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Successful Geothermal Operation Management: Technology Adoption of Oil and Gas Drilling Rig Systems

Opeyemi Bello[1], Catalin Teodoriu[1], Ogunlana Oluwafemi[2] and Olatunji Olayiwola[2]

[1]Mewbourne School of Petroleum and Geological Engineering, University of Oklahoma, USA

[2]Institute of Petroleum Engineering, TU Clausthal, Germany

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ABSTRACT

The development of any oil, gas, or geothermal well is capital intensive, and a substantial part of the cost is related to the drilling. In a recent project report of a geothermal drilling operation in Germany, 36% of the project operational cost is allocated to the drilling rig. As geothermal well drilling is very comparable to oil and gas drilling, with the same principle of rotary drilling rig turning the bit. This signifies that proper drilling rig selection in any drilling operational activity is very decisive, playing a vital role in the design of a cost-effective drilling program for geothermal wells. A wrong choice can lead to downtime, drilling performance and economical effect in terms of unnecessary operation cost.

The Oil and Gas drilling industry is a technology dependent industry, leveraging on the emerging technologies in robotics and automation have played a strategic role for operational success in today's modern rigs system by saving costs, time saving, and increasing safety, improving operating efficiency and solving many optimization problems. Newer and compact rigs are designed to be more productive, provide more reliable uptime, meeting new safety requirements and have a lot more built-in safety features than older rigs.

An effective technology transfer and tapping into some of these successfully applied technologies in oil and gas industry will contribute positively to geothermal development, most especially drilling performance by eliminating incidents, increase productivity, minimize downtime and costs and optimize operational efficiency.

In this study, we first review the existing drilling rigs for geothermal applications with technology comparisons of the rig systems to oil and gas drill rigs. The influence of transfer in terms of drilling performance, increasing operational efficiency while keeping high safety standards were investigated and summarized. The paper further describes some of the currently tapped in and emerging technologies in oil and gas drilling operations that could benefit geothermal drilling operations. This includes robotics, IoT, drones, data analytics, artificial

intelligence and other hardware and software tools allowing to make faster and better decisions, eliminating human error, reduce costs and increase productivity and revenue.

1. Introduction

Geothermal energy, being derived from the earth's magnetic heat as a source of electricity or to heat cool building; is one of mankind’s major global resources playing an enormous potential effect in many industrial and developing countries through predominately mature technology (Bello et al., 2013). Studied shows that geothermal energy systems have a modest environmental footprint with a potential to become the world’s lowest cost source of sustainable thermal fuel for near-zero emission, base-load direct use, and power generation (Lukawski M.Z., et al, 2018). However, wells that are drilled to tap geothermal energy differ from the much more numerous oil and gas wells. Geothermal wells are usually hotter and are often drilled in harder rocks. There are currently six recognized geothermal resources, namely: hot dry rock (HDR), hydrothermal, magma, EGS, waste heat and geo-pressured. Figure 1shows the geothermal electricity generation capacity be country and the estimated distribution of global growth heat flow in milliwatts per square meter (mW/m²).

