Controlled Directional Drilling in Kenya and Iceland (Time Analysis)

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Keywords

Geothermal wells, directional drilling, time analysis, casing, logging, cementing

ABSTRACT

Directional drilling enables more wells to be drilled from the same pad, allows for fewer rig moves, less surface area disturbance hence making it easier and cheaper to exploit the resource. The technique allows the driller to steer the well to the target with high precision allowing for exploitation of resources that would otherwise be difficult or impossible to reach. Almost 50% of the total time in directional drilling is spent on activities that are not related to actual cutting of the formation. Minimising time spent on these activities will reduce the total drilling time per well and reduce drilling costs. Average depth drilled per day in Iceland is about 56m, and for Kenya it is about 48 m. Average depth of the Icelandic wells is 2379m drilled in 41 days while the average depth for Kenyan wells is 2830m drilled in 58 days. Compared to Iceland, drilling rate in Kenya lags behind by 4 days for the same depth. For power projects the cost of drilling geothermal wells for production or reinjection is about 40% of the project's total investment. Half of the drilling cost comes from rental of the rigs and services while the other half is from materials and infrastructure.

1. Introduction

Directional drilling is a special drilling operation used when a well is intentionally curved to reach a bottomhole location (Vieira, 2009). Directional wells are drilled with various patterns with the inclined angle of the wells varying from a few degrees to more than 90°. The quickest way to gauge the drilling performance or effectiveness of a well is to view the progress graph, depth vs. working days, found in drilling reports. The first thing to look for is the number of days the actual drilling took and then the number and duration of "flat spots" where there is no advancement in depth. "flat spot analyses" is done to identify where and what problems were encountered. The total number of days is an indicator of the well cost (for wells with a day-rate contract). (Sverrir, et al,2011).

Two casing designs are typically used in geothermal well drilling worldwide, wells with 9⅝″ production casing, large wells with 13⅜″ production casing. Both of these designs have three cemented casing strings with roughly the following depths: surface to 90 m, anchor to 300-400 m and production casing to 800-1200 m after which there is slotted liners running down to the bottom. The wells studied in this report have the same casing design; standard diameter wells with 9⅝″ production casing.

2. Comparison of Directional Drilling in Kenya and Iceland (Time Analysis)

The comparison and analyses is based on drilling histories of 12 wells in Olkaria Kenya and 14 Wells from the Hengil field, Iceland. All of these wells were directionally drilled and the casing and bit sizes used were the same. The Hengill high-temperature field is one of the largest in Iceland. It is located 30 km east of Reykjavik. The Hengill volcanic system is composed of crater rows and a large fissure swarms. It is located on the eastern border of the Raykjanes Peninsula, SW-Iceland. The Hengill volcanic system has a 100 km long NE-SW axis, 3–16 km wide, extending from Selvogur in the southwest to Armannsfell in the northeast. The Hengill central volcano covers an area of about 40 km2 (Björnsson et al., 1986).

The Greater Olkaria Geothermal Area (GOGA) in Kenya is divided into seven fields, Olkaria East (Olkaria I), Olkaria Northeast, Olkaria Central, Olkaria Northwest, Olkaria Southwest, Olkaria Southeast and Olkaria Domes. It is situated south of Lake Naivasha on the floor of the southern segment of the Kenya rift. The wells studied in this report are from Olkaria I and Olkaria Domes field. Olkaria I has been producing power since 1981 when the first of the three 15 MWe units was commissioned (Lagat, 2004). Olkaria Domes is currently undergoing production drilling. It will eventually be developed as Olkaria IV where a 140 MWe power plant is scheduled to be developed (Cherutich, 2009).

2.1 Time Analysis — Raw Data

This section deals with raw data. The tables and figures represent the actual work done. Drilling of these wells was performed in steps; each step is identified by a different casing. The Icelandic naming style for the stages has been adopted for the Kenyan wells. In this report, for Kenyan wells, the surface drilling (0–60 m) has been given the name step 0. Table 1 shows the steps of a typical well for both Kenya and Iceland.

