PERFORMANCE ASSESSMENT OF DRILLING RIGS USED IN GEOTHERMAL APPLICATIONS

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ABSTRACT

Geothermal drilling rigs, like oil and gas drilling rigs, employ the hook load capacity as the main discriminating factor when deciding which rig size to use. Hook load capacity becomes important for deep wells, as is the case for Enhanced Geothermal Systems (EGS).

For all drilling rigs, the depth of the planned well determines basic rig requirements like hoisting capacity, power system, mud circulation system and the pressure control system. When selecting the most cost-efficient geothermal drilling rig, the use of a compact design would save money by reducing mobilization costs, fuel consumption and make geothermal resources more cost competitive. Also, environmental concerns such as rig 'footprint' make smaller rigs more attractive.

This paper summarises the investigation of existing compact rigs used for drilling geothermal wells. Criteria to aid the selection of optimum geothermal drilling rigs are proposed. Case studies are presented where tailored drilling rigs, inclusive of the latest technology, have been implemented. Finally, the paper shows a comparative study of drilling utilisation factor based on various drilling rigs and different types of geothermal resources (i.e. EGS vs. hydrothermal).

1. INTRODCUTION

Geothermal energy, which is derived from the earth's magnetic heat; is one of mankind's major global resources for use in heat and electricity markets in many industrial and developing countries through predominately mature technology (Oswaldo, 2007). 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 recognised geothermal resources, namely: hot dry rock (HDR), hydrothermal, magma, EGS, waste heat and geo-pressured. These six systems may be classified according to their physical and geological characteristics which reveal individual geothermal energy potentials.

In its simplest form, the drilling rig can be seen as equipment that provides the motive power to rotate the bit, allow weight on the bit to crush the rock beneath, circulate the drilling fluid and hence achieve the drilling action. Operational requirements and economics dictate the sophistication of drilling rigs.

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 (Griffin 2010). The concept of drilling rig performance used in geothermal application has been associated with a rig size, mechanical capability, drilling rigs size, mechanical condition, horse power rating and maximum load. Most of the criteria used to select a drill rig will be 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 primary 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 used as shown in Figure 1

In the early 1980's, a new system called 'top drive' was introduced and is now commercially accepted. In a top drive rig, the drill string was turned by an electric or hydraulic motor hanging beneath the travelling block. This technique has the advantages of allowing the driller to, reduce connection time by working with stands (i.e. two or three joints of pipe screwed together) instead of adding drill pipe one joint at a time as the hole advances, and the driller can rotate and circulate while tripping into the hole. The cost of top-drive rigs is high in daily rental terms, but it is often cost-effective to use one.

Besides price, there are many considerations that influence the rig choice, such as rig capacity, rig footprint, fluid cleaning, drill string and bottomhole assembly (BHA), blow out preventer (BOP) equipment, high-temperature capability, crew and training, and instrumentation.

Rig selection for geothermal applications is often more complicated than it first appears, but the key to a successful choice is to have a clear and detailed view of what is needed for the project.

The authors undertook a comprehensive literature review in order to identify the essential criteria needed to compare the performance of compact drilling rigs used in geothermal applications, the results of which are described in detail below.

2. REVIEW AND COMPARISON OF DRILLIG RIGS USED FOR GEOTHERMAL APPLICATIONS

2.1GENERIC CLASSIFICATION OF GEOTHERMAL DRILLING RIGS

Drilling rigs are equipment used to explore and produce oil and gas from subsurface reservoirs, to drill water wells in aquifers, to tap into geothermal sources and for various civil and mining applications. Drilling rig can be classified by the power they use: electric, mechanical, hydraulic and pneumatic. Both conventional and unconventional drilling rigs consist of five main subsystems; pipe rotation, drilling fluid circulation, hoisting, power supply and blow-out prevention.

Geothermal drilling requirements are very much like those for oil and gas drilling. However, 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.

In order to make the geothermal projects more compatible, new compact rig designs take into account the following criteria to makes them environmentally friendly; modular construction, low noise emission, high hook load capacity, easily camouflaged, smart power supply and small footprint.

The various types of drilling rig for geothermal applications, both conventional (which uses draw works and “block and tackle” system) and unconventional (which uses hydraulic or pinion and rack hoisting system), and from different manufacturers are summarised below.

