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Geothermal Drilling Experience with an Innovative Drill Rig

Bernhard Prevedel[1], Jürgen Binder[2], Rainer Jatho[3], Berthold Kibellus[4] and Lothar Wohlgemuth[1]

[1]Deutsches GeoForschungsZentrum, Telegrafenberg, 14473 Potsdam, Germany;
[2]Herrenknecht Vertical GmbH, Im Heidenwinkel 5, 77963 Schwanau-Allmannsweier, Germany;
[3]Bundesamt für Geowissenschaften und Rohstoffe, Stilleweg 2, 30655 Hannover, Germany
[4]H. Anger's Söhne Bohrgesellschaft GmbH, Gutenbergstrasse 33, 37235 Hessich Lichtenau, Germany;

Prevedel@gfz-potsdam.de

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ABSTRACT

In order to efficiently explore and develop geothermal resources, it is most important to enhance the drilling performance as well as to reduce the costs of drilling. This is achieved through an adaptation of existing drilling techniques to the special requirements of the geothermal market. InnovaRig is a new drill rig based on the rig type Terra Invader 350 (TI-350) from Herrenknecht-Vertical GmbH with innovative characteristics for scientific drilling and industrial applications. Designed by GFZ Potsdam, Germany's international research centre for geosciences, in cooperation with the industrial partners Herrenknecht Vertical and Angers' and Sons drilling company, it exceeds the modern requirements of drilling. With a compact design and small environmental footprint it reduces manpower and operational costs to a minimum (fig.1). Innovations in the deep drilling technology have been made in the areas of noise protection, energy saving, automation and comprehensive cost reduction. The development is based upon the drilling technology of oil and gas well construction rigs and the experience and requirements gained in former geothermal energy projects. InnovaRig represents an innovative drilling rig tailored for scientific drilling projects as well as commercial projects likewise and has already stood successfully the first operational drilling projects in Germany and will further support the fast implementation of geothermal projects in Europe and other locations worldwide.

1. INTRODUCTION

Exploration for geothermal resources require drilling solutions that address the lowest possible formation damage, maximum characterization of the target geology, high deviation and large diameter directional drilling as well as intelligent well completion designs.

The preferred way to drill a geothermal producing zone would be with low pump volume at under-balanced conditions. Aerated mud systems operated in reverse circulation, (counter-flush) mode do provide such minimized impact on the formation, even with large bit sizes at penetration rates equivalent to oilfield rotary drilling. InnovaRig can switch from one drilling method to the other in a matter of a hours. The optimal formation evaluation and geologic characterization of the geothermal reservoir would be to drill it with core drilling techniques. Wireline coring systems can provide an efficient and safe way to recover hundreds of meters of large diameter (94 mm) cores at close to 100% recovery even in sedimentary formations. Its low mud circulation characteristics, combined with an under-balanced aerated hole opening thereafter, will assure maximum information recovery from the production zone under least reservoir damage and maintenance of best borehole stability conditions for later complementary logging runs.

A high angle and horizontal well profiles does provide sometime large exposures to a producing reservoir and can therefore maximize water productivity and hence improve financial performance of a geo-thermal project. Such wells will however require in addition complex intelligent well completions, in order to maintain a uniform productivity over its entire length in a heterogeneous reservoir over their entire life time.