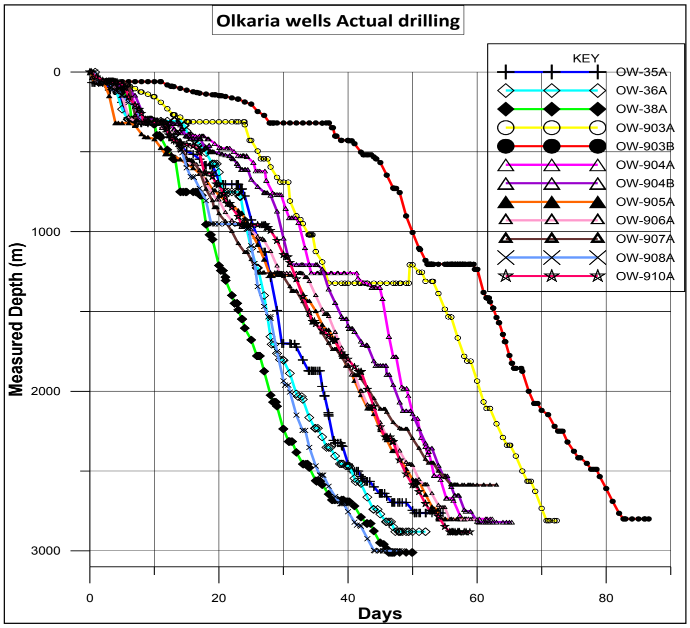

Figure 1. Depth versus days graph for drilled Olkaria wells.

Table 1. Drilling phases.

Kenyan Wells		Icelandic Wells	
Steps	Depths (m)	Steps	Depths (m)
0	0-60	Pre-dri.	0-90
1	60-300	1	90-300
2	300-1000	2	300-800
3	1000-2800	3	800-2300

For the comparison to be as close as possible, step 0 and pre-drilling times were not included in all the analysis except in the determination of average depth drilled per day (ADD/D) which did include step 0 for the Kenyan wells. This is because a smaller rig was usually used for pre-drilling from the surface to 80–90 m for Icelandic wells. The wells studied, their depths and the time taken to drill them are shown in Table 2. Figure 1 shows the drilling progress for the Kenyan wells. Wells OW-903A and 903B took the longest time to drill. This is because cementing took a longer time and a gas blowout delayed drilling.

2.2 Normal Distribution Curve for Average Depth Drilled Per Day (ADD/D)

Average depth drilled per day (ADD/D) indicates the average depth in meters drilled in 24 hours. High ADD/D indicates that the well was drilled in a shorter time hence at a lesser cost. A normal distribution curve will indicate how spread of ADD/D is and indicate the average ADD/D for all the wells. The results in Tables 3 and 4 are calculated using Equations (1) to (3).

Table 2. Summary of wells studied. Pre-drilling for Iceland and step 0 for Kenya not included.

Icelandic Wells				Kenyan Wells			
Well No	Depth (m)	Drilled Depth (m)	Days	Well No	Depth (m)	Drilled Depth (m)	Days
HE-03	1887.00	1792.00	39	OW-903A	2810.89	2748.39	71.33
HE-04	2008.00	1930.40	45	OW-903B	2800.00	2740.00	76.04
HE-05	2000.00	1904.00	45	OW-904A	2799.31	2731.14	57.08
HE-06	2013.00	1935.00	37	OW-904B	2820.00	2755.20	62.48
HE-13	2397.00	2318.70	44	OW-905A	2800.00	2738.00	56.21
HE-26	2688.00	2596.00	54	OW-906A	2804.49	2742.22	57.23
HE-36	2808.00	2703.00	45	OW-907A	2588.22	2527.72	58.92
HE-51	2620.00	2520.00	34	OW-908A	3000.00	2937.65	45.38
HE-53	2507.00	2438.00	57	OW-910A	2881.73	2819.38	54.75
HE-54	2436.00	2342.00	29	OW-35A	2763.00	2697.61	52.71
HE-55	2782.00	2681.00	37	OW-36A	2880.00	2817.00	48.77
HE-57	3118.00	3023.00	40	OW-38A	3010.00	2949.30	46.92
NJ-24	1928.60	1849.60	35				
NJ-25 c	2098.00	1993.00	28				
Average	2378.90	2287.60	40.64		2829.80	2766.97	57.32

