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Survey on Effective and Feasible Emerging Technologies for EGS Well Drilling

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ABSTRACT

Geothermal well drilling differs from oilwell drilling in some points, although both use the same rotary drilling methods. The primary point in drilling geothermal wells may be the formation temperature; this temperature is higher in geothermal wells than typical oil wells even at the same depths. In addition to the extremely high-temperature environment, two other critical issues are the frequent occurrence of severe lost circulation in naturally fractured or fault zones and very low penetration rate because of volcanic or granitic hard and abrasive formations. The increase in drilling costs because of these problems peculiar to geothermal well drilling will be a barrier, particular, for the development of enhanced geothermal systems (EGSs) as a promising renewable energy option for future. To reduce the drilling costs in EGS well drilling, we surveyed the applicability of emerging technologies being developed in the oilwell drilling industry. In this study, we evaluate the effectiveness and feasibility of these emerging drilling technologies for EGS development and discuss future tasks.

1. INTRODUCTION

The primary point of difference between drilling geothermal wells and oilwells may be the formation temperature; this temperature is higher in geothermal wells than in typical oil wells even at the same depths. In contrast, the formation pressure is generally low and sometimes subnormal or lower than the hydrostatic pressure in the typical geothermal development field. Figure 1 shows a comparison of the target reservoir pressure and the temperature range for oil and gas development and geothermal development. The pressure and temperature range categorized in the “HP/HT” area in the figure is now the target toward which exploration and exploitation are actively conducted. Moreover, the development target is extending to the “Ultra HP/HT” category, and correspondingly, the development of drilling equipment and materials is in progress by the oil and gas industries worldwide. However, geothermal development target is to achieve a much higher temperature range, as observed in the “HP/HT hc” category in the figure, and for which, the current drilling technology and equipment are not adequate.

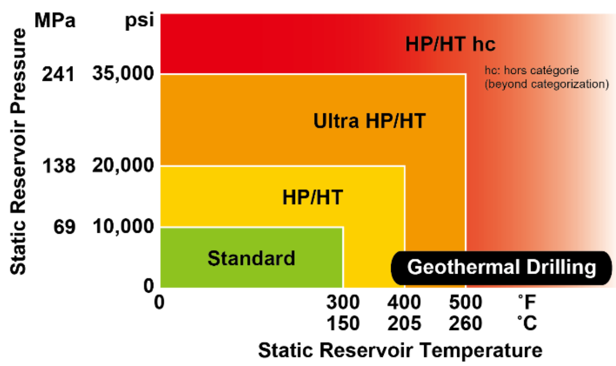

Figure 1: High pressure/high temperature (HP/HT) environment classification of the target pressure and temperature ranges for geothermal resource development in comparison with the oil and gas development. (Naganawa, 2014)

Geothermal development differs technically from oil and gas development, as shown in Table 1. In typical geothermal development fields, the formation temperature reaches approximately 250°C–350°C even at relatively shallow depth of 1,000–2,000 m, although the formation temperature in a typical oil field is at most approximately 200°C at a depth of 5,000 m. Thus, the heat-resistance performance of downhole tools and materials is the most critical issue. In addition, in a geothermal field, volcanic or granitic hard and abrasive formations are typical, resulting in a very low rate of penetration (ROP). On the other hand, the formation pressure in a geothermal field is typically low or subnormal, unlike that in an oil and gas field. Therefore, low-density and low-solid drilling mud or sometimes aerated fluid that has lower density than brine must be used. Nevertheless, severe lost circulation frequently occurs when drilling at low pressure and naturally fractured or fault zones. In many cases, the lost circulation encountered during geothermal drilling is a total loss, and the use of lost circulation materials (LCM) to stop it is insufficient. Typically, a lost circulation zone is blindly drilled out, and a cement plug must be embedded to stop the lost circulation. The restriction requiring the use of low-density drilling mud is disadvantageous for effective cuttings transport or hole cleaning in enhanced geothermal system (EGS) for directional drilling applications. It causes a barrier to safe well control operations during H_2S or CO_2 influx from the formation being drilled.