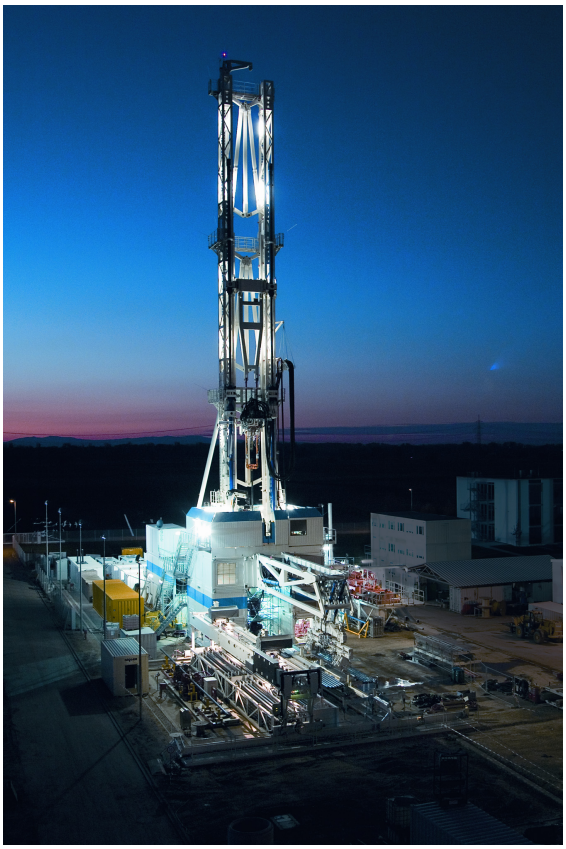

Figure 1: Night view of InnovaRig at the Herrenknecht manufacturing plant in Germany, occupying a 30 x 80 m drill pad and the 50 m high illuminated mast standing ready to receive drill-pipe from the automatic pipe-handler loading doubles from the pipe-rack to catwalk.

2. INNOVARIG BASICS

Geothermal drilling targets primarily in Europe are located in depths between 2500 and 5000 m depth which require typically a drill rig with a hook load capacity between 300

and 400 tons, which are also frequently contracted by the oil and gas industry and therefore in short supply in Europe. [1] For this reason, the Herrenknecht-Vertical company, a subsidiary of the Herrenknecht AG tunnelling company, decided to build a 350 ton hook load capacity semi-automatic rig with special view on the domestic geothermal market (fig.2).

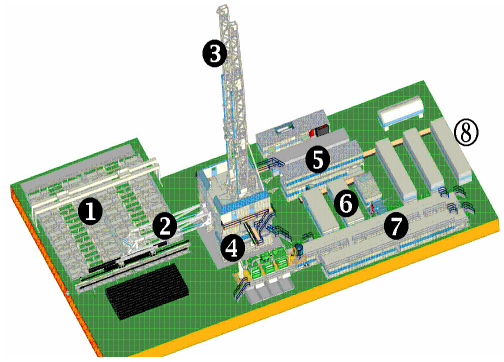

Figure 2: Layout of the InnovaRig main components: 1. Pipe rack, 2. Pipe handling system, 3. Derrick with hydraulic elevator, 4. Substructure with rig floor and blow out prevention system, 5. Electrical energy transformer, 6. Mud pumps, 7. Mud conditioning system with mud tanks, shale shakers, centrifuges, desanders, desilters, 8. Diesel power plant.

The basic features of this rig are:

- Mast and Hoist System is hydraulically driven with a double cylinder system. The nominal hook load is 3500 kN, along with a maximum over-pull capacity to 4000 kN, with that InnovaRig offers a depth capacity of approximately 5000 m.

- The Pipe Handling System comprises automatic hands-off-technology. A combined pipe manipulator bridge, pipe handler and iron roughneck technology reduces strenuous physical work on the drill platform to a minimum. Machine time cycle and thread connection make-up quality is such ensured to be uniform for all drilling phases and pipe types.

- Four Drilling Techniques are integrated in the rigs operating modes: rotary drilling, standard oilfield coring, wireline coring and reverse circulation airated drilling. Two new developed top drive systems, for rotary drilling and wireline coring, give maximum performance in adjusting the rig to the selected drilling mode.

- Mud System, Mud Pumps and Tanks are capable to drilling requirements of all four drilling techniques mentioned above.

3. INNOVARIG FOR SCIENCE

The GFZ–German Research Center for Geosciences designed and developed InnovaRig specifically for their scientific drilling projects within the research scope of "System Earth" at the GFZ as well as the International Deep Drilling Program – ICDP, for which GFZ acts as its drilling engineering and operational support arm <www.icdp-online.de>. The rig is based on Herrenknecht-Vertical's TI-350 model with special advancements and modifications for the particular needs of scientific requirements during research drilling projects as well as enhanced operational efficiency at, for example, commercial geothermal projects. [2] Compared to standard platforms, it offers innovative features, like:

- Coring is facilitated by a two top drive system adjustable to all kinds of coring techniques. The smaller high-speed top drive can be attached as an integral part to the standard top drive to avoid additional additional equipment on the rig floor. An integrated wireline winch and coring pump and InnovaRig's modified mud tank system enable a fast change from classic rotary drilling to the wireline coring techniques.