2.1.1 CONVENTIONAL DRILLING RIG

- **ITAG’s 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



Figure 1: A rotary drill rig. Finger and Blankenship (2010)

equipped with three sound-proof generator units with an installed power rating of 2,640 kW. The units are characterised by low fuel consumption.

- **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.

- **MB Century Drilling’s 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.

- **Lightning Rig 100**

The Lightning Rig 100 uses modern AC technology, which improves control of working machines (e.g. draw works, pumps, top drive) and has better energy efficiency. The rig can drill to depth up to 6000 m, due to the high hook load capacity of 450 tons. The base structure and the mast can be erected without the need for cranes, so the truck loads necessary for a rig move are approximately halved decreasing the rig move time compared to the same class of rigs, and so reduces cost (Geodynamics, 2008).

- **Bentec Euro Rig 350t**

Rig 350t is a multipurpose rig that has been also used for hydrothermal drilling. The rig has a hook load capacity of 350 t and a vertical lift mast consisting of three units with an A-frame, all dimensions being adapted for European road transport limits (conventionally, the following dimensions are considered as standard for European roads: 3 m width, 13 m length, 30 t weight) . Additional equipment, such as mud separation systems, tank systems, mud pumps, air compressors and heating system, are all modularized. The rig can move within 5 days using 55 containers (BEN 2013).

2.1.2 UNCONVENTIONAL DRILLING RIGS

The current unconventional drilling rigs are characterised chiefly by new designs for their hoisting systems to allow very high load capacity within small structures. Other key features of these rigs are: 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

- **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 mobilisation and demobilisation 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).

- **National Oilwell Rapid Rig**

The Rapid Rig is a singles rig as it has pipe handling capability to rapidly pick up/lay down, make up/break out drill pipe and run casing and be able to mobilise/demobilise in approximately 8 hours. The rig is rated for approximately 3300 m and has a hook load rating of 225 t with AC electrical supply draw works rated to 1000 hp and gear driven with a regenerative dynamic braking system. The top drive is controlled from a climate controlled driller‘s cabin on the mud pit side. It has a foot print of 56 m by 30 m (NOV 2013).

- **Drilltec Rig VDD 370**

For deep drilling applications, the Rig VDD 370 is very suitable. It has a hook load capacity of 370 tons and can drill up to 5000 m depth. The rig features an automatic pipe handling system that, like its top drive, is hydraulically driven (Back 2005). The modular construction permits safer and quicker rig moves using standard container sizes (40 ft), , so no special road transportation permits are needed. It has a low construction height of 31 m and small footprint of 1575 m², making it a good option in urban areas. Noise generating equipment is kept in insulated housing to reduce the overall noise levels. Over a distance of 300 m, the noise level of only reaches 49 dbA during drilling applications, which provides very low noise pollution for local residents adjacent to the rig site.

- **Herrenknecht Terra Invader 350 (TI-350)**

The TI-350 ‘box-on-box’ is capable of reaching geothermal resources at depths of 2500 m to 5000 m. The height of the derrick is 52 m with 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 (Binder and Ruder, 2008). 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 maximise 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.

3. SELECTION AND EVALUATION CRITERIA FOR GEOTHERMAL DRILLING RIGS

This sections describes the methodology in assessing the performance of drilling rigs used in geothermal applications in terms of demonstrated performance, drilling depth, hook load, footprint, drilling depth, hoisting power system, derrick and substructure and environmental impact. Table 2 gives the key issues associated with each of the criteria used to evaluate the aforementioned drilling rigs for geothermal wells.

The attributes and critical parameters are selected after reviewing the published existing drilling rigs for geothermal application. The upper and lower limits for every rig ranged between 1 (-), 2 (0) and 3 (+) are denoted by signs respectively. The base line is taken to be 2 (0), representative of an improved conventional rig, that is a depth of > 4000m. No weighting factors are assumed for the various technical parameters. Also, all parameters are considered to be independent from the others. Of course this may not be a fully realistic scenario; however, each real-life situation would require an ad hoc, in depth assessment, which goes beyond the scope of this paper.