Table 1: Differences in drilling between geothermal wells and oil and gas wells. (Naganawa, 2014)

	Oil and Gas	Geothermal
Temperature	At most approximately 200°C at a depth of 5000 m	**250°C–350°C even at depth of 1000–2000 m ⇨ Highly Heat-Resistant Downhole Tools and Mud Cooling System**
Formation	Sedimentary Rock	**Sedimentary/Base Rock ⇨ Low ROP**
Pressure	High Formation Pressure ⇨ High Density Mud required	**Generally Low Formation Pressure ⇨ Low-Density or Aerated Mud**
Lost Circulation	LCM	**Frequent Occurrence in Fracture Zones ⇨ Cement Plug**
Cuttings Transport	Difficult in Highly Inclined Wells	**More Difficult because of low-density mud**
Formation Fluid	Some contain CO_2 and/or H_2S Gas	**Difficult in the prevention of H_2S and/or CO_2 gas because of low-density mud**

To reduce EGS well-drilling costs, we surveyed the applicability of emerging technologies being developed in the oilwell drilling industry (Naganawa, 2014). We then evaluated the effectiveness and feasibility of these emerging drilling technologies with respect to EGS development and discussed the future tasks in this study.

2. HIGH TEMPERATURE

2.1 Heat Resistance Performances of Downhole Tools and Materials

Table 2 summarizes a comparison of temperature limitations of downhole tools and materials currently with those from almost 20 years ago. There are some tools available for use in high-temperature environments over 200°C; however, any tool that uses elastomer components for sealing parts has a temperature limitation of approximately 175°C. Although heat-resistance performances have progressed during these 20 years, the overall temperature limitations of rotary drilling equipment remain below the typical geothermal development conditions.

Table 2: Temperature limitations of downhole tools and materials. (Naganawa, 2014)

		1996*	2014
Bit	Roller Cone	150°C	**288°C**
	Diamond	400°C	
	PDC		**350°C**
Drilling Fluid	Water Base Mud (Low Solid)	300°C	**300°C**
	Water Base Mud (High Density)	240°C	**250°C**
	Oil Base Mud	260°C	
	Synthetic Oil-Base Mud (SBM)		**315°C**
Directional Drilling	Positive Displacement Motor (PDM)	150°C–170°C	**190°C**
	Turbine Motor	350°C	**300°C**
	Rotary Steerable System (RSS)		**175°C**
	Single-Shot Survey Tool	250°C	
	MWD		**230°C**
Casing/Cementing	Liner Hanger	230°C	**340°C**
	Cement	260°C	**399°C**
	Float Shoe/Collar	200°C	**230°C**
	Stage Tools	260°C	**176°C**
	Cement Bond Log (CBL)	230°C	**260°C**
Completion	Perforator	170°C–210°C	**260°C**
	Packer		**315°C**
Wireline Logging	Temperature	300°C	
LWD	Temperature		**175°C**
	Gamma Ray, PWD		**230°C**

* Data from Morita et al. (1997)

2.2 Downhole Cooling Method

We have an experience with extremely high-temperature formation drilling in Japan. A geothermal exploration well "Kakkonda WD-1a," whose maximum formation temperature was estimated to be more than 500°C, was drilled in 1995, and the overall temperature limitation of the downhole tools used was approximately 150°C. The solution employed at that time was the top drive system (TDS) cooling method (Saito et al., 1998). As shown in Figure 2, the downhole temperature was successfully cooled and maintained below 170°C by continuous mud circulation implemented by a top drive drilling system combined with high-temperature stable drilling mud and closed-type surface mud cooling systems. This technology has not been popular in geothermal well drilling. However, using the TDS cooling method, the continuous circulation of mud during the running of the pipes into the hole was successfully achieved.

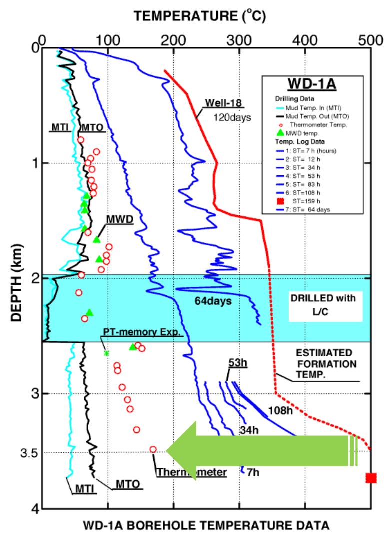

Figure 2: Temperature profile for the "Kakkonda WD-1a" well drilled in 1995. (Source: website of Geothermal Engineering Co., Ltd.)

Although the heat-resistance performance of downhole tools and materials has been steadily improving, downhole cooling by mud circulation is still an essential drilling operation for geothermal well drilling.