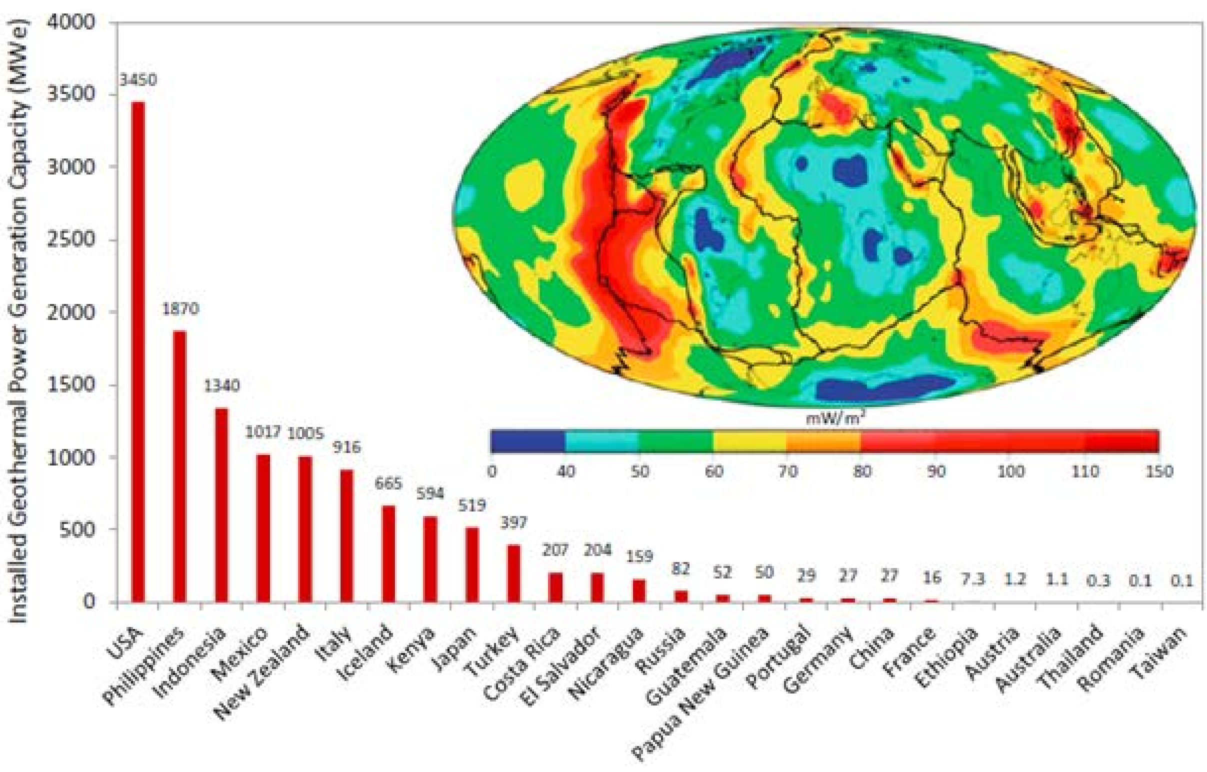

Figure 1: Geothermal electric installed capacity by country in 2015. This figure also illustrates global average heat flow in milliwatts per square meter and tectonic plate boundaries (black lines). (Reference Lukawski M.Z., et al, 2018)

Drilling rig selection is one the major bottom line during the development phases of both hydrocarbons and geothermal wells, based on comprehensive consideration of a variety of influences for its purpose. Both operations are highly cost intensive as it involves the services of personnel and array of machinery and materials for the duration of drilling the well. Report mentioned that geothermal projects tend to be more expensive than oil and gas drilling by 23% to 40% for a given depth (Lukawski et al., 2014).

The problem of drilling rig performance and selection has always been viewed as the most important responsibility during the well design phase of a field development (hydrocarbon or geothermal wells. The general conception of drilling rig performance used in the geothermal application has been associated with a rig size, mechanical capability, drilling rigs size, mechanical condition, horsepower rating and maximum load. Most of the criteria used for the rig selection are derived from well parameters; especially borehole diameter, depth and casing design. The planning and designing of the well will establish the borehole diameter, which is the principal criterion for whether the well is considered a slim hole or a conventional well. However, in geothermal applications, a large diameter is required; thus, a conventional rotary rig will be a good candidate. The foremost difference amid conventional hydrocarbon and geothermal drilling is the characteristics of the source rock.

Adams (1985) stated that many existing companies most especially operators are applying more effort in rig selection since it is important for the safety, efficiency, and cost of the well. Griffin (2010) also stated that drilling rigs that lead the industry in performance and safely at minimum cost are what drilling owners or operators strive to have, as these rigs will work in many different markets. Thus, with oil and gas drilling industry edging on technological progress, some of these mentioned key performance indicators could be met by reaching the well depth in a safe and controlled manner.

The oil and gas drilling industry is a technology dependent industry. Tremendous technological progression has been made in the development and enhancement of both conventional and unconventional rigs for the hydrocarbon development, for example in onshore applications. Advances in technologies have enabled the industry to reach new sources for oil and gas, saving costs, increasing safety, improving operational efficiency and reducing the environmental impact during the drilling operation.

Although conventional and improved conventional drilling rig types have been mostly used for different operations over the years, the unconventional over the years has rapidly gained the trust of most operators and well designers. With the recent adaption of technology as a form of automation which has shown proven advantages, newer and compact rigs are designed to be more productive, provide more reliable uptime, meeting new safety requirements and have a lot more built-in safety features than older rigs. Thus, adopting some of these newer and compacted unconventional drilling rigs will play a strategic role in the operational success of geothermal development.

This paper summarizes the existing drilling rigs for geothermal applications with technology comparisons of the rig systems to oil and gas drill rigs. The influence of transfer in terms of drilling performance, increasing operational efficiency while keeping high safety standards were also investigated. The study furthermore highlighted some of the currently tapped in and emerging technologies in oil and gas drilling operations that could benefit geothermal drilling operations allowing to make faster and better decisions, eliminating human error, reduce costs and increase productivity and revenue.

2. Oil and Gas Drilling Rig Systems

A rotary drilling rig can also be classified into three types: the conventional (traditional) or conventional, improved type and unconventional type. Teodoriu and Falcone (2008) defined the *traditional drilling* rigs as any type of that is being designed in accord with established forms and conventions with low load capacity with high structure. The *improved conventional* type allows high load capacity, high mechanization and increased safety. *Unconventional* drilling rigs are defined as any type of rig that is not conforming to state-of-the-art conventional systems. Most of the current *unconventional* drilling rigs in the market are characterized mainly by new designs for their hoisting systems to allow very high load capacity within small structures. Other important features of these rigs include electrical hydraulic drives; ability to use the AC electrical supply from a city power grid; low height (single derrick); high load capacity; partially or fully automated control systems, and modular construction.

