The United Nations University

GEOTHERMAL TRAINING PROGRAMME
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Reports 2000
Number 14

SELECTION OF A FUTURE GEOTHERMAL DRILLING RIG FOR KENYA

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ABSTRACT

The main objective of this report is to determine the technical specifications of a future geothermal drilling rig for Kenya. Analysis is made as a guide in the selection of the principal components of a geothermal drilling rig. It is planned that both vertical and directional wells with a 3000 m and 2500 m depth limit, respectively, will be drilled. International requests for information were floated to reputable rig manufacturers for comparison purposes to obtain their recommendations. The results obtained showed that a mast with a hook-load of 200 tons would suffice and optimum power input required to the mud pumps, rotary table (top drive) and drawworks is 746 kW of power each. A three diesel engine-generator set with a total output capacity of around 1.8 MW of electric power is sufficient for the planned drilling programme.

1. INTRODUCTION

Kenya is one of the developing countries situated in East Africa. The government has set a goal for the country to become industrialized by the year 2020. In order to achieve this goal, the energy sector needs to expand very fast to supply additional energy to new industries. The country has renewable energy sources such as hydro, geothermal, solar and wind but imports non-renewable fossil fuels for its transportation sector and for a part of the electricity generation. Kenya has vast geothermal resources; the largest known geothermal fields are illustrated in Figure 1. From Olkaria and other geothermal resources, 576 MW of electrical power is expected to be developed over the next 17 years, through private and public investments.

So far, scientific studies and exploration work have been carried out on the Longonot and Suswa geothermal prospects. Drilling in three phases has yet to be done in these two fields; exploratory drilling to delineate the resource, appraisal drilling to prove the resource, and finally production drilling. Currently, Kenya Electricity Generating Company Ltd. (KenGen), which is responsible for the geothermal resource assessment programme (GRAP), owns and operates only one old National Oilwell N370 mechanical rig. This rig is not able to keep the pace of developing 576 MW of electric power in the next 17 years. As a result, a new rig purchase is planned to make the geothermal energy generation expansion feasible.

Geothermal drilling rigs are mainly manufactured by oil and gas drilling rig manufacturers, based on their many years of experience. It is very tricky to purchase a geothermal drilling rig. This is because for geothermal drilling rigs, not all the components and sizes used for oil and gas drilling rigs are appropriate. In this report, rating of the main rig components is analysed to make sure that correct items are bought for drilling the geothermal wells.

FIGURE 1: Location map of geothermal fields in Kenya (KenGen, 1999)

2. ELECTRICAL ENERGY SITUATION IN KENYA

2.1 Current status

The present electrical energy demand in Kenya grows at around 6% per year. The country's current demand stands at 950 MW against an effective installed capacity of 850 MW. Out of this, 80% comes from hydro, which is normally adversely affected by weather patterns. Drought periods hit the country at a frequency of roughly 10 years. Geothermal generation is 5%, and 15% is by fossil fuel as illustrated in Table 1. At the moment the country is experiencing a prolonged drought, which has caused a very high generation shortfall from hydro generation, forcing a situation where electricity demand is met through rationing.

TABLE 1: Current primary energy supply for year 2000

Sources	Installed capacity (MW)	Effective capacity (MW)	Energy budget (GWh/year)
Hydro	681	580	3270
Fossil fuel	230	213	725
Geothermal	57	57	370
Total	968	850	4365
Current peak power demand 950 MW			

It is estimated that the demand for electrical energy will almost triple if the average of 6% growth rate per year is maintained for the next 17 years. In order to sustain this rapid growth, plans are under way to expand generation facilities to cope with the increase in demand. According to government plans, an additional 313 MW is expected to be generated from hydro, 576 MW from geothermal resources, 762 MW from medium speed diesel and 250 MW from low speed diesel. This generation expansion plan is estimated to cost about USD 3.35 billion, a huge amount of money, which is expected to come from the government and private sector. Over the next 5 years, it is expected that 271.5 MW of additional capacity will be constructed with public sector financing and 249 MW by independent power producers (Mwangi, 2000).

Out of the planned 576 MW to be developed from geothermal resources, half is expected to be developed by the public sector and the rest by the private sector. In order to achieve this goal, detailed scientific studies and exploration drilling are required in several geothermal prospects outside Olkaria in order to prove the resource and prioritize the areas. Scientific exploration work has been done in Longonot and Suswa prospects and exploration drilling is planned to follow. Surface exploration will then be done in Menengai and other fields to the north of Olkaria along the Rift Valley. Experience has shown that production drilling may have to be done by the government for 30-50% of the required steam to reduce investment risks before the private sector is interested in further development. Kenya has enormous geothermal energy potential, which is underdeveloped. The potential for geothermal energy for electricity production is by scientific methods (Ng´ang´a, 1998) estimated to be around 2000 MW, but only 57 MW are now being generated. Currently 45 MW are coming from the Olkaria I power plant of KenGen, and 12 MW from the Olkaria III power plant, which is still under construction by an independent power producer (Orpower 4 Inc.). It will generate up to 64 MW when it is completed. The Olkaria II power plant, whose construction has also been started by KenGen, will generate up to 64 MW once completed.