3. LOST CIRCULATION AND PRESSURE MANAGEMENT

Under- or near-balanced operations using aerated mud are sometimes employed in geothermal drilling to prevent severe lost circulation. At the same time, the managed pressure drilling (MPD) method is sometimes applied in oilwell drilling with a narrow mud window. Typical MPD methodologies are the constant bottomhole pressure (CBHP) method and pressurized mud cap drilling. As shown in Figure 3, normal MPD methods, including CBHP and pressurized mud cap drilling, using a rotating control device (RCD) at the well head apply a backpressure at the surface to the annulus.

For pressure management during the simultaneous occurrence of lost circulation and gas kick, as anticipated in EGS wells, MPD is a possible option for safe well control operations. However, under such conditions, the backpressure to be applied may be negative, and that is not a normal MPD operation (Naganawa, 2015). This type of MPD may be also effective for borehole instability and pipe-sticking problems, as well as for equivalent circulating density (ECD) management in directional wells, all of which lead to rig time and total cost reductions.

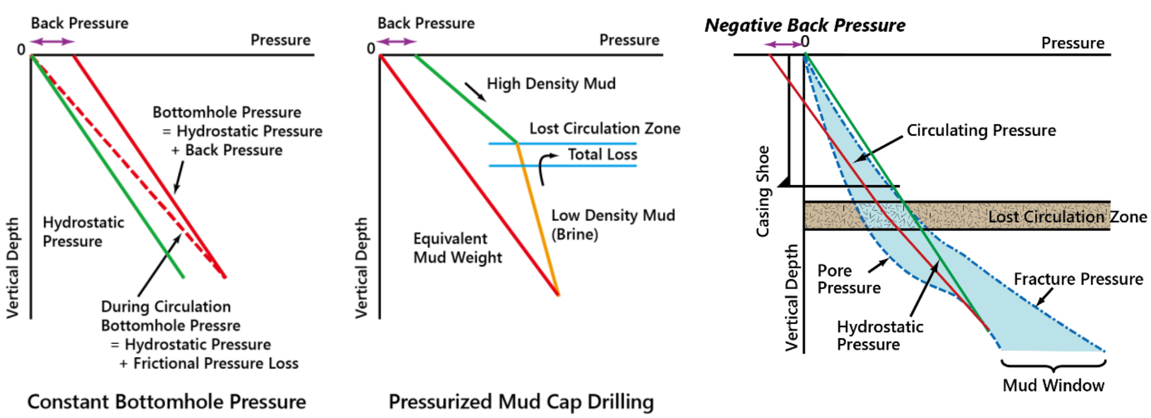

Figure 3: Typical managed pressure drilling variations (left) and the new MPD concept (right). (Naganawa, 2015)

Recent advances in MPD technology, as shown in Figure 4, include the continuous mud circulation system. This system is effective for maintaining downhole pressure even when making connections, thus making pressure management more accurate. The continuous mud circulation also has the advantage of downhole cooling.

