UNITED NATIONS
UNIVERSITY

GEOTHERMAL TRAINING PROGRAMME
Orkustofnun, Grensasvegur 9,
IS-108 Reykjavik, Iceland

Reports 2012
Number 16

REPORTING AND EFFICIENCY ANALYSIS IN GEOTHERMAL WELL DRILLING

Nickson Owiti Karewa
Kenya Electricity Generating Company – KenGen
Geothermal Resource Development
P.O. Box 785-20117, Naivasha
KENYA
nowiti@kengen.co.ke, owyttinic@gmail.com

ABSTRACT

Effective management of geothermal well drilling requires proper collection, analysis and presentation of drilling data from the onset to the completion and testing of the well. The interpretation and evaluation of all available information regarding geology, structure, geophysics, flow paths, temperature and surface conditions are accomplished by an interdisciplinary team consisting of geologists, physicists, geochemists, reservoir scientists, and drilling engineers who work together on a common platform as opposed to each discipline developing their own ideas independently. The integrated information and data collected from actual drilling operations can then be applied in the optimization of the drilling process resulting in improvements and, consequently, better wells being drilled.

The process from the correct siting and design of the well to the completion and testing of the well must be well planned with data from each stage of the well documented. All the technical and environmental aspects must be identified and addressed at the onset of the project to avoid future hitches and delays. This means all approvals must be obtained in time and all materials needed for the drilling processes available for use.

During the actual well drilling, the record of activities, the bottom hole assembly (BHA), and casing, drilling fluids and other materials, directional information and other aspects of drilling must be recorded daily. This information is used for invoicing and helps in the operation's analysis and performance of various drilling aspects.

This report gives an outline of the inputs and reports generated during the well drilling process and uses RIMDrill software, which is a rig to office drilling information system for drilling contractors (Infostat, 2012), for bookkeeping and to store and analyse well data with the aim of using the information in optimizing the drilling processes. The daily reports, according to the format of the International Drilling Contractor Association (IADC), and non-IADC report data are generated at the rig site and transferred to a central office where data is consolidated for the entire rig fleet. The program defines the major time and cost areas and provides critical information for accounting. It also supports analysis for management and for operational decision making which can significantly impact the drilling process, cost and time.

1. INTRODUCTION

The goal of any geothermal drilling project is to realize the well in a safe manner and according to its purpose and to complete it with minimum cost. This optimization may, therefore, influence where the well is drilled, the drilling technology applied, as well as the well measurements that are carried out and used to optimize future well drilling. Geothermal drilling is a complex process that utilises extensive machinery, a wide range of technical expertise and a lot of financial muscle that is needed to pull the whole operation together. The ultimate objective of geothermal drilling is to make a hole to gain access to the deep seated resource. To make the hole we use a drilling rig whose function is to transfer energy to the bottom of the hole, to break the formation, and flush out the cuttings. Most equipment and technology used in geothermal drilling is adopted from the oil and gas drilling industry.

The technical nature of geothermal drilling means a good understanding of the various operations are well understood by the parties involved. The BHA design and configuration is the key to the success of the drilling operation. It is a given that the BHA will dictate the weight that can be applied on the bit, the direction of the hole, and the ease with which the operation will proceed. This must, therefore, be carefully planned and designed to ensure the optimization of the drilling process. Drilling fluids are required to remove cuttings from the well during drilling, to cool and lubricate the drill bit and drill string, to apply pressure to formation fluids to control flow into or out of the well, and to cool the formation, particularly prior to cementing casings. The choice of drilling fluid is, therefore, important. The right additives must be used, and in proper proportions, to achieve the desired effect. After drilling the hole, casing is run into the hole and then cemented at each stage. The casing design must be done well; the cementing operation is a key and the way it is done is vital for the overall performance of the geothermal well.

Whether the well is vertical or directional affects the choice of the BHA, though the general drilling procedures are similar for both cases. The type of well trajectory affects the performance properties in terms of the torque to rotate the drill string. The choice of drill bit affects the rate of penetration and the overall drilling time. Bit selection is, therefore, vital and must consider among other things the formation hardness, and bit economics such as the life of the bit and cost. The selection of the right bit will ensure that the number of trips made in and out of the well are minimized, thereby reducing the overall time it takes to drill a well.

Analysis of drilling efficiency considers whether the drilling operations are carried out in the shortest time and at a competitive cost. To be able to achieve this, a balance must be achieved between: the drilling processes, in terms of whether it is aerated drilling or otherwise; the type and quality of materials used as they directly affect the cost; and the design in terms of whether it's a directional or vertical well which affects the efficiency of the drilling. Considerations applied in well design, drilling practices and associated challenges are discussed in this report.

2. TECHNICAL DOCUMENTS

2.1 Site selection report

The key to successful drilling of any geothermal well is correct siting and well design based on a clear definition and understanding of the drilling target which, in turn, is based on all information available at that time (Axelsson and Franzson, 2012). This is achieved through the creation of a comprehensive and up-to-date conceptual model. Also, information from other sources plays a role. The interpretation and evaluation of all available information regarding geology, structure, geophysics, flow paths, temperature and surface conditions are accomplished by an interdisciplinary team consisting of geologists, physicists, geochemists, reservoir scientists, and drilling engineers, all working together on a common platform, as opposed to each discipline developing their own ideas independently. Table 1 lists most research methods relevant for defining geothermal drilling targets.

The principal geothermal drilling targets are in fact structures, or volumes, of adequate permeability and sufficiently high temperature to yield adequately productive wells. The permeability structure of a geothermal system is usually not well defined, but is usually quite complex and not known until a certain number of wells have been drilled into the geothermal system. Once this structure becomes well known and clearly defined, drilling success usually peaks. In early stages of development of geothermal systems, the knowledge upon which well siting is based is normally limited but increases with time as more data is obtained from wells already drilled and the conceptual models are updated.

TABLE 1: Contribution of different types of geothermal research to targeting of four different types of geothermal wells; the symbol P indicates a primary research method most often applied while S indicates a secondary method, which is not applied in all cases (Axelsson and Franzson, 2012)

Research	**Exploration wells**	**Production wells**	**Make-up and step-out wells**	**Reinjection wells**
Geological mapping	P	P	P	P
Mapping of faults/fractures	P	P	P	P
Surface manifestation mapping	P	P	P	
Ground temperature surveying	S	S	S	
Chemical-content/isotope surveying	P	P	P	
Aerial photos and satellite imagery	S	S	S	S
Remote sensing (e.g. infrared)	S	S	S	
Hydro-geological studies	S	S	S	S
Temperature gradient of wells	S	S	S	P
Magnetic mapping	S	S	S	S
Gravity mapping	S	S	S	S
Resistivity surveying	P	P	P	P
Seismic studies	S	S	S	S
Borehole lithology		P	P	P
Feed-zone inventory		P	P	P
Temperature/pressure logging		P	P	P
Borehole fracture imaging		S	S	S
Well testing		P	P	P
Discharge testing		P	P	
Temperature/pressure monitoring		P	P	
Chemical monitoring		P	P	
Gravity monitoring		S	S	S
Micro-seismic monitoring		S	S	S
Tracer testing				P
Reservoir modelling		S	P	P

2.2 Drilling program and drawings

Upon successful siting of the well, the drilling team will go ahead and prepare a drilling program. The detailed drilling program includes the casing design, blow-out prevention and wellhead design and layout of the drill site. The program has a step by step schedule giving detail procedures on how to carry out each activity during the drilling of the well. Depending on whether the drilling services are hired or being done in-house, the program usually gives details from the mobilization of the rig through the drilling phase to the well testing at the end of drilling with the rig still in the well.

A typical drilling program currently prepared by KenGen contains the following sections:

a) WELL DATA: This part contains the details about the physical location of the well. It gives the name of the area and the field, the coordinates, the elevation and the target of the well in terms of depth and direction.

b) OBJECTIVE: This section states the type of well to be drilled and the purpose for which it is drilled, i.e. whether it is an exploratory well, appraisal well, production well, reinjection well, make-up well or otherwise.

c) GEOLOGY: This section is very vital in the drilling program as it provides information on the formations. The details of this section are normally derived from the prognosis provided by the geologist. It has a sub-section on the stratigraphy of the area giving details on the expected structures, circulation loss points and recommends the drilling fluids to be used at different depths.
    - Information contained in the geological section of the program is the sampling program. Normally, cutting samples are collected at 2 m intervals while the inflowing and outflowing drilling fluids are collected at 50 m intervals.
    - The program also has details about coring; in most cases, this is not included because the stratigraphy for the areas is often well known. However, the geologist may request spot cores if the need arises.
    - The casing point depth is a critical factor that is contained in the geological section of the drilling program. The precise casing point is picked by the geologist, the rig manager, and the drilling engineer on the basis of lithology, lost circulation zones and the presence of competent rock during the drilling operation. For the production casing, the casing shoe has to be in a formation where the temperature is higher than ~220°C.
    - In some cases the program provides information that might aid during directional drilling, mainly in terms of the target structures. Figure 1 shows the well design for well OW-717A in Olkaria with details on the hole size, casing size, drilling fluid (mud and aerated water) and information on directional drilling.

d) ANTICIPATED DRILLING PROBLEMS: This section derives some information from the stratigraphy. It outlines the types of formation expected at different depths and the anticipated loss areas and, consequently, recommends the drilling fluid type and density. This is given for the whole well.

e) DRILLING PROGRAM: The earlier sections were mostly about the geology and related information. The concurrent sections gives step by step details on the drilling operations from the rigging-up of the drilling rig to testing of the well. It highlights the key operations and procedures that must be observed keenly during the drilling process. It provides a guide on the key drilling parameters as the revolutions per minute (RPM), weight on bit (WOB), drilling fluid circulation rates etc.

    The drilling program is structured in such a way that it provides information about the well per section. It provides precise details on drilling the hole, running the casing in the hole and cementing of the casing. It gives details on the BHA to be used at different stages and for different operations, the drilling fluid, how to handle any related drilling problems, nippling the blow up preventer (BOP) up and down, and drilling out cement among other details.

    On casing and cementing, the drilling program gives details on the operations prior to, during, and after running the casing. Cementing is done according to the cementing program, cement slurry properties and the number of hours of waiting on the cement. This is given for all the casings from the surface to the production casing. Figure 2 shows the casing string and liner for well OW-717A.

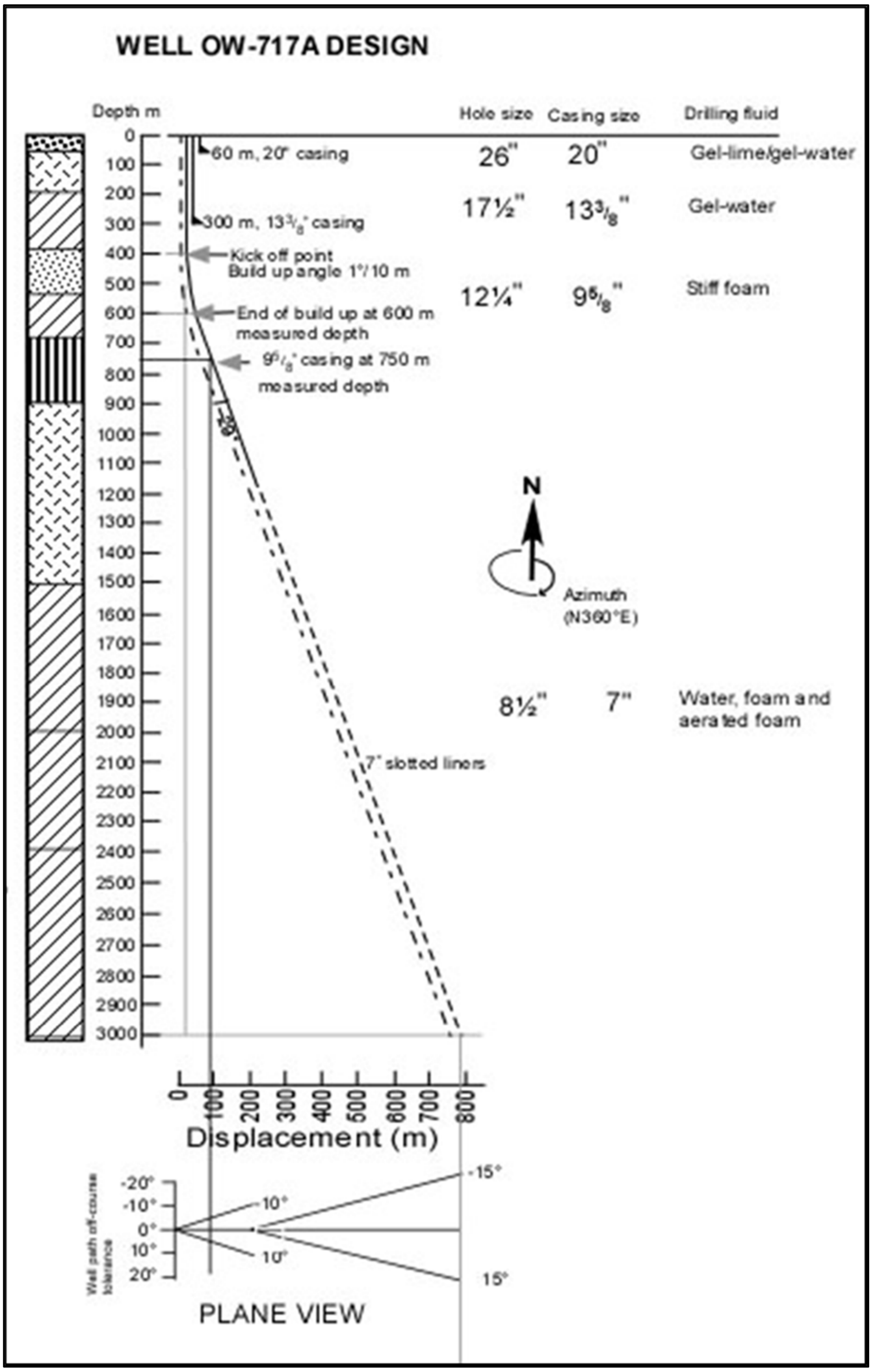
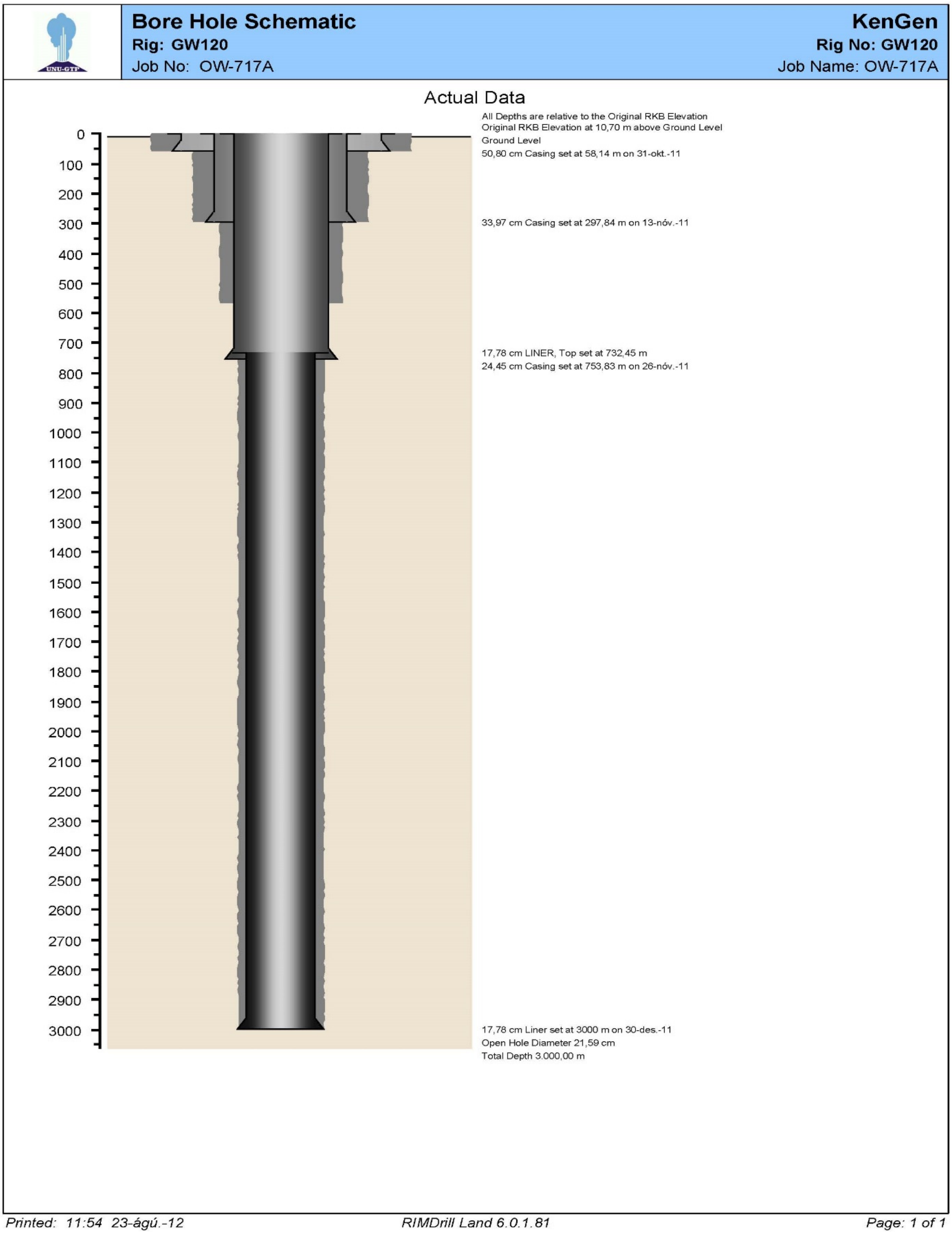


FIGURE 1: Well OW-717A design (KenGen, 2011)

f) WELL MEASUREMENTS: The completion test is done before the master valve is installed. In Kenya this is done by the reservoir department, which undertakes all the measurements that are necessary for a completed well. A typical well testing program used in Olkaria (Kenya) is attached in Appendix I.

g) MATERIAL TRANSFER: The material record is vital for determining the final cost of the well; all the materials supplied must be listed.