Table 1: Comparison of conventional and unconventional rigs for geothermal application

Technical Parameters	**Conventional Rig**	**Improved Conventional Rig**	**Unconventional Rig**
Drilling Depth (m)	<4000	□ 4000	□ 5000
Hook Load Capacity	150-400 t	200-450 t	225-370 t
Power Packs	Diesel-Electric driven	Electrically driven (including AC-AC Technology)	Electrically driven (AC Generators & AC Drivers) or fully hydraulic transmission
Structural Height	Double or triple stand	Double or triple stand	Single or double stand
Drilling Rig Automation	Absent/Low	Present/High	Present/High
Automated pipe Handling Equipment	Absent (Keller Spinner)	Present	Present
Monitoring System	Absent	Present	Present
Noise Pollution	High	Low	Low
Carbon Emission	High	Low	Low
Automatic Braking System	Absent	Present	Present
- Rig up/Rig down time	Longer time		Shorter time
- Mobilisation Cost	Higher cost		Lower cost
- Rig Move for Transportation	35 – 40 loads		22 – 30 loads
Drilling Rigs Pipe Used	3 drill pipes		1or 2 drill pipes
Braking System	Mechanical main brake and Hydraulic Auxiliary brake	Mechanical disk main brake and Hydraulic Auxiliary brake	Regenerative AC or hydraulic brake

Table 2: Criteria used to evaluate existing drilling rigs for geothermal application

Criterion	Key Issues
Demonstrated Performance	**Reliability Performance (Efficiency and Safety only)**
Hook Load	**Maximum weight that the hoisting system of a drilling rig is designed to handle**
Footprint, mobilisation and demobilisation	**Transportability by normal trucks, no special permits required, time for mobilisation and demobilisation**
Drilling Depth	**Ability to drill deeper**
Hoisting Power System (Draw works)	**Fast Line Load and fast Line Velocity**
Derrick and Substructure	**Height, Hook Load and Set Back Capacity**
Environmental Impact	**Noise Pollution, Net Energy Consumption**

Table 3: Comparative overview of geothermal drilling rigs for geothermal resources

Drilling Rigs	Demonstrated Performance	Hook Load	Foot-print	Drilling Depth	Hoisting Power System	Derrick Substructure	Environmental Impact
A	+	-	**0**	-	-	-	+
B	+	+	**0**	+	-	+	+
C	+	+	**0**	-	-	+	+
D	+	-	**0**	-	-	-	+
E	+	+	**0**	**0**	-	+	+
F	+	+	**0**	**0**	-	+	+
G	+	+	**0**	+	+	+	+
H	+	+	**0**	**0**	-	-	+
I	+	+	**0**	**0**	+	+	+

4. RESULTS AND DISCUSSIONS

Table 3 shows results of statistical analyses of the reviewed existing geothermal drilling rigs based on the key criteria.

From Fig.2, it is clear that the drilling rig “A” and “D” have the lower output based performance. Their shallow drilling depth and hoisting draw work power rating keep them far away from the target base line and thus they are ranked as less desirable options. However, they both seem to have advantages over aforementioned rigs with low derrick and high automatisation and substructure.

On the other hand, other drilling rigs met the optimal specification, with drilling rig “B”, “E”; “I” and “G” having more features that make them

acceptable and more viable for geothermal drilling. Both rig "B" and "G" have an advantage over the others based on their greater depth capacity.

Table 1 showed that both improved conventional and unconventional rig can be used to drill up to 5000 m. The rig would be required to have an average minimum hook load rating of 250 t. The benefits of top-drive are considerable, as are having minimal torque and pipe handling systems, especially for rig downtime and deep drilling in high temperatures.

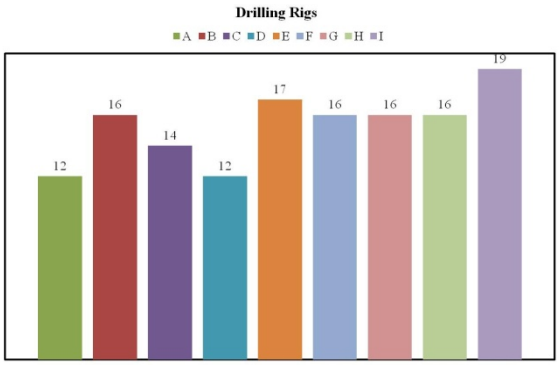

Figure 2: Performance evaluation of drilling rigs for geothermal application

However, Non-conventional drilling rigs have advantages over the conventional type in terms of smaller footprint and lower emissions, but with the increase in depth of EGS, the conventional type of drilling rigs are still the only viable solution (Teodoriu and Falcone 2008).