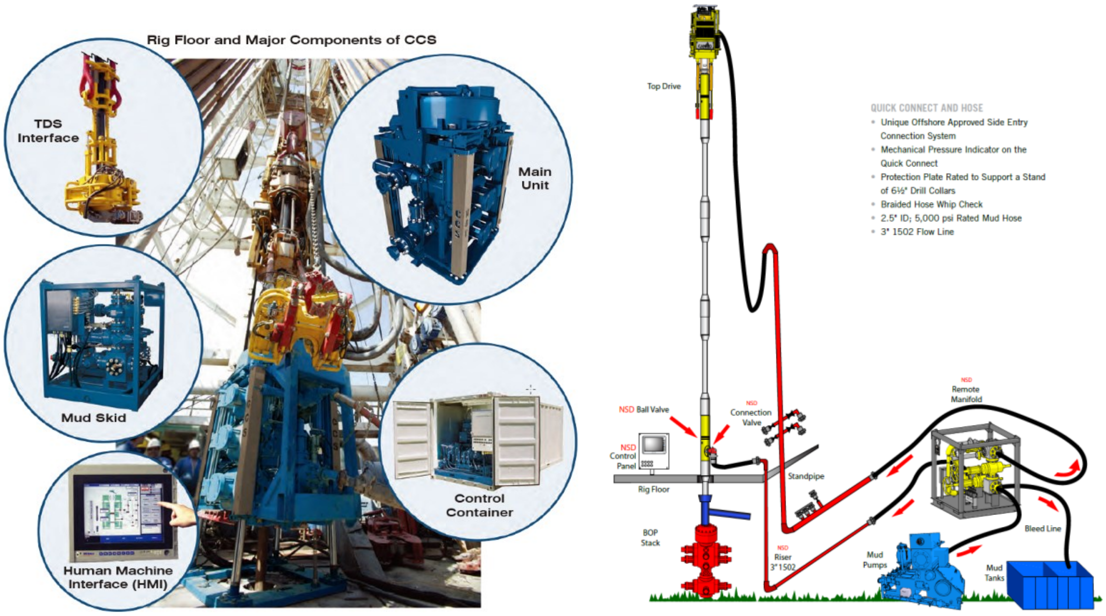

Figure 4: Examples of continuous mud circulation systems (left: National Oilwell Varco CCS brochure, right: Canrig Non Stop Driller brochure)

4. BIT TECHNOLOGY FOR HARD FORMATIONS

4.1 Application of PDC Bits to Geothermal Well Drilling

Depending on the structure and drilling mechanism, rotary drilling bits are classified as roller or fixed cutter bits. Among these, milled tooth bits, tungsten carbide insert bits, and PDC (polycrystalline diamond compact) bits are the most popular and most frequently used. Generally, PDC bits provide higher ROPs but are more expensive than roller bits. For use in geothermal drilling, PDC bits have the advantages of long life and high heat resistance because of the lack of elastomer-seal rolling components. However, PDC bits demonstrate poor performance when drilling abrasive and cohesive formations or hard formations in the geothermal field. Therefore, to date, insert bits designed for hard formations have generally been used in geothermal well drilling. However, PDC bits demonstrate good performance and have more than 60% of the market share in oilwell drilling, as shown in Figure 5.

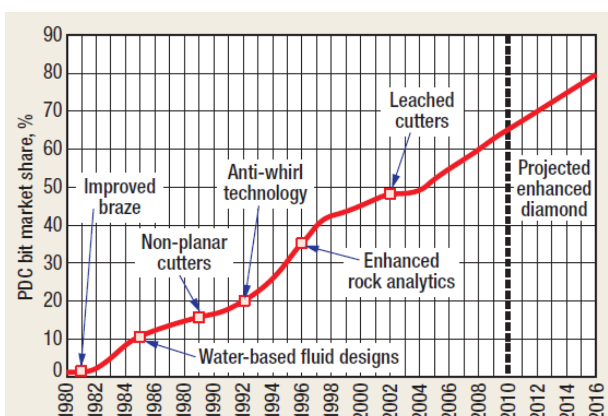

Figure 5: PDC bit market share with its development history. (Bellin et al., 2010)

Recent advances in PDC cutter technology have enhanced bit performance and durability across a wider range of lithologies than was previously possible (Bruton et al., 2014). With these enhancements, PDC bits were tested in a geothermal well drilled in Japan (Okada et al., 2014). Results showed that by using PDC bits for 12 1/4 and 8 1/2-in. hole sections, reductions were achieved in the number of round-trip operations for bit changes and improvements occurred in the rates of penetration, all of which led to significant reductions in rig time.

4.2 Novel Drilling Systems

In the 1960s, concepts of novel drilling systems, as shown in Figure 6, were already being presented to replace conventional rotary drilling bits (Maurer, 1966). While conventional drill bits have a mechanical rock breaking mechanism, these new concept drill bits use thermal spalling, melting, or vaporization action generated by electric, laser, microwave, or nuclear energy. However, these novel drilling systems were never implemented because high power generation necessary for these drilling systems requires large and heavy equipment that is difficult to install in downhole tools.