Generally, conventional drilling techniques for geothermal development are applied as long as the drilling process has not yet entered the production zone. For drilling into and through crystalline petrothermal (i.e hot dry rock or enhance geothermal reservoirs) reservoirs, studies recommended using adapted applications for geothermal well drilling. Geothermal drilling rig requirements are very much like those for oil and gas drilling, in terms of design and operational procedures. Conversely, geothermal drilling poses some specific requirements for the selection of a drilling rig: drilling depth (EGS are generally below 5000 m), max hook load (needed for casing running), higher substructure (needed for the BOP stack), mud capacity and cooling. Where EGS wells are concerned, everything rises because of larger well and casing size, deeper drilling targets (5000 m) and hard rock drilling which require intensive tripping; therefore, rigs need to be taller. As drilling rate decreases, the wellbore size becomes smaller or the bit runs decrease as less rotary torque and pump power is desired. The main point at these conditions is on hoisting power to reduce or manipulate the overall tripping time. In application of casing drilling or managed pressure drilling to geothermal development, the load handling capability of the derrick and the top drive is of critical concern. Thus, running the casing deep limits the static depth ranging of the derrick. For managed pressure drilling, the height of the substructure must accommodate a tall BOP stack.

In order to make the geothermal projects more compatible using oil and gas drilling systems and increase public acceptance, new compact rig designs take into account the following criteria to makes them environmentally friendly; modular construction, smart power supply, small footprint, and technology sophistication entailing low noise emission hydraulically driven rig, automated control systems, monitoring units, soundproofed housing system, iron roughneck, pipe handling system (PHS) and skidding system with gains in customer specific solutions, safety and efficiency.

Summarized below are selected types of drilling rig for oil and gas operations based on the aforementioned three classifications that can be adapted to geothermal well development.

2.1 Unconventional Drilling Rigs

2.1.1 Herrenknect Terra Invader 350 (Innova Rig)

The TI-350 ‘box-on-box’ high tech drilling rig is capable of reaching geothermal resources at depths of 2500 m to 5000 m. The height of the derrick is 52 m with a hook load capacity of 350

t. The rig has a hydraulically driven hoist system and noise reduction arrangements that use insulated housing for the mud pumps and prime movers. The TI-350 noise level, over a distance of 150 m, does not exceed the volume level of a normally operated radio (less 60 dB). This is a great advantage, not only for the people living in close vicinity of the drill site but especially for the rig crew. In order to reduce the drilling cost and maximize the safety conditions, an automatic pipe handling system, a low maintenance cylinder draw works and new iron roughneck (hands-off technology) had been designed so that the rig can be run by a four-man crew. Another innovation is the derrick, which can be moved up to 10 m without the relocation of the whole drilling rig, saving time and money.

2.1.2 Huisman's LOC 400

According to the manufacturer, the demand for fast operation, flexibility, safety, and quicker rig moves to global locations triggered the development of the automated LOC 400. The LOC 400 was designed to take advantage of advanced equipment automation and integrated 3rd party services into the rig design in order to reduce the time, hazards and costs of drilling a well. Flat time while drilling a well and in between wells is also reduced through offline activities and quick rig moves. The drilling rig is equipped with an automatic pipe handler enabling highly efficient and safe handling of both casing and drill pipe. Furthermore, through intelligent design, drilling a well with the LOC 400 requires less fuel than typical rigs.

Some other advantageous features are related to efficiency and safety that entails offline BOP testing, craneless rig moves, efficient autodriller, on board casing running tools. The LOC 400 drilling rig system benefits are safety management through design, performance and energy efficiency. They include lower operating costs; safety; small footprint; lower fuel use; out of sight small rig structure; low noise and highly integrated control system.

2.1.3 European Land Rig 1500 RIG

The versatile drilling rig system is built to specific market requirements and unique need. The rig is configured to operate optimally in geological locations with stringent regulations or unrelenting, rugged environments for safety, quality, and environmental protection. A complete rig walking system package to maximize efficiency and minimize environmental impact. Adhering to strict noise regulations, the European Land Rig integrates noise suppression provisions in the generator buildings, drill floor wind-walls, HPU skid and more to achieve a noise limit of 55 decibels at a distance of 100 meters. Similarly, the rig system is designed with an integrated control system for managing, controlling and monitoring rig floor equipment for safe and efficient operations. The driller's cabin with configurable control screens and a CCTV screen maximize the driller's operational efficiency and awareness.

European Land Rig 1500 beneficial package entails safety, quality, environmental impact; comfortable operating conditions, mobility, drilling control system; connectivity and support

2.1.4 Precision Super Triple 1200 (ST 1200)

Super Triple 1200 is a powerful and versatile drilling rig delivering high performance and value service to deep development drilling operations, overcoming the challenges of a tough economic environment by delivering predictable performance and repeatability.

The drilling rig is designed to exceed performance standards required by top operators by offering highly automated features designed to improve operational efficiencies, provide a safer working environment, and deliver consistent results. Through his unique umbilical connection system, the ST-1500 moves from well-to-well without having to disconnect from the backyard complex. Furthermore, the Top-Drive is integrated into the mast to reduce the number of loads and prevent damage during transport. The use of hydraulics, a BOP handling system and modular design ensure safe and efficient rig up, down and moves.

Other features include small footprint, mechanized pipe-handling keeps workers out of harm's way and helps ensure operational efficiency, flexible XY Walking System - walk with a full setback and transfer tank, available 7500 psi high pressure fluid system to achieve maximum horizontal lengths and extremely flexible location configurability

2.1.5 Akita 850 XE

The 850 XE is an integrated walking rig system with depth capacity ranging from 12,000 to 30,000 feet. This state-of-the-art designed AC 1,800 hp rig for multi-well pad drilling for both conventional and unconventional resource development.