5. CRITERIA FOR GEOTHERMAL DRILLING RIG SELECTION

5.1 Drilling Rig Automation

As Frank (2009) stated, the drilling industry hasn't yet seen paradigm shifts in surface equipment in recent years. Driving up to a land rig today is nearly the same experience as it was 30 years ago. The drilling industry has undergone three eras of technology evolution: mechanisation, semi-automation, and local automation. The 1970s saw the introduction of equipment such as power slips, iron roughnecks, and top drives that reduced labour on the rig floor. The 1990s witnessed a transition and reconstruction period for the onshore oil and gas drilling industry and saw these component technologies, which are integrated and developed as whole drilling systems, to include the entire rig. From this transition evolved a more mobile, modular, efficient, environmentally friendly, economic, and safe drilling system. The key to this evolution was development and integration of drilling rig automation technology and the programmable logic controller.

Automation has reduced the number of people needed on the drilling floor, so removing people from potentially dangerous activities, and reducing the number of accidents, especially in the dangerous activity of running casing. In 1996, the introduction of the stabberless pipe system improved pipe running capability and reduced casing and tubing running times considerably without compromising safety. A typical automated drilling system of a modern drilling rig is shown in Figure 3. These efforts have provided incremental improvements by cutting corners and removing overlapping once-linear activities, improving drilling efficiency on the rig floor and safety benefits. Activities can be monitored in real time, and performance predicted and workflow procedures adjusted to create more efficient operations. A mass move towards drilling automation requires an investment beyond software development. Modern rigs, with control systems wired to communicate and respond to a digital system, are needed.

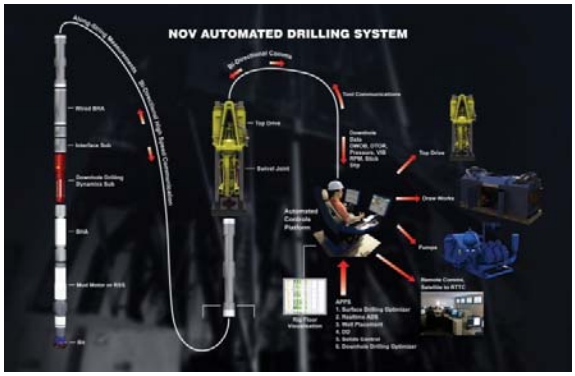

Figure 3: Automated Drilling System. Tony et al. (2012)

5.2 Energy Efficient Drilling Rig Equipment Components

The energy demand on a drilling rig is variable depending on which part of the drilling rig equipment is in operation and what depth is being drilled. Three types of equipment account for most of the rig power demand: mud pumps, rotary table and draw works. Since the mud pumps and rotary table operate at all times during drilling, their total power demand is large, and they account for a large continuous demand except during tripping when they are shut down and the draw works demand nearly all the rig power. Although tripping requires considerable power, it is less than the power

demand during drilling, while the remaining power rig power demand is for auxiliary usage.

Almost all new rigs are built with all electric Silicon-Controlled Rectifier (SCR) technology that supplies AC current from multiple AC generators has been rectified to DC for high power demands of the DC motors in the mud pumps, rotary table and drawworks. This technology has replaced older rig technology that paired each DC motor with a specially sized DC generator supplement by an AC generator for auxiliary needs. The flexibility and the efficiency of the SCR rig justify the common use nowadays of such a rig, even if its initial cost is slightly higher. Indeed, the use of AC power on the SCR rig distributes power through the drilling equipment by eliminating downtime due to failure, powering auxiliary loads without an additional AC generator, and providing better engine efficiency for low fuel consumption and reduced subsequent emissions.

5.3 Use of Energy Storage Devices

Most of the unconventional power generating technologies need an energy storage system to affect an environmentally friendly system. There are several commercially viable energy storage systems that are being improved for hybrid electric vehicles (HEV's) today. Major advances are being made regularly. Types of devices that hold the most promise to solve energy storage problems are batteries, flywheels and ultra capacitors.