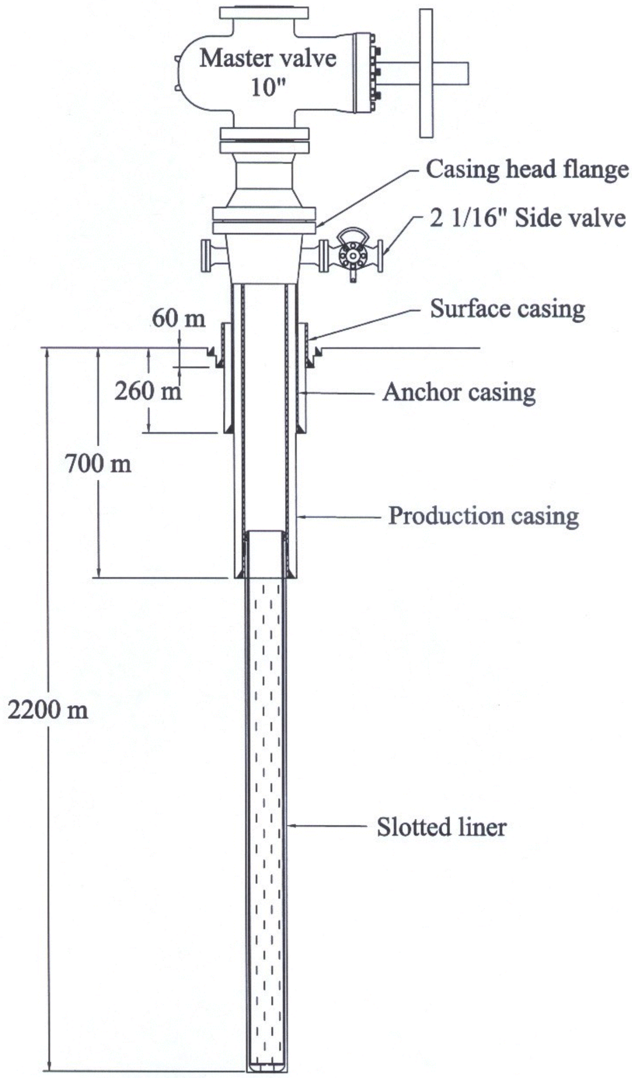
2.2 Future geothermal energy expansion

The 1998 *National power development plan update* calls for additional 576 MW of geothermal power by the year 2017. The plan assumes that seven 64 MW power plants will be built. The process of developing a geothermal resource involves exploration, appraisal drilling, production drilling and power plant construction. An average of 34 MW of geothermal power will have to be developed every year. The average electrical generation potential from a geothermal well in Kenya has historically been around 3 MW per well. This means that in order to meet the current *National power development plan*, at least 12 production wells must be drilled every year over a period of 17 years. The current N370 drilling rig is not able to drill this number of wells per year and a new rig is thus urgently needed. Well trained manpower is available in Kenya today to operate the two rigs.

3. CASING PROGRAMME

The well's casing programme is prepared in compliance with the practice codes for deep geothermal wells which includes casing strings and liners (New Zealand Standard No 2403, 1991). This requires casing to prevent the hole from collapsing, to support drilling and permanent wellheads, to contain well fluids, to control contamination of subsurface aquifers, to counter circulation losses during drilling, and to protect the integrity of the well against corrosion, erosion or fracturing. Casing strings and liners for typical wells are illustrated in Figure 2. The following description is for the Case 1 (Figure 2) well.

Surface casing: The 26" diameter hole is drilled to 60 m, the hole cased with 20" × 94 lb/ft casing and cemented back to surface. The drilling fluid is water-based bentonite mud, or water in case of loss of return circulation.



CASING	DEPTH	CASE 1	CASE 2
	(m)	(dia)	(dia)
Surface casing	60	20"	22 1/2"
Anchor casing	260	13 3/8"	18 5/8"
Production casing	700	9 5/8"	13 3/8"
Slotted liner	2200	7"	9 5/8"

FIGURE 2: Casing programme of geothermal wells in Kenya

Anchor casing: The 17 ½" diameter hole is drilled to a depth between 250 and 400 m. The hole is cased back to the surface with 13 ⅜" × 54.5 lb/ft K55 buttress thread (BTC) steel casing, and cemented back to the surface. The drilling fluid is water based bentonite mud. Water or stiff foam will be used in case of severe loss of return circulation.

Production: The 12 ¼" diameter hole is drilled to a depth between 600 and 1200 m. The hole is cased back to the surface with 9 ⅝" × 40 lb/ft K55 buttress thread (BTC) steel casing and cemented back to the surface. The drilling fluid is mud, water, stiff foam, or aerated mud or water.

Open hole: The 8½" diameter hole is drilled to a maximum depth of 3000 m for vertical wells and 2500 m for directional wells. The hole is lined with 7" × 26 lb/ft K55 buttress thread (BTC) steel slotted casing extending up from the well bottom past the 9 ⅝" casing shoe, with an overlap of about 28-30 m. The drilling fluid is aerated water.

4. DRILLING FACILITY UPDATE

4.1 History of drilling in Kenya

In 1976 the then East African Power and Lighting Company Limited bought the first rig, called T12. This was largely in view of the high capital costs involved in harnessing hydropower. The drilling section of KenGen, then known as Kenya Power Company (KPC), expanded with the purchase of the second rig

(N370) in 1980. Both T12 and N370 drilled the production wells for the 3 × 15 MW Olkaria geothermal power plants where the first unit was commissioned in 1981 and the other two in 1982 and 1985, respectively. The N370 rig still in service has aged, completing its economical life in 1995, but the T12 rig was retired and scrapped. To keep the facility alive for KenGen's future use and to lower costs compared with contracting services, KenGen is considering purchasing a new and modern rig.

4.2 Current drilling rig

The current National N370 rig is a mechanical rig where the power to major rig components such as the rotary table, drawworks and mud pumps is provided through a mechanical power transmission. The diesel engines are located close to the load centres to be driven and belts, pulleys, and chains transmit the power, and sprockets send engine power to various parts of the rig. On a mechanical rig, the compound transfers and directs the power of the engine. A compound consists of several sprockets and chains. Each engine drives a set of these heavy-duty sprockets. The engine sprockets turn a set of chains running between each engine. Additional sets of chains and sprockets in the compound transfer the power to the rotary table and drawworks.

4.3 Future drilling rig

There are three different types of rigs on the market today; mechanical, electric and fully hydraulically operated rigs. KenGen intends to procure a diesel-electric rig as its future geothermal drilling rig. An electric rig does not require chains and sprockets to transfer power. Most new rigs today on the market are electric, because they allow variable speed operation and good control and are easier to rig up and maintain than the mechanical rigs. On an electrical rig, each diesel prime mover has an electric generator connected directly to it. Cables then conduct the electricity to the electric motors as illustrated in Figure 3. Each electric motor is attached directly to the equipment that requires power, such as the drawworks, the rotary table or the top drive, and the mud pumps and the DC motors are controlled by a silicon controlled rectifier (SCR) system.