Other features include a drilling control system, iron roughneck, 850,000 lbs Max. hook load, 750,000 lbs walking setback rating, integrated AC 500 Ton Top Drive and dual position capable catwalk system. The 850 XE also features new and pending patent Offline Stand Builder (OSB) which allows the buildup and rack back of triple stand of tubulars while the rig is actively drilling.

2.1.6 Bauer TBA 300

TBA 300 can be used to drill deep geothermal wells in addition to conventional oil and gas wells. It can drill up to 5000 m depth and has a hook load capacity of 300 tons. Improvements to this rig include hydraulically driven components, like the top drive and pipe handling system. The hybrid hoisting system uses cable for handling casing and hydraulic cylinders for heavy lifting of drill pipes. The modular construction and the hydraulic components permit fast mobilization and demobilization times, which are a major requirement for these new compact rig types. The primary energy supply can be fed from a city power grid and, in case of an energy shortage, a diesel operated generator can be employed instead. The low derrick height of 41 m and small footprint of 759 m² make this rig very suitable for urban areas (BAU 2013).

2.1.7 KCA T-700

KCA 7-700 is highly automated, heavy land rig with a small-footprint. The rig has a 480-metric-ton hook load capacity and drilling depth capacity up to 7,400 meters. The rig has an overall height of 151 ft, relatively low of typical rigs of that size, and a mast height of 113 ft to minimize noise emissions. The rig also can be operated from the public power grid, which further reduces noise emissions.

The key design feature is the highly automated, integrated pipe-handling system designed to advance the hands-off philosophy, whereby the pipes are picked up from ground level and transported to well center by automatic sequence. The system increases operational efficiency while decreasing the human interaction on the rig floor, thus enhancing our ability to provide safe, effective and trouble-free operations. The rig includes skidding capacity for drilling on cluster locations. It is designed for tripping speeds of 600 meters/hr and “unlimited” setback capacity.

2.1.8 NOV Rapid Rig

Rapid Rig is an efficient land rig delivering maximum speed, safety, and performance in a compact drilling package. The Rapid Rig is designed with a 250 ton hook load capacity for shallow to moderate well depths, approximately 3300 m with AC electrical supply draw works rated to 1000 hp and gear driven with a regenerative dynamic braking system further reduce environmental impact at the well site. The fully automated rig floor, coupled with a revolutionary pipe-handling system, reduces crew size and accident exposure while providing a comfortable and efficient work environment. Also, the drilling rig system incorporated pipe handling capability to rapidly pick up/lay down, make up/break out drill pipe and run casing and be able to mobilize/demobilize in approximately 8 hours. The Rapid Rig's smaller size and self-deploying design allow for ease of transport and faster onsite rig-up/down.

Some of the rig system features will make a positive impact to drilling performance through lowering of transport cost, reduction of transport loads, fast, efficient pipe handling, accident exposure minimized and compact well footprint.

2.2 Improved Conventional Drilling Rigs

2.2.1 BENETEC 450 t AC EURO RIG

The BENTEC 450 t AC EURO RIG is a highly mobile and new land drilling rig representing all environmental and safety solutions as well as technological progress. The modular built rig is engineered with a fast-move philosophy and is classified as one of the most modern European land drilling rigs that meets the special requirements of the European market. The EURO RIG is low emission built in compliance with the latest European regulations.

The design features include drilling depth of 23,600 ft / 7,200 m, freestanding mast, small footprint, noise reduced equipment, less NPT with integrated Top Drive. The main drilling equipment is AC-powered.

2.3 Conventional Drilling Rigs

2.3.1 KCA Deutag T-45

The heavy 2000 hp land rig has a maximum hook load of 450 t with a maximum drilling depth of approximately 7000 m. The mast height is 45 m (KCA 2013). The T-45 rig, which was refurbished in 2009, was used to drill two ultra-deep (below 5000m) geothermal wells in Basel in Switzerland. It has a dual power supply, using diesel-electric generators or Alternative Current (AC) from the grid.

2.3.2 MB Century Drilling Rig 27

The conventional drilling Rig 27, which can be used for oil and gas or geothermal operations, has a static hook capacity of 340 t and can drill to a depth of 4,420 m (MBC 2013). The operator has drilled a vertical geothermal production well underbalanced into hot fractured granite at 4300 m in the Cooper Basin, Australia.

2.3.3 ITAG Rig 40

Rig 40's hook load of 200 metric tons, is higher than that of standard mobile rigs. It can be easily adapted to match the operator's space requirements because of its modular design (Drilling Contractor, 2005). In view of the space limitations on narrow access roads and small production sites, Rig 40's compact design requires fewer truck loads during rig moves. The rig move does not require special permit for road transportation. The mast is raised vertically on location with the use of a hydraulic cylinder, requiring less space. The rig is equipped with three sound-proof generator units with an installed power rating of 2,640 kW. The units are characterized by low fuel consumption.

Summary

Table 1 shows the performance indicators comparison between the three classified rig types; conventional, improved conventional and unconventional rigs that can be adapted to geothermal development. The principal specifications are categorized as follows; rig applicability, mechanical/technical capability, technology sophistication, environmental impact, drilling rig automation and add-in technologies like the integration of big data analytics (BDA) for intelligent well management and performance drilling software.