5.3.1 Flywheels

Flywheel energy storage (FES) works by accelerating a rotor at a very high speed and maintaining the energy in the system as rotational energy. The energy is converted back by slowing down the flywheel. Very-high-speed flywheel systems are promising energy storage means for hybrid vehicles and systems. Flywheels store kinetic energy in a high-speed rotor. They provide many advantages over chemical batteries, including high specific energy, high specific power, long cycle life, high energy efficiency, low maintenance requirements, reduced environmental contamination, reduced sensitivity to temperature and cost effectiveness.

To maintain efficiency, the flywheel system is operated in a low vacuum environment to reduce drag. The key features include negligible maintenance, long life (20 years or 10s of thousands of deep cycles) and environmentally inert material.

5.3.2 Batteries

There any many battery technologies currently in use or being developed, with lead-acid (Pb-acid), nickel cadmium (NiCd), and nickel metal hydride (NiMH) being the most promising technologies. Batteries have a limited number of charge/discharge cycles and take time to charge and discharge because the process involves chemical reactions with non-instantaneous rates. These chemical reactions are accompanied by parasitic thermal release that causes the battery to heat up. Batteries have a limited life cycle with a degrading performance. Once used, disposal becomes a significant environmental concern.

Metal-Air Batteries: Metal-air batteries are the most compact and, potentially, the least expensive batteries available. The main disadvantage, however, is that electrical recharging of these batteries is very difficult and inefficient. The anodes in these batteries are commonly available metals with high energy density like aluminum or zinc that release electrons when oxidized.

Lead-Acid Batteries: This is one of the oldest and most developed battery technologies. It is a low cost and popular storage choice for power quality (reactive power compensation), uninterruptible power supply and for compensation of peak power consumption. Its application for energy management, however, has been very limited due to its short cycle life. The amount of energy (kWh) that a lead-acid battery can deliver is not fixed and depends on its rate of discharge.

5.3.3 Electrochemical Capacitors

Electrochemical capacitors (EC) store electrical energy in the two series capacitors of the electric double layer (EDL), formed between each of the electrodes and the electrolyte ions. The capacitance and energy density of these devices is thousands of times larger than electrolytic capacitors. The electrolyte is either aqueous or organic. The aqueous capacitors have a lower energy density due to a lower cell voltage, but are less expensive and work in a wider temperature range. In comparison to lead-acid batteries, they have lower energy density, but they can be cycled tens of thousands of times and are much more powerful than batteries (fast charge and discharge capability).

5.3.4 Superconducting Magnetic Energy Storage (SMES) System

SMES technology uses the superconducting characteristics of low-temperature materials to produce intense magnetic fields to store energy. It has been proposed as a storage option to support large-scale use of photovoltaic and wind as a means to smooth out fluctuations in power generation. The stored energy can be released back to the network by discharging the coil. The power conditioning system uses an inverter or rectifier to transform alternating current (AC) power to direct current or convert DC back to AC power. The inverter accounts for about 2-3 % energy loss in each direction. The advantage of this storage system is

that power is available almost instantaneously and very high power output is provided for a brief period of time. Also, there is no loss of power as there are no moving parts. A disadvantage is that the energy content of SMES systems is small and short-lived, and the cryogenics (cold temperature technology) can be a challenge.

5.4 Optimisation of Platform Design

The method included a foundation composed of permanent foundation units, a substructure mounted on the foundation and a derrick mounted on the substructure for drilling for oil or the like in remote areas. The permanent foundation units, substructure, and derrick are all comprised of members that can be transported to the remote area by a helicopter or similar transport. The foundation is suggested for use in mountains, marshy or swampy land located anywhere that is not easily reached by conventional ground transportation or conventional floating platforms (Rogers, 2006). The preferable material is aluminium or an alloy of aluminium; with the new platforms concept designed adhere to stricter standards than older platforms and ability to drill in sensitive areas without disturbing the ground surface. The legs are adapted to be driven or otherwise inserted into the ground to support the elevated drilling platform. The platform modules may be transportable by aircraft or special purpose vehicles that are adapted to cause minimal harm to the environment.