- Fast Logging is a central feature of InnovaRig. A dedicated permanent storage rack for logging tools is installed on the rig's platform, as well as special equipment for the logging cable guidance to allow for quick logging set-up and geophysical data acquisition.

- Scientific Sampling is done with a special collector for cutting sampling and a new mud gas analysis device based on mass spectrometry for measuring the distribution and behaviour of hydrocarbons, hydrogen, radon and noble gases in the continental crust during the drilling process. As these elements are minor components in most rocks they can be used as indicators of the fluid sources and they are thus helpful in trying to solve questions of fluid generation, evolution, and ages. Hydrogen in particular has possibly the potential to trace sliding friction due to its formation by a mechano-chemical process. The geochemistry of gases and naturally occurring rare gas (incl. noble gas) tracers in fluids has been also used successfully in the past to calculate the time scale of fluid flow within the deep crust.

- Data Management is supported by on site, online data acquisition. The software control system is collecting from the rigs LAN continuously approx. 8500 different machine control variables at 250 ms sampling rate. This large data base is permanently recorded on site over the entire drilling phase in a "black-box" hard drive and also available via real-time satellite communication or Internet to the GFZ head-quarter in Germany. A drilling information system is monitoring from this data base the rigs drilling performance and the drill bits geologic location. InnovaRig's Drilling Information System (DIS) is integrated into the ICDP Drilling Information System (International Continental Scientific Drilling Program) and available to all GFZ managed scientific drilling projects. [3]

4. DRILLING INNOVATIONS

The structure of InnovaRig with a drilling pad foot print of only 9 x 10 m is extremely compact and allows a flexible arrangement of auxiliary machinery around its core structure. With this flexibility, a total drilling construction area of 2400 sqm (30 m x 80 m) can be achieved, which is very favourable for drilling in urban or other difficult-access areas and rather small for a rig with such a depth capacity, compared to a classic oil rigs.

The operation of InnovaRig is characterized by a maximum implementation of hands-off technology, which will ensure during drilling phases a shift of only 4 people to run the rig. Core of this technological advancement is the automatic pipe handling system, the maintenance free hydraulic draw-works and the Iron-Roughneck for hands-off pipe connection make-up and break. The rig can further skid from one well location to the other over a distance of max. 10 m without

disassembly of the mast and substructure and repositioning of the rig's mud tanks and power plats. This represents significant time and hence cost savings between the drilling of 2 wells, i.e. when drilling a doublet of one injector- and one geothermal water production well.

Due to the integration of a comprehensive waste, emission and noise management system, the rig can be operated in urban areas without the need for expensive noise cancellation and protection walls or even rig housing constructions.

In summary, these innovations are:

- Specialized rig design for implementation of tools and equipment particular for scientific drilling,
- Variable application of rotary drilling, standard coring and wireline coring and air drilling,
- Modular rig design and high safety standard due to high automation,
- Integrated energy concept for an insulated diesel-generator or electric-grid powered operation or any combination of both tailored to the specific situation for a local electric grid,
- Hydraulic hoist and feed system, hence no need for a drilling line,
- Hook load directly supported by the substructure (box-on-box),
- Hoist constructed to handle singles as well as doubles of drill- and casing pipes,
- Integration of well proven drilling technologies from oil and gas drilling,
- Environmental engineering and design, like design-integrated noise attenuation, reduced size for the drill site, Zero discharge
- Drilling capability @ low cost.