Table 3. ADD/D for different Icelandic wells.

ADD/D (x) (m/day)	Class Interval	Frequency	x^2 $(m/day)^2$	f(x)
42.31	37-41	0	1790.23	0.061
42.77	41-45	3	1829.44	0.063
42.90	45-49	3	1840.22	0.063
45.95	49-53	3	2111.28	0.077
47.60	53-57	0	2265.76	0.084
48.07	57-61	0	2311.12	0.086
52.30	61-65	0	2735.01	0.100
52.70	65-69	0	2777.05	0.101
52.85	69-73	2	2792.67	0.101
71.18	73-77	2	5066.39	0.065
72.46	77-81	1	5250.37	0.060
74.12		0	5493.43	0.052
75.58		1	5711.58	0.046
80.76		0	6521.95	0.027

Table 4. ADD/D for different Kenyan wells.

ADD/D(x) (m/day)	Class Interval	Frequency	x^2 $(m/day)^2$	f(x)
37.01	31-33	1	1369.42	0.066
32.34	33-36	0	1045.96	0.032
45.15	36-39	1	2038.54	0.127
42.77	39-42	1	1829.08	0.114
48.07	42-45	1	2310.60	0.132
46.90	45-48	2	2200.02	0.132
41.14	48-51	3	1692.28	0.102
63.21	51-54	0	3995.93	0.031
49.08	54-57	1	2408.54	0.131
50.50	57-60	0	2550.67	0.126
56.31	60-63	1	3170.77	0.085
60.15	63-66	1	3618.01	0.052

ADD/D becomes the variable (x) which is the parameter being studied. The range is the difference between the maximum ADD/D and the minimum ADD/D. It is used in finding the size of the class interval. The mean is the average of the sample taken. Variance and standard deviations (S^2 and S) are statistical parameters found as shown in Equations 1 and 2. The function f(x) is the so called probability function, which is based on normal distribution giving the same values for mean and standard deviation as calculated from our samples and is as shown by Equation 3 (Chatfield, 1983)

$$S^2 = \frac{\sum x^2 - (\bar{x}n)}{n-1} \quad (1)$$

$$S = \sqrt{S^2} \quad (2)$$

$$f(x) = \frac{1}{\sqrt{2\pi S}} e^{-\frac{(x-\bar{x})^2}{2S^2}} \quad (3)$$

Where S^2 = Variance
x = Variable under study
$\bar{x}$ = Sample mean
n = sample size/population
S = Standard deviation
e = Euler's number, a constant given as (2.71828...)

Using Equations (1) to (3), various parameters were calculated for Kenyan and Icelandic wells as presented in Tables 3 and 4.

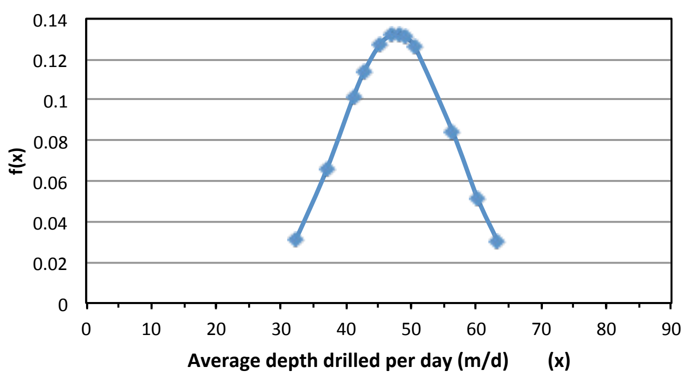

Figure 2. Normal distribution curve for Kenyan wells.