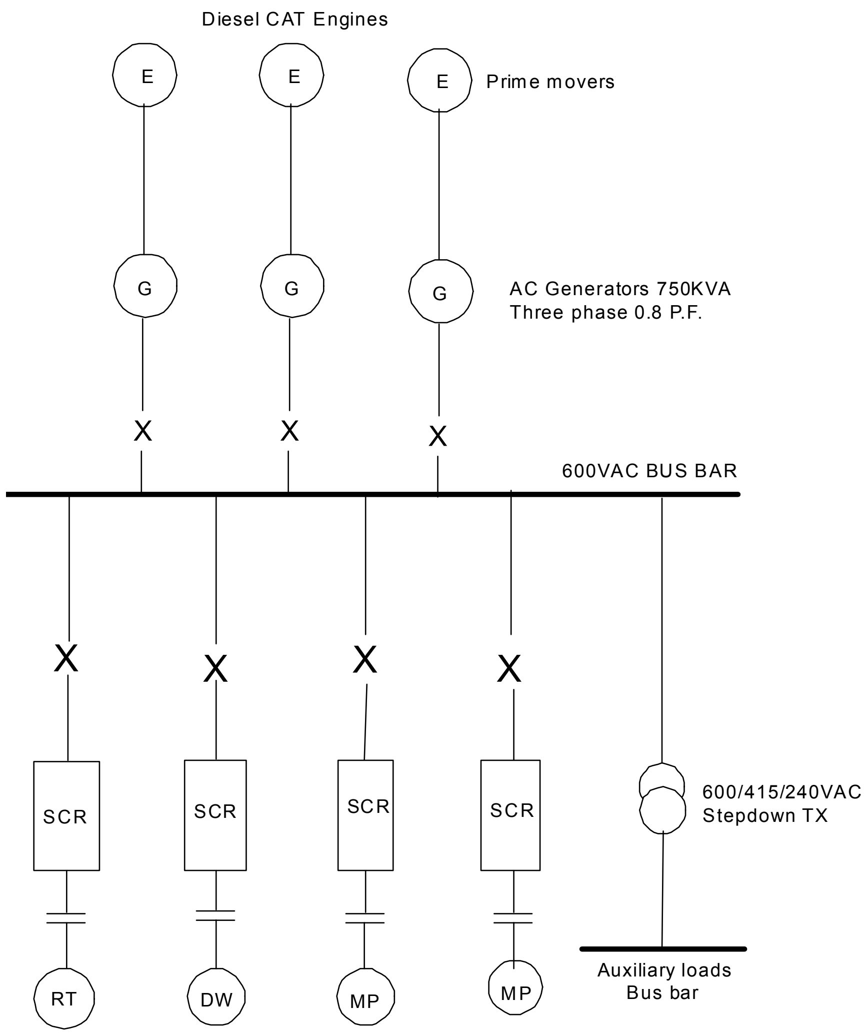


FIGURE 3: Single line diagram of a diesel-electric system

5. RIG SIZE SPECIFICATIONS

5.1 Factors affecting rig selection

The depth a rig is capable of attaining is of major concern to the owner when deciding on a drilling programme. The casing programme affects the rotary table size, hoisting requirements and pump capacity to clean the hole. Exploratory drilling or slim holes versus large diameter casings for production wells, must be decided. The main factors affecting the rig selection are: (L'Espoir, 1984)

- Mast total gross capacity;
- Hook load of mast and drawworks;
- Capacity and pressure rating of rig pumps and power;
- Size of hole in the rotary table to handle large diameters;
- Height of substructure to accommodate BOP stack;
- Size of drill pipe (4½" or 5").

Other factors to be analysed when determining a suitable drilling rig include location of the well and rig size (layout). Economics also come into play.

5.2 Requirements for high-temperature geothermal drilling

Geothermal drilling rig equipment and technology are based for the most part on the many years of experience of oil and gas exploration and production drilling. There are very few manufacturers specialising in building geothermal drilling rigs. In light of this, it is important to understand what is special about geothermal drilling even before calculating and selecting the major rig components. The main things to take note of are (Thórhallsson, 2000):

- Downhole temperatures of 200-350°C;
- Pressure gradient hydrostatic or less;
- Drilling in igneous rock, basalt to acidic rocks (high in silica);
- Danger of steam blowouts;
- Zones with large or total circulation losses;
- Poor hole condition-collapses, stuck drill pipe;
- Special material for construction e.g. steel grades, high-temperature cements;
- Open holes for long sections with slotted liners, e.g. 700-2200 metres;
- Production through casing, no tubing strings;
- Simple drilling muds, water or aerated fluids used for drilling;
- Air used to drill under-pressured vapour-dominated reservoirs;
- No fire or explosion hazard;
- Low pollution.

The above factors affect the selection of the most desirable components for a geothermal drilling rig when it is being bought from gas and oil rig manufacturers.

5.3 Determination of mast capacity

The individual components of the rig must be balanced so that each unit performs its allotted task efficiently. For example, a rig would not be properly balanced if the power plant was large enough to drill 5000 m yet the mast could handle only 2000 m. The mast is the most critical component of the rig that determines the rig's depth limit (McCray and Cole, 1959). The travelling block exerts the hook load weight on the crown block. The force (weight) exerted on the crown block is then distributed equally onto the rig mast. The mast should, therefore, be properly designed to carry the largest dry weight of the drilling string and casing loads exerted on it by these two major loads, plus an allowance for fishing operations. Tables 2, 3 and 4 illustrate the possible dry weights exerted on the travelling block by the drilling string and casing to drill 2200 m and 3000 m deep geothermal wells described in Chapter 3.

TABLE 2: Total dry weight of drilling to 2200 m, for Case 1 of the casing programme

Item	**Description**	**Size (")**	**(lb/ft)**	**(kg/m)**	**Depth (m)**	**Total weight (tons)**
1	Surface casing	20	94	140	60	8.4
2	Anchor casing	13 ⅜	54.5	81	260	21.1
3	Production casing	9 ⅝	40	60	700	41.7
4	Slotted liner	7	26	39	1500	58.0
5	Drilling string / 20 tons drill collar	5	19.5	29	2200	83.8

TABLE 3: Total dry weight of drilling to 2200 m, for Case 2 of the casing programme

Item	**Description**	**Size (")**	**(lb/ft)**	**(kg/m)**	**Depth (m)**	**Total weight (tons)**
1	Surface casing	22 ½	117	174	60	10.5
2	Anchor casing	18 ⅝	87.5	130	260	33.9
3	Production casing	13 ⅜	54.5	81	700	56.8
4	Slotted liner	9 ⅝	40	60	1500	89.3
5	Drilling string / 20 tons drill collar	5	19.5	29	2200	83.8

TABLE 4: Total dry weight of drilling to 3000 m, for Case 1 of the casing programme

Item	**Description**	**Size (")**	**(lb/ft)**	**(kg/m)**	**Depth (m)**	**Total weight (tons)**
1	Surface casing	20	94	140	60	8.4
2	Anchor casing	13 ⅜	54.5	81	300	24.3
3	Production casing	9 ⅝	40	60	1000	59.5
4	Slotted liner	7	26	39	2000	77.4
5	Drilling string / 20 tons drill collar	5	19.5	29	3000	107.1

In order to determine the maximum load imposed on the mast (gross load rating of the mast) by the crown block, (see illustration in Figure 4) the mast is cut in half between the crown block and travelling block by an imaginary line. Double arrows symbolize the number of lines pulling down the crown block while the number of lines pulling up on the travelling block are symbolized by single arrows. Therefore, the maximum gross load divided by the number of lines pulling down will dictate the maximum allowable single

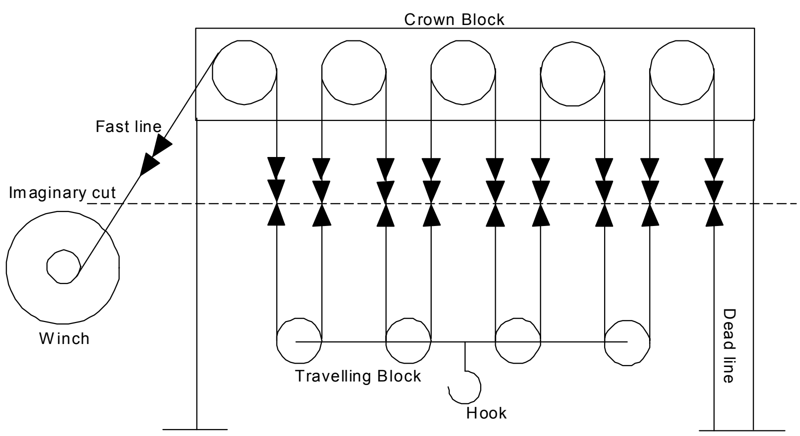


FIGURE 4: Rotary drilling line string-up on the crown and travelling blocks

line pull. The load in the wireline, expressed in tons of tension, is constant in the line from the drum to the dead line anchor. Thus, the usable maximum static hookload for Figure 4 is the number of lines pulling up on the travelling block multiplied by the single line pull.