In swampy areas, legs could be rotated in with a power swivel to the proper depth of penetration. The platform design modules interlace where any spillage onto the platform decks would be routed and contained within the bucket elements of the modules for containment and proper recovery and disposal.

6. CASE STUDY

Table 4 shows investigated geothermal projects and drilling rigs used. Based on the performance selection criteria set (see Table 2), the unconventional drilling rigs have the potential to meet the requirements for the exploration drilling of EGS projects. However, improved conventional drilling rigs can be an alternative if there is high demand for unconventional drilling rig types. Figure 4 shows performance evaluation of drilling rigs used for different known geothermal projects in comparison to what typical drilling rigs for geothermal operations should fulfil.

According to the performance evaluation, it can be seen that the major parameters that make a drilling rig suitable for geothermal applications are the hook load and total installed power, including pump capacity. It must be noted that the automation was not considered here as a major impact parameter.

It must be mentioned that the rigs compared within this paper are drilling rigs that have been used for EGS geothermal projects only. At the time of writing, more efficient improved conventional rigs existed on the market, but they were only associated with oil, gas or hydrothermal drilling applications. It is worth mentioning here that the KCA T-700 has a small footprint for a heavy land rig. Using the same performance evaluation procedure presented here, this rig would attain 20 out of 20 points, but the rig has not been used in any geothermal application to date.

If automation, as a major safety parameter, is included the above performance evaluation will look as shown in figure 5. It must be noted that for this evaluation, the non productive time (NPT) was not considered, due to the lack of information in the public domain, and also because NPT is affected not only by drilling rig characteristics, but also by other unpredictable factors.

7. CONCLUSIONS

The future of geothermal energy expansion relies on the procurement of modern rigs which meet the requirements based on reliability, performance and environmental impact. Therefore, the development of an efficient framework for performance evaluation and optimum selection of drilling rigs for geothermal wells will become indispensable. The future generation of rigs should be capable of drilling both vertical and directional wells with depths greater than 5000 m.

This paper compared the specifications of existing drill rigs used for geothermal EGS projects. The proposed rig selection criteria are demonstrated performance, drilling depth, hook load, footprint, hoisting power system, derrick and substructure, pump capacity and environmental impact. The result of this study shows that performance (as declared by the manufacturers), hook load, footprint and environmental impact are major factors and optimal decision of a drilling rig for geothermal wells. This implies that system must be efficient, good quality with safety and low emission.

It is of utmost importance that new technologies be implemented in order to maximise drilling cost effectiveness. There are very few manufacturers specialising in building geothermal drilling rigs. In light of this, it is important to understand what is special about geothermal drilling even before calculating and selecting the major rig components.

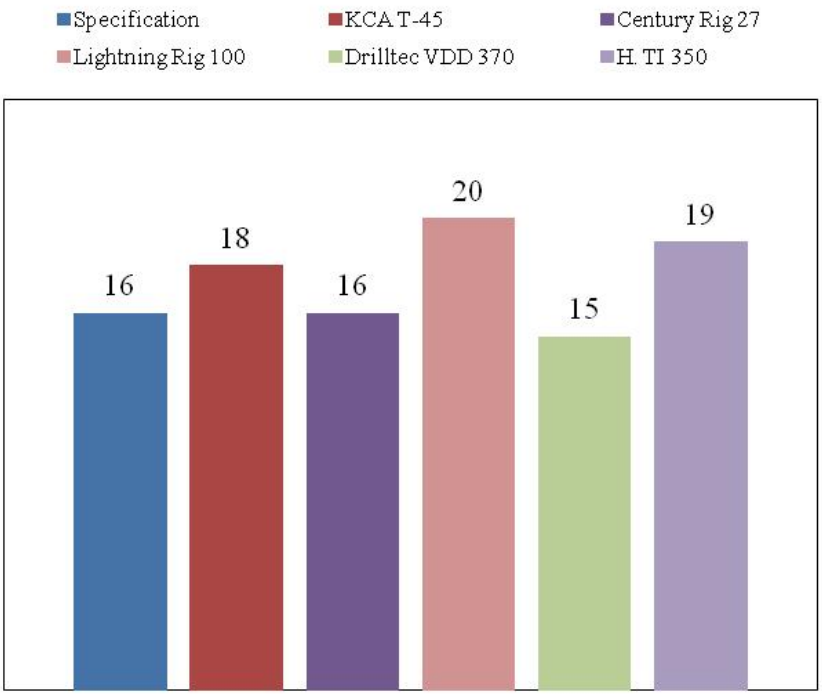

Figure 4: Performance evaluation of drilling rigs used for investigated geothermal projects