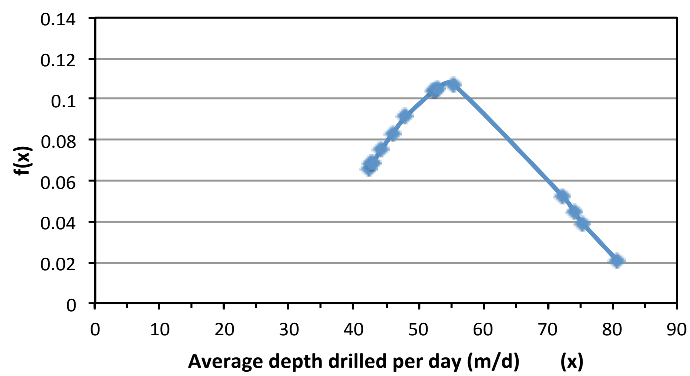

Figure 3. Normal distribution curve for Icelandic wells.

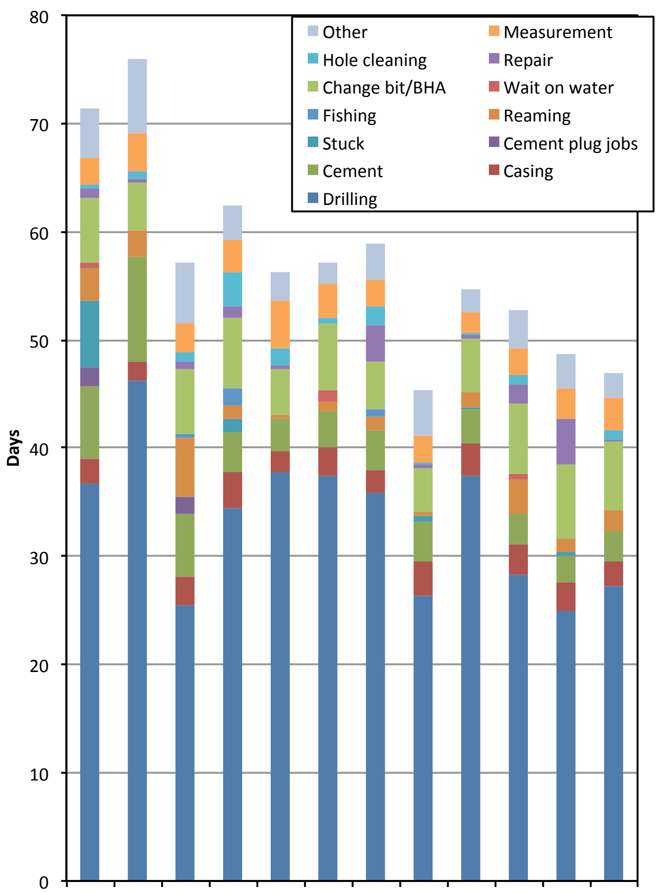

Figure 4. Time analysis for different activities for Kenyan wells.