The total dry weight of the entire drillstring should not exceed 75% of the static hookload rating. This allows a reserve pulling capacity of 25% in a dry hole. For drilling directional wells, an overpull of 50-100 tons should be available.

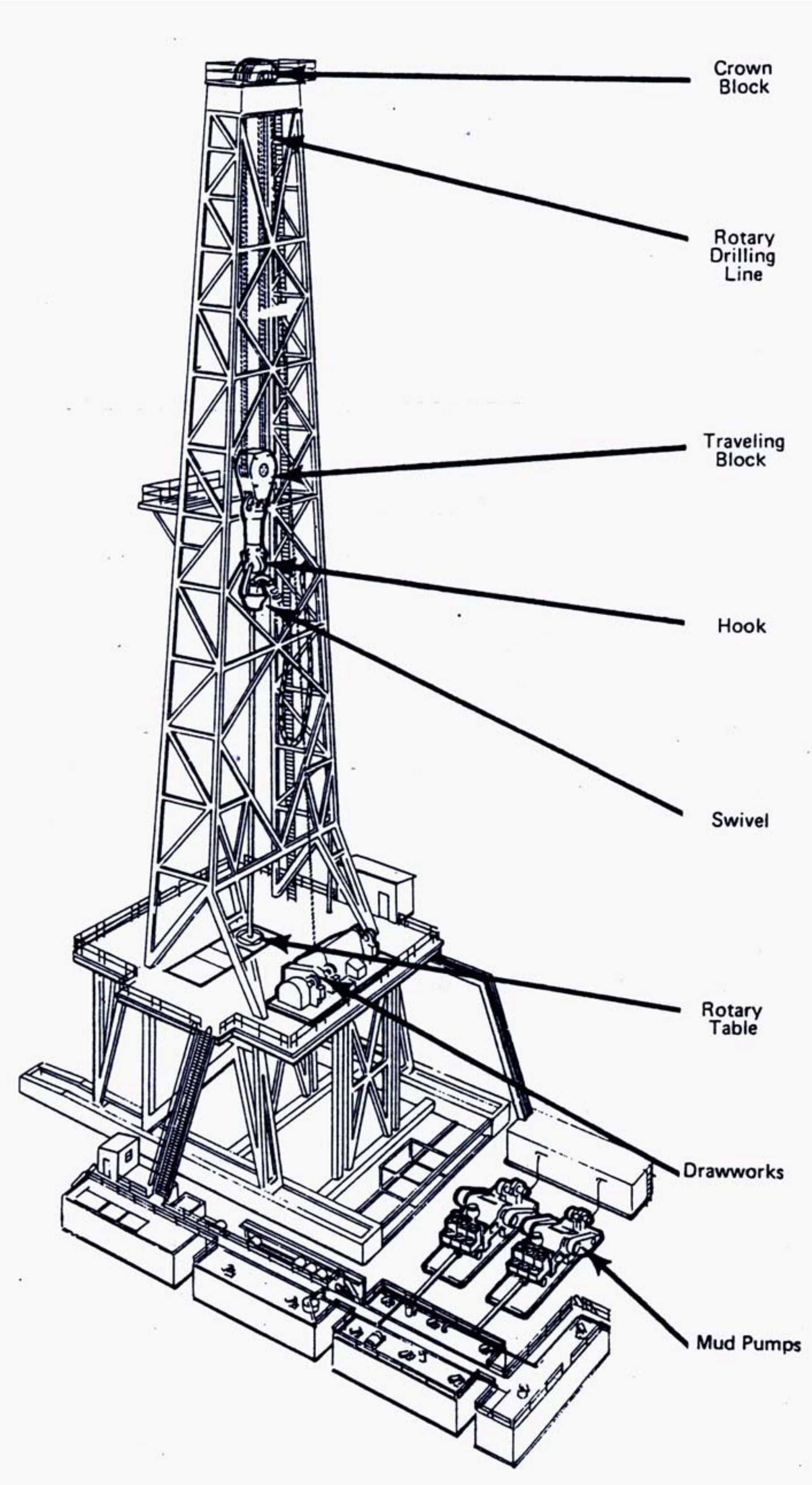


FIGURE 5: A convectional drilling rig

5.4 Hoisting system

The hoisting system consists of the drawworks, the derrick (mast), the crown block, the travelling block, and wire rope drilling line as illustrated in Figure 5. On a hydraulic rig the hoisting is by means of a hydraulic cylinder. The function of the hoisting equipment is to get the necessary equipment in and out of the hole as rapidly as is economically possible. The principal items of equipment that are used in the hole are the drilling string, casing, and miscella-neous well surveying instruments such as logging and hole-deviation instruments. The drilling string is one of the most important considerations in the design of the hoisting equipment, although casing loads and fishing operations may be the largest loads imposed on the derrick. During a drilling operation, the drill bit becomes worn at frequent intervals, necessitating its removal and replacement, which requires removal of the entire drill string.

The drawworks is one of the largest and heaviest pieces of equipment on a rig. It has a spool-shaped revolving drum around which the drilling line is wrapped. It has several shafts, clutches, brakes, and chain-and-gear drives. The motor and clutch are the main factors in determining the maximum single line pull of the drawworks. The brakes are usually matched to the single line pull. The load and the pulling speed determine the mechanical power expended.

The power for the drawworks is obtained by the following equation (Gabolde and Nguyen, 1999):

$$P = \frac{9.81 \times M \times v}{n} \tag{1}$$

where P = Power in kilowatts (kW);
M = Mass (tons);
v = Hoisting velocity (m/s);
n = Transmission efficiency.

5.5 Fluid circulation system

The drilling fluid circulates through many pieces of equipment, including the mud pump, the standpipe, the rotary hose, the swivel, the kelly (or the top drive), the drill pipe, the drill collars, the bit, the annulus, the return line, the shale shaker, and the mud tank, as shown in the fluid circulation system component illustration in Figure 6.

