3. COST SAVINGS EXAMPLE

In order to demonstrate the dramatically significant cost savings potentially realized by having a greatly increased rate of penetration (ROP), a sample calculation was carried out for a typical geothermal well. The drilling history and configuration for this 2,930 m (8,940 ft) deep well drilled in 1997 is recorded in Fig. 6.

This well took 67 days to drill and complete, and the major sections were drilled with 17-1/2 inch and 12-1/4 inch diameter bits. The original ROP values for these sections were 3.0 m/h and 1.5 m/h respectively. These are typical ROP values for roller cone bits in hard rocks. The worldwide averages range from 2 to 5 m/h. If the potentially enhanced ROP, using a hydraulic percussion hammer, are taken to be 5 and 10 times those recorded for this example then very rapid drilling of the two major sections is achieved. As shown, there will be a rather large savings in the days needed to drill the well, namely 35.2 and 39.6 days respectively. This is an average time savings of about 37.5, or 56 %. However, when these time savings are converted to the time dependent costs (e.g., rig rate, rentals, etc.) the average cost savings is reduced to about 34%. The result is an approximate cost saving of US $600,000 from the total cost of US $ 1.87 million.

These large cost reductions of about 1/3 of the total cost are significant. However, this example illustrates that nearly 2/3s of the cost remain after higher ROP is achieved. Therefore, other elements of well drilling and construction must be targeted for further cost reductions. That is: casing, cementing, tripping, and other costs (e.g., mobilization and de-mobilization, and drill pad preparation) must be lowered by new innovative technologies and practices.

4. DISCUSSION

4.1 Use of Percussion Drilling

The example presented above clearly indicates that significant cost savings are possible by substituting a suitable hydraulic percussion hammer for the usual roller-cone bits. This is completely in accord with the field tests and observations made by Schoemakers (1997). Savings up to perhaps as great as 30 % may be realized. However, the hydraulic hammer must have a durability of at least that of roller-cone bits, and preferably longer. Also obviously, the percussion hammer must be ultra-high temperature rated without temperature sensitive components. It is also very evident from the example presented that additional measures must be taken if the desirable improvements in costs of the order of 50 % or greater are to be achieved, Carson et al., 1982.

4.2 Suggested Advanced System Directions

It is clear that any advanced geothermal drilling solutions must approach the cost reduction problem as a complete system. Although incremental improvements can be achieved by use of percussion drilling, to obtain major cost reductions a revolutionary approach is required.

Two directions to be considered are:

- an extension of the dual-wall drillstring by use of casing-drilling (Gaddy 1999, Tessari et al., 1999, and Tessari et al., 1999a). This approach will eliminate drillstring round trips. The problem area introduced is making the modifications needed for high-temperatures. However such an approach opens up the possibilities for "smart drilling"; and
- the selection of an all-hydraulic drill rig (changes in the surface equipment). This approach has been taken in Europe (Gaddy 1999) and indicates that major savings, perhaps as much as 30 %, can be realized with such new rig equipment. It is ideal for handling the casing-drilling methods mentioned above.

Thus far the AGDS design team and the feasibility study have not addressed such further innovations.

5. CONCLUSIONS

This report supports the following conclusions:

- the petroleum drilling industry has demonstrated that a hydraulic percussion hammer can increase the rate of penetration by factors of 10 to 15 compared to drilling hard rocks with roller-cone bits;
- greatly increased ROP can save about 50% of the drilling time for a typical USA geothermal production well with only the method of drilling changed;
- 50% time savings only results in a 1/3 cost reduction due to the other fixed costs in geothermal well construction costs;
- therefore, it is evident that to make further major cost reductions, the other elements of well drilling and completion must be improved and costs lowered significantly; and
- as a consequence of such analyses reported here, a designed-for-purpose advanced geothermal drilling system is needed.

The AGDS international design team has understood this, and therefore must complete further extensions of the feasibility study that is underway.

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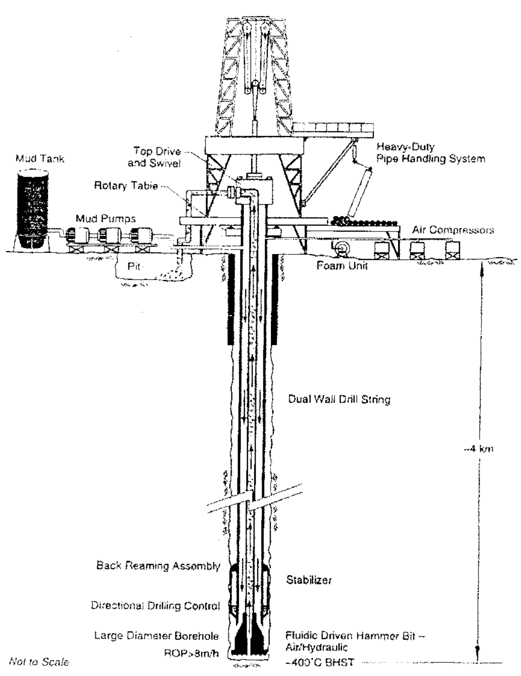

Figure 1. Schematic Conceptual Sketch of Proposed Advanced Geothermal Drilling System.