5. INNOVARIG TECHNICAL SPECIFICATIONS

For InnovaRig, the Herrenknecht-Vertical company, a subsidiary of the Herrenknecht AG tunnelling company, as the manufacturer publishes following technical specifications for the operational envelope of the TI-350 series drill rig:

Table.1: InnovaRig Operating Specifications

Drilling depth	4000–5000 m
Regular hook load	3500 kN
Nominal rotary speed	220 rpm
Rotary torque	40 to 75 kNm
Wireline coring speed	500 rpm
Wireline coring torque	12 to 18 kNm
Tripping speed	500 m/hr
Hoist cylinder stroke	22 m
Drive power up to	4000 kW
Rig weight approx.	3700 kN
Mud pumps	3 x 1000 kW
Wireline coring mud	1 x 600 kW
Mud pressure max.	350 bar
Mud tank system	240 m^3
Generator set	3 x 1540 kVA
Drill pipe rack capacity	7000 m
Wireline coring winch	5000 m, d=12.7 mm

6. GEOTHERMAL FIELD EXPERIENCE

InnovaRig was the second drilling unit built on the TI-350 concept out of the Herrenknecht-Vertical works in SW-Germany, and was handed over to GFZ in May 2007. The rig started in November of the same year the fist well of a geothermal doublet at the outskirts of Munich/Germany. The project featured an injector and one producer well drilled from the same drilling pad with an 8 m wellhead separation at the surface. The wells were planned to penetrate the Malm carst at a vertical depth of approx. 4000 m and with a well deviation of 1000-1300 m each from the surface location in the SE or NW direction. Borehole inclination in the producing formation was approx. 55 to 60 deg in both of the wells (fig.3).

The first well of the doublet was successfully completed on schedule in March of 2008 after 116 drilling days. After extended acidizing of the limestone formation and production testing for 2 months, the rig was skidded in its erected position 8m sideways to the new wellhead location. The second well was completed after a long repair phase on collapsed pipe after an extended water production test, in August 2008. Extended production tests revealed the commercial viability for future electricity production on that site.

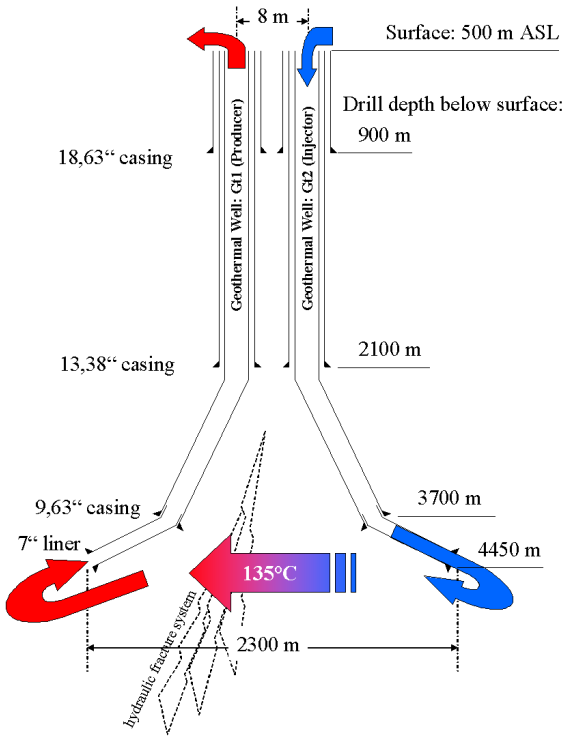

Figure 3: Doublet well in the South German Malm Carst formation with a production capacity of 4 MW electrical.

After this extended field test of the newly delivered InnovaRig in South Germany, the rig was scheduled to return to the manufacturer yard for 6 weeks for maintenance/repair and outstanding rig upgrades.

Following this upgrade, the rig moved to Hanover in order to drill a single-well geothermal project for the German Geological Survey, called GeneSys.

This project will realize a worldwide new and innovative geothermal concept of a single geothermal well, based on a single pipe heat exchanger basis (fig.4). This GeneSys well,

located within the Hanover city limits, is targeting the Middle Buntsandstone formation of the Upper Triassic. Two sandstone layers will be penetrated by the 8,5" bottom well section at an approx. depth of 3700 to 4000 m. The two layers will be hydraulically connected by means of a hydraulic water frac after reaching target depth at 4200 m. The well will be cased and cemented with a 7" production casing and the 2 producing sandstone layers perforated and tested before running the 5,5" production tubing string. [4]

This pipe for later water injection will carry a permanent production packer, to be set inside the 7" production casing in between the 2 perforation sections. Cool water from the surface heat exchanger will be pumped down the tubing to the lower sandstone layer, exit the well through the perforations in the casing, migrate along the fracture zone to the upper sandstone layer and enter the GeneSys well again at the upper perforation. [5] The approx. 150°C hot water will be produced to the surface at a rate of approx. 25 m^3/hr via the tubing annulus and converted in the thermal power-plant at the surface to 2 MW heat for the office building of the federal Geocenter in Hanover by the start of 2011.