Bore Hole Schematic
Rig: GW120
Job No: OW-717A

KenGen
Rig No: GW120
Job Name: OW-717A

Actual Data

All Depths are relative to the Original RKB Elevation
Original RKB Elevation at 10,70 m above Ground Level
Ground Level
50,80 cm Casing set at 58,14 m on 31-okt.-11

33,97 cm Casing set at 297,84 m on 13-nóv.-11

17,78 cm LINER, Top set at 732,45 m
24,45 cm Casing set at 753,83 m on 26-nóv.-11

17,78 cm Liner set at 3000 m on 30-des.-11
Open Hole Diameter 21,59 cm
Total Depth 3.000,00 m

Printed: 11:54 23-ágú.-12 *RIMDrill Land 6.0.1.81* *Page: 1 of 1*

FIGURE 2: Casing string and liner for OW-717A (generated by RIMDrill Land 6.0.1.81)

h) FOAM AND AERATED DRILLING: The drilling program also gives details on aerated drilling, which is usually the preferred drilling fluid. It gives information on:
- The type and capacities of compressors (primaries and booster).
- Foam details on when to be used and the foam parameters which include surfactant (soap) concentration and flow rate.

- Aerated water flow rates for different sections of the well and the air/water ratio.
- Unloading; while there are many methods of unloading the hole, it is recommended that the hole be unloaded from the bottom using the minimum strokes on the mud pump. This method is fairly quick and reduces shock waves into the formation to a minimum, which could cause sloughing in weak formations.
- Record keeping; the pressure, temperature and flow rate must be recorded and kept. Other data such as fuel consumption must also be properly kept for future reference.
- Details on corrosion control are also important and are contained in this section of the drilling program. Information on how to check and maintain the key parameters within the allowable levels are highlighted.

As a planning tool, the drilling program proposes how the drilling will progress and how long the drilling will last. The whole operation is divided into stages for easier management with details on when key operations, mainly running in casing and cementing, are expected to be conducted. This is presented in a graph of depth (m) versus time (days) and acts as a bench mark against which the progress of drilling is measured. Figure 3 shows such a graph of drilled depth versus time for well OW-717A.

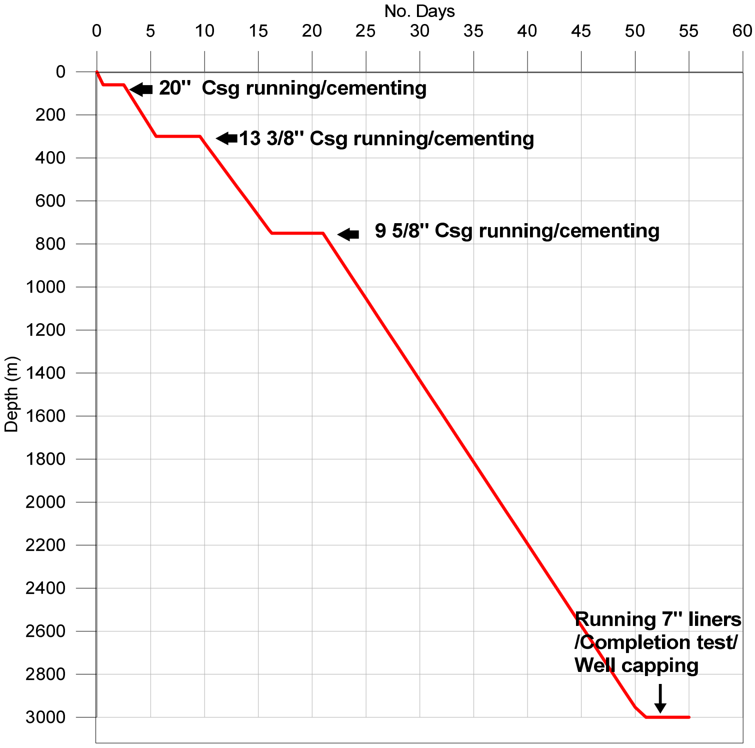


FIGURE 3: Graph of drilled depth versus days for well OW-717A (KenGen, 2011)

The drilling program also gives details on the well head assembly. The permanent wellhead components include (Hole, 2008a):

- *Casing Head Flange* (CHF) usually, and preferably, attached to the top of the Anchor casing – but in some instances is attached directly to the top of the production casing. The casing head flange may incorporate side outlets to which side valves are attached.
- *Double flanged expansion / Adaptor spool*: Side outlets may be incorporated into the expansion spool (as an alternative to those on the CHF).
- *Master Valve*: A typical wellhead assembly for a 'Standard' diameter well completed with an 8 1/2" diameter production hole section, 9 5/8" production casing and 13 3/8" anchor casing is illustrated schematically in Figure 4.

2.3 Specifications and drawings for infrastructure

The drilling process cannot be successful without certain infrastructure being in place. The infrastructure should be able to support the drilling equipment and the demands for the well. The infrastructure needed prior to and during drilling includes:

- Rig platform and ponds;
- Access road;
- Temporary power;
- Water supply;
- Material sources;
- Waste water facility; and
- Camp facility.

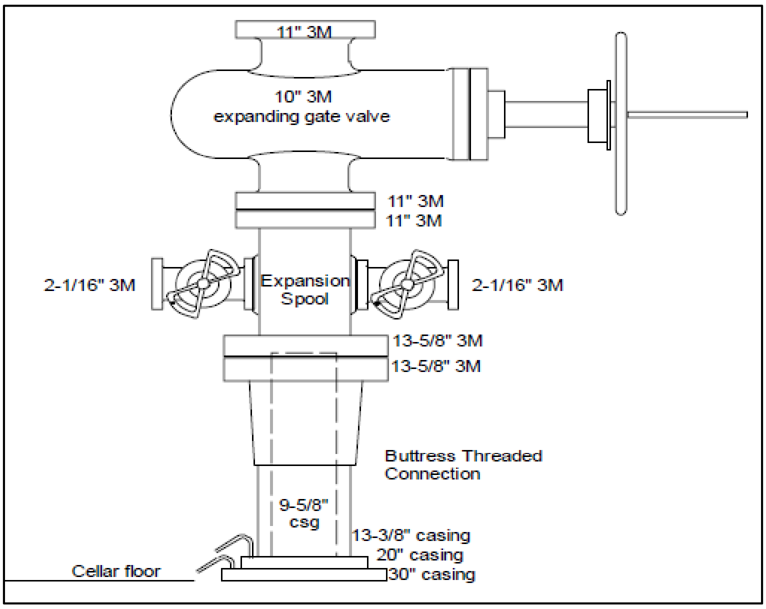


FIGURE 4: Completion well head (Hole, 2008a)

Rig platform: The rig platform acts as the foundation of the drill rig and must therefore be levelled and compacted prior to drilling operations. This is normally done either by the drilling crew or by a different section as is the case in KenGen where the infrastructure department constructs the platforms. Depending on the size of the rig, the drilling platforms are of different sizes including:

- Very small rigs (55 t) 15 × 45 m;
- Small rigs (200 t) 50 × 100 m; and
- Large rigs (400 t) 80 × 200 m.

The drilling platform provides for the following functions:

- Site for the well and cellar;
- Support for the weight of the drilling rig and auxiliary equipment;
- Support for cement and mud tanks;
- Firm ground for large mobile cranes;
- Waste pond and sump next to platform;
- Containment of waste fluids and oil spills;
- Storage area for casing and consumables;
- Site for offices, spares storage, workshops and canteen; and
- Vehicle traffic for crew and materials.

Figure 5 shows the typical layout of a platform for the rotary rigs used in Olkaria, Kenya; it covers an approximate area of 8,000 m^2 with dimensions of 100×80 m.

Access: Access to the drilling site before and during the drilling operation is of great importance, given the size and weight of the drilling rig, associated equipment and the materials used during drilling. Depending on the actual location of the drilling site, the access needed may range from docks for ships, roads, and an airport. This will ensure that trucks are able to reach the site with the materials that are required during the drilling process.

Temporary power: A power supply is necessary to power auxiliary equipment and for lighting the drilling area. To prevent disruptions, in cases of power outages, generators are usually connected with an automatic switch-over panel. The power must be of a correct voltage and phase (usually three phases) given the heavy equipment that are to be powered.

Water supply: Water is very crucial in the drilling process and the supply must be sufficient and sustainable. Besides being used in the actual drilling to clean the hole, and cooling the well among other functions, it is also used in key operations such as the cementing process. For this reason, the water supply system must be well designed to ensure the water is at the site whenever needed. The design takes into consideration the discharge rate, and the delivery point elevation. The pipeline should be able to withstand the pressure from the water source to the rig site. The pumping unit should be able to pump the required flow to the required elevation. The drilling site could be next to a major water source such as a lake or a river, but in other cases it could be far off from any natural water source. In that case, water boreholes are normally sunk. Where there is water scarcity, waste water from discharging geothermal wells may be used as drilling water after ponding, to reduce its silica concentration.

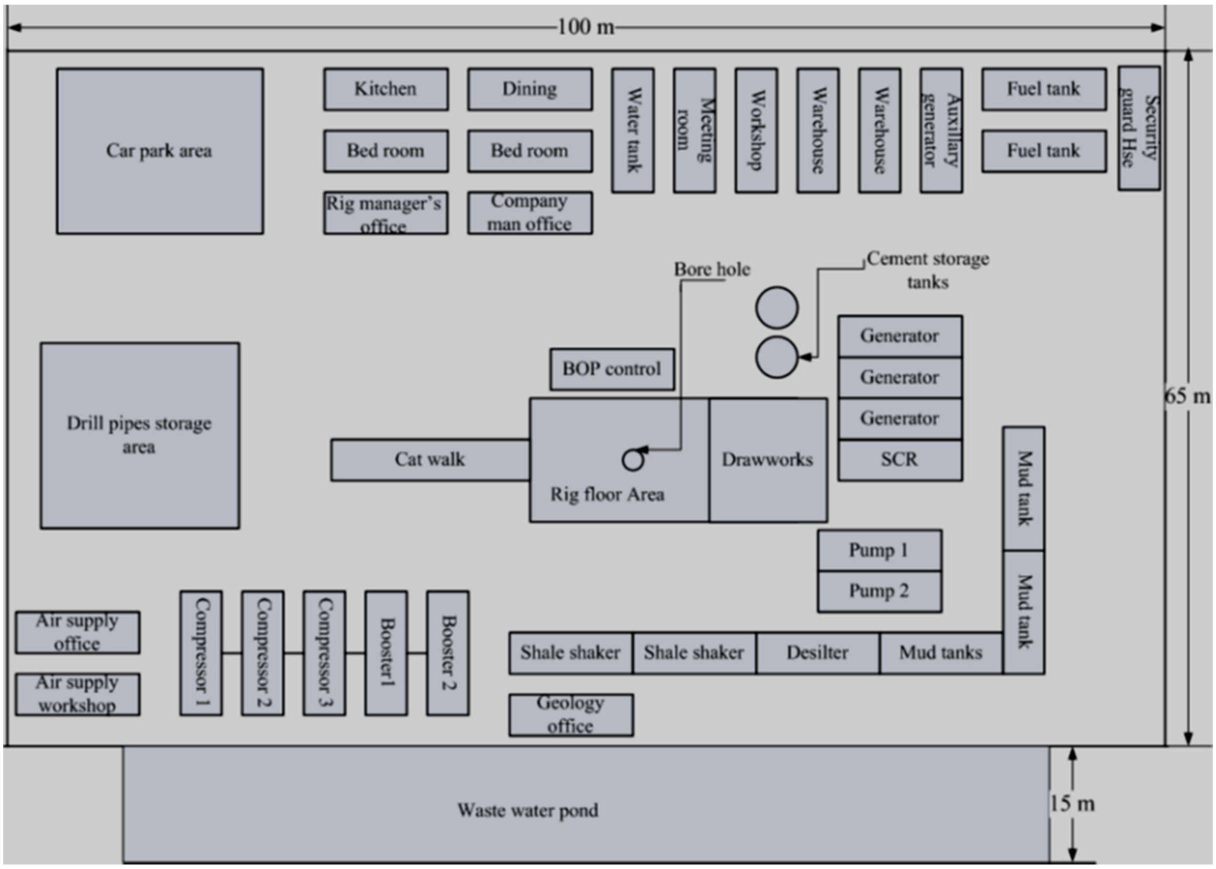


FIGURE 5: Typical well platform used in Olkaria, Kenya

2.4 Tender documents for rig and materials

Procurement of drilling services and materials differs from one country to another with the majority of countries relying on drilling contractors for the provision of drilling services. The contract environments, that are currently utilized by the geothermal well drilling industry, range from unit time rate (day rate), unit meter rate, through to turnkey contracts. Hole (2008b) enumerates the components of geothermal drilling operations which must be provided and executed. The activities and processes may be provided to an owner under a large number of totally separate and discrete service contracts or, conversely, under one lead contract, or any mix between the two.

In many cases, the contracts are based on bids from the drilling contractor and a host of other service and material providers for drilling mud, cementing services, directional services, casing, drill bits etc. Contracts for services are usually based on day rates. For public utilities and projects funded by development banks, the drilling and material supply contracts go for international open tendering.

In integrated contracts, on the other hand, there is one contract, usually with the drilling contractor, that covers all the drilling services and materials. These contacts are usually based on day rates but may be priced per meter and unit prices for materials, as is the case for Iceland.

The contracts must clearly define the 'scope of work' of a drilling services contractor with a split of responsibility between the Owner and the Contractor.

2.5 Environmental Impact Assessment

A supply of secure, equitable, affordable and clean sustainable energy is indispensable for future prosperity. Geothermal energy is one of the most promising among renewable energy sources due to its potential for reliable power generation and direct use with little greenhouse gas emission (Fridleifsson, 2001; Rybach, 2003). The environmental impacts must, nevertheless, be assessed and proper mechanisms to address them put in place. While the fundamentals of various energy projects like hydro are well known and defined, the characteristics of geothermal utilization are very different. The utilization of geothermal energy is dynamic, where the information is being gathered and processed continuously during the time of the utilization.

Environmental impacts, resulting from geothermal development, vary during the phases of development and between sites. Kristmannsdóttir and Ármannsson (2003) listed the main environmental impacts associated with geothermal development:

- Surface disturbance;
- Physical effects of fluid withdrawal;
- Noise;
- Thermal effects;
- Chemical pollution;
- Biological effects; and
- Protection of natural effects.