The *rig applicability* comprises of well class, climate operational condition, depth capability, mast height and type, availability of casing drilling technology, substructure height, size of drill pipe (DP), hoisting system and trip time. The *mechanical/technical capability* entails the maximum hook load of the drilling rig, lines strung, the setback capacity, rig power system, availability of top drive (TD), maximum TD, BOP stack size, drawworks capacity and drive system and lastly the mud pump capacity. The following sub-criteria are linked under the *technological sophistication*; automated control systems, monitoring units, soundproofed housing system iron roughneck, pipe handling system (PHS) and skidding system.

Table 1: Performance indicators comparison between conventional, improved conventional and unconventional drilling rigs

Performance Indicators	Conventional Rig	Improved Conventional Rig	Unconventional Rig
Rig Applicability	High	High	Very High
Mechanical/Technical Capability	High	Very High	Very High
Technological Sophistication	Moderate	High	Very High
Drilling Rig Automation	Absent/Low	Present/Moderate	Present/High
Environmental Impact	Moderate	Low	Low
Integration of BDA for Intelligent Well Management	Absent	Absent	Low progress
Performance Drilling Software	Absent	Absent	Low progress

3. Technology Progress in Oil and Gas Drilling Operations

3.1 State of the Art Drilling Technologies

Continued investment in drilling technologies is important as exploration for hydrocarbons goes deeper and longer and more complex from challenging rock formations. Hence, the development aspects to overcome drilling challenges is through the development of new technologies increasing revenues, lower costs, improve safety and maximizing efficiency in delivering a quality well.

Few of these developed and dominant technologies transforming drilling operations are described below.

3.1.1 Casing while Drilling (CwD)

Casing wile Drilling (CwD), also known as Casing Drilling is one of proven technologies that can save both operational cost and time. The focal point of this technology is to eliminate classic casing runs and isolate formations during drilling process by using standard casing string as an alternative to conventional drill string.

Some of the well-known benefits of this techniques include reduction time for tripping in and out, and the risk involved with it, as the time consumed for tripping the DS in and out of the well is nullified; improving drilling efficiency and mitigate drilling hazards hence minimize NPT; decreases overall costs by means of reducing potential need for remedial tubulars (Maggi, 2006). CwD serves a hazard mitigation solution, being recommended for application in shallow gas, high borehole instability formations and abnormal pressure zones; drilling time and cementing saving; Prevention and minimize losses while drilling (smearing effect). This technology needs a rig equipped with a top drive and efficient pump and mud system.

3.1.2 Percussion Drilling (Down-the Hole Hammer, DHH)

Meng et al. (2007) revealed that percussion tools can increase Rate of Penetration (ROP) by 2-15 times in hard rock compared to conventional rotary drilling with tri-cone or Polycrystalline Diamond Compact (PDC). The drilling principle consists of a combination of percussion and rotation with compressed air as the flushing medium. Special procedures, though, can also comprise flushing with water. The flushing medium is pressed through the drill pipes, down-the-hole hammer and drill bit and is forced back out at the mouth of the borehole, along with the loosened drill cuttings, through the annular gap between the drill pipes and the borehole wall.

DHH technology is intended to enhance the deep drilling capability. DHH transmit intensive impact energy with low energy loss, resulting to good rock breakage, high penetration rates and high productivity. Adapting this type of technology will work in high temperature environments of geothermal wells proving the following benefits including friction reduction; combines axial movement with rotational torque and speed to improve bit efficiency (increases ROP); Bit damage prevention; oscillates the BHA up to 10 times per second hence improving weight transfer and low operational cost.

Hard, fractured formations which are typical in geothermal formations, like igneous or volcanic rocks or metamorphous sediments are good candidate for percussion drilling. DTH hammer tools will greatly help the geothermal drilling industry to make their drilling activities far more economic, high productivity, optimal borehole quality and great reliability.

3.1.3 Expandable Technology- Tubulars

An alternative way of cutting off drilling cost is by maintaing downhole size by leveraging on expandable tubular concept. Expandable technology allows tubulars to expand in situ, and it has been successfully applied in many drilling operations with proven results because they offer the potential for a "monoborehole" and drilling to depths no longer limited by initial borehole diameter. It is commonly used for zonal isolation in depleted or trouble zones as a drilling liner. It was also found to be very useful for extended reach in brownfields without losing the tubular diameter for maximum production.

Geothermal construction can benefit from this technology as it allows casing and hole size reduction and corresponding rig size reduction that can lead to significant drilling cost saving. Additionally, the possibility of reaching depth could be increased by this technology for contingency casing string, leading to reduction in replacement well costs while improving economic ROI.

3.1.4 Closed Loop Drilling Automation

A closed loop system is defined simply as a mechanical and chemical system that allows an operator to drill a well without using a reserve mud pit. Closed loop systems have become more dependable and efficient, making drilling without a mud pit an economically attractive alternative in many oil and gas drilling operations. A closed loop system includes some solids control equipment (such as the shaker, desander, desilter, and proper centrifuge), which may already be on the rig, and a polymer flocculation unit, which is not part of a conventional rig's solids control system.