The mud pumps draw in the drilling fluid through the suction line from the mud tanks and send it out through the discharge line and to the rest of the fluid circulation system. Prior to equipment evaluation and selection, drilling fluids and hydraulics programmes are prepared. The programme considers at least the following aspects for every stage of drilling:

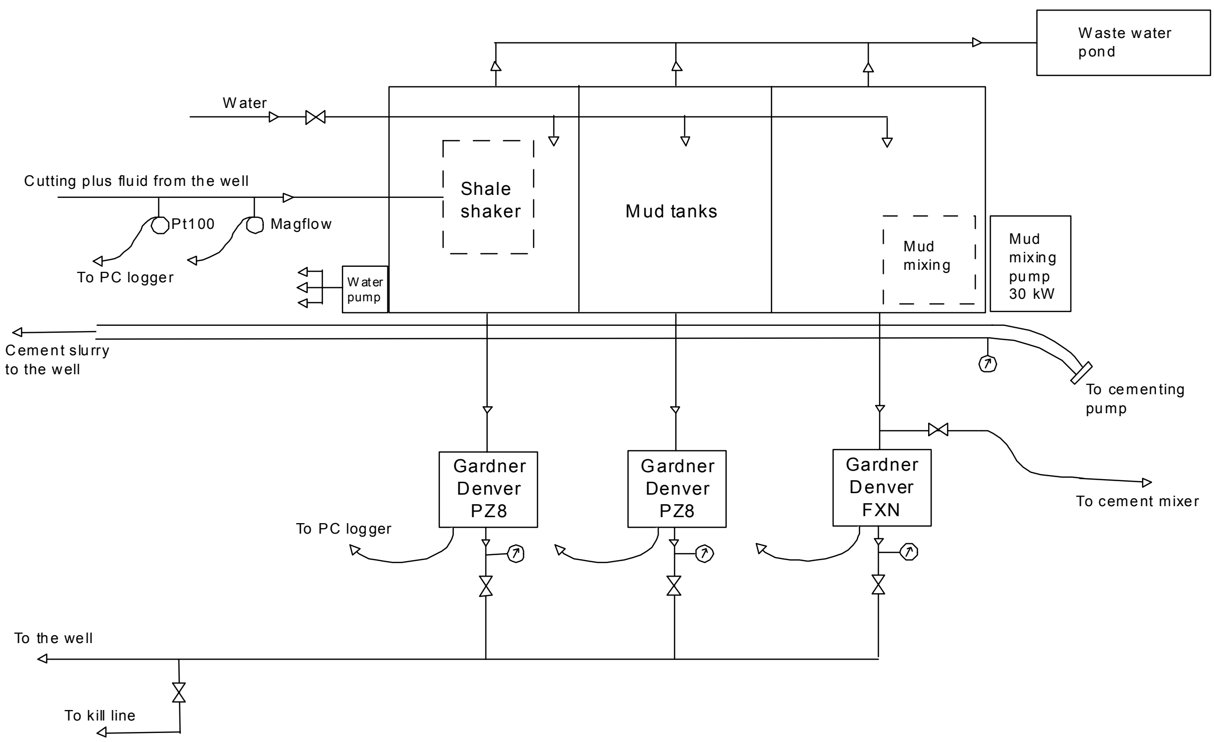


FIGURE 6: A schematic diagram of a fluid circulation system

- The type of drilling fluid to be used and its properties;
- Minimum annular velocities necessary to ensure adequate removal of cuttings from the well;
- Pressure losses through each component of the circulation system;
- The need for a cooling tower;
- Ability to cool and quench the well.

5.6 Determination of mud pump capacity, pressure and power

The mud pump is a very critical piece of equipment of the principal drilling rig components. It pumps the drilling fluids through the circulation system. Incorrect selection of the mud pump in terms of its capacity and pressure ratings can make achieving the desired well depth target very difficult. Therefore, selection of the correct mud pump to match a particular drilling programme is very important. Geothermal wells are of large diameter and drilled with water which requires relatively large pumps. In order to determine the capacity (l/s) and pressure (bar) parameters of the mud pumps, the drilling programme must be known. This includes hole diameter, hole depth, diameter and style of drill-pipe, drilling fluids, and all related equipment. For drilling with a down-hole motor, the driving power is derived from the drilling fluid (extra pressure loss).

The pump discharge capacity must be enough to obtain an annular upflow velocity sufficient to remove all the cuttings from the borehole. The required pump flowrate (Q, l/s) is calculated based on the annular volumes and required upflow velocity (Ton, 1997).

$$Q = (V_h - V_p) \times v \tag{2}$$

where V_h = Volume of the well (l/m);
V_p = Volume of drill pipe (l/m);
v = Annular velocity (m/s).

Knowing the flowrate (Q, l/s) the individual pressure drops are calculated from friction loss curves of the surface equipment, the drill pipe and drill collars, and the drill bit. The total pressure losses (p, bar) are obtained by summing up the individual losses. The pump pressure rating must be more than 1.5 times the total pressure losses. These pressure losses are comprised of

$$p = p1 + p2 + p3 + p4 + p5 \tag{3}$$

where $p1$ = Losses through surface equipment;
$p2$ = Losses through drill pipe/drill collars;
$p3$ = Losses through the rock bit;
$p4$ = Losses between the outer diameter of the drill pipe and drill collar, and wall of the hole;
$p5$ = Losses in the mud motor (when used, e.g. directional drilling).

Tables 5, 6 and 7 list the various values of pressure losses when drilling the 17 ½”, 12 ¼” and 8 ½” holes at the respective flow rates. Once the correct pump flowrate values (Q, l/s) and the total pressure losses (p,bars) are known, then the power of the mud pump can be calculated by applying Equation 4 (Gabolde and Nguyen, 1999).

$$P = \frac{p \times Q}{10 \times n_m \times n_t} \tag{4}$$

where P = Mud pump power (kW);
Q = Flow rate (l/s);

p = Pressure (bar);
n_m = Pump effeciency = 0.85;
n_t = Transmission efficiency = 0.65-0.9 (1.0 for electric motor case).

TABLE 5: Pressure losses Case 1 (17 ½" hole, 260 m);
DDH - Drilling data handbook (Gabolde and Nguyen, 1999)

Item	Description	Drill pipe (“)	Size of hole (“)	Depth (m)	Dp/100m (bar)	50 l/s Dp (bar)	DDH section
1	Surface equipment	Case 4				3.32	G30
2	Drill pipe	5	17½	110	1.99	2.189	G41
3	Drill collar	10	17½	150	10.32	15.48	G46
4	Drill bit	17½	17½			4.39	G51
5	Drill collar- open hole annular	10	17½	150	2	30	G63
6	Drill pipe - open hole annular	5	17½	50	0	0	G67
7	Drill pipe - cased hole annular	5	20	60	0	0	G67
	Total pressure losses					**55.4**	

TABLE 6: Pressure losses for Case 2 (12 ¼" hole, 700 m)

Item	Description	Drill pipe (“)	Size of hole (“)	Depth (m)	Dp/100m (bar)	62.7 l/s Dp (bar)	DDH* section
1	Surface equipment	Case 4				4.96	G30
2	Drill pipe	5	12¼	530	2.98	15.794	G41
3	Drill collar	10	12¼	170	15.42	26.214	G46
4	Drill bit	12¼	12¼			6.48	G51
5	Drill collar - open hole annular	10	12¼	170	1.27	2.159	G62
6	Drill pipe - open hole annular	5	12¼	270	0.06	0.162	G67
7	Drill pipe - cased hole annular	5	13¾	260	0.06	0.156	G67
	Total pressure losses					**55.9**	