Surface disturbance arises from development including roads, well pads, drilling of groundwater and geothermal wells. Deposition of waste soil and drill fluids, including cuttings and mud, contributes to the physical effects. Noise from flow testing, the drill rig and other auxiliary equipment such as compressors and generators must be kept to acceptable levels. Steam spray during flow testing of wells has a temporary adverse impact on the local vegetation, affecting the biodiversity of the area. Air pollution due to emissions of geothermal gases in the geothermal steam must be addressed. Carbon dioxide adds to the greenhouse effect and hydrogen sulphide is poisonous in high concentrations. All these and other impacts must be well assessed and addressed by independent auditors before licences are issued by the relevant environmental bodies.

2.6 Policy, legal and administrative frameworks

Geothermal projects, like other major infrastructure projects, by their very magnitude and nature require a lot of official approvals and licences for the various phases of development, from exploration to utilization. This, therefore, calls for early consultation with public agencies, local and governmental authorities, Non-Governmental Organizations (NGO‘s) and stakeholders. These consultations in the early stages of the project ensure that different views are discussed and hopefully resolved before the project is implemented.

The energy authority, environmental agency, local authorities, local health inspectorate, and NGO‘s are but some of the bodies that are consulted and from whom licences are sought. The principal law for any major project in Kenya is the Environment Management and Coordination Act (EMNCA) of 1999 and the Environmental Impact Assessment and Audit Regulation of 2003. Other national legislations relevant for geothermal development in Kenya include (GDC, 2011):

1. Geothermal Resources Act of 1982 and supplementary legislation of 1990 and the second schedule of EMCA of 1999;
2. The Electric Power Act (Cap 48);
3. The Forest Act (Cap 385);
4. The Water Act (Cap 372);
5. The Water Act (2002) Part VI Section 94;
6. The Factories & Other Places of Work (Noise Prevention & Control Rules) Act 2005 (Cap. 514);
7. The Wildlife Conservation and Management Act;
8. The Environmental Management (Air Quality) Regulations (2008);
9. The Occupational Safety and Health Act (2007);
10. The Environmental Management (Solid Waste) Regulations (2006);
11. The Environmental Management (Water Quality) Regulations (2006);
12. The Environmental (Impact Assessment and Audit) Regulations (2003);
13. The Agricultural Act;
14. The Public Health Act (Cap 242 Revised Edition 1986);
15. The Chief's Authority Act (Cap 128 Revised Edition 1998);
16. The Local Government Act (Cap 265 Revised Edition 1998) & Regulations (1966), Section 145;
17. The Penal Code (Cap 63 Revised Edition 1985);
18. The Petroleum Bill (2002);
19. The Foods, Drugs and Chemical Substances Act (Cap 254 Revised Edition 1992);
20. The Use of Poisonous Substances Act (Cap 247 Revised Edition 1983);
21. The Radiation Protection Act (Cap 243 Revised Edition 1985);
22. The Irrigation Act (Cap 374);
23. The Fisheries Act No. 5 of 1989;
24. The Lakes and Rivers Act (Cap 409);
25. The Land Planning Act (Cap 303);
26. The River Authorities Act (Cap 443);
27. The Way Leaves Act (Cap 292);
28. The Antiquities and Monuments Act (Cap 215); and
29. The Workmen's Compensation Act (Cap 236 Revised Edition 1988) Part II.

Besides the legislation, there are international guidelines that govern the development of geothermal resources; Kenya is also a signatory to a number of international treaties and conventions. Those that are relevant to geothermal projects in Kenya include:

- The United Nations Framework Convention on Climate Change (UNFCCC), which has established an ultimate objective of stabilizing greenhouse gas (GHG) emissions at a level that would prevent anthropogenic interference with global climate; and
- The 1994 Convention for Biological Diversity, whose objective is conservation of biological diversity, the sustainable use of its components and fair and equitable sharing of the benefits arising out of the utilization of genetic resources.

Lake Naivasha was designated as a RAMSAR site in 1995 under the international convention on "The Convention on Wetlands of International Importance". Table 2 below lists the permits and licences required for geothermal project development in Kenya.

TABLE 2: Licenses and permits required for geothermal development in Kenya (GDC, 2011)

Legislation/Other requirement	License and/or permits
Geothermal Resources Act of 1982 and supplementary legislation of 1990	Geothermal resource exploration license
EMCA, 1999	EIA license
The Factories and Other Places of Work (Noise Prevention and Control Rules) Act 2005 (Cap.514)	Noise emission license
Environmental Management (Water Quality) Regulation, 2006	Effluent discharge license
Environmental Management (Solid Waste) Regulation, 2006	Waste disposal site license License to generate hazardous waste
Electric Power Act electricity	Generation license
Environmental Management (Air Quality) Regulations, 2008	Emission discharge license
The Water Act (2002) Part VI, Section 94	Water abstraction permit

2.7 Description of daily reports

Daily reporting of the drilling operations and all well related activities is important in the management and monitoring of geothermal well drilling.

2.7.1 Rig daily reports (2 tour-IADC form)

The daily report gives up-to-date progress of all the activities taking place at the rig and is filled out for every 12 hour shift. This is done either on a logging book or on a computer program. The rig daily report describes the work, tracks time, material usage, cost, and reports on upcoming activity. For the purposes of this report as part of the UNU-GTP training, the daily reports are recorded and analysed using RIMDrill software, which is widely used by geothermal drilling contractors. The data entry is done by the toolpusher at the rig during the shift.

The reports are printed in conformity with the IADC standards (IADC, 1992). The parameters and details captured in the daily reports include:

- Rig information;
- Drilling parameters;
- Time record;
- Mud record;
- Deviational record;
- Material inventory;
- BHA and bits;
- Casing information;
- Auxiliary equipment details;
- Safety information;
- Drilling crew details; and
- Equipment failures.

Time records must be well captured and documented since they are not only used as reporting parameters but also in the operational analysis to aid in the optimization of the drilling processes and in tracking the cost. The time distribution on the various operations in the process of drilling the well is the key in the overall analysis, making the time records a vital part of the rig's daily report. The various drilling processes are recorded and coded, among them:

- Rigging up and down;
- Actual drilling;
- Reaming;
- Circulating;
- Tripping in and out;
- Repair of rig and auxiliary equipment;
- Cut and slip of the drill line;
- Wireline logging;
- Running casing;
- Cementing casing and cement plug operations;
- Waiting on cement;
- Nippling up the BOP;
- Testing the BOP; and
- Other operations include equipment testing, lay down and picking up singles among others. There are about 80 operational codes that can be entered and new ones can be added.

The time spent on each of the above operations is recorded, has a special numeric code, and the whole time record is then used in the operations time analysis as part of the in-depth analysis of rig operational activities.

Bits: Optimization of the drilling process, from the view point of time and cost, is extremely crucial in the drilling of a geothermal well. Once the parameters are given, the selection of drill bits and correct configuration of the rest of the BHA can be made based on experience.

In the analysis of drilling operations (Miyora, 2010), the tripping time normally constitutes a large percentage of the overall well drill time. This, therefore, implies that if it is possible to reduce or minimize the number of trips (pulling out of hole and running in hole), the total drill time will be significantly reduced. Selecting a drill bit that can drill more before wearing out can solve this problem. However, the cost of a long lasting bit is usually higher and, when optimizing the drilling process, cost is also a key factor and must be considered in the final proposal. For optimum selection, calculation of the actual bit cost per meter drilled is useful.

The bit record, therefore, provides a good avenue for analysing the performance of the bit in terms of the rate of penetration, fluid properties, and bit type when it comes to selecting the bit that lasts longer and drills more, thereby reducing the overall drilling time and cost. The used bit records give information on:

- The hours run by the bit and total number of revolutions;
- The depth interval of the hole drilled by the bit;
- Details on the bit including type (IADC code), size, make, model, size of jets, number of runs;
- Gauging of the used bit (IADC grading system).

BHA and drill string: The drilling performance is directly affected by the overall drilling system and the operational parameters that form the core of engineering the drilling of a geothermal well. This involves maintaining the integrity of the drill string, managing the hydraulic pressures, ensuring effective hole cleaning and determining the pressure limits of the open hole in order to maintain wellbore integrity. The drill string serves the following purposes:

- Conduit for the drilling fluid from the mud tanks down to the bit;
- Transmits the torque via the Kelly drive or from the top drive to the drill bit;
- Applies weight on the bit; and
- Lowers and raises the bit.

The drill string is made up of three sections, namely the BHA, heavy weight drill pipes (HWDP) and the drill pipes. The rig's daily report gives details on the components of the BHA and drill string including, most importantly, the weights. The BHA is made up of the drill bit, bit sub with a check valve, the drilling stabilizers which keep the assembly centred in the hole, and the drill collars which apply weight to the bit. For directional drilling, a mud motor and MWD may be added just above the bit. Some drill collar strings also have a hydraulic jar in case the drill string gets stuck. The components are joined together using threaded connections with short subs used to connect dissimilar threads. The weight of the string, especially the collars, is important in estimating the amount of WOB that can be applied on to the bit and in case of a stuck string what amount of overpull is required to overcome the weights. It is, therefore, important to keep good records of all the components of the drill sting. For the drill collars, the exact outside diameter of each must be known, in case a fishing job for a broken collar needs to be performed.

Casing tally: The choice of casing depths and specification of the material's weights and connections is vital to the success and safety of the well drilling process and to the integrity and life of the well. The casing design and specification process includes reviewing the required services of the casings, determining the setting depths and checking possible failure modes.

In general, the shallower and outer casing strings are necessary for the drilling operations, while the inner strings are required for production purposes. The drilling process follows a sequence of drilling to a certain depth, running and cementing a casing string, establishing a wellhead (drilling or final), which allows the drilling of the next smaller diameter section to proceed. As a minimum, two, but usually three or more, completely cemented, concentrically located, steel casing strings are obligatory both from a technical and legal sense for a geothermal well.

Before the casing tally is prepared, the casing setting depth must be determined. For a typical geothermal well, the setting depths for the casings are determined based on the following criteria (Hole, 2008a):

Surface or conductor casings strings. These are the largest casings which are set at a shallow depth and are employed to prevent loose near-surface material collapsing into the hole. The setting depth of the casing shoe will be estimated from geological deduction, but may be altered to reflect conditions found during the course of drilling, and may have to contain hot fluid under pressure if there is a thermal zone close to the surface.

Anchor or intermediate casing strings. These casings are intermediate in diameter and in setting depth, and are set to support successive wellheads (usually including the permanent wellhead) and to contain drilling and formation fluids of relatively high temperature and pressure. Setting depths will be chosen from expected formation rock and fluid conditions to provide adequate permanent anchorage and additional security against drilling problems, including blowouts.

Production casing. This casing is smaller in diameter and set at greater depth than previous casings, and is used primarily to convey steam and water to the surface, but it is also important in facilitating drilling to total depth and to preventing unwanted leakage of fluids into or out of different aquifers. The depth of this string should be chosen first, on the basis of the expected depths and temperatures of fluids to be excluded from production.

The casing tally gives the length of each casing joint, the diameter of the casing, the weight, the steel grade, the connection type. It also gives information on the centralizers, hangers and all other components which make up the casing string. This data is entered on a special casing tally form or into RIMDrill software.

Drilling fluids are required to remove cuttings from the well during drilling, to cool and lubricate the drill bit and drill string, to apply pressure to formation fluids to control flow into or out of the well, and to cool the formation, particularly prior to cementing casings. Various drilling fluids are selected according to reservoir pressures and temperatures and to the drilling techniques to be utilised. Hole (2008c) outlines the important fluid properties, including:

- Slip velocity which is the upwards annular drilling fluid velocity required to impose an upward drag force on a cuttings particle, equal to the downward gravitational force on that particle;
- Thixotrophy, which is the ability of a drilling fluid to hold cuttings in suspension during periods of no circulation, and of releasing the cuttings from suspension at the surface;
- Fluid viscosity;
- Fluid velocity; and
- Gel strength.

Water alone is the preferred drilling fluid for geothermal wells, due to its low cost and for causing less formation damage than mud. Aerated water is used in many cases, especially after losses are encountered. When bit diameters are above 12 ¼", the flow rate is insufficient for adequate cutting transport and then drilling mud is used. The most commonly used geothermal drilling mud is water based bentonite mud, which typically comprises bentonite clay, water and caustic soda. Other chemicals may be added to control the physical properties of the fluid as required by the downhole conditions, and these will include:

- Thinners to control viscosity and gel strengths;
- Fluid loss control agents to control the loss of water from the mud which in turn controls excessive build-up of wall cake;
- Weighting materials such as barite to increase mud density (rare in geothermal); and
- Loss of Circulation Materials (LCM) to aid in reducing the loss of drilling fluid to the formation.

The rig's daily report gives details on the drilling fluid properties at every stage of drilling the geothermal well in the form of a mud report. The mud report gives properties of the mud: pH, density, viscosity, temperature, weight, and filtrate. Also included in the daily report is an inventory of the mud consumption during the shift and, sometimes, the costs. This helps in inventory control and in the cost analysis for different stages of drilling and comparison between different wells.

Directional drilling is a special drilling operation used when a well is intentionally curved to reach a bottom location (Vieira, 2009). There are some significant advantages, including increased potential for encountering permeability and, therefore, production; greater flexibility in selecting well pad locations relative to the well target; and it introduces the possibility of drilling a number of wells from a single well pad. Having established the drilling target and the casing setting depths, the three dimensional geometric track of the well needs to be determined. In Kenya and most other countries, the directional wells normally assume a ´J´ shaped well profile comprising an initial vertical section to the 'kick-off' point (KOP), followed by a curve of constant radius determined by the "rate of build" to the end of build (EOB), followed by a straight section hole at a constant angle from the vertical: (final drift angle), as depicted in Figure 6.

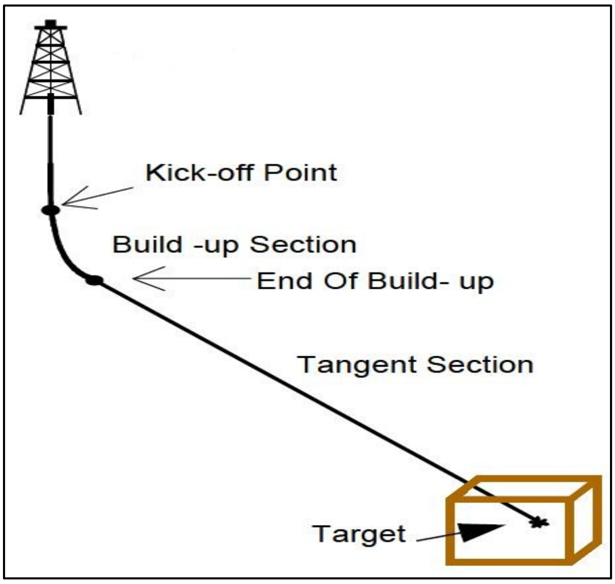


FIGURE 6: ´J´ Shape well (Vieira, 2009)

During the drilling process, the angle of inclination and the radius of curvature (azimuth) are measured after every specified depth of drilling. These are recorded and then used as input to a program where they are analysed. This report utilizes RIMDrill software to analyse the directional data and the output given in the form of an elevation, plan and 3D graphs.

The rig's daily report gives the survey information in a table format and provides information on the tool depth and actual drilled depth during the deviation survey.

2.7.2 Mud logger (geologist) report

Besides the rig's daily report that mainly reports on the drilling related activities, other daily reports are prepared including the geologist's daily report.. This report provides the geological details of the formations encountered over a 24 hour period of drilling. The report contains the following:

- Lithology encountered during the last 24 hours of drilling, covering the rock type, alteration minerals and intrusions; this information is obtained from the cuttings;
- Temperature of the inflow and outflow drilling fluid;
- Loss zones which are an indication of where aquifers were encountered;
- Details on the casing, especially the casing setting depth;
- Deviation survey to tell whether the well is on track to the target structure; and
- Comments on the drilling parameters including WOB, rate of penetration (ROP), pump pressure, torque and fluid losses.

The mud report presents the mud properties, volume accounting and material usage and cost.

2.7.3 Special reports: wireline logging, well testing, cementing

There are special operations which are carried out in the process of drilling a geothermal well that are reported separately. These include cementing, logging, and well testing.

Cementing is one of the crucial operations in geothermal well development that must be done right and requires good design and execution in the field. The preparations needed to be done before a cementing job is carried out are defined by Bush and O'Donnell (2007) and the Drilling and Completion Committee (1995). The cement's properties are defined and the quantities determined. The cements and cement additives that are selected and cement lab tests performed to confirm the slurry properties e.g. thickening time. The cementing practices utilised are an integral part of sound well design, construction and well integrity.