Closed-loop systems use sensor output or feedback as a means of controlling the machinery and ultimately processes that performs drilling optimization tasks by using high-speed downhole and surface data. The system allows surface equipment on the rig to be controlled in response to downhole data.

Using closed loop drilling automation will improve drilling performance with control of downhole weight on bit (DWOB); mitigating well control related risk; stick-slip mitigation, equivalent circulating mud density (ECD) management; improve downtool reliability; mechanical specific energy parameter optimization and improving economics. The longer it takes to drill a well, the less economically beneficial a closed loop system will be.

3.1.5 Hydrothermal Spallation Drilling

Kant (2016) cited that improving actual technology and developing alternative drilling technologies are possible means of reducing cost for hard rock drilling operations. Amongst the mentioned alternative drilling technologies are Flame jet drilling (Spallation drilling), Laser assisted rotary drilling and Electro pulse drilling.

Thermal spallation, the basis of flame jet drilling can be broadly defined as the fragmentation of a brittle solid into small, disk like flakes by rapidly heating a relatively small fraction of the solid. Thermal stresses caused by expansion of the solid with increasing temperatures lead to failure of the solid. Literature further revealed that the necessary temperatures and heat fluxes needed to induce thermal spallation in the high pressure, high density deep borehole environment could be achieved using hydrothermal flame technologies.

Hydrothermal spallation drilling benefits contain reduced drill bit wear and tripping time; high penetration rates; no contact with the rock which improves the trajectory control; drillability and reduction of drilling costs. Extending the application of thermal spallation drilling to developing geothermal resources will require developing a drilling system capable of drilling deep boreholes (2-10 km deep).

Other promising drilling technologies solutions are *Electric plasma drilling, Chemical plasma, GeoJetting (water jet) drilling and Laser drilling.*

3.1.6 Smart Rig System Technologies

The high demand of oil and gas has resulted to high risks and costs in operational activities. Thus, one of the possible solutions to lower risk is the introduction of automation and robotics into the drilling operations. Some of the developed and deployed smart technology integrated in drilling rigs are explained below as a function of well integrity monitoring, cost effectiveness and safe operation.

a. Intelligent Top Drive System

The DQ80BSC rig intelligent top drive system is mainly designed for the ultra-deep wells and complicated wells (Taian, 2019). It includes a sheave configured to receive a drilling line, a frame coupled with the sheave and configured to transmit a weight of a tubular string suspended therefrom to the sheave, a controller, and a sensor in communication with the controller. The sensor is configured to directly measure one or more physical parameters of a drilling operation and provide data representing the one or more physical parameters to the controller. A big advantage of this system over conventional top drive system is the ability to automatically adjust with the change of drilling conditions. The intelligent rotating speed and torque control system of DQ80BSC top drive system can automatically identify the drilling conditions according to the set value of the rotating speed and torque of the top drive system and the actual value returned from the downhole drill string and make real-time adjustment to the rotating speed and torque output characteristics of the top drive main spindle to effectively control the drill string is being impacted, twisted off or dropped out due to the sudden change of the downhole torque. Additionally, the risk of drill string failure and bit wear is greatly reduced and the service life of the drill bit and drill string is prolonged. DQ80BSC top drive system with sliding control technology for steering drilling can mitigate the friction resistance and the viscous capillary effect between the drill string and the borehole wall in the oriented hole, stabilize the drilling pressure and prolong the service life of the bit by forward and reverse reciprocating swing of the drill string on the basis of not affecting the orientation. Thus, improved ROP while drilling cycle can be shortened.

b. Rack and Pinion Technology

Rack and pinion technology has been successfully deployed in several other sectors including cog railways, elevators and automobiles.

Most modern drilling rigs utilize electric rack and pinion technology which enables precise control of block position required for advanced automation. They can both pull and push, utilizing thrust, not gravity. Since no wire is used, an uninterrupted connection between the hoisting system and the vertical movement of the drillstring is established, posing an accurate positioning and control of the drillstring along the well path. Some of the offered advantages of rack and pinion mechanism include the elimination and need for a drawworks, drill line, block and hook; compactable and ideal for managed pressure drilling, casing drilling, horizontal wells; there is no requirement for cutting and slipping the drill line. These types of rig system are automated, can be easily mobilized, require lesser personnel to operate, are quieter with a smaller footprint, and increases the probability of success on the job site.

c. Rigtelligent Control System (RCS)

Most modern rig systems are equipped with intelligent operating controls to further enhance drilling performance. The Rigtelligent controls from Nabors are integrated with advanced downhole tools, as the control system enables the automation of repetitive tasks and alerts the driller of any potential issues.

As the driller is tasked to manage more downhole technologies, the system incorporates wiring, sensing and decoding devices that readily integrate with downhole directional drilling tools. Drillers can utilize the RCS system to perform simultaneous tasks that were previously done in sequence, hence reducing NPT. Some of the proclaimed benefits include the ability to add additional rig services in controls, such as mud logging; intelligent" alarms that feature trend analysis in order to anticipate future breakdowns; synchronized top-drive operating data and alarms to the PLC clock for further analysis

d. Drilling Data & Analytics – RigWatch Suite (Nabors)

A comprehensive rig monitoring system that combines drilling, pit volume totalizer (PVT), measurement while drilling (MWD) and mud logging data. They help operators in making accurate and fast decision making and enhance operational efficiency. Additionally, an electronic drill recorder and PVT can be scaled to perform comprehensive drilling efficiency optimization in order to meet the needs of any customer. The system visualization flexibility features improved the interpretation of instrument data.