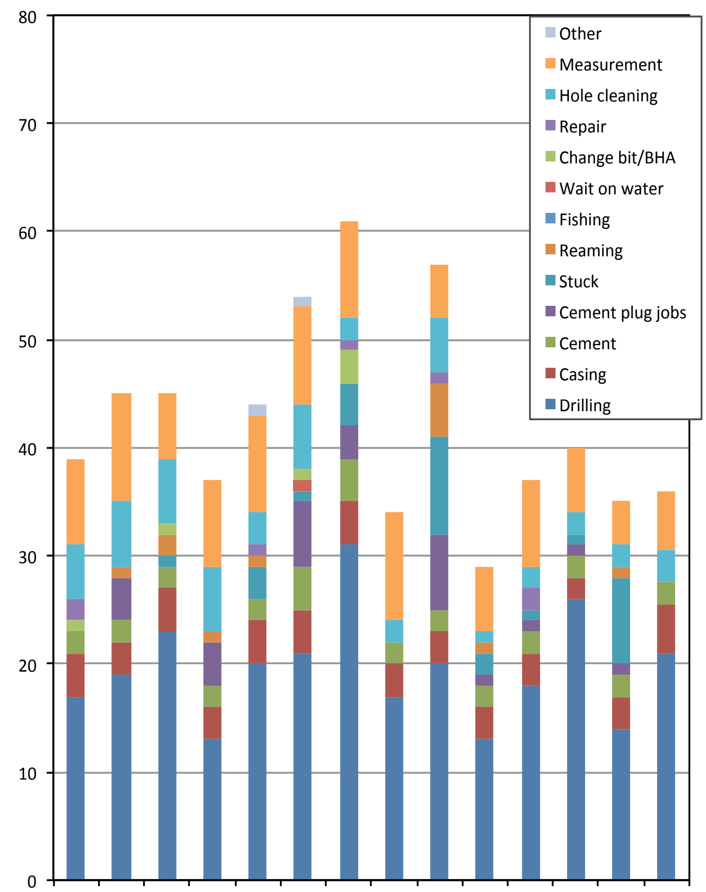

Figure 5. Time analysis for different activities for Icelandic wells.

Table 5. Kenyan wells; Time analysis (days) for different activities during directional drilling.

Well No.	Drilling Steps	Well Depth (m)	Drilling	Casing	Cem.	Cement Plug jobs	Stuck	Ream	Fishing	Wait on Water	Change Bit/ BHA	Repair	Hole Clean-ing	Log.	Other	Total
ow-903A	Step 0	60.5	0.73	0.29	2.08	1.38	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	4.63
	Step 1	309.4	9.65	1.13	5.21	0.00	0.00	1.00	0.00	0.38	0.50	0.00	0.19	0.00	1.29	19.33
	Step 2	1319.2	10.19	0.50	1.54	1.63	6.25	1.46	0.00	0.25	1.71	0.25	0.17	0.19	1.81	25.94
	Step 3	2810.89	16.88	0.71	0.00	0.00	0.00	0.46	0.00	0.00	3.77	0.63	0.00	2.22	1.41	26.06
		TOTAL	**37.44**	**2.63**	**8.83**	**3.00**	**6.25**	**2.92**	**0.00**	**0.63**	**5.98**	**1.02**	**0.35**	**2.41**	**4.51**	**75.96**
		(%)	**49.29**	**3.46**	**11.63**	**3.95**	**8.23**	**3.84**	**0.00**	**0.82**	**7.87**	**1.34**	**0.47**	**3.17**	**5.94**	**100**
OW-903B	Step 0	60	2.13	0.13	7.50	0.00	0.00	0.54	0.00	0.00	0.00	0.00	0.04	0.00	0.21	10.54
	Step 1	319.19	16.02	0.50	7.63	0.00	0.00	0.63	0.00	0.00	0.54	0.04	0.15	0.00	0.63	26.13
	Step 2	1204	11.58	0.58	2.08	0.00	0.00	0.88	0.00	0.00	0.75	0.00	0.00	0.21	5.83	21.92
	Step 3	2800	18.65	0.71	0.00	0.00	0.00	0.90	0.00	0.00	3.12	0.25	0.58	3.29	0.50	27.99
		TOTAL	**48.38**	**1.92**	**17.21**	**0.00**	**0.00**	**2.94**	**0.00**	**0.00**	**4.41**	**0.29**	**0.77**	**3.50**	**7.17**	**86.58**
		(%)	**55.88**	**2.21**	**19.88**	**0.00**	**0.00**	**3.39**	**0.00**	**0.00**	**5.09**	**0.34**	**0.89**	**4.04**	**8.28**	**100**
OW-904A	Step 0	68.17	2.17	0.54	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	1.00	4.92
	Step 1	316	2.79	0.83	1.46	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.08	0.00	1.58	6.96
	Step 2	1259	11.88	0.63	4.29	1.54	0.00	5.17	0.33	0.00	1.21	0.21	0.67	0.25	2.96	29.13
	Step 3	2799.31	10.77	1.29	0.00	0.00	0.00	0.19	0.00	0.00	4.69	0.50	0.13	2.48	0.96	21.00
		TOTAL	**27.60**	**3.29**	**6.50**	**1.54**	**0.00**	**5.56**	**0.33**	**0.00**	**5.90**	**0.71**	**1.33**	**2.73**	**6.50**	**62.00**
		(%)	**44.52**	**5.31**	**10.48**	**2.49**	**0.00**	**8.97**	**0.54**	**0.00**	**9.51**	**1.14**	**2.15**	**4.40**	**10.48**	**100**
OW-904B	Step 0	64.8	1.54	0.29	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.88	3.46
	Step 1	322	4.71	0.54	1.25	0.00	1.21	0.00	0.88	0.00	0.25	0.17	0.33	0.00	1.17	10.50
	Step 2	1206	13.00	1.75	2.46	0.00	0.00	0.38	0.00	0.00	1.88	0.17	0.27	0.52	0.83	21.25
	Step 3	2820	16.75	1.04	0.00	0.00	0.00	0.88	0.75	0.00	4.40	0.75	2.50	2.50	1.17	30.73
		TOTAL	**36.00**	**3.63**	**4.46**	**0.00**	**1.21**	**1.25**	**1.63**	**0.00**	**6.52**	**1.08**	**3.10**	**3.02**	**4.04**	**65.94**
		(%)	**54.60**	**5.50**	**6.76**	**0.00**	**1.83**	**1.90**	**2.46**	**0.00**	**9.89**	**1.64**	**4.71**	**4.58**	**6.13**	**100**