TABLE 7: Pressure losses for Case 3 (8 1/2" hole, 2200 m)

Item	Description	Drill pipe (“)	Size of hole (“)	Depth (m)	Dp/100m (bar)	40 l/s Dp (bar)	DDH* section
1	Surface equipment	Case 4				2.22	G30
2	Drill pipe	5	8½	2030	1.33	26.999	G41
3	Drill collar	7¼	8½	170	9.41	15.997	G46
4	Drill bit	8½	8½			3.07	G50
5	Drill collar - open hole annular	7¼	8½	170	2.64	4.488	G60
6	Drill pipe - open hole annular	5	8½	1330	0.26	3.458	G66
7	Drill pipe - cased hole annular	5	9⅝	700	0.12	0.84	G67
	Total pressure losses					**57.1**	

5.7 Air compressor

Selecting an air compressor is just as critical as selecting a mud pump. This is of major concern in drilling programmes where air and foam are to be used as drilling fluids. A minimum return air velocity of 15.0 m/s is needed for proper hole cleaning while a return velocity of 25.0 m/s is considered good and will prevent the bit from crushing the same cuttings over and over again.

A proper air compressor can be chosen only when the reservoir pressure and the hole size and depth are precisely known (Njee, 1986).

6. RIG POWER PLANTS

6.1 Determination of prime-mover ratings

The power plant is the heart of a drilling rig. The power developed by the rig power plant is used principally for three operations: (McCray and Cole, 1959)

- Rotary table or top-drive system;
- Hoisting;
- Drilling fluid circulation.

In addition to these major functions, several auxiliary operations are powered by the rig power plant. In order to properly select the size of the rig prime mover, the power requirements of the hoisting, rotating and mud pumps must be known. The size of all the main and auxiliary equipment, such as: mast, mud pumps, rotary table, transmission, crown block, travelling block, hook, mud cleaning and mixing equipment, light plants, etc., must match the rig power. The power plant should also have adequate power for directional drilling. This is because the steerable motor for directional drilling requires extra hydraulic power from the pumping units.

6.2 Comparison of mechanical and electric power transmission rigs

A diesel-electric rig has several advantages over a mechanical rig. For one thing, a diesel-electric rig eliminates the heavy and complicated compound and chain drive. By eliminating the compound, the rig-up crew does not have to worry about getting the compound lined up with engines and the drawworks. Aligning the engines, the compound, and the driven components can be time consuming. What is more, in a diesel-electric drive, the crew can place the engines well away from the rig floor, because power cables that send electricity to the motors can be relatively long. Remote engine placement reduces noise and vibration on the rig floor, thus making the drilling crew's job a little more pleasant (Baker, 1996).

In a mechanical drive on the other hand, the engine must be fairly close to the components being driven. The mechanical elements of the compound are large and bulky and, unlike electric cable, cannot easily be run long distances. Since the drawworks must be on or very near the rig floor, the engines in a mechanical set-up must therefore also be near the rig floor.

6.3 Choice of electric motor for major power drives

On an electric rig all the power drives are provided by appropriate AC or DC electric motors. The choice of a particular motor for use in a given drive depends on the torque-speed characteristics of the drive. There are two types of drives found on a modern electric rig. These are constant speed drives (CSD) and variable speed drives (VSD). In both cases, the energy is supplied to the process through the motor shaft. Torque and speed are the only physical quantities that describe the state of the shaft. The rotary table (or the top drive), the drawworks and mud pumps require variable speed drive. This is because the flow of energy from the prime mover to these processes needs to be controlled. Very high torque at zero speed is at times required for these three principal processes. The GE 752 DC series and shunt traction motors are, hence, well suited in such situations where high torque at low speeds is needed. Other drives, which require a constant supply of energy to the process, use AC electric motors, e.g. mud mixers, centrifugal pumps (McNair, 1980).

6.4 Auxiliary systems

In addition to the three principal operations in drilling, circulating, rotating, and hoisting, several miscellaneous functions are performed which require power from the same source as the principal operations. Careful consideration must be given to the placing of the auxiliary equipment in the power arrangement or else adequate power may not be delivered to one of the principal operations when needed. Some of these miscellaneous functions are:

- Rig lighting system;
- Shale shaker;
- Mud mixer;
- Water/mud transfer pumps;
- Air compressors;
- Air fans or blowers for the cooling SCR system;
- Power for hydraulically operated BOP accumulator;
- Power for rig shacks/offices (light, heating, cooking, air-conditioning).

An extra reserve power capacity must be taken into consideration when deciding on the overall rig's power to cater to any additional miscellaneous power requirement in the future.

6.5 Rig instrumentation system

The rig instrumentation system provides real-time information to the driller and the geologist about the parameters of the well being drilled. Among the information that instruments provide on a drill rig are:

- Weight on bit (WOB);
- Pump pressure (standpipe pressure);
- Mud pump stroke per minute (SPM);
- Revolution per minute (RPM) on rotary table;
- Rate of penetration (ROP) / depth;
- Temperature in (T_1) and out (T_2) of the circulating fluid;
- Torque on the drill pipe;
- Return flow of the fluid from the well;
- PIT level.

This data is gathered for economic considerations and for safety of personnel and equipment. Each instrument provides data to improve drilling performance, reduce equipment wear, anticipate potential well blowouts and prevent overloads. This data is also very valuable for geological/reservoir data as it provides information such as location of loss zones, etc. Each rig has all or some combinations of electrically operated instruments to record rig data.

On most rigs, the instruments are individually mounted and terminated to sensors located at the point of measurement (see illustration in Figure 7). The sensor data is combined into a single readout data acquisition logger. The output readouts from the data logger are connected to computer for online display and saved on the server for future analysis and print out. Figure 8 illustrates a schematic of a data-logger system from the sensor to the computer with remote monitoring at the drilling headoffice.