During cementing operations, various parameters are recorded as part of the monitoring of the cementing's execution and for post-job analyses. The data acquisition system of the cementing unit is used to record the pumping rate, cement slurry density and volumes pumped during the cementing job. Also recorded are pressure tests and times, start time for the job, start and stop time for each fluid pumped, start of displacement and any observed pressure. These records form part of the cementing report. In the post-job evaluation, it is important to carry out acoustic logs (CBL) to assess the effectiveness of the cement job. This is advised because for the cementing job to be considered successful there must be an excellent bond between casing and cement and between the cement and the formation.

Logging: In the course of drilling and after drilling the well, several logs are run into the well to give information on the location of loss zones, structure, physical properties and performance of the geothermal system penetrated by the well. The information on performance and conditions of a well is important during drilling as it provides information on the reservoir and the success of the drilling, but is also useful in solving drilling problems.

After every logging operation, a logging report is generated which, depending on the purpose for carrying out the log, will direct the next course of action. The logging report gives a parameter as it changes with depth and time. Temperature and pressure logs are the most important geothermal well logs but there is a wide range of parameters that can be derived from geophysical logging. The data are collected either directly by connecting the logging tool to a logging unit on the surface through a cable and registered there, or the data is stored inside a memory tool and extracted at the surface once the tool is out of the well. Such logging, however, is not carried out daily and, therefore, a report is only given after logging has been carried out.

The well logging report includes the results of all borehole logging operations, including (Thórhallsson, 2012):

- Temperature logs, which show where the losses are, where the drill string is stuck etc.;
- Pressure logs, for step rate injection tests;
- Calliper logs, which show where there are cavities and collapses, even fractures; they are used to estimate cement volumes for casing cementing;
- Lithological logs, which complement the cutting analysis and other well information;
- Static formation test, by Horner plot, of the temperature recovery on the bottom;
- Quality of the casing cement, cement bond log (CBL); and
- Borehole imaging: borehole televiewer and borehole video.

Well testing: Immediately after completion of drilling, a slotted or perforated liner is run into the open hole production section of the well; the blow out preventer stack is removed from the wellhead; and, if not previously fitted, the master valve is attached to the wellhead. At this point drilling operations are finished, but it is the usual practice to carry out a series of tests on the well, utilising the drilling rig equipment, and in particularly the rig pumps, before rigging down and removing the rig from the well site.

The "completion tests' carried out on a geothermal well immediately after completion of the drilling activities provide a collection of data which characterise the well, the formations surrounding the well, and the geothermal resource into which the well has been drilled. These tests allow for an early assessment of the likely production by measuring the injection capacity of the well, for understanding the characteristics of the geothermal resource.

A well completion report is then prepared after all the tests are done and these form part of the report on a geothermal well.

2.8 Well completion report

Once the well has been completed and the drilling equipment moved to the next drilling site, a comprehensive well report is prepared. The well completion report covers, in detail, the well information, the drilling details, materials used, and the cost of the well. It also incorporates the geological aspects of the well. A brief outline of each section of a well completion report is given below:

Well and equipment information: This section of the report provides details of the well's physical location, planned and actual details in terms of depth and direction (for directional wells). It also gives details of the drilling equipment and other contracted services.

Drilling details: This section provides a detailed record of the drilling activities. It explains how each section of the well was drilled and includes the actual drilling summary report which shows daily activity from the day the well was spudded to its completion. The directional survey data and reports are also given in this section with details of all deviational surveys (depths, inclination and azimuth), and the graphs generated from the data.

Drilling materials: This section details an inventory of all materials used in drilling and completing the well. Emphasis is given on the casing details represented in a tally form, the cementing details given in the cementing report, mud information given in the mud report, and bit details given in the bit records.

Costing: This is an important section of the completion report as it provides the costs of the well. It incorporates the costs of all aspects of the well: drilling materials and service cost, infrastructure cost, reservoir well testing cost, and geological cost. The cost information is not always included.

Geological details: This section provides a summary of the geology of the well encountered over the course of drilling. This is normally provided by the borehole geologists and is extracted from the borehole geology and hydrothermal mineralisation report of the well. The report is divided into the following main parts:

- Geological and tectonic settings;
- Surface exploration;
- Borehole geology;
- Hydrothermal alteration and temperature distribution; and
- Aquifers.

3. OPERATIONS ANALYSIS

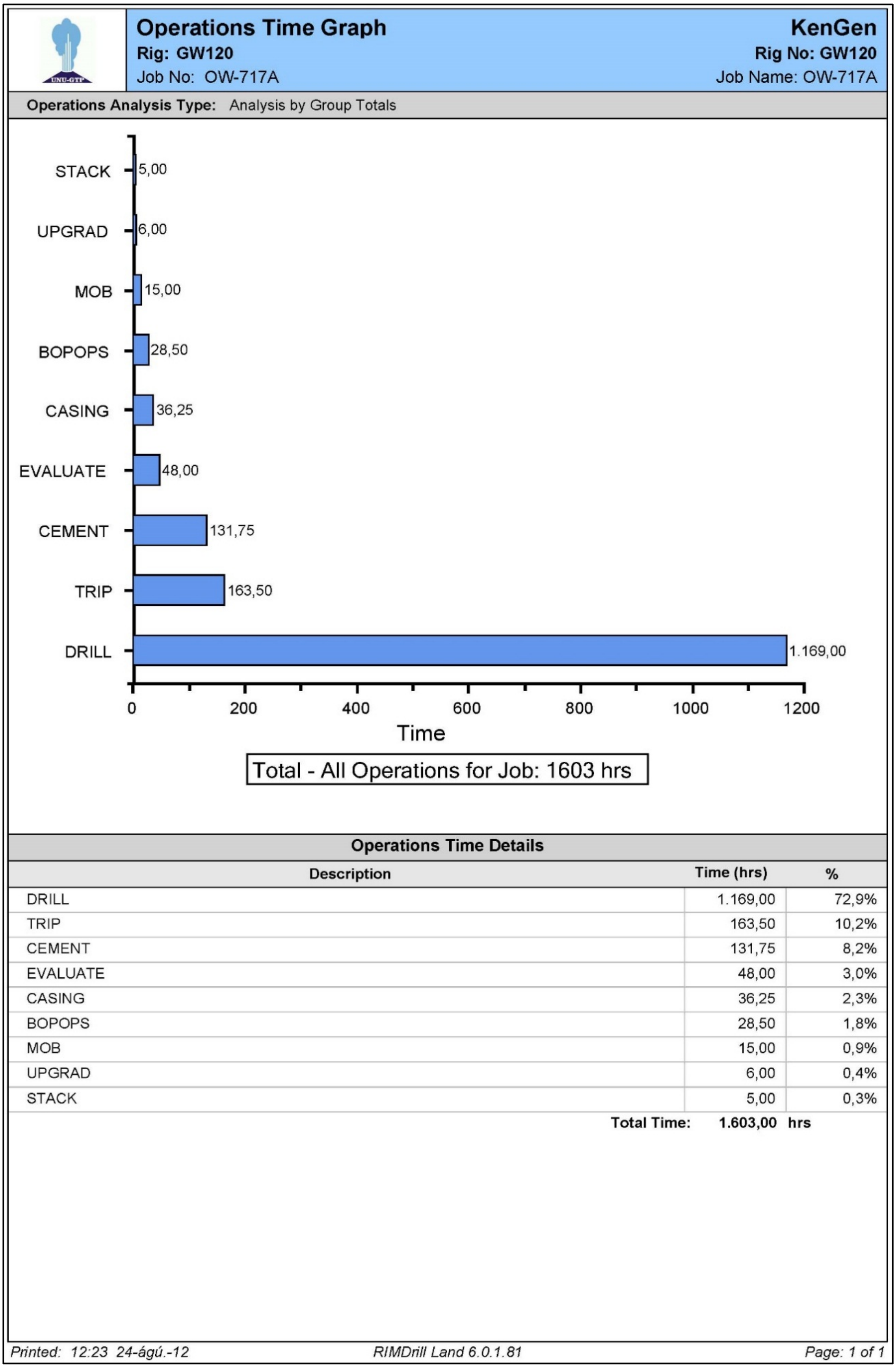
The analysis in this report was done by using RIMDrill software after all the relevant data had been entered into the program by the author for two wells drilled in Kenya. More information about RIMDrill Software and its application is discussed in the next chapter of this report.

3.1 Time analysis

Miyora (2010) presented results from a time analysis comparing the drilling performance of drilling selected wells in Kenya and Iceland. Using RIMDrill software, the number of hours spent on each operation on each shift was entered into the operations section of the daily reporting page. These were then represented on the operations time graph showing the percentage of the total time spent on each operation. Figure 7 shows an operations time graph for well OW-717A generated using the Rim Drill software.

As part of the rig's operational analysis, breakdown of the operations time analysis was according to the IADC code. An example is where tripping is given an IADC code and the proportion of time spent on tripping determined. Under tripping, there are isolated operations such as tripping in, tripping out or changing the BHA. These were again analysed independently and the proportion of time spent on each determined. Figure 8 shows an operations time analysis by operations group for well OW-717A.

The depth versus time graph also provides a good overview of the progress of drilling the well (Figure 9). From the planned progress data and the actual progress, it is easy to see how many days behind or ahead of plan the drilling was. The graph also shows which section of the well contributed to the delay or to fast progress. This could then be related to other sections of the overview reports such as the rig's downtime report. Figure 9 shows a graphical report on the progress of well OW-717A.



Operations Time Graph
Rig: GW120
Job No: OW-717A

KenGen
Rig No: GW120
Job Name: OW-717A

Operations Analysis Type: Analysis by Group Totals

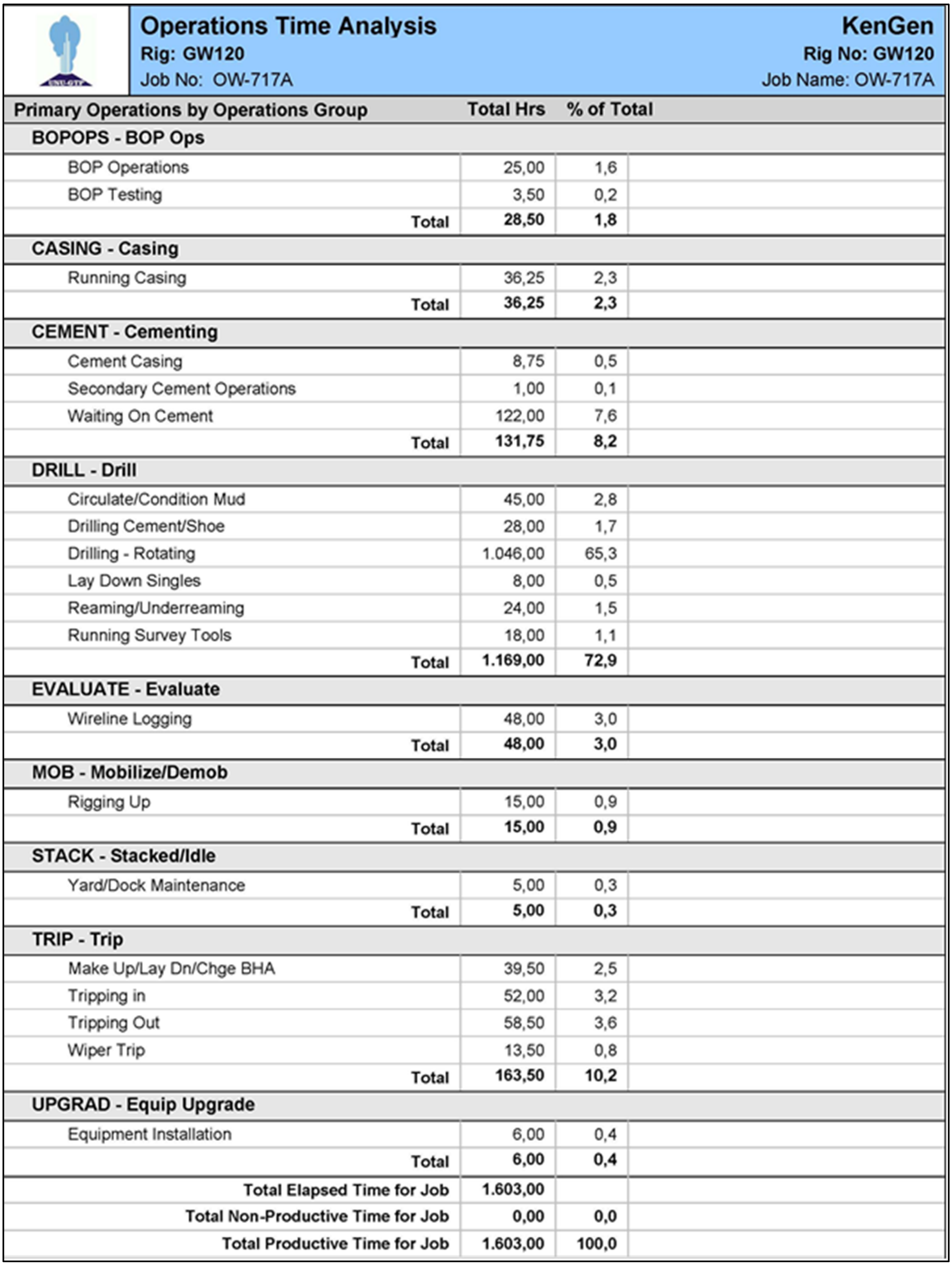
Total - All Operations for Job: 1603 hrs

Operations Time Details

Description	Time (hrs)	%
DRILL	1.169,00	72,9%
TRIP	163,50	10,2%
CEMENT	131,75	8,2%
EVALUATE	48,00	3,0%
CASING	36,25	2,3%
BOPOPS	28,50	1,8%
MOB	15,00	0,9%
UPGRAD	6,00	0,4%
STACK	5,00	0,3%
Total Time:	**1.603,00**	**hrs**

Printed: 12:23 24-ágú.-12 *RIMDrill Land 6.0.1.81* *Page: 1 of 1*

FIGURE 7: Operations time graph for well OW-717A
(generated by RIMDrill Land 6.0.1.81)



Operations Time Analysis **KenGen**
Rig: GW120 **Rig No: GW120**
Job No: OW-717A Job Name: OW-717A

Primary Operations by Operations Group	Total Hrs	% of Total
BOPOPS - BOP Ops		
BOP Operations	25,00	1,6
BOP Testing	3,50	0,2
Total	**28,50**	**1,8**
CASING - Casing		
Running Casing	36,25	2,3
Total	**36,25**	**2,3**
CEMENT - Cementing		
Cement Casing	8,75	0,5
Secondary Cement Operations	1,00	0,1
Waiting On Cement	122,00	7,6
Total	**131,75**	**8,2**
DRILL - Drill		
Circulate/Condition Mud	45,00	2,8
Drilling Cement/Shoe	28,00	1,7
Drilling - Rotating	1.046,00	65,3
Lay Down Singles	8,00	0,5
Reaming/Underreaming	24,00	1,5
Running Survey Tools	18,00	1,1
Total	**1.169,00**	**72,9**
EVALUATE - Evaluate		
Wireline Logging	48,00	3,0
Total	**48,00**	**3,0**
MOB - Mobilize/Demob		
Rigging Up	15,00	0,9
Total	**15,00**	**0,9**
STACK - Stacked/Idle		
Yard/Dock Maintenance	5,00	0,3
Total	**5,00**	**0,3**
TRIP - Trip		
Make Up/Lay Dn/Chge BHA	39,50	2,5
Tripping in	52,00	3,2
Tripping Out	58,50	3,6
Wiper Trip	13,50	0,8
Total	**163,50**	**10,2**
UPGRAD - Equip Upgrade		
Equipment Installation	6,00	0,4
Total	**6,00**	**0,4**
Total Elapsed Time for Job	**1.603,00**	
Total Non-Productive Time for Job	**0,00**	**0,0**
Total Productive Time for Job	**1.603,00**	**100,0**

FIGURE 8: Operations time analysis for well OW-717A (generated by RIMDrill Land 6.0.1.81)