Table 4: Summary of drilling rigs in geothermal projects

Geothermal Projects	**Well Depth (m)**	**Capacity**	**Drilling Rig Used**
Groß Schönebeck (Germany)	**4500**	**5000 m/ 1600 HP**	**Rig VDD 370**
Kawerau	**3000**	**4200 m/ 1200 HP**	**MB Century Rig 27**
(New Zealand)			
Cooper Basin (Australia)	**4400**	**6000 m/ 2000 HP**	**Lightning Rig 100**
Basel (Switzerland)	**5000**	**7000 m/ 2000 HP**	**KCA Deutag T-45**
GeneSys (Germany)	**4200**	**5000 m / 2200 HP**	**InnovaRig,**
			Herrenknecht Vertical

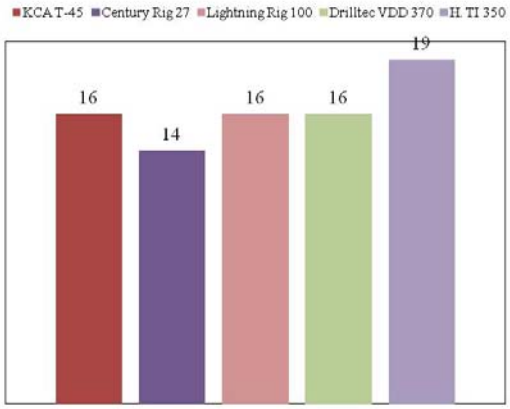

Figure 5: Performance evaluation of drilling rigs used for investigated geothermal projects including automation

8. REFERENCES

Back, M. Development and Operation of Innovative Drilling Systems, Hannover Messe, (2005)

Binder, J. and Ruder, M. Entwicklung einer neuen Bohranlagentechnik für tiefe Geothermie, Erdöl Erdgas Kohle 124. Heft 11, (2008).

DC (2005) Drilling Contractor. ITAG's New Rig Provides State-of-the-Art Technology. Drilling Contractor May/June (2005).

EPRI (2013) Electric Power Research Institute, www.epri.com

Frank, S. New-Concept land rig design based on parallel operations. May/June Issue, Drilling Contractor (2009)

Griffin, H. Evaluation of Precision Drilling Super Single Performance. IADC/SPE Drilling Conference and Exhibition held in New Orleans, Louisiana, USA, 2-4 February (2010).

Geodynamics Limited, Annual Report, (2008).

Huenges, E., Moeck, I., Zimmermann, G., Saadat, A., Frick, S., and Norden, B. EGS in the Permian of the Northeast German Basin. Geothermal Energy Utilisation Conference, Dallas 2008.

John, F. and Doug, B. Handbook of Best Practices for Geothermal Drilling, (2010).

John D. Rogers, 2006. Assessments of Technologies for Environmentally Friendly Drilling Project: Land-Based Operations, (2006).

Oswaldo, L. INTERFACEHS - A Journal on Integrated Management of Occupational Health and the Environment - v.1, n.3, Art 3, April 2007.

Teodoriu, C. and Falcone, G. Comparing Completion Design in Hydrocarbon and Geothermal Wells: The Need to Evaluate the Integrity of Casing Connections Subject to thermal Stresses. Geothermics, Vol. 38, (2009), pp. 238 – 246.

Tony, P., Andrew B., Hege K.., and Brad, A. Building an Automated Drilling System Where the Surface Machines are controlled by down hole and Surface Data to Optimize the Well Construction Process. IADC/SPE Drilling Conference and Exhibition, San Diego, California, USA (6-8 March 2012)

KCA (2013) http://www.kcadeutag.com

ITAG (2013) http://www.itag-celle.de

MBC (2013) http://www.mbcentury.com

BEN (2013) http://www.bentec.de

BAU (2013 http://www.bauer.de

NOV (2013) http://www.nov.com

MBC (2013) www.mbcentury.com