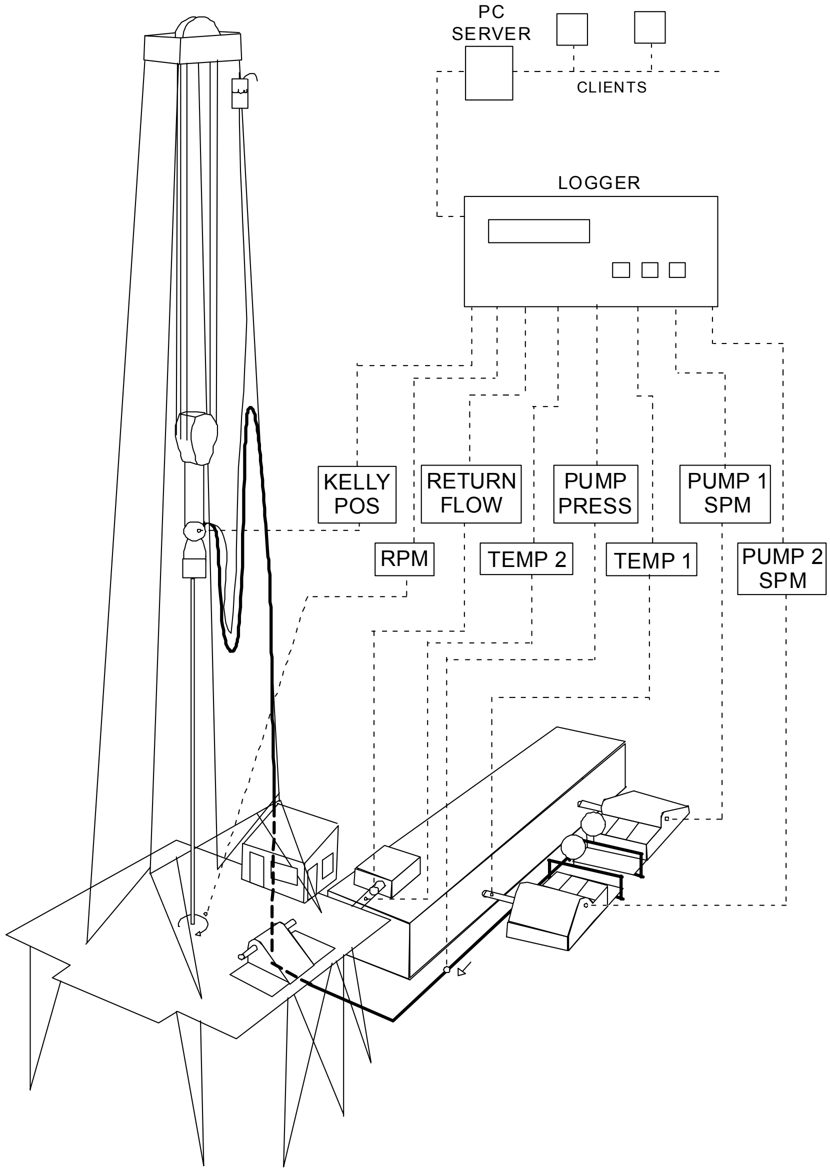


FIGURE 7: Drilling rig instrumentation system

7. RIG SELECTION

7.1 Rig manufacturers contacted

Requests were sent to ten rig manufacturers, out of which five responded positively. These five firms presented rigs with different specifications based on the information provided about the well design (Figure 2). Table 8 shows the comparison of the major rig features offered by these manufacturers. The very detailed technical specifications received covered 50-100 pages. It is outside the scope of this paper to analyse and compare all the features. That is a part of the procurement process. No price information was requested for the same reason. The offers received by each of the manufacturers are briefly described below.

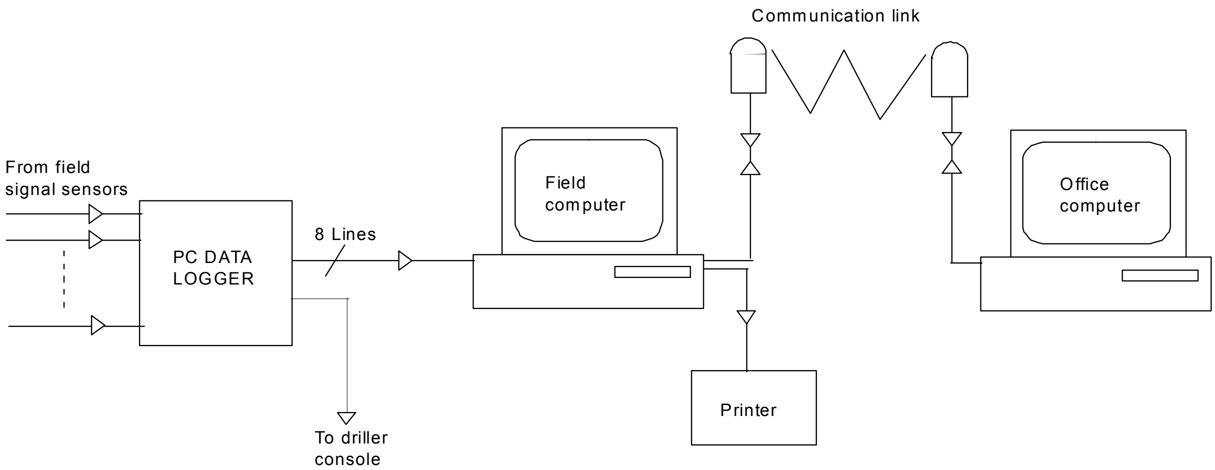


FIGURE 8: Schematic diagram of a data-logger system

TABLE 8: Comparison of rig features offered by the different manufacturers

Company name	**TESCO Corporation**	**National-Oilwell**	**Cooper Man. Co.**	**Crown Industries**	**Bentec Gmbh**
Description					
Mast					
Depth capability	3000 m	3500 m	3500 m	3500 m	3500 m
Height	30.5 m	41.5 m	41.5 m	43.3 m	47.5 m
Gross nominal capacity	-	-	270 tons	381 tons	340 tons
Static hook load	200 tons	230 tons	180 tons	272 tons	275 tons
Travelling block					
Max lines strung	8	10	8	10	10
Rating of the assembly	200 tons	230 tons	265 tons	300 tons	350 tons
Swivel head					
Static capacity	250 tons	-	250 tons	193 tons	272 tons
Working pressure	-	-	-	345 bar	310 bar
Top drive	Yes	Yes	-	Yes	Yes
Static loading	250 tons	250 tons	-	350 tons	-
Max RPM	220 rpm	200 rpm	-	-	-
Substructure					
Nominal height	6.5 m	5.4 m	7.6 m	7.6 m	7.9 m
Set back load	150 tons	136 tons	136 tons	181 tons	158 tons
Total capacity	300 tons	-	295 tons	272 tons	382 tons
Drawwork					
Max input power	746 kW	-	746 kW	746 kW	820 kW
Rated capacity	250 tons	-	-	229 tons	230 tons
Auxiliary brake	Yes	Yes	Yes	Yes	-
Rotary equipment					
Opening size	27.5"	27.5"	27.5"	27.5"	27.5"
Static loading	368 tons			-	170 tons
Max RPM	200 rpm				210 rpm
Mud pumps					
Number of mud pumps	2	2	2	2	2
Max input power	746 kW	969 kW	746 kW	1193 kW	746 kW
Max working pressure	344 bar	400 bar	210 bar	345 bar	340 bar
Max flowrate	55 l/s	60 l/s	52 l/s	-	43 l/s
Power plant					
Engine-generator system	3		3	2	2
Continuous power	600 kW		840 kW	1465 kW	1050 kW
Gen. Max. Power	634 kW		-	-	-
Gen. Output voltage	600 V		600 V	600 V	600 V
Generator frequency	50 Hz		50 Hz	60 Hz	50 Hz
Mudtanks					
Numbers	2	6		2	4
Capacity	60 m^3	320 m^3	-	190 m^3	270 m^3

Tesco Corporation. This company is offering a Tesco modular, all hydraulic, self elevating drilling rig rated at 3000 m with a 4½” drill pipe, with swing-up, and telescoping double mast. The rig is designed to move using pickers and convectional tractor-trailer units. Except for the substructure, mast package, pipe tubes and prime mover, all equipment is housed in standard shipping containers, which are typically 2.44 m wide × 6.1 m long × 2.59 m high. The mast can accommodate a Tesco 250 tons top drive.