As tens of gigabytes of data being collected from nearly any type of instrument, it executes advanced algorithms against this data to help improve drilling efficiency, monitor rig performance and track equipment usage. The accumulated data can be presented using dozens of different visualization tools that allow rig site personnel to quickly and efficiently respond to changing environmental and process conditions. These integrated systems have been shown to improve ROP, assist in the delivery of custom data applications, and decrease non-productive time.

Other smart drilling rig system technologies include *Automated Pipe Handling System, Integrated Drawworks*

3.1.7 Big Data Analysis and Intelligent Oilfield Assets Management

In the past 20 years, several monitoring and measurement sensor systems have been designed and developed to collect various types of downhole data. In general, downhole data includes high resolution pressure and temperature, high frequency pressure, multiphase flow rate, phase cut, distributed sensing data from distributed acoustic sensors (DAS), distributed temperature sensors (DTS), discrete distributed temperature sensors (DDTS), discrete distributed strain sensors (DDSS), time-lapse seismic, electrical potential and production logging tools. There are several technologies that can be used in monitoring and measurement sensor systems such as electronic sensors (pressure and temperature, quasi-distributed temperature, single and multiphase flow meters, streaming potential, permanent 3D resistivity based on electromagnetic method, permanent downhole seismic); fiber optic sensors (pressure and temperature, quasi-distributed temperature and quasi-distributed strain sensors, single and multiphase flow meters); permanent downhole seismic sensors, distributed temperature and distributed strain sensors; distributed acoustic/vibration sensors; distributed pressure sensors (Bello et al, 2017). The application areas can be grouped into the following categories: condition monitoring, well performance, well stimulation, flow assurance, advanced completions and reservoir characterization. However, these techniques cannot satisfy all of the requirements of cost effectiveness, accuracy, long-term measurements, and real-time monitoring of oil and gas assets. Wireless sensors are currently being deployed as a low–cost alternative to reduce sensor systems using micro-electro-mechanical systems based on sensors integrated with wireless sensors networks. The design of the downhole monitoring systems can be divided into the following components: sensors, data storage, data transmission, database management, data filtering, data mining (data analytics), events detection, data integration into models, decision making and reporting.

Since downhole big data are collected from many different sources by different data acquisition devices, database integration becomes a crucial aspect of downhole big data analytics. The data from different platforms and applications are usually heterogeneous, independent and mutually closed. More so, the data structure, format and quality vary widely hence data are only accessible through specialized API invocations. Many downhole big data analysis, data-driven and model-driven decision making tasks cannot be completed without database integration.

Figure 2 shows a structure of the downhole big data analytics for intelligent well and reservoir management. It entails data collection, transmission and storage; data cleaning and pre-processing; data integration and feature selection; data mining and knowledge discovery; representation, visualization and application; intelligent decision making and real-time interaction; and intelligent well and reservoir management. This intelligent data analytics management workflow can be adapted to geothermal development to maximize the value from the gathered data during drilling operations by identifying key drilling performance and cost-saving opportunities.

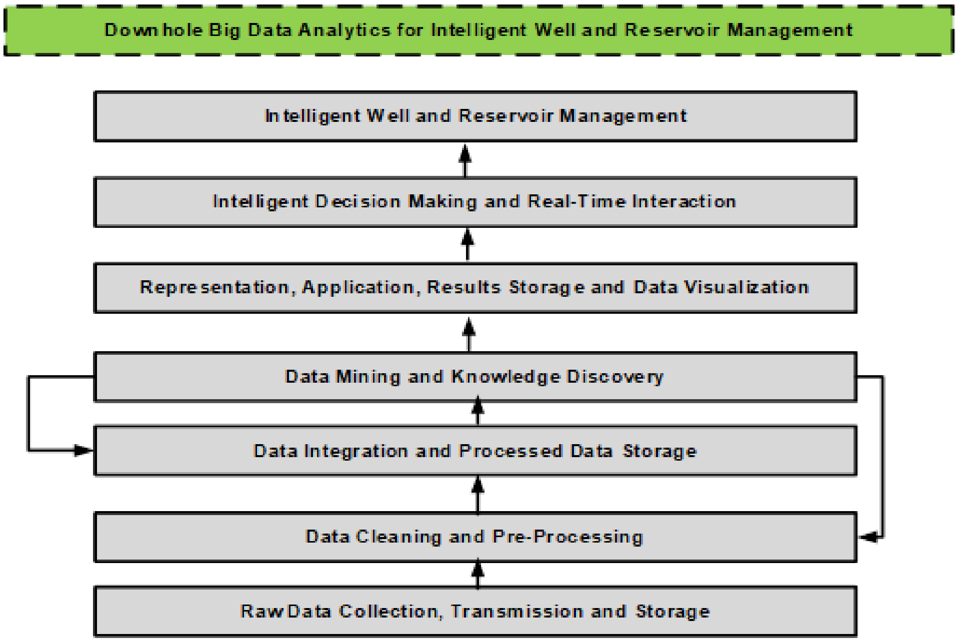

Figure 2: Downhole Big Data Driven Intelligent Well and Reservoir Management Workflow (Bello, 2017)

