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Controlled Pressure Drilling Applications for Enhanced Geothermal Systems

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ABSTRACT

The adoption of new technologies, like controlled pressure drilling (CPD), has been identified as a way of reducing well costs associated with deep enhanced geothermal systems (EGS). CPD methods, particularly air drilling (AD), managed pressure drilling (MPD) and underbalanced drilling (UBD), are an aggregation of techniques that utilize a closed and pressurized wellbore by utilizing a rotating control device (RCD) instead of the conventional practice of drilling with the hole open to the atmosphere. The utilization of these methods usually translates to more effective and efficient drilling operations. Though these methods, especially air drilling, have commonly been used to drill conventional geothermal wells, they have not yet been largely utilized in improving the drilling operations of EGS systems. In EGS drilling, MPD and UBD methods have been tried, but AD, which has the greatest potential among the three to increase the drilling rate in hard rocks, has hardly been involved. This paper focuses on the potential of CPD methods, whether individually or in combination, for improving the economics of drilling EGS systems, in light of recent advances in CPD technology.

1. INTRODUCTION

Controlled pressure drilling (CPD; **Figure 1** for the CPD Wheel) methods utilize a closed and pressurized wellbore instead of the conventional practice of drilling with the hole open to the atmosphere. These methods utilize a rotating control device (RCD; **Figure 2**) to close the well at surface, thereby allowing for greater and more precise control over the pressure profile of the well, which translates to more effective and efficient drilling operations. The RCD is designed to direct the flow of drilled cuttings brought up by the aerated fluid away from the rig through the tee installed below it into the blooie line. The rubber seal unit rotates with and seals around the drillpipe and tooljoint when making connections or tripping in or out of the hole. The three main types of CPD methods are: 1) air drilling (AD); 2) managed pressure drilling (MPD) and; 3) underbalanced drilling (UBD). AD is mainly geared towards increasing the rate of penetration, MPD reduces rig non-performance time, while UBD minimizes reservoir damage and increases productivity.

Air drilling, the application of air, mist, aerated liquid or foam fluid systems to lower the density of the drilling fluid, is mainly intended at reducing costs by drilling faster. It is a widely accepted technique for drilling geothermal wells for a variety of reasons, examples of which are minimization of circulation losses, increase in penetration rate, material savings, elimination of differential sticking, lesser water requirements, the ability to discharge during drilling, and the prevention of formation damage. The technique and the four different types of fluid systems (air, mist, aerated liquid and foam) it involves have been proven to produce positive results in geothermal applications worldwide.

The International Association of Drilling Contractors (IADC) defines MPD as an adaptive drilling process used to precisely control the annular pressure profile throughout the wellbore (2005). The objectives of MPD are to ascertain the downhole pressure environment limits and to manage the annular hydraulic pressure profile accordingly. It is intended to avoid continuous influx of formation fluids to the surface. Any influx incidental to the operation will be safely contained using an appropriate process.

The same organization defines underbalanced drilling (UBD) as a drilling activity employing appropriate equipment and controls where the pressure exerted in the wellbore is intentionally less than the pore pressure in any part of the exposed formations with the intention of bringing formation fluids to the surface.

2. CONTROLLED PRESSURE DRILLING AND ENGINEERED GEOTHERMAL SYSTEMS

The United States Department of Energy report written by Massachusetts Institute of Technology scholars on engineered or enhanced geothermal systems (EGS) with the title “The Future of Geothermal Energy: Impact of EGS on the US in the 21st Century”, stated that EGS are different from conventional or high-grade geothermal systems in the sense that high-grade hydrothermal resources have high average thermal gradients, high rock permeability and porosity, sufficient fluids in place, and an adequate reservoir recharge of fluids, while all EGS resources lack at least one of these (MIT, 2006). An example it provided of an EGS resource is reservoir rock that may be hot enough but not produce sufficient fluid for viable heat extraction, either because of low formation permeability/connectivity and insufficient reservoir volume, and/or the absence of naturally contained fluids. EGS, as defined in the report, would exclude high-grade hydrothermal resources but include conduction-dominated, low-permeability resources in sedimentary and basement formations, as well as geopressured, magma, and low-grade, unproductive hydrothermal resources.