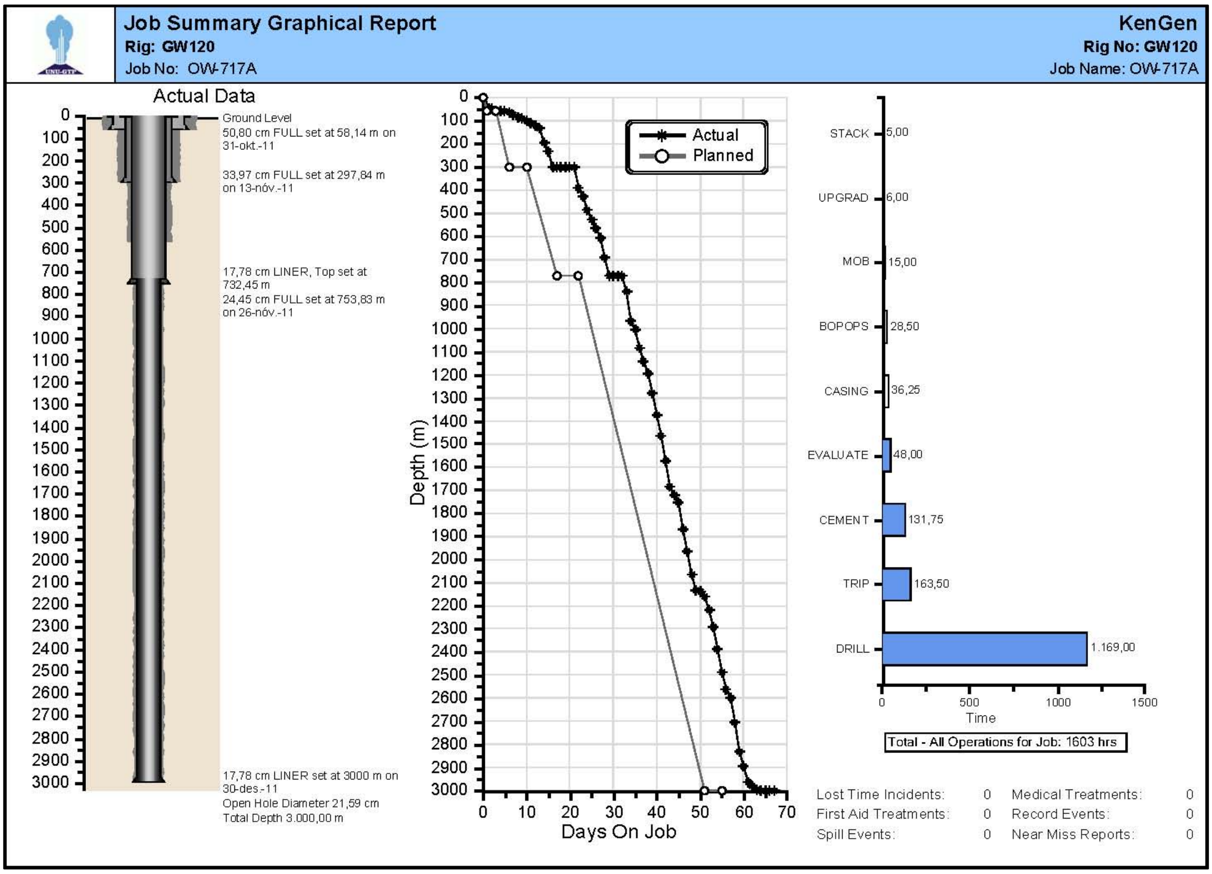


FIGURE 9: Job summary graphical report (generated by RIMDrill Land 6.0.1.81)

3.2 Cost analysis

The cost of drilling geothermal wells for production and reinjection is about 40% of the project's total investment, explaining why the subject of cost and risk often comes up and how it can be minimised (Thórhallsson, 2012). As a critical aspect of optimization of geothermal well drilling, the cost of materials and services must be well defined. The nature of the contract, whether it is one integrated contract or many contracts, will affect the way the cost is analysed. The costs report group includes the following reports:

- Cost versus depth graph showing actual and planned costs for a single job and for a group of jobs;
- Cost query where a flexible report of daily costs can be filtered by division, field, job, dates, account codes, and/or vendors;
- Daily cost report giving cost information for a single operating day;
- Job summary report showing a summary of actual costs for the job;
- Weekly costs giving the daily cost for expenditures by day of the week; and
- Vendors' costs showing daily costs with vendor cost associations; can be filtered by job, vendor, and/or date range.

An authority for expenditure (AFE) has to be prepared and signed off by the operator before commencing the project with an estimate of the cost of realizing a well or a part thereof. Accounting entries under the respective AFE allows economical evaluation of the drilling project. Within the AFE, all cost items are listed as they are known or can be estimated at the planning stage. During drilling, a close follow-up of the actual cost and a comparison with the estimated (and authorized) ones can be done on a daily basis on the RIMDrill platform. With RIMDrill software it is possible to analyse the cost per unit depth that is drilled, per section of the well, or per shift to enable identification of efficient processes for the purposes of optimizing the drilling process. The AFE for well site preparation, rig mobilization and rigging up, rig rental, drilling mud, bits and tools, casings and formation evaluation.

3.3 Key Performance Indicators (KPIs)

Key Performance Indicators (KPIs) can be defined as the time taken to perform certain repetitive operations during the drilling of a well or over a specified time frame (Infostat Systems, 2012). It can be used to measure how each rig performs these operations over a given time frame and how it compares with other rigs in the fleet or by different contractors. KPI data can also be used to establish a baseline level of performance for each defined KPI category against which each rig's individual performance can be measured. RIMDrill software, aside from its ability to capture KPI data, also provides powerful output reporting tools for data analysis. The performance graphs are generated for individual rigs and allow for comparisons between other rigs with the ultimate goal of identifying the best practises that can then be applied to optimize the drilling process.

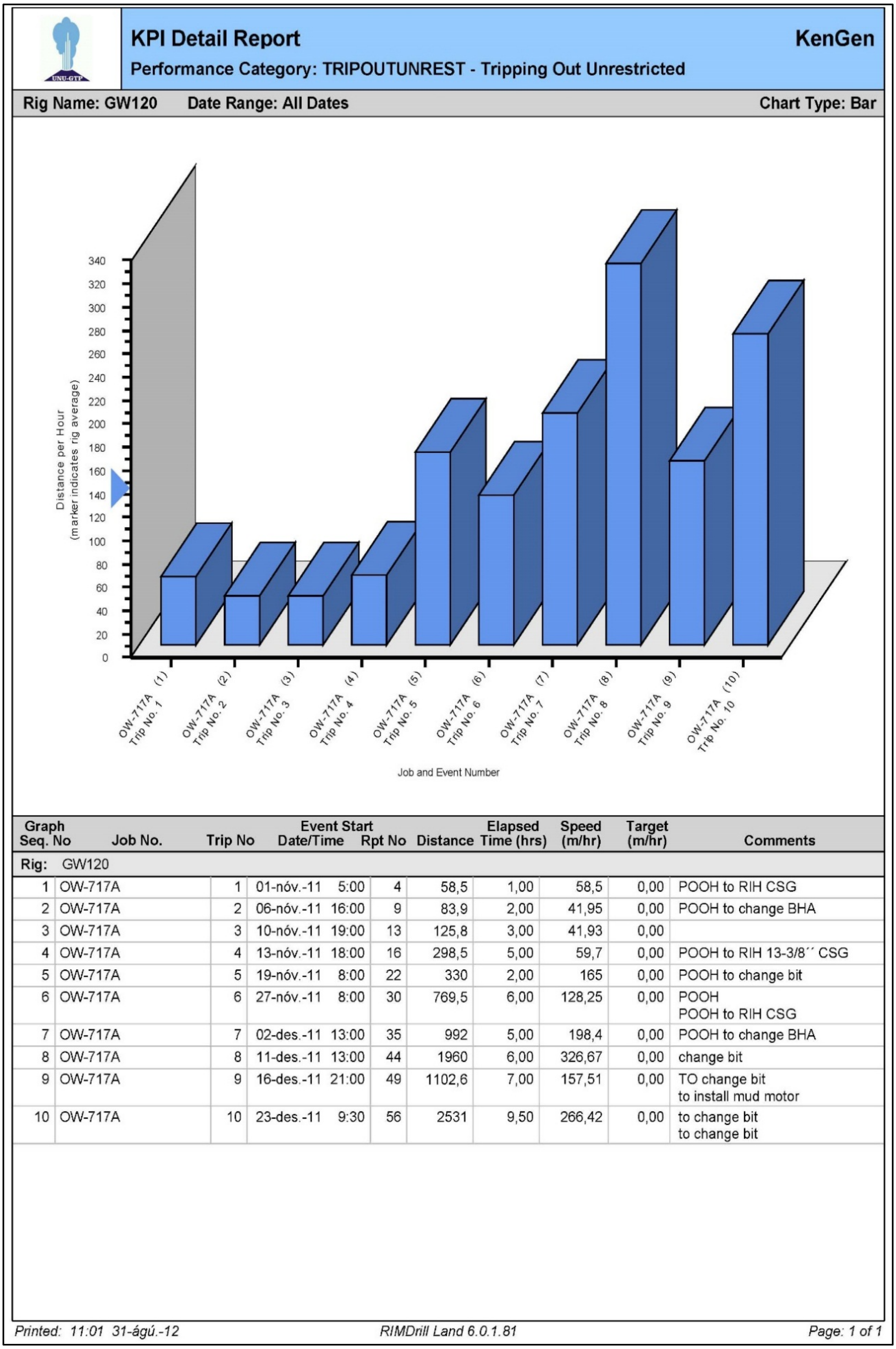
The KPIs allow one to measure the performance of any operational activity and compare that activity's measurements with similar activities on other rigs or on the same rig over time. Effective use of KPIs requires both planning ahead for which KPIs to measure, at what level of detail, and a diligent approach to data collection. A KPI type in the software can be assigned to any operations code, after which KPI data will be collected for that operation. The data can then be reviewed and analysed in KPI reports. For each KPI operation, multiple KPI sub-codes can be created to collect more detailed information for the operation. The default setting for RIMDrill software is for the users to enter KPI data but this can be made optional, though it is not recommended.

The KPI must be configured correctly from the start to enable correct, complete and meaningful review of the data. The KPIs are not retroactive and, thus, will not apply to any data that were entered before KPIs were configured.

KPIs can be measured with respect to four different metrics, called KPI types:

a) *Time:* this is a simple comparison of elapsed time spent performing an activity; for example, BOP handling operations;
b) *Count rate:* this is a count per unit of time (hour) for a particular operation; for example, picking up or laying down drill pipe;
c) *Length rate hour:* this is in feet or meters per hour for a particular operation; for example, running casing; and
d) *Depth rate hour:* this is similar to length rate hour, but instead of a length, requires a start and end depth. A length is determined from the difference of the inputs. For example, tripping in or out of the well.

The KPIs are defined in the RIMDrill program with the option of adding more by the user, depending on the specific needs. The handing of the KPI is simplified by integrating the data entry with that of the daily operations reporting function. Figure 10 shows a performance graph for rig GW120. Figure 11 shows a comparison between rigs GW120 and GW116.



KPI Detail Report **KenGen**

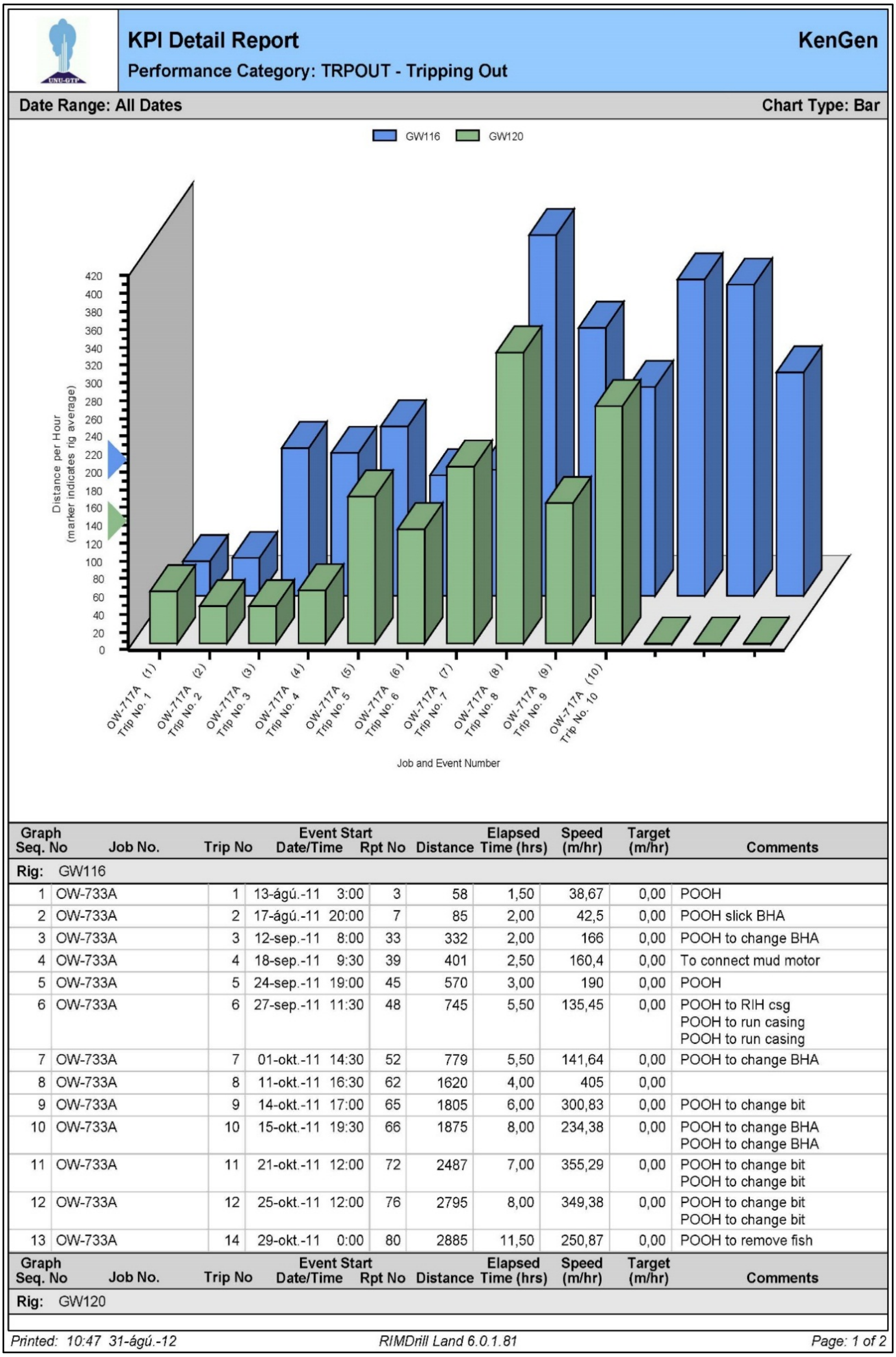
Performance Category: TRIPOUTUNREST - Tripping Out Unrestricted

Rig Name: GW120 **Date Range: All Dates** **Chart Type: Bar**

Graph Seq. No	Job No.	Trip No	Event Start Date/Time	Rpt No	Distance	Elapsed Time (hrs)	Speed (m/hr)	Target (m/hr)	Comments
Rig: GW120									
1	OW-717A	1	01-nóv.-11 5:00	4	58,5	1,00	58,5	0,00	POOH to RIH CSG
2	OW-717A	2	06-nóv.-11 16:00	9	83,9	2,00	41,95	0,00	POOH to change BHA
3	OW-717A	3	10-nóv.-11 19:00	13	125,8	3,00	41,93	0,00	
4	OW-717A	4	13-nóv.-11 18:00	16	298,5	5,00	59,7	0,00	POOH to RIH 13-3/8´´ CSG
5	OW-717A	5	19-nóv.-11 8:00	22	330	2,00	165	0,00	POOH to change bit
6	OW-717A	6	27-nóv.-11 8:00	30	769,5	6,00	128,25	0,00	POOH POOH to RIH CSG
7	OW-717A	7	02-des.-11 13:00	35	992	5,00	198,4	0,00	POOH to change BHA
8	OW-717A	8	11-des.-11 13:00	44	1960	6,00	326,67	0,00	change bit
9	OW-717A	9	16-des.-11 21:00	49	1102,6	7,00	157,51	0,00	TO change bit to install mud motor
10	OW-717A	10	23-des.-11 9:30	56	2531	9,50	266,42	0,00	to change bit to change bit