3.1.8 Artificial Intelligence Methods in Drilling System Design and Operations:

The number of publications on the application of AI in drilling operations indicates that this is a potential methodology to reduce drilling cost, increase drilling operation safety, by using previous experiences hidden in reports or known by experts. The core objective of AI in the drilling dynamics field so far has been to accurately predict the likely performance of variant factors contributing to real-time drilling success in terms of time, safety and the adopted drilling practice. Estimation of pre-drilling settings (rig, logistics and associated drilling risks), presumptions on probable formation response while drilling (gradients, abnormal behaviors and bit conduct), 'experienced' pattern recognition and selection of specific procedural equipment (drilling, casing and tubing pipes, drilling mud and cement material) and real-time monitoring and downhole control of bit and BHA behavior (vibrations, torque limits and incident-management) have been some of the focuses of industry consultants and oil and gas experts during the recent years. For his reason, the development and up-gradation of precise generic models and efficient data processing methods are required to prescribe a near-accurate impression of drilling operations when direct and real-time data is not available (Bello et al., 2015).

The complexity of the drilling operations and the unpredictable operating conditions (uncertainties regarding tool/sensor response, device calibration and material degradation in extreme downhole pressure, temperature and corrosive conditions) may sometimes result in non-accurate drilling data, hereby misleading the driller about the actual downhole situation. The indulgence of smart decision making models and optimized real-time controllers in the drilling system can also, therefore, provide the driller with a number of quick and intelligent propositions on key drilling parameters and on suitable preventive or corrective measures intended to bring the conditions back to an optimum drilling stage (Dashevskiy et. al, 1999).

Drilling success, depending on prevalent conditions, is a function of several general factors. These include the selection of best technologies and tools, procedural optimization, concrete problem-solving, accurate prediction and rapid decision-making. Figure 3 shows sub-categories based on the applicability of AI in drilling operations.

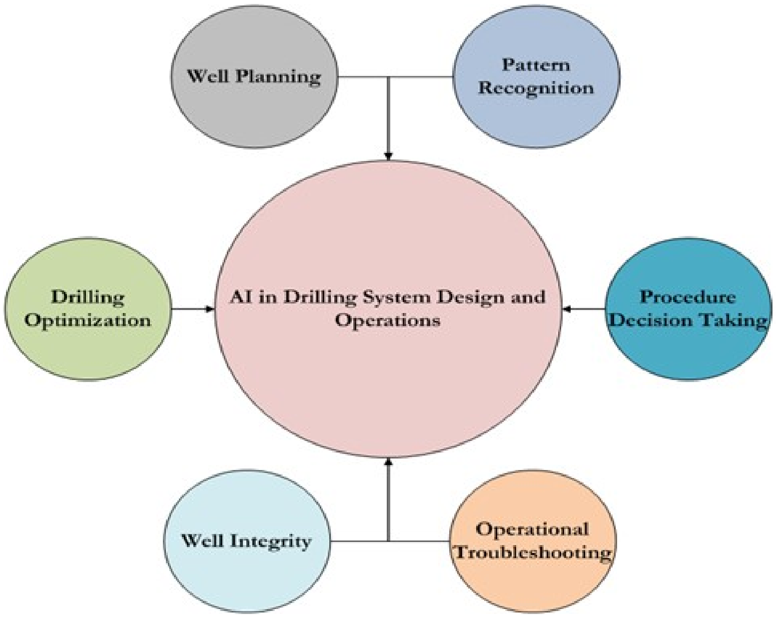

Figure 3: Application of AI in the drilling sector

Conclusions

The following conclusions can be drawn from this study:

i. It can be deduced that modularity, high automation, modularity, technology innovation and environmental impact mobility are principal performance indicators operators looked for in rig selection for consistent performance and cost reduction in oil and gas drilling development.

ii. It has become evident that major operators in the E&P industry not only call for the value of their invested money from rig contractors but demand for continuous good performance of existing drilling rigs with minimum downtime.

iii. The future of geothermal energy expansion relies on the procurement of modern rigs which meet the requirements based on reliability, performance and environmental impact.

iv. It is of utmost importance that oil and gas technology transfer makes it possible to maximize geothermal development drilling cost effectiveness and move closer to operational excellence.

v. The use of modern oil and gas rig systems in geothermal well development will help deliver operational safety combine with drill time saving by optimizing drilling performance and improving efficiency.

vi. Leveraging on data analytics for geothermal well development will provide access to a vast amount of data to help make better and faster decisions real-time enhancing performance and reducing overall costs.

vii. The knowledge transfer of BDA technology will not only validate use case for huge data in drilling systems design and operation management but bring substantial value resulting to cost reduction, high failure risk mitigation, NPT reduction and improvement on HSE performance.

Abbreviations

EGS	Enhanced Geothermal System
ROI	Return of Investment
DS	Drill String
NPT	Non-Productive Time
PLC	Programmable Logic Controller
HSE	Health, Safety and Environment
E&P	Exploration & Production

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