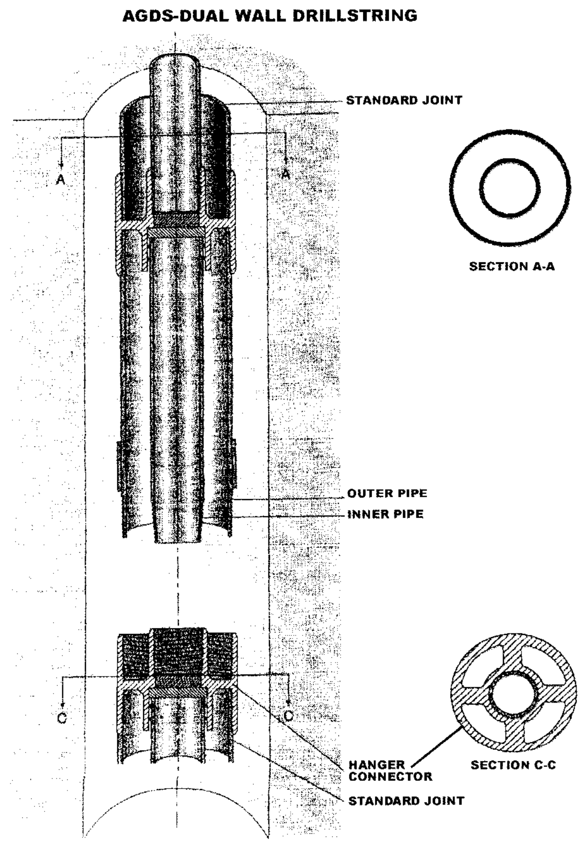

Figure 2. Proposed AGDS Dual-Wall Drillstring.

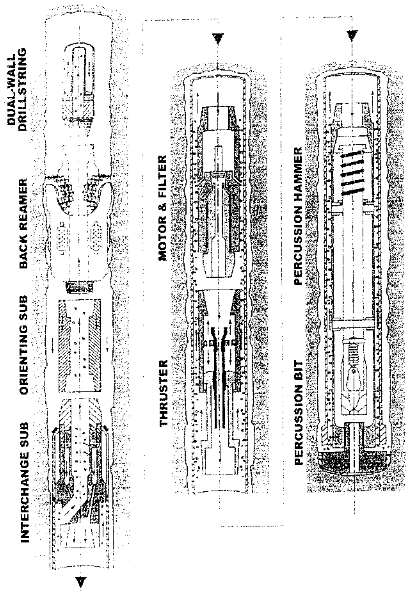

Figure 3. Conceptual Sketch of the Sub-components for the Proposed AGDS BHA. These Sub-Components require further design and analyses in order to complete the Feasibility Study.

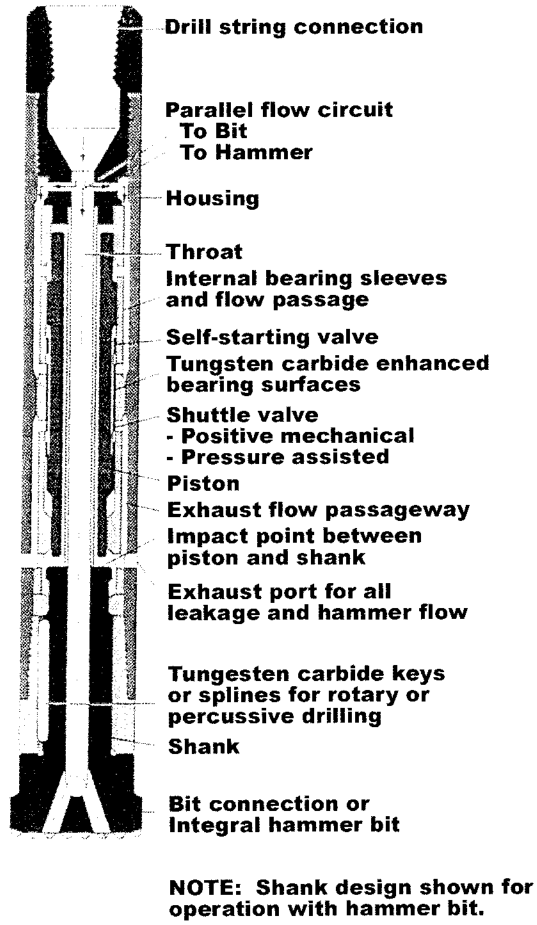

Figure 4. Cross Section Sketch for the Novatek (Hall et al., 1995) Hydraulic Percussion Hammer Under Development for Geothermal Applications.