Printed: 11:01 31-ágú.-12 *RIMDrill Land 6.0.1.81* *Page: 1 of 1*

FIGURE 10: Performance graph for rig GW120



KPI Detail Report **KenGen**

Performance Category: TRPOUT - Tripping Out

Date Range: All Dates **Chart Type: Bar**

Graph Seq. No	Job No.	Trip No	Event Start Date/Time	Rpt No	Distance	Elapsed Time (hrs)	Speed (m/hr)	Target (m/hr)	Comments
Rig: GW116									
1	OW-733A	1	13-ágú.-11 3:00	3	58	1,50	38,67	0,00	POOH
2	OW-733A	2	17-ágú.-11 20:00	7	85	2,00	42,5	0,00	POOH slick BHA
3	OW-733A	3	12-sep.-11 8:00	33	332	2,00	166	0,00	POOH to change BHA
4	OW-733A	4	18-sep.-11 9:30	39	401	2,50	160,4	0,00	To connect mud motor
5	OW-733A	5	24-sep.-11 19:00	45	570	3,00	190	0,00	POOH
6	OW-733A	6	27-sep.-11 11:30	48	745	5,50	135,45	0,00	POOH to RIH csg POOH to run casing POOH to run casing
7	OW-733A	7	01-okt.-11 14:30	52	779	5,50	141,64	0,00	POOH to change BHA
8	OW-733A	8	11-okt.-11 16:30	62	1620	4,00	405	0,00	
9	OW-733A	9	14-okt.-11 17:00	65	1805	6,00	300,83	0,00	POOH to change bit
10	OW-733A	10	15-okt.-11 19:30	66	1875	8,00	234,38	0,00	POOH to change BHA POOH to change BHA
11	OW-733A	11	21-okt.-11 12:00	72	2487	7,00	355,29	0,00	POOH to change bit POOH to change bit
12	OW-733A	12	25-okt.-11 12:00	76	2795	8,00	349,38	0,00	POOH to change bit POOH to change bit
13	OW-733A	14	29-okt.-11 0:00	80	2885	11,50	250,87	0,00	POOH to remove fish

Graph Seq. No	Job No.	Trip No	Event Start Date/Time	Rpt No	Distance	Elapsed Time (hrs)	Speed (m/hr)	Target (m/hr)	Comments
Rig: GW120									

Printed: 10:47 31-ágú.-12 *RIMDrill Land 6.0.1.81* *Page: 1 of 2*

FIGURE 11: Comparison between rigs GW120 and GW116

4. CASE HISTORY OF WELL OW-717A IN OLKARIA, KENYA

4.1 Description of the RIMDrill software

RIMDrill is a rig to office drilling information system for drilling contractors (Infostat Systems, 2012). It includes the ability to capture all of the data required to complete the industry standard IADC daily drilling report and to output this data on an officially licensed IADC-formatted report. The key design goals for RIMDrill are to ensure ease of use for the rig site user while providing a powerful set of data analysis and data distribution tools for the office user. Daily IADC and non-IADC report data are entered at the rig site and transferred to a central office where data is consolidated for the entire rig fleet. A comprehensive suite of business analysis tools uses the data in this central database to provide critical information to support analysis for management and operational decision makers. While the application is designed to be easy to use for rig site users, it incorporates tools for flexible access to such critical information as rig downtime, KPI performance and HSE data.

A broad range of rig and operational data, including tour data for the IADC report, is entered into the rig site RIMDrill system. At the end of the reporting day, an officially approved IADC daily drilling report is created and a copy of all entered data is sent to a central RIMDrill system in the office using the built in communications module. These data are then available for automated distribution to all stakeholders or for those who need direct access to data using the RIMDrill interface. Data can be analysed on a rig by rig basis or results can be compared between multiple rigs.

RIMDrill contains all of the features required for a complete drilling information system. Rig based systems collect and store a wide range of daily report data including all of the data necessary to create an officially approved and licensed IADC daily drilling report. When used in the office environment, the system acts as a central data store for all rig data. Over 40 summary reports, graphs and schematics are available to provide both rig and office users with the tools to better understand and manage their operations, including the tracking of KPI data.

To meet the broad range of reporting requirements in the drilling industry, several versions of the application have been developed and optimized to meet the specific needs of users:

RIMDrill standard
The standard version of RIMDrill is available in two editions:

- *Offshore edition* – optimized for the reporting and business analysis requirements of floaters and jack-up rig fleets; and
- *Onshore edition* – optimized for the reporting and business analysis needs of onshore rig fleets.

The onshore edition of the RIMDrill standard version was used for the training exercise.

RIMDrill IADC is a minimised version for the creation of only the IADC daily report.

RIMBase is similar to RIMDrill, but is used to merge data from several rigs. RIMBase is a reporting solution for daily drilling reports and related well information. Daily report data such as costs, operational activities and engineering events, along with information in other formats such as documents, scans and photos are incorporated into a single well file for permanent storage and retrieval. The application includes a tightly integrated set of daily reports, communications, report distribution and data analysis functions. A key design goal is to provide the rig user with a straightforward installation and configuration path and an intuitive user interface.

4.2 Description of RIMDrill report structure selected for Olkaria

RIMDrill software provides an array of options that can be adopted by different contractors in their daily operations and reporting. Before proceeding with data entry, several tasks need to be completed to configure RIMDrill correctly. For the purpose of this report, with regard to drilling operations in Olkaria, the following structure was selected for reporting and analysing:

- The system is configured as a rig installation where it uses RIMDrill to enter daily rig information and sends database updates to an office site;
- Two tours (shifts) for the daily IADC reports with start times of 0800 and 2000 hrs. are named as day tour and night tour, respectively;
- The units of measure are set as per the drilling data handbook (Gabolde and Nguyen, 2006);
- The IADC codes are used as they are inbuilt within the software; and
- The KPIs used are the default ones, with additional KPI targets: waiting on cement (WOC) and logging speeds (LOG), added by the author.

The software also provides room for adding or modifying the KPIs and other parameters as needs arise over time. The program is comprehensive and most of its features are used without modifications. The performance categories defining the KPIs selected for Olkaria are given in Table 3.

TABLE 3: KPI targets and their codes selected for Olkaria

Code	Description	IADC code	KPI type	Event name
WOC	Waiting on cement	13	TIME	Event
WASH	Change wash pipe	8	TIME	Event
TRPOUT	Tripping out	6	DEPTH_RATE_HR	Trip
TRPIN	Tripping in	6	DEPTH_RATE_HR	Trip
PICKUP	Pick up singles	21	COUNT_RATE	Run
LOG	Wireline logging	11	DEPTH_RATE_HR	Event
LAYDN	Lay down singles	21	COUNT_RATE	Run
CUTDL	Cut and slip drill line	9	TIME	Event
CASE	Running casing	12	LENGTH_RATE_HR	Event
BOPT	BOP testing	15	TIME	Event
BOPO	BOP operations	14	TIME	Event
BHA	Make up/lay Dn/change BHA	6	TIME	Event

For each KPI operation, one can create multiple KPI sub-codes to collect more detailed information for the operation. An example is where we can measure BOP handling operations as a KPI, but we are also interested in various sub-components of the BOP handling process. First we assign the TIME KPI type to the operations code for BOP operations. Then create KPI sub-codes for functional testing BOP, moving BOP over wellhead, nippling up BOP, etc. This set-up would allow us to compare BOP operations as a major category and also compare the discrete act of nippling up the BOP. The sub-codes allow for further detailed analysis of various drilling operations.

4.3 Data entry in RIMDrill for well OW-717A

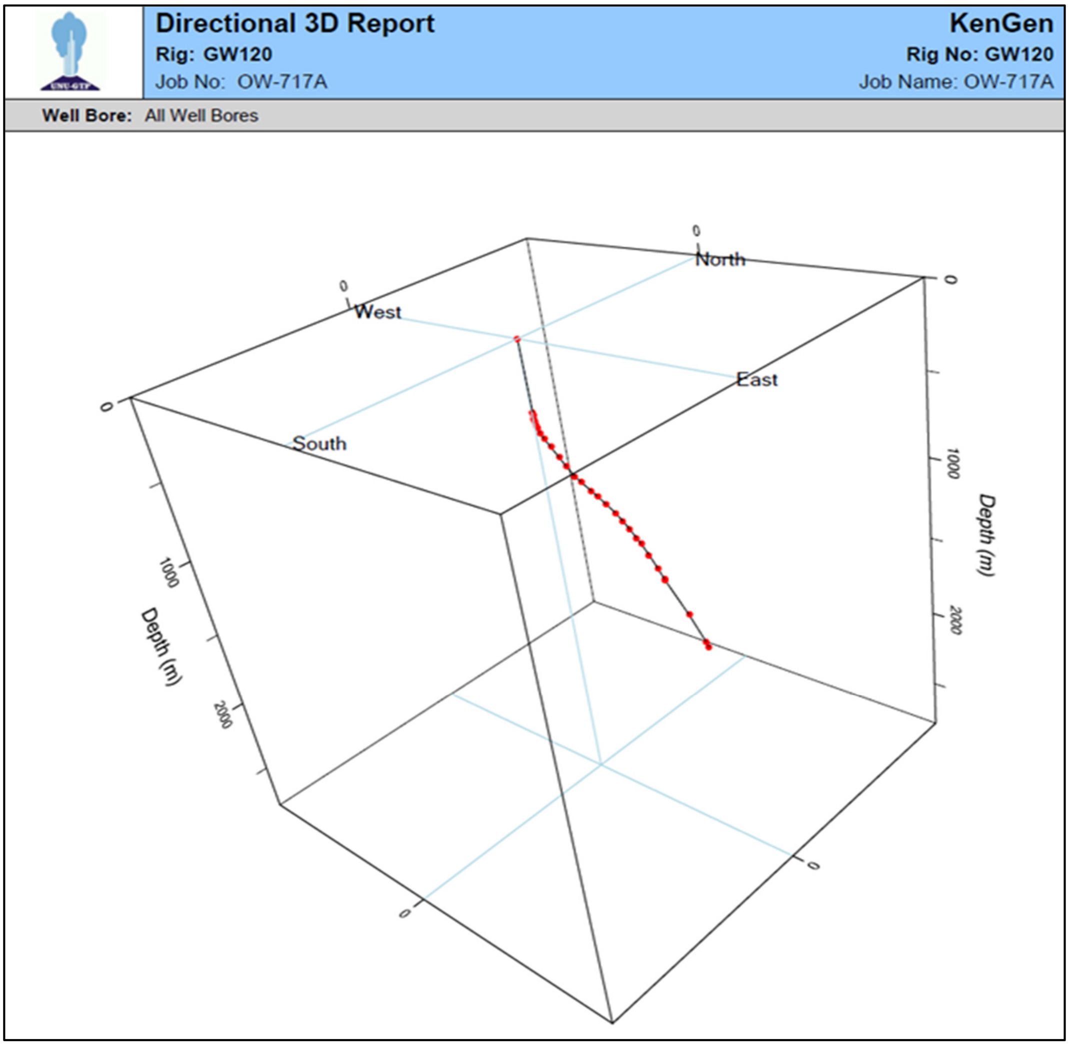
A lot of information is gathered and reported for all phases of geothermal development. The proper handling of all of this has become easier in the digital age but consequently, it has also increased the amount of information. Given that RIMDrill is a rig to office information system and the report data are entered at the rig site, the data entry function should be without complications for the rig crew. As indicated earlier, the key design goals for RIMDrill are to ensure ease of use for the rig site user while providing a powerful set of data analysis and data distribution tools for the office user. The setting of the software is such that the parameters, as they are read on the rig instruments, are entered into the respective tabs as they are without modifications. The entry, however, must be entered accurately as any errors will be reflected in the reports and the analysis made out of the reports. In an effort to simplify the KPI data entry function for rig users, it is tightly integrated with the daily operations reporting function.

4.4 Generation of reports

The system acts as a central data store for all rig data when used in the office environment. Over 40 summary reports, graphs and schematics are available to provide both rig and office users with the tools to better understand and manage their operations, including the tracking of KPI data. The reports are designed to assist with operational, cost, and performance analyses. Directional reports, which include the 3D report shown in Figure 12, the elevation report shown in Figure 13 and the plan report in Figure 14, are some of the important reports generated from RIMDrill software.

Other reports that can be generated from RIMDrill software include (Infostat Systems, 2012):

1) Daily reports which comprise an IADC daily drilling report, a daily contractor report (single page or multi page version) and a daily operator report.