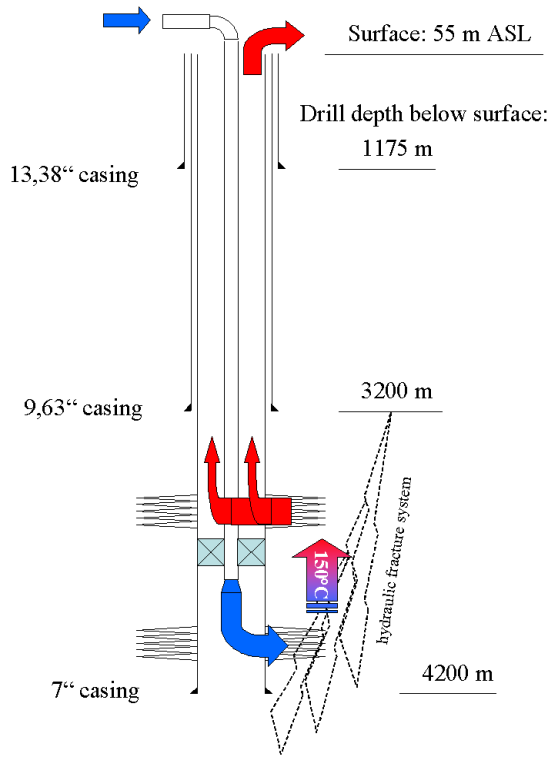

Figure 4: Single well in the North German sandstone formation with a production capacity of 2 MW thermal.

By copy date of this paper, the well had reached successfully its first casing setting depth at 1175 m. Despite massive hole stability problems in the upper 17,5" well section, the 13.38" casings were set and cemented after a 5 day strenuous casing running procedure with a Drilling-with-Casing Method (DWC). This technique allows rotating the casing while running in the hole by means of the rigs top-drive combined with a special Casing-Torque Head at a continuous speed of 80 rpm and at the same time mud circulation as high as 2000 l/min. On bottom of this casing string is a special and drillable casing shoe installed, equipped with Diamond cutters in order to give the string a cutting edge to drill itself down through obstructed well sections from after-fall from unstable open hole well sections (fig.5).

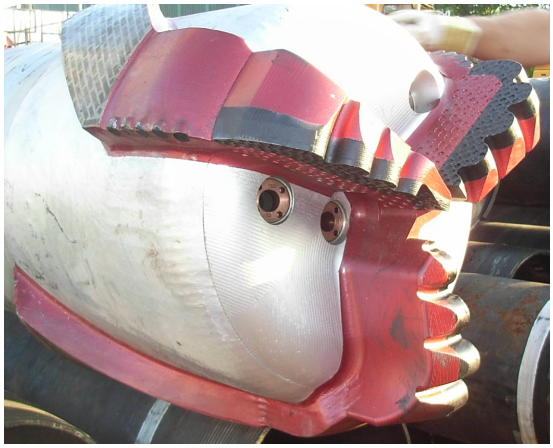

Figure 5: Bottom casing shoe equipped with a DWC-drill head with poly-crystalline diamond cutters and mud jets.

7. CONCLUSIONS

The new rig design has successfully proven in now 3 geothermal well drillings, that innovative design and industrial style numerical control systems can improve the work procedures in drilling operation significantly, to the extend, that a double joint and as such considered mid-sized drill rig can stand up to the tripping speeds of a classic triple-pipe oil rig with no major problem, with a fraction of footprint and noise emissions, and still keep the day rates competitively low.

Advanced data processing and automated drilling can further reduce the work load on the drilling crews substantially. That will result in fewer accidents and hazardous situations as well as it will allow to reduce the shift on such a computerized new generation rig to eventually half of that compared to conventional oil rigs.

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