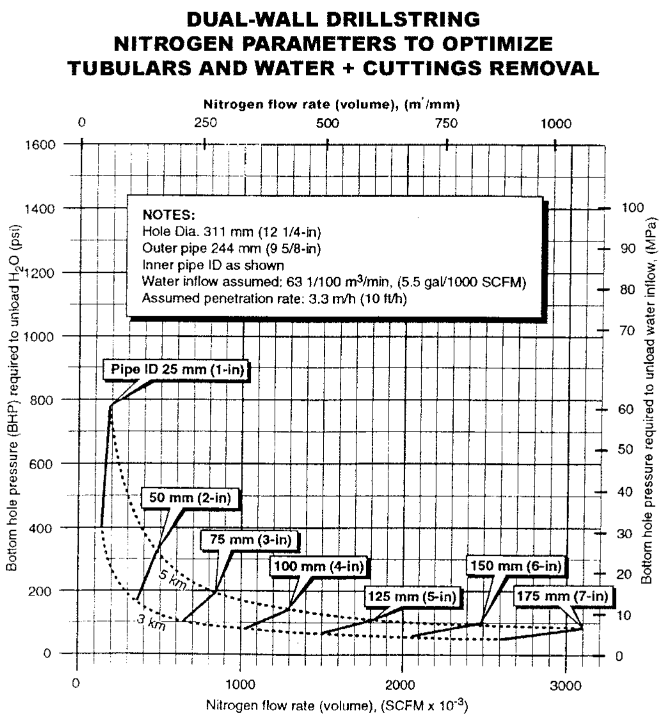

Figure 5. Optimization Calculations for Dual-Wall Drillstring Used with Air/Nitrogen.

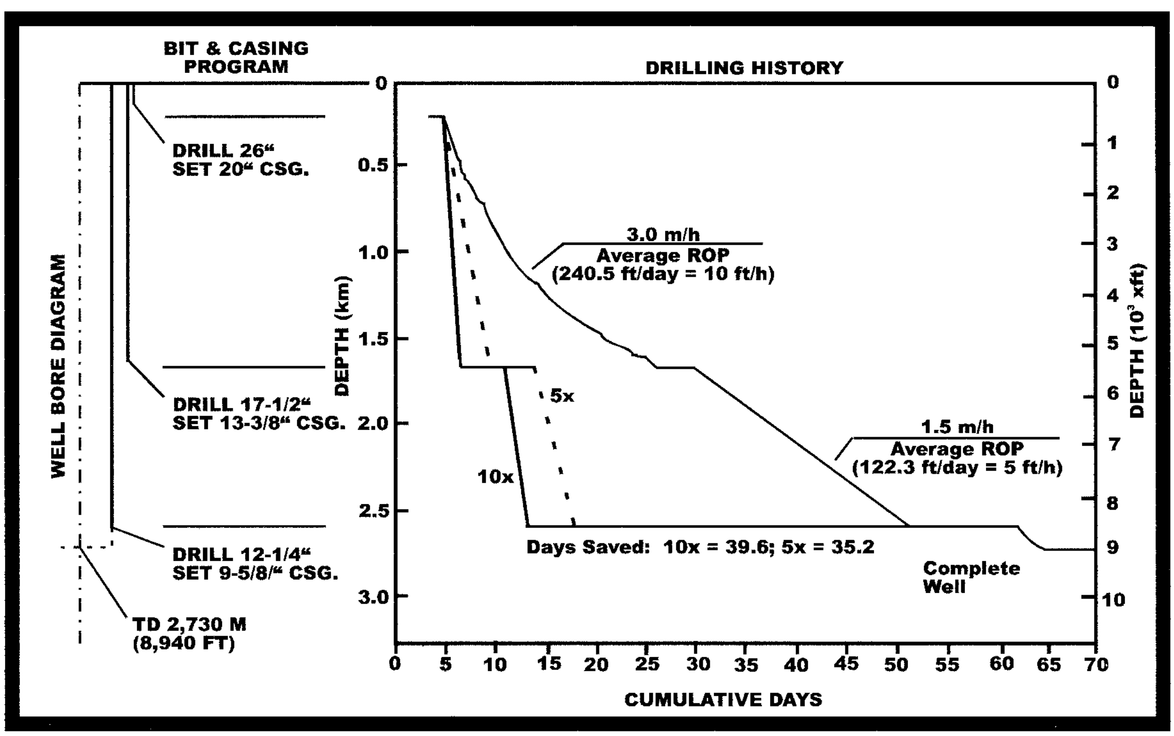

Figure 6. Drilling History for Typical Recent (1997) Geothermal Production Well, Showing Time Savings for Increased ROP.