Applied to EGS, CPD methods have the potential for increasing the rate of penetration (ROP), reduce fluid losses, allow for the management of wellbore pressures, and enable testing wells while drilling. Air drilling or aerated fluid drilling methods have the most potential for increasing ROP. Underbalanced methods can provide reservoir protection and reduce fluid costs. Managed pressure drilling gives control over pressure and over drilling hazards like losses, gains and collapse. CPD methods can also enable inflow testing, allowing for the drilling of only as much formation as required, though it is important to note that there are temperature limits for this.

Historically, CPD methods have been rarely used in the drilling of EGS worldwide, and conventional drilling methods are the norm. It has only been in recent years that managed pressure drilling, and then underbalanced drilling, were used to drill EGS wells, particularly in Australia. Air drilling and aerated fluids drilling has been used in drilling high-grade geothermal resources, but no record of its application has been found for EGS.

3. CONTROLLED PRESSURE DRILLING APPLICATIONS IN ENGINEERED GEOTHERMAL SYSTEMS

All the CPD methods hold promise for greatly improving the economics of EGS projects, most of which are currently concentrated in Australia, where 33 companies have applied for 282 geothermal licenses (Australian Government, 2008). However, of the three CPD types, only UBD and MPD have so far been used to drill EGS systems, more particularly in the EGS drilling operations of Geodynamics Ltd. in Australia. Most of the data provided below on the application of UBD and MPD methods in Australia is based on the results published by Geodynamics in their annual reports (2004-2008).

Managed pressure drilling, as applied by Geodynamics in the EGS wells they have drilled in the Cooper Basin, was defined by the company as “exactly balancing the pressure from the well with a combination of heavy weight drilling fluid and back pressure”. The method was first utilized by Geodynamics in 2004 for drilling the Habanero-2 well, its first deep geothermal production well, which was completed to a depth of 4,359 m (14,301 ft). According to Geodynamics (2004), operations in Habanero-2 did not only have to manage high over-pressures (5,200 psi / 35.85 MPa) and temperatures (250°C / 482°F), but also had to cope with much higher than expected permeabilities of the fractures in the target granites, developed as a result of previous hydraulic stimulation in the Habanero-1 well.