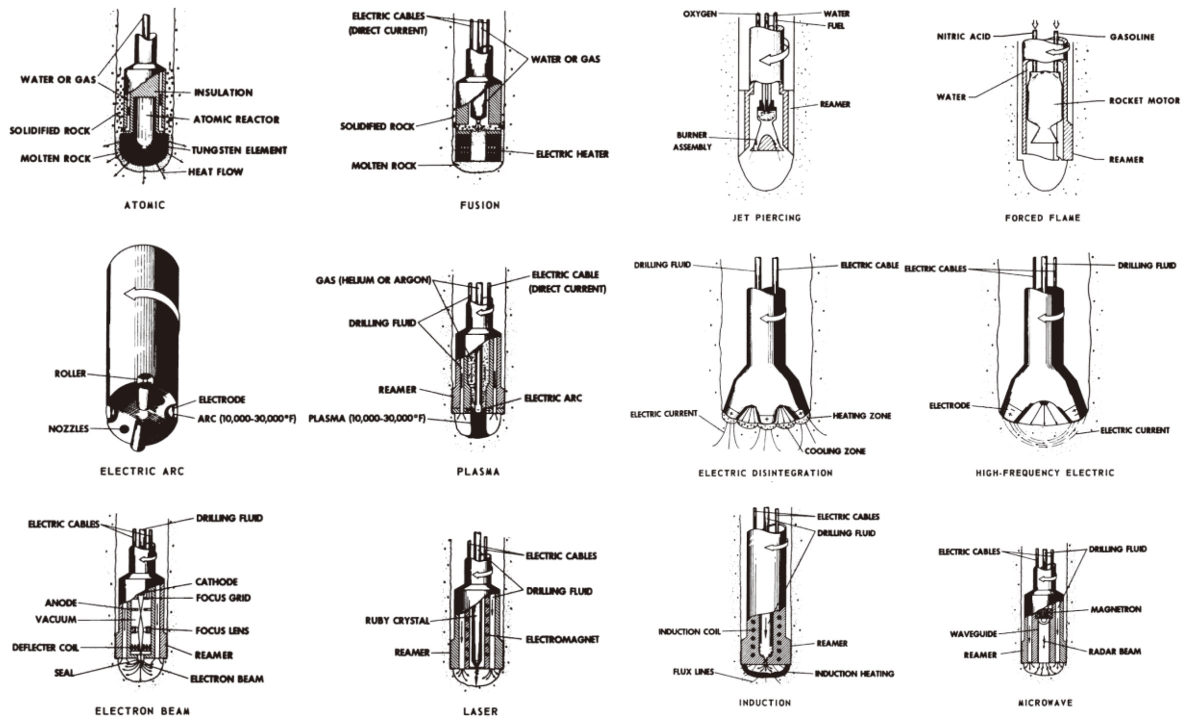

Figure 6: Various novel drilling system concepts. (Maurer, 1966)

Among these systems, research and development on laser drilling have been renewd since 2000 in some institutes such as the Colorado School of Mines, the Argonne National Laboratory, and the Japan Oil, Gas and Metals National Corporation (JOGMEC). While a laser drilling system is not yet commercialized, the development of laser and PDC-hybrid bits is progressing with funding from the US Department of Energy (Figure 7).

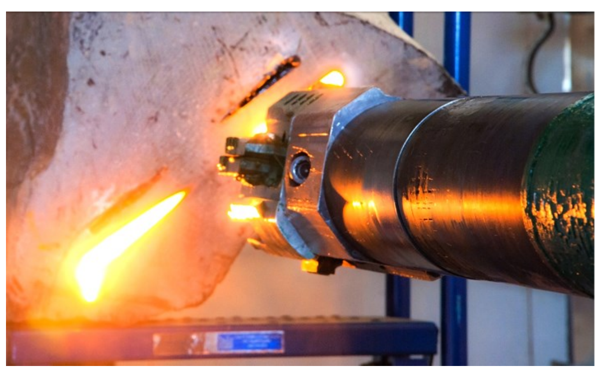

Figure 7: A prototype of laser and PDC-hybrid bits. (Zediker et al., 2012)

5. CONCLUSIONS

- Research and development for EGSs is now active in various countries around the world, including the US oil and gas industry, which has also focused its effort on the development of downhole tools and various drilling services for geothermal drilling.

However, cost reductions are more critical in geothermal resource development than in oil and gas development and may be a barrier in application of newly developed oilwell drilling technologies to geothermal drilling.

- Although the heat-resistance performances of downhole tools and materials have been steadily improving, downhole cooling using mud circulation is still required in geothermal well drilling operations. For future EGS development, the use of new mud circulation equipment may be appropriate to avoid any interruption of circulation during connection operations.

- Currently, measuring lost circulation is highly dependent on symptomatic methods such as blind drilling, LCM, and cement plugs. There is no versatile and reliable method for any type of severe lost circulation problem encountered in the geothermal field. Advanced pressure management using MPD technology should be considered in the planning phases as a potentially fundamental solution for lost circulation.

- There are many technology concepts that were presented and tentatively developed in the past but were never implemented because of the lack of sufficient elemental technology in electronics or materials at that time. However, some technologies such as the rotary steerable system (RSS) and the wired drill pipe have been implemented after several years of progress in elemental technologies. The development of novel drilling technologies is anticipated.

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