National Oilwell. This company is offering an IRI 1100 E series drilling rig consisting of model 2346 SHL drawworks, Baylor 5032 assist brake, provisions for one GE 752 series wound electric motors driving into transmission and all mounted on a four axle rig trailer. The substructure is a hydraulic telescoping type. The mast is three section telescopic and will accommodate Bowen 250 tons top drive. Racking capacity is for 4½" drill pipes ranged in triplets. Other items include hydraulic catworks, utility boom, pipe slide, back up posts, two BOP dollies and track system, a self-contained hydraulic power skid package, racking board, belly board, crown jib, and powered reserve line spool. The rig is also equipped with a self-contained hydraulic power skid package on a single axle trailer. It has an independent electric rotary drive mounted in the substructure.

Cooper Manufacturing Corporation. This company is offering a Cooper 1000 HP electric desert trailer-drilling rig with self-elevating telescoping mast. The mast has a wind capacity of 85 miles per hour with pipe racked in and 120 miles per hour on a bare mast. The mast is with raising cylinders. The mast will also include an adjustable racking board with a capacity of 110 stands triplets of 4½" drill pipes, 5 stands of 6¼" drill collars, 8 stands of 8" drill collars. The racking platform is with a safety chain for fingers, access catwalk, adjustable diving board with hinged extension, hinged floor slabs (drillers side only) and handrails. The rig has a provision for installing a 350 tons top-drive system

Crown Industries, Calgary, Alberta. The rig has a telescoping free standing mast sized to accommodate a top drive and drill with triple stands of range 2 drill pipes. The rotary table is hydraulically operated and the top drive can be either hydraulic or DC electric. This is the largest rig of those listed in Table 8.

Bentec GmbH Drilling and Oilfield systems. The company is offering Bentec 1000 HP and 2000 HP onshore drilling rigs. The 1000 HP drilling rig is capable of drilling a maximum depth of 3500 m, while the 2000 HP can drill up to 5000 m. The rig has both the option of a top-drive and rotary table.

7.2 Rig selection criteria

From the foregoing discussion it has been shown that Kenya can choose her future geothermal drilling rig from a wide selection of rig types meeting similar specifications. The choice of the rig to be purchased will entirely depend on the economical and technological factors, which are outside the scope of this report. In the final rig selection process, many factors will filter down, but only the basic one such as size of the major components has been considered in this report (see Table 8). The mast should have a minimum hook load capacity of at least 200 tons with the travelling block having a maximum of 8 or 10 lines strung. The swivel head should have a static capacity of at least 250 tons with 350 bars maximum working pressure. The mud pumps should have an output of 60 l/s and be able to pump at 120 bars pressure. The substructure should be at least 6 m of nominal height to be able to accommodate the BOP stack. The drawworks, the rotary table and the mud pumps should have a minimum input power of 746 kW each. The opening of the rotary table selected is 27½". This will allow running the biggest casing and bit size to pass through (see Figure 2).

It is desired that the rig be electric with both top-drive and rotary table for intermittent use. A rig equipped with a top-drive system (TDS) has several advantages over one with only a rotary table. Rotation and circulation are always possible while connected. The benefits derived from being connected while rotating and circulating are (Saito and Sakuma, 2000):

- There is less chance of sticking when adding drill pipes, especially where there are circulation losses;
- One can continue drilling even if there is a large in-fill when adding drill pipe (rotary will not engage the kelly bushing);
- Cooling of bit and down-hole tools (MWD) at all times when running into a hot hole thus increasing their life;
- There is a possibility of using a keyhole reamer while tripping out;
- Quicker connection time as one can add 1 stand (3 drill pipes) at a time.

Top-drive also results in ease of control of rotation during drilling, coring and fishing operations. The only disadvantage of a top-drive system is the extra cost of equipment and the increase in rig-up time.

8. CONCLUSIONS

The future of Kenya's geothermal energy expansion entirely relies on the procurement of a new modern rig to supplement the current N370 drilling rig. The new rig should be capable of drilling both vertical and directional wells. The additional rig will speed up drilling of new geothermal wells for the building of more power plants. By so doing, Kenya can reduce its reliance on imported fossil fuel for part of her electricity generation.

This study analysed the main requirements that the new rig will have to meet, based on the well design of future wells. The depth and diameter selected from the well translates into a hook load and pump output which in turn affects the power requirements. These requirements were sent to ten rig manufacturers and they were asked to submit a proposal along with technical specifications. No cost information was requested, as that is a part of the procurement process. Very detailed technical specifications were received from five major rig builders. To compare these and find out what rig rating was offered, the defining parameters were tabulated. From this it is clear that a relatively large rig is required, especially as it is to drill vertically to 3000 m or directionally to 2500 m. The rig would be required to have a minimum hook load rating of 200 tons and a pump output of 60 l/s, translating into a power requirement of 746 kW. Such a rig would be outfitted with 1.8 MW generators. The benefits of top-drive are considerable, especially for deep drilling in high temperatures. It allows good cooling of the bit and results in less serious sticking or keyhole problems. It is, therefore, proposed that at least one of the rigs in Kenya should have the option of a top-drive system (TDS). There exists a large pool of experienced geothermal drillers with KenGen (gained from drilling since 1976). This means that tapping an abundant source of local power and making use of the skills readily available, Kenya can alleviate the present electric power shortage. This makes it ever more pressing that a new rig be purchased.

ACKNOWLEDGEMENTS

My grateful thanks are due to many people without whose help this report would not have been produced. I am particularly grateful to Dr. Ingvar Birgir Fridleifsson, the director of the UNU Geothermal Training Programme, for giving me a chance to come and be trained in drilling technology; Mr. Lúdvík S. Georgsson for providing all the guidance and Mrs. Gudrún Bjarnadóttir for her motherly love. Many thanks go to my supervisor, Mr. Sverrir Thórhallsson, for his guidance and advice which led to the production of this report. I am grateful to my employer, Kenya Electricity Generating Company, for granting me the sabbatical leave to come and attend this important course. Special thanks also go to my dear wife Esther for the moral support accorded me during my stay in Iceland.

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