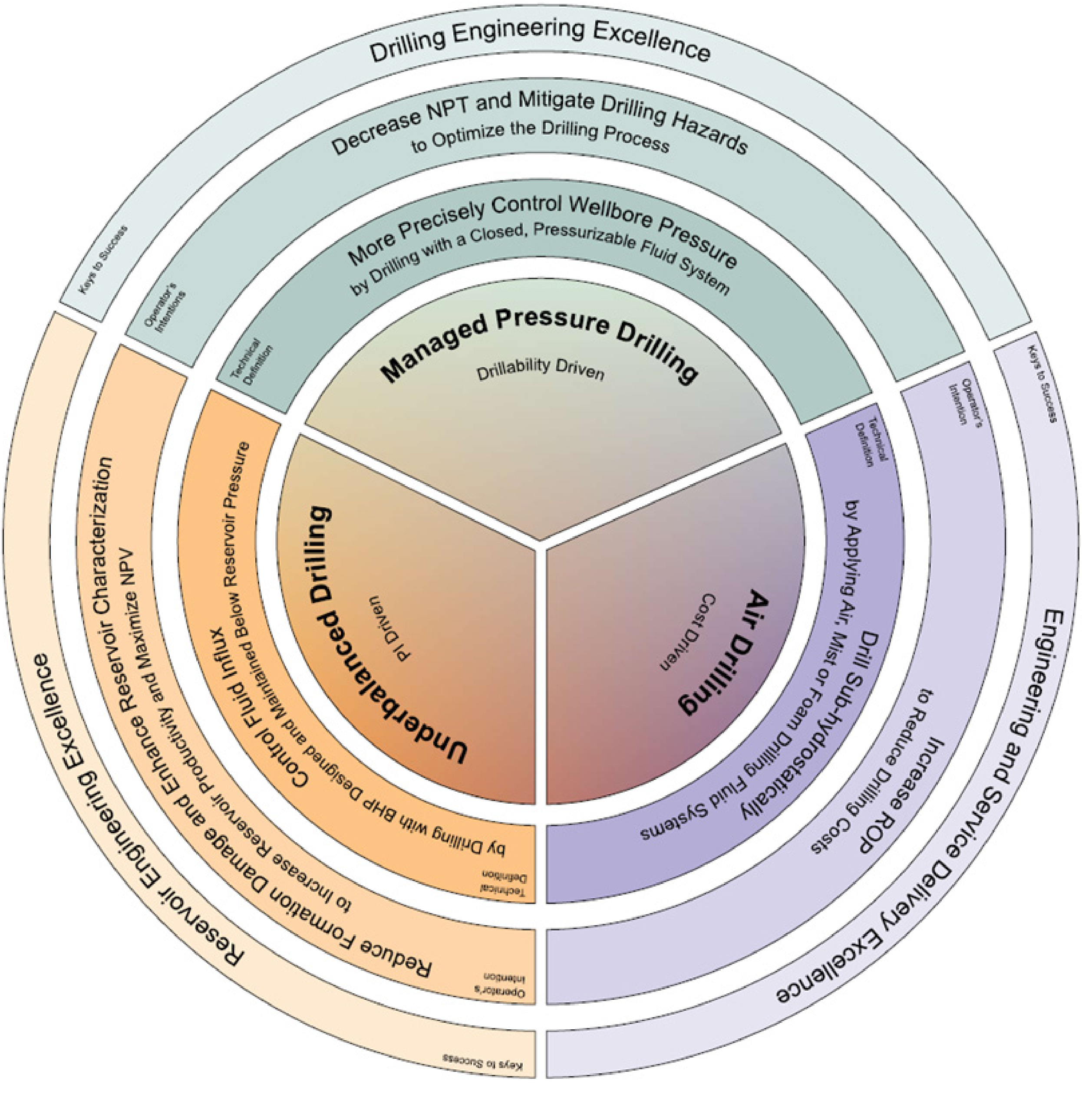

Figure 1: Weatherford controlled pressure drilling wheel.

The MPD variant used in Habanero-2 is called Constant Bottomhole Pressure or CBHP. It is uniquely useful in this particular application due to pore-pressure estimate uncertainty, as often associated with deep-well high-temperature/high-pressure (HTHP) drilling and complex geological environments, can be easily accommodated by simple adjustment of applied annulus surface backpressure.

Figure 2: One of the recent rotating control device (RCD) models.

As described by Weatherford (2005), CBHP enables "walking the line" between the pore- and fracture-pressure gradients. The objective of the method is to drill with a lighter fluid so that bottomhole pressure (BHP) is maintained constant, whether the fluid column is static or circulating. The loss of annulus flowing pressure when not circulating is compensated for by applied surface backpressure. An RCD, rigged up above the annular blow-out preventer, and an additional choke facilitate this control. During connections, when the mud pumps are stopped, the choke is closed to apply annulus backpressure at surface, thereby ensuring that a constant BHP is maintained.

The end result of using CBHP is that, as the hole is being drilled ahead or circulated clean, BHP does not change from its static value. The benefits these bring are as follows: drilling can be carried out with less ECD, the formation fracture-pressure gradient is less likely to be exceeded, losses are not incurred, and the hole section can be drilled deeper. CBHP MPD allows deeper setting of casing shoes and may ultimately reduce the total number of casing strings required for reaching well total depth (TD). This advantage allows reaching TD with a hole size large enough to ensure well productivity objectives.

Underbalanced drilling was also used by Geodynamics for a well intervention on the Habanero-2 well. Geodynamics decided to use a different drilling approach using fully underbalanced drilling with water using a snubbing unit in order to eliminate the problem of lost drilling mud into the reservoir that has caused damage to the fracture permeability during previous drilling and were expecting to increase the drilling rate of penetration (ROP), as compared to balanced drilling (Geodynamics, 2006).

Reviews of the UBD operation recommended that "the next drilling campaign take place with a conventional drilling rig operating under MPD for the bulk of the granite section (Geodynamics, 2007)". The combination of full UBD with a snubbing unit was deemed not efficient for drilling the large sections of granite above the target fracture zone as it exacerbated spalling (breaking off of small rock fragments) within the well, leading to hole cleaning and stuck drill pipe problems (Geodynamics, 2007).

After experimenting with and abandoning UBD with a snubbing unit as a drilling approach following completion of an independent technical review, Geodynamics decided to drill a new commercial-scale well, Habanero-3, with a larger diameter 8-1/2" hole, as opposed to the previous 6" holes on Habanero-1 and 2, using MPD methods.

MPD was also used to drill the section below the 7 inch casing for Habanero-1. The process designed in-house by Geodynamics, was also used in Habanero-3 to help control drilling operations when overpressured fractures within the stimulated reservoir were intersected. Managed pressure drilling has therefore been used throughout all the Habanero wells of Geodynamics, as well as for the recently drilled well Jolokia-1.