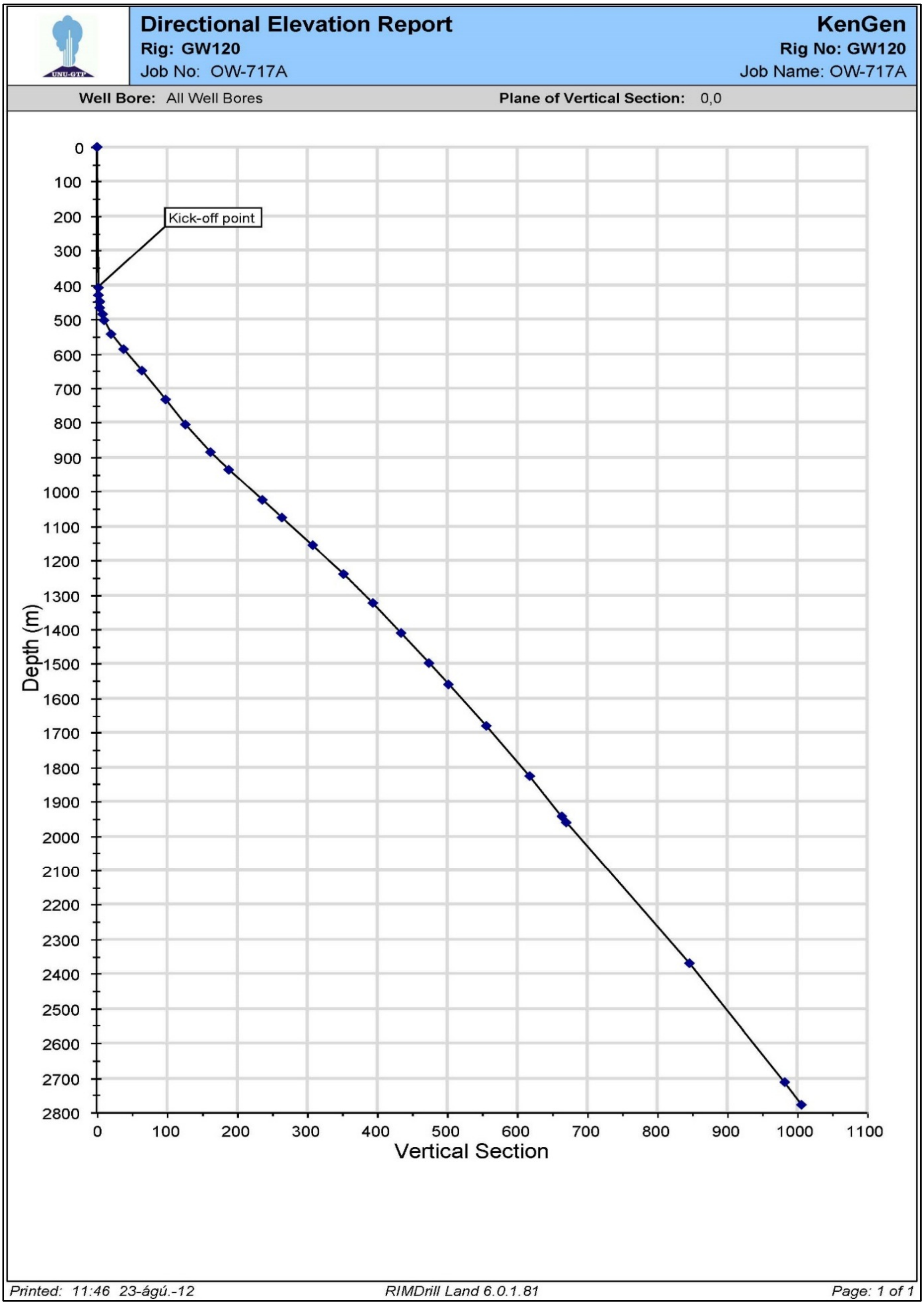


Directional 3D Report
Rig: GW120
Job No: OW-717A

KenGen
Rig No: GW120
Job Name: OW-717A

Well Bore: All Well Bores

FIGURE 12: Directional 3D report for well OW-717A



Directional Elevation Report **KenGen**

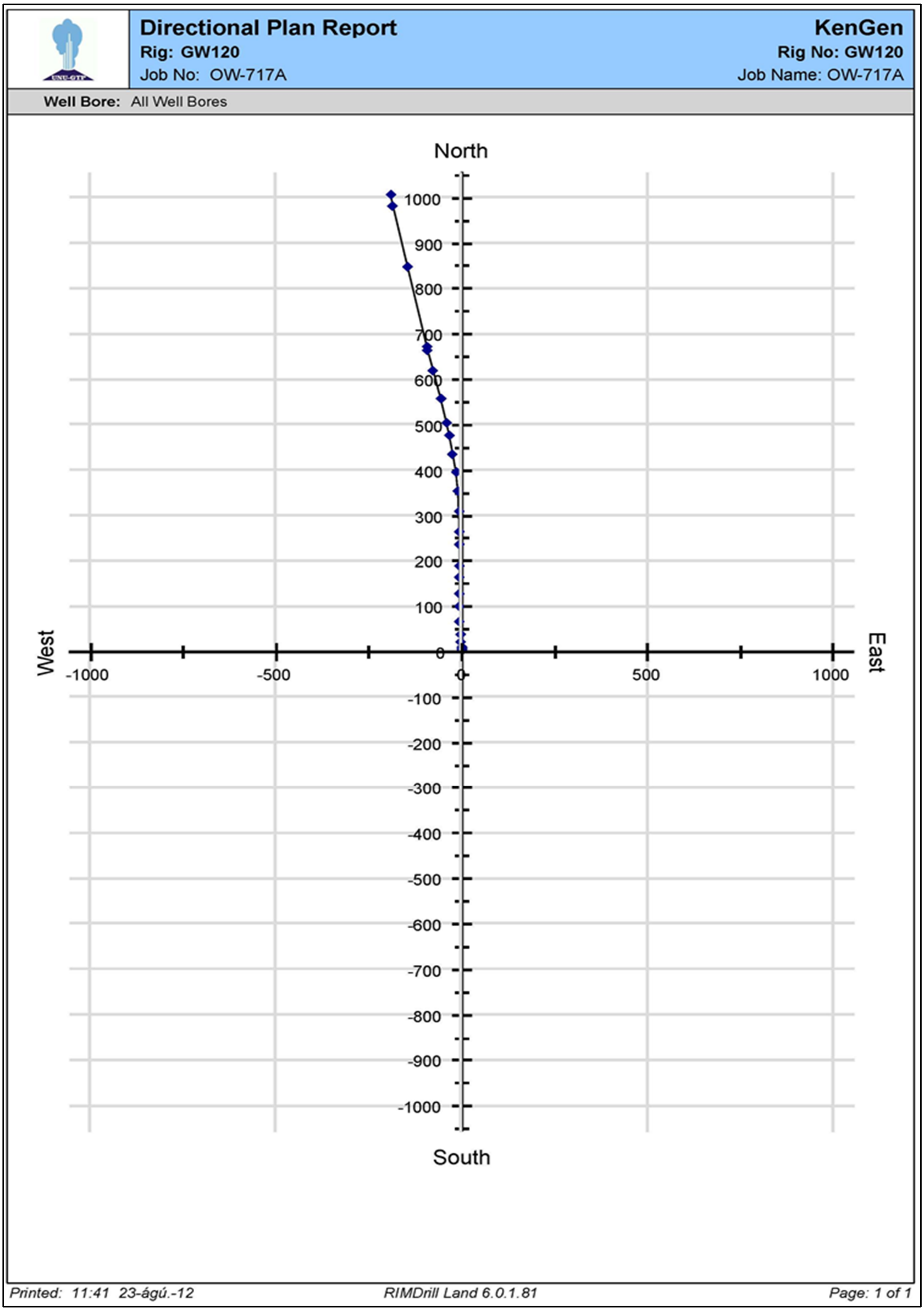
Rig: GW120 **Rig No: GW120**

Job No: OW-717A Job Name: OW-717A

Well Bore: All Well Bores **Plane of Vertical Section:** 0,0

Printed: 11:46 23-ágú.-12 *RIMDrill Land 6.0.1.81* *Page: 1 of 1*

FIGURE 13: Directional elevation report for well OW-717A



Directional Plan Report **KenGen**
Rig: GW120 **Rig No: GW120**
Job No: OW-717A Job Name: OW-717A

Well Bore: All Well Bores

Printed: 11:41 23-ágú.-12 *RIMDrill Land 6.0.1.81* *Page: 1 of 1*

FIGURE 14: Directional plan report for well OW-717A

2) Management overview reports, which provide the management with an overview of rig activities. They include a daily rig summary report, a rig downtime report, a job summary report (a section of it is shown in Figure 15), a weekly operations report and an operations time breakdown graph.
3) Rig operational analysis reports which are designed to give an in-depth analysis of rig operational activities. They include an operations time analysis breakdown, shown in Figure 7, a weekly/monthly operations summary report, an operations activity chronology, a day versus depth plot and an operations query report.
4) Rig performance reports which are analysed for rig performance indicators and rig downtimes. They include a rig individual performance report as shown in Figure 10, a rig comparison report as given in Figure 13, and multi well days versus depth plot.
5) Engineering reports, for analysing drilling engineering parameters. They include days versus depth, borehole schema, a BHA graphical report (shown in Figure 16), a BHA list report, a bit summary report, a survey report and a directional 3D graph.
6) Health, safety and environment (HSE) reports which report on HSE related information. These include a safety report and a medical/accident report.
7) Data integration tools which are reports designed to help streamline other in-house information processes such as payroll and customer billing. They include an operational charge rate analysis, an employee payroll report and a payroll summary.

4.5 Performance efficiency analysis

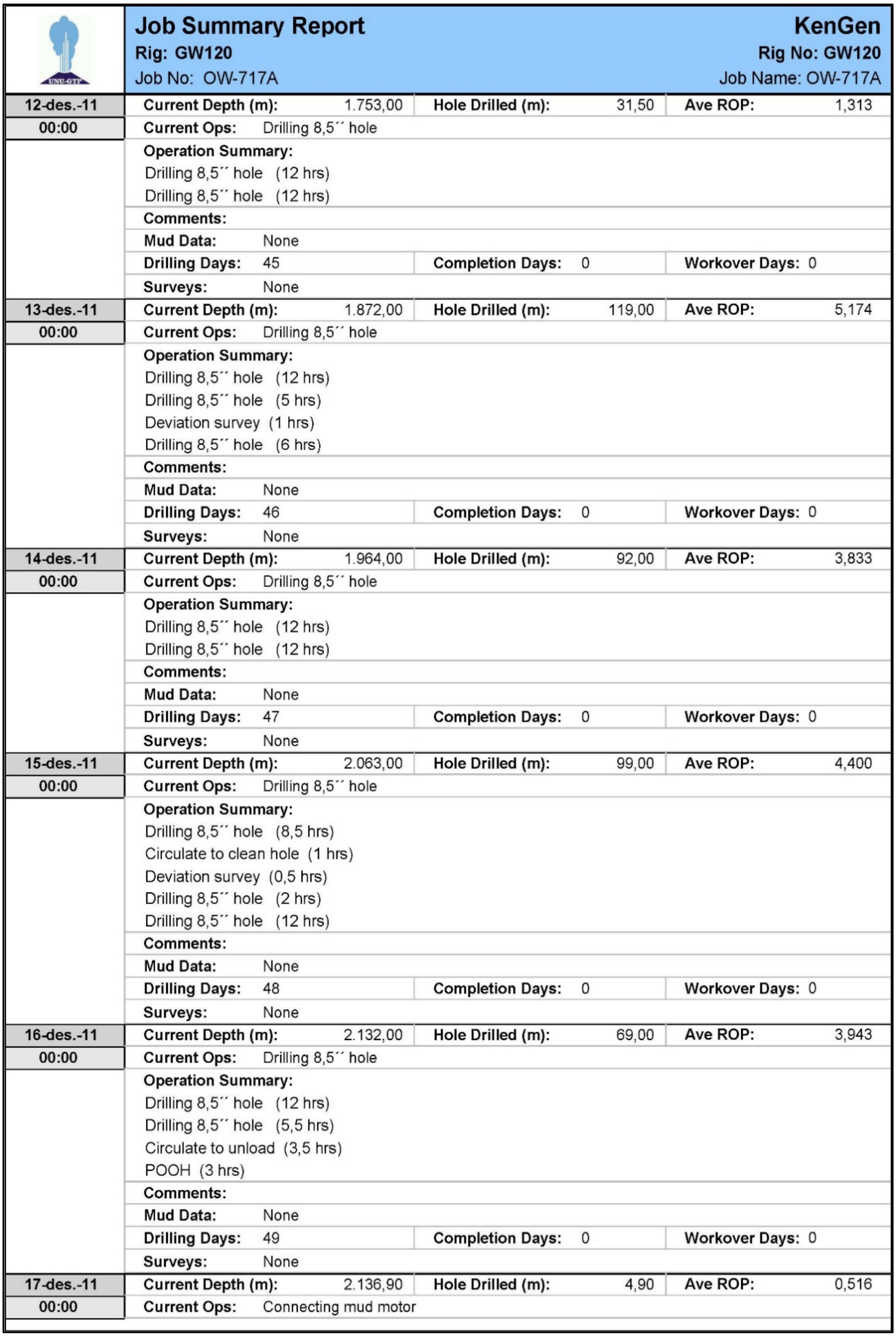
The performance of any operational activity can be assessed by using the KPIs. The KPI form provides numerous display options, including:

- Single rig or multi-rig: View data for one rig or compare data for multiple rigs. For a single rig, one can view data for all jobs or one job. Figure 10 shows a performance graph for Rig GW120 used for drilling well OW-717A. For multiple rigs, one can choose as many rigs as desired; the only limit is the ability to decipher the data in the resulting report. Figure11 is an example of such output for multiple rigs, Rig GW120 and GW116.
- Date range: View a specific time segment of the KPI data. This makes it possible to obtain information for a certain range of time over the period of drilling the well. This is possible for a rig or multiple rigs and for a job and also for one or more performance categories.
- Performance categories: View data for any of the KPI operation codes. Print individual reports or one combined report for all KPI operation codes.

The efficiency analysis is finally given in terms of performance reports and graphs which can be retrieved by use of the operations query. The query gives a flexible report of operations activities, and can be filtered by division, field, job, dates, phase, operations group, operations code, non-productive activities, and/or specific text in the activity description.

The Standard Query Language (SQL) execution tab is used to define and save SQL statements to run against the RIMDrill database. The most used function in SQL is the SELECT function. Results for SELECT queries display in a table grid that one can view in RIMDrill and export in XML or XLS (spreadsheet) format. The export file is saved in the reports folder within the RIMDrill folder. File names follow the format: DataExport_<Table Name>_YYMMDDHHNN.<XML or XLS>, where YYMMDDHHNN is the current date/time and <Table Name> is the first table in the FROM clause of the SQL statement.

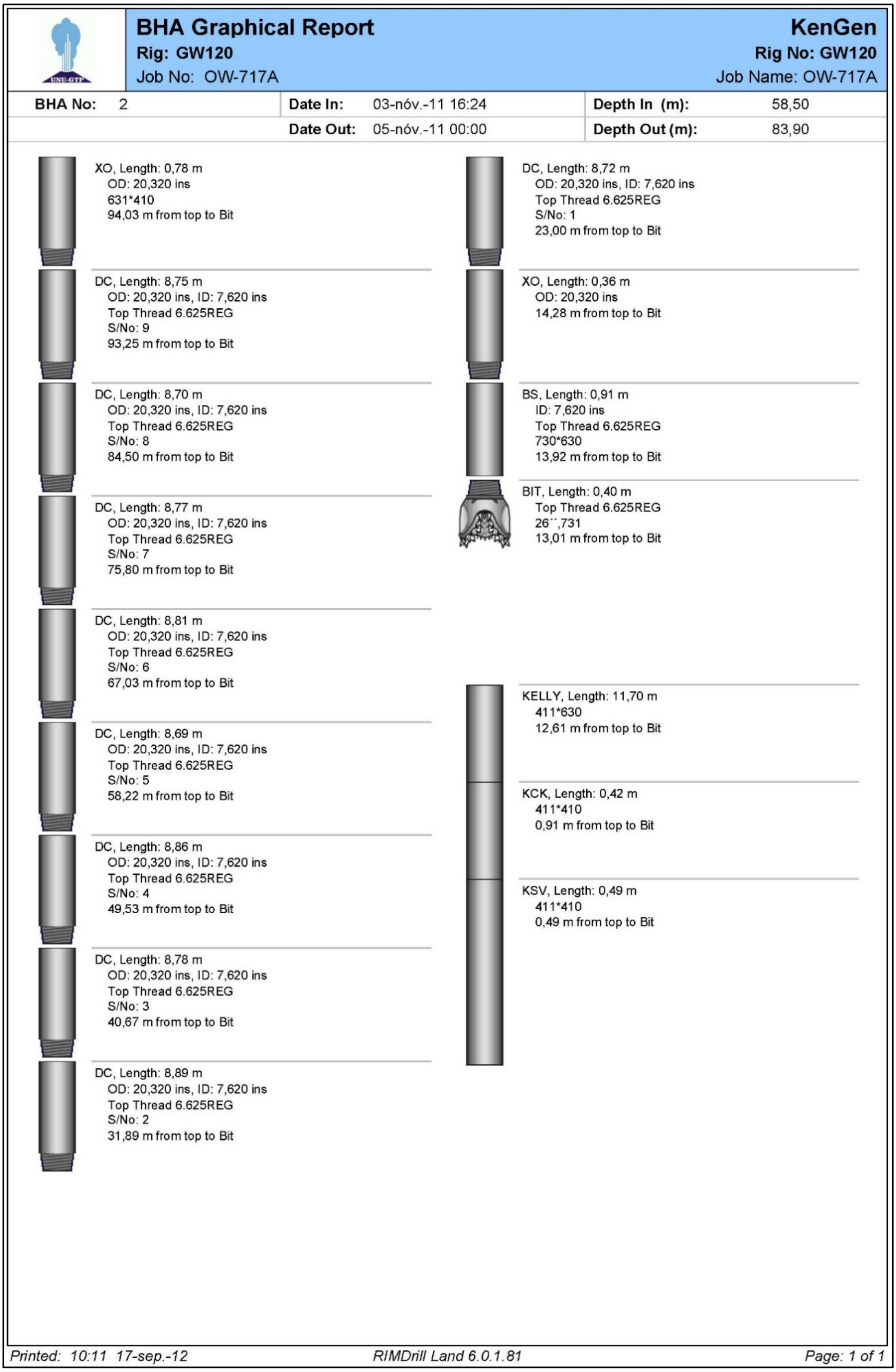
It is possible to define a new SQL query to carry out and output several performance analyses. Example of an SQL query (select function) by this author is given below with the output result shown in Table 4. More examples of the queries are given in Appendix II.



Job Summary Report **KenGen**
Rig: GW120 **Rig No: GW120**
Job No: OW-717A Job Name: OW-717A

12-des.-11	**Current Depth (m):**	1.753,00	**Hole Drilled (m):**	31,50	**Ave ROP:**	1,313
00:00	**Current Ops:**	Drilling 8,5´´ hole				
	Operation Summary:					
	Drilling 8,5´´ hole (12 hrs)					
	Drilling 8,5´´ hole (12 hrs)					
	Comments:					
	Mud Data:	None				
	Drilling Days:	45	**Completion Days:**	0	**Workover Days:**	0
	Surveys:	None				
13-des.-11	**Current Depth (m):**	1.872,00	**Hole Drilled (m):**	119,00	**Ave ROP:**	5,174
00:00	**Current Ops:**	Drilling 8,5´´ hole				
	Operation Summary:					
	Drilling 8,5´´ hole (12 hrs)					
	Drilling 8,5´´ hole (5 hrs)					
	Deviation survey (1 hrs)					
	Drilling 8,5´´ hole (6 hrs)					
	Comments:					
	Mud Data:	None				
	Drilling Days:	46	**Completion Days:**	0	**Workover Days:**	0
	Surveys:	None				
14-des.-11	**Current Depth (m):**	1.964,00	**Hole Drilled (m):**	92,00	**Ave ROP:**	3,833
00:00	**Current Ops:**	Drilling 8,5´´ hole				
	Operation Summary:					
	Drilling 8,5´´ hole (12 hrs)					
	Drilling 8,5´´ hole (12 hrs)					
	Comments:					
	Mud Data:	None				
	Drilling Days:	47	**Completion Days:**	0	**Workover Days:**	0
	Surveys:	None				
15-des.-11	**Current Depth (m):**	2.063,00	**Hole Drilled (m):**	99,00	**Ave ROP:**	4,400
00:00	**Current Ops:**	Drilling 8,5´´ hole				
	Operation Summary:					
	Drilling 8,5´´ hole (8,5 hrs)					
	Circulate to clean hole (1 hrs)					
	Deviation survey (0,5 hrs)					
	Drilling 8,5´´ hole (2 hrs)					
	Drilling 8,5´´ hole (12 hrs)					
	Comments:					
	Mud Data:	None				
	Drilling Days:	48	**Completion Days:**	0	**Workover Days:**	0
	Surveys:	None				
16-des.-11	**Current Depth (m):**	2.132,00	**Hole Drilled (m):**	69,00	**Ave ROP:**	3,943
00:00	**Current Ops:**	Drilling 8,5´´ hole				
	Operation Summary:					
	Drilling 8,5´´ hole (12 hrs)					
	Drilling 8,5´´ hole (5,5 hrs)					
	Circulate to unload (3,5 hrs)					
	POOH (3 hrs)					
	Comments:					
	Mud Data:	None				
	Drilling Days:	49	**Completion Days:**	0	**Workover Days:**	0
	Surveys:	None				
17-des.-11	**Current Depth (m):**	2.136,90	**Hole Drilled (m):**	4,90	**Ave ROP:**	0,516
00:00	**Current Ops:**	Connecting mud motor				

FIGURE 15: Job summary report



BHA Graphical Report **KenGen**
Rig: GW120 **Rig No: GW120**
Job No: OW-717A Job Name: OW-717A

BHA No:	2	**Date In:**	03-nóv.-11 16:24	**Depth In (m):**	58,50
		Date Out:	05-nóv.-11 00:00	**Depth Out (m):**	83,90

XO, Length: 0,78 m
OD: 20,320 ins
631*410
94,03 m from top to Bit

DC, Length: 8,75 m
OD: 20,320 ins, ID: 7,620 ins
Top Thread 6.625REG
S/No: 9
93,25 m from top to Bit

DC, Length: 8,70 m
OD: 20,320 ins, ID: 7,620 ins
Top Thread 6.625REG
S/No: 8
84,50 m from top to Bit

DC, Length: 8,77 m
OD: 20,320 ins, ID: 7,620 ins
Top Thread 6.625REG
S/No: 7
75,80 m from top to Bit

DC, Length: 8,81 m
OD: 20,320 ins, ID: 7,620 ins
Top Thread 6.625REG
S/No: 6
67,03 m from top to Bit

DC, Length: 8,69 m
OD: 20,320 ins, ID: 7,620 ins
Top Thread 6.625REG
S/No: 5
58,22 m from top to Bit

DC, Length: 8,86 m
OD: 20,320 ins, ID: 7,620 ins
Top Thread 6.625REG
S/No: 4
49,53 m from top to Bit

DC, Length: 8,78 m
OD: 20,320 ins, ID: 7,620 ins
Top Thread 6.625REG
S/No: 3
40,67 m from top to Bit

DC, Length: 8,89 m
OD: 20,320 ins, ID: 7,620 ins
Top Thread 6.625REG
S/No: 2
31,89 m from top to Bit

DC, Length: 8,72 m
OD: 20,320 ins, ID: 7,620 ins
Top Thread 6.625REG
S/No: 1
23,00 m from top to Bit

XO, Length: 0,36 m
OD: 20,320 ins
14,28 m from top to Bit

BS, Length: 0,91 m
ID: 7,620 ins
Top Thread 6.625REG
730*630
13,92 m from top to Bit

BIT, Length: 0,40 m
Top Thread 6.625REG
26´´,731
13,01 m from top to Bit

KELLY, Length: 11,70 m
411*630
12,61 m from top to Bit

KCK, Length: 0,42 m
411*410
0,91 m from top to Bit

KSV, Length: 0,49 m
411*410
0,49 m from top to Bit

Printed: 10:11 17-sep.-12 *RIMDrill Land 6.0.1.81* *Page: 1 of 1*

FIGURE 16: BHA graphical report

Query: How long was each BHA in use?

```
select jobid, datetimein, datetimeout,
DateDiff('ww', datetimein, datetimeout) as weeks_in_hole,
DateDiff('d', datetimein, datetimeout) as days_in_hole,
DateDiff('h', datetimein, datetimeout) as hours_in_hole,
bhalength, drillinghrs
from BHA Info;
```

TABLE 4: Results showing time taken for the BHA in hole derived from the SQL query above

jobid	datetimein	datetimeout	weeks_ in_hole	days_ in_hole	total_hours_ in_hole	bhalength	drillinghrs
OW-717A	28.10.2011 12:00	31.10.2011 00:00	1	3	60	72.02	61.0
OW-717A	3.11.2011 16:24	5.11.2011 00:00	0	2	32	94.03	
OW-717A	5.11.2011 14:35	12.11.2011 00:00	1	7	154	197.31999	
OW-717A	16.11.2011 15:41	19.11.2011 00:00	0	3	57	194.39	
OW-717A	12.11.2011 15:52	22.11.2011 00:00	2	10	225	158.4	
OW-717A	20.11.2011 16:34	25.11.2011 00:00	0	5	104	196.22	
OW-717A	28.11.2011 11:14	30.11.2011 00:00	0	2	37	264.45	
OW-717A	30.11.2011 13:38	15.12.2011 00:00	2	15	347	292.45	

5. CONCLUSIONS AND RECOMMENDATIONS

This paper has discussed how information gathered during the process of drilling a geothermal well is stored and how the reports generated are used in analysing the performance with the intent of optimizing the drilling process. A lot of information is gathered and reported for all phases of geothermal development. The proper handling of all the data generated has become easier in the digital age but, consequently, the amount of information and what is required has also increased. To be able to provide a comprehensive analysis, all the necessary data must be collected and entered accurately into the relevant software or program; otherwise the outcome of any analysis will not be useful.

Computer programs make the handling, storage and processing of data much easier and the analysis of efficiencies faster and more accurate, as seen with the RIMDrill software. Several parameters can be analysed and benchmarks set for future reference. This is made possible by use of the KPI through which performances of different crews and equipment can be assessed and compared. RIMDrill allows for transfer of data from the source to the processing centre and stores the same in a database from which the data can be retrieved for future reference and used for comparing performances between crews, wells and/or rigs.

Some of the benefits of systematic analysis of pars drilling jobs is the new knowledge that allows drilling operations to be completed within the shortest time and at a competitive cost. To be able to achieve this, a balance must be obtained between the drilling processes, materials selection and the design of the well itself. Higher efficiency and better optimization of the drilling process can be achieved by undertaking among other things:

- Using high mobility rigs which require less time for mobilization;
- Simple drill sites and ponds for containment (even without ponds);
- BOP stacks that take less time to install;
- Using larger diameter drill pipes for lower pump power and oil consumption;
- Improving on time spent on running casing and for cementing;
- Minimum clearance casing programs and using the right cementing techniques;
- Improved ROP by using the right bits, correct BHA configuration and accurate instrumentation;
- Automating processes like pipe handling to reduce time and cost.

ACKNOWLEDGEMENTS

I would like to extend my heartfelt gratitude to the Government of Iceland and United Nations University Geothermal Training Programme (UNU-GTP), under the leadership of Director, Dr. Ingvar Birgir Fridleifsson and Deputy Director, Mr. Lúdvík S. Georgsson, for offering me the Fellowship to take part in the 2012 UNU-GTP programme. I would also like to thank sincerely Ms. Thórhildur Ísberg, Mr. Ingimar G. Haraldsson, Ms. Málfrídur Ómarsdóttir and Mr. Markús A.G. Wilde, for their assistance and support during my stay in Iceland. Many thanks go to my supervisor Mr. Sverrir Thórhallsson for his guidance and for sharing his vast knowledge and experience throughout my training and especially while writing my report. I am also grateful to my employer, KenGen, for supporting me and granting me the permission to attend the training in Iceland.

Special thanks go to my family, especially my wife Molly and our unborn baby for their love and patience. I would also like to thank my colleagues, the 2012 Fellows for their help, support and encouragement during our stay in Iceland. Most important, I would like to thank the Almighty God for his unwavering love, care and guidance.

REFERENCES

Axelsson, G., and Franzson, H., 2012: Geothermal drilling targets and well siting. *Presented at "Short Course on Geothermal Development and Geothermal Wells", organized by UNU-GTP and LaGeo, Santa Tecla, El Salvador,* 16 pp.

Bush, G., and O'Donnell, K., 2007: *Global cementing best practices* (Rev. 1). Occidental Oil and Gas Corp., Global Drilling Community, 65 pp.

Drilling and Completion Committee, 1995: *Primary and remedial cementing guidelines*. Drilling and Completion Committee, Alberta, Canada, 17 pp.

Fridleifsson, I.B., 2001: Geothermal energy for the benefit of the people. *Renewable and Sustainable Energy Reviews, 5,* 299-312.

Gabolde, G., and Nguyen, J.P., 2006: *Drilling data handbook* (8th ed.). IFP publications, Editions Technip, 541 pp.

GDC, 2011: *Environmental and social impact assessment report, Menengai geothermal power project*. Geothermal Development Company, Ltd., unpublished document, 14 pp.

Hole, H.M., 2008a: Geothermal well design-casing and well head. *Presented at "Petroleum Engineering Summer School", Dubrovnik, Croatia, Workshop 26*, 7 pp.

Hole, H.M., 2008b: Geothermal well drilling services contracts. *Presented at "Petroleum Engineering Summer School", Dubrovnik, Croatia, Workshop 26*, 3 pp.

Hole, H., 2008c: Drilling fluids for drilling of geothermal wells. *Presented at "Petroleum Engineering Summer School", Dubrovnik, Croatia, Workshop 26*, 8 pp.

IADC, 1992: *Drilling manual* (11th ed.). International Association of Drilling Contractors, USA.

Infostat Systems, 2012: *RimDrill overview.* Website: infostatsystems.com/drilling-contactors-RIMDrill/RIMDrill-for-drilling-contactors

KenGen, 2011: *Well OW-717A completion report.* KenGen – Kenya Electricity Generating Co., Ltd., Kenya, unpublished report, 26 pp.

Kristmannsdóttir, H., and Ármannson, H., 2003: Environmental aspects of geothermal utilization. *Geothermics 32,* 451-461.

Miyora, T.O., 2010: Controlled directional drilling in Kenya and Iceland. Report 20 in: *Geothermal Training in Iceland 2010.* UNU-GTP, Iceland, 365-390.

Rybach, L., 2003: Geothermal energy: sustainability and the environment. *Geothermics, 32,* 463-470.

Thórhallsson, S., 2012: *Geothermal drilling technology.* UNU-GTP, Iceland, unpublished lecture notes.

Vieira, J.L., 2009: *Controlled directional drilling* (4th ed.). Petroleum Extension Service, Austin, TX, 133 pp.

APPENDIX I: Well measurements programme

Completion tests program will be as follows:

1. *Dummy run:* Run the dummy tool to check the maximum clear depth (MCD) and that the well is free from any obstructions before running in the down-hole logging instruments. (Estimated time is 2 hours).
2. *Pre-injection temperature and pressure (T/P) profile:* Conduct a pre-injection temperature and pressure profile to determine the appropriate depth to station the tools for step pumping test. The suggested logging depth interval is 300 ft in the production casing and at depth intervals of 150 ft in the main hole up to the maximum clear depth. (Estimated time 6 hours).
3. *Step pumping:* Run the temperature and pressure tool to the selected depth. Station the tool at that depth for 10 minutes before starting the pumps at 1000 litres per minute (lpm). Continue pumping for 4 hours after which increase the pumping rate to 1300 lpm and maintain it there for 3 hours, then increase the pumping rate to 1600 lpm for 3 hours and finally increase the pumping rate to 1900 lpm for a further 3 hrs. (Estimated time 15 hours).
4. *T/P profile while pumping:* Retrieve the tools and take a temperature and pressure profile while pumping at 1900 lpm. The surveyed depths to be as in step (2) above. (Estimated time 7 hours).
5. *Pressure fall-off:* While still pumping at 1900 lpm station the tools at the selected depth determined from step (2) above and wait for 10 minutes before turning off the water supply. Monitor pressure fall-off for 8 hours after which the instruments should be retrieved before proceeding to the next step. (Estimated time 10 hours).
6. Depending on the results of step (3) above, a complete repeat of the step pumping may be required, exactly as stated above.
7. If (3) and (6) are unsuccessful, run the temperature and pressure tools to the selected depth. Station the tools for 10 minutes, then pump at the maximum pumping rate for 3.5 hours, depending on the results from (5) above. If step (5) was unsuccessful, then switch off the pumps for 5 hours. But if this test is unsuccessful due to an error that can be corrected, then it should be repeated by restarting the pumps followed by a pressure fall-off.
8. *Heat-up T/P profile:* At the end of the fall-off test, take a temperature and pressure profile as in step (2) above. (Estimated time 6 hours).
9. After completion tests, heat up profiles shall be done at expanding time intervals of 1, 2, 4, 7, 14 and 28 days.

It should be remembered that should step (3) be unsuccessful due to a fault that can be corrected, then it should be repeated immediately.

Nota bene:

(a) From step 1 to 8, the 5 inches drill pipe piece for recovery tube extension shall be firmly held by the pipe rams of the BOP.
(b) Later heat-up temperature and pressure profiles (T/P) shall be done through the master valve.
(c) Experience at OW-904A, OW-903A and OW-905A has proved that the sub-structure of the GWDC rig is too low to allow for wellhead equipment for down hole runs to be mounted on the master valve. GWDC must, therefore, remove part of the rig floor 24 hours after step (8) of the completion tests to allow KenGen to conduct the 1day heat-up run.
(d) The total estimated time for the completion tests is 46 hrs.

APPENDIX II: SQL queries and output results

Query:

```
select jobid, datetimein, datetimeout,
round(DateDiff('d', datetimein, datetimeout),1) as days_in_hole,
 Mdout, Mdin,
 round( (mdout - mdin),1 ) as md_diff,
 round( ( (Mdout - MDin) / DateDiff('d', datetimein, datetimeout) ),1) as meters_pr_day,
 round(bhalength,1) as bha_length,
 drillinghrs
from BHAInfo;
```

Results:

jobid	**datetimein**	**Datetimeout**	**days_in _hole**	**Mdout**	**Mdin**	**md_diff**	**meters _pr_day**	**bha_ length**	**drillinghrs**
OW-717A	2011-10-28 12:00:00	2011-10-31 00:00:00	3.0	58.5	0.0	58.5	19.5	72.0	61.0
OW-717A	2011-11-03 16:24:00	2011-11-05 00:00:00	2.0	83.9	58.5	25.4	12.7	94.0	
OW-717A	2011-11-05 14:35:00	2011-11-12 00:00:00	7.0	298.5	83.9	214.6	30.7	197.3	
OW-717A	2011-11-16 15:41:00	2011-11-19 00:00:00	3.0	416.0	298.5	117.5	39.2	194.4	
OW-717A	2011-11-12 15:52:00	2011-11-22 00:00:00	10.0	567.0	416.0	151.0	15.1	158.4	
OW-717A	2011-11-20 16:34:00	2011-11-25 00:00:00	5.0	769.5	567.0	202.5	40.5	196.2	
OW-717A	2011-11-28 11:14:00	2011-11-30 00:00:00	2.0	784.0	769.5	14.5	7.2	264.5	
OW-717A	2011-11-22 13:38:00	2011-12-15 00:00:00	23.0	2102.0	784.0	1318.0	57.3	154.8	

Query:

```
select jobid, operationscode, sum(elapsedtime) as sum_elapsed_time
from dailyoperations
where jobid='OW-717A'
group by jobid, operationscode
order by operationscode;
```

Results:

jobid	**operationscode**	**sum_elapsed _time**
OW-717A	BHA	30.5
OW-717A	BOPO	25.0
OW-717A	BOPT	3.5
OW-717A	CASE	36.25
OW-717A	CIRC	45.0
OW-717A	CMTC	8.75
OW-717A	CMTS	1.0
OW-717A	DRCMT	28.0
OW-717A	DRILR	1046.0
OW-717A	EQINST	6.0
OW-717A	LAYDN	8.0
OW-717A	LOG	48.0
OW-717A	MAINT	5.0
OW-717A	REAM	24.0
OW-717A	RIGU	15.0
OW-717A	SURV	18.0
OW-717A	TRPIN	61.0
OW-717A	TRPOUT	58.5
OW-717A	WIPE	13.5
OW-717A	WOC	122.0