AD methods have the potential to cut drilling costs by 15% to 20% by maximizing the penetration rate, have not yet been utilized fully for EGS, although aerated fluids drilling has been largely applied in drilling high-grade geothermal fields in the Philippines, Indonesia and New Zealand (Toralde, Sosa and Nas, 2008). No record of air drilling and aerated fluids drilling use has been found for EGS in the region.

4. CONTROLLED PRESSURE DRILLING EQUIPMENT AND MATERIALS FOR ENGINEERED GEOTHERMAL SYSTEMS

Aside from MPD and UBD, the use of AD methods, especially with recent advances in CPD technology, can be utilized to improve the economics of EGS wells. Developments in AD technology that have applications in EGS involve higher temperature and pressure capabilities for both the equipment and materials used in the process.

As mentioned in the MIT report, "to extract thermal energy economically, one must drill to depths where the rock temperatures are sufficiently high to justify investment in the heat-mining project". For generating electricity, this will normally mean "drilling to rock temperatures in excess of 150°C to 200°C; for many space or process heating applications, much lower temperatures would be acceptable, such as 100°C to 150°C". Higher pressures also have to be dealt with, as evidenced by the Geodynamics experience, where the presence of over-pressured granite sections have produced pressures as high as 5,200 psi (35.85 MPa), as well as temperatures up to 250°C (482°F).

Recent advances in CPD technology have included the development of RCDs, air hammers (Figure 3), foam systems, and corrosion control chemicals that are able to withstand higher temperatures and pressures, making them uniquely applicable to EGS systems.

Progress in deep hot air drilling has been made with the development of a high-temperature air hammer that is designed to work in temperatures of up to 205°C (400°F).

Hammers capable of withstanding higher temperatures are under development. Among the high-temperature features of the new hammer are a blow tubeless design, high temperature spring seats, choke, “O” rings, check valve seal, feed tube housing washer and feed tube compression ring. This type of air hammers have been successfully tested in the US and in China, and have been proven to increase the drilling rates of penetration by as much as 500%. In China, the technology was successfully used to drill a 12-1/4” hole with a bottomhole temperature of 191°C (375°F) up to 4,300 m (14,108 ft), producing a ten-fold increase in penetration rate. Issues associated with air drilling, however, like water production (wet formations), hole stability, gas production (small amounts of gas can be handled) and hydrogen sulfide presence, need to be addressed beforehand.

Figure 3: Air hammers and bits.

New RCD models (Figure 2) that are able to handle drillpipe sizes up to 6-5/8 inches and tool joint diameters up to 8-1/2 inches, which are useful for extended-reach horizontal wells and ultra-deep vertical wells common in EGS that require large-diameter drillstrings, are now available. These RCDs can withstand pressures of up to 2500 psi / 17.2 MPa (dynamic) and 5000 psi / 34.5 MPa (static), and are applicable for the application of either MPD, UBD or AD in the reservoir section of EGS systems, where the pressure is closer to lithostatic, instead of hydrostatic, values. Butyl stripper rubbers capable of withstanding steam exposure and temperatures of as much as 121°C (250°F) continuously are available.

High-temperature corrosion control systems that are job-specific combinations of three corrosion inhibitors to provide quick passivation and long-term protection for downhole tubulars and hardware at temperatures up to 500°F (260°C) and are particularly suitable for EGS applications are currently available. A high-temperature foam system is under development.

5. CONCLUSION

The adoption of new technologies, like controlled pressure drilling (CPD), is required to reduce well costs associated with deep engineered geothermal systems (EGS). CPD methods, which are an aggregation of techniques that utilize a closed and pressurized wellbore by utilizing a rotating control device (RCD), are geared towards more effective and efficient drilling operations. Managed pressure drilling (MPD) and underbalanced drilling (UBD) have so far been used to drill EGS systems. No record has been found of the application of AD methods in EGS, despite of the fact that it has the potential to reduce drilling costs by as much as 20% by maximizing the penetration rate. In light of recent advances in CPD technology, the feasibility of utilizing these methods, AD in particular, to improve the economics of drilling EGS systems have increased, as CPD equipment and material capable of handling higher pressures and temperatures are being developed and tested.

The varying nature and geology of the EGS systems, as well as the different approaches that have been taken by the companies pursuing their development, however, will require the customization of CPD methods based on the applications required.

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