Table 6. Icelandic wells; Time analysis (days) for different activities during directional drilling.

Well No.	Drilling Steps	Hole Depth	Drilling	Casing	Cement Plug Jobs	Cem. Plug	Stuck	Ream	Fishing	Wait on Water	Change Bit/ BHA	Repairs	Hole Clean-ing	Log.	Other	Total
HE-03	1. step	324	4	1	1								1	1		8
	2. step	812	5	1	1								1	2		10
	3. step	1887	8	2							1	2	3	5		21
			17	**4**	**2**						**1**	**2**	**5**	**8**		**39**
			43.59	**10.26**	**5.13**						**2.56**	**5.13**	**12.82**	**20.51**		**100**
HE-04	1. step	305	4	1	1								1	2		9
	2. step	789	4	1	1	4							3	4		17
	3. step	2008	11	1				1					2	4		19
			19	**3**	**2**	**4**		**1**					**6**	**10**		**45**
			42.22	**6.67**	**4.44**	**8.89**		**2.22**					**13.33**	**22.22**		**100**
HE-05	1. step	303	3	1	1								2	1		8
	2. step	802	6	1	1								1	1		10
	3. step	2000	14	2			1	2			1		3	4		27
			23	**4**	**2**	**0**	**1**	**2**			**1**	**0**	**6**	**6**		**45**
			51.11	**8.89**	**4.44**	**0.00**	**2.22**	**4.44**			**2.22**	**0.00**	**13.33**	**13.33**		**100**
HE-06	1. step	310	4	1	1	4							2	1		13
	2. step	813	4	1	1			1					1	2		10
	3. step	2013	5	1									3	5		14
			13	**3**	**2**	**4**		**1**					**6**	**8**		**37**
			35.14	**8.11**	**5.41**	**10.81**		**2.70**					**16.22**	**21.62**		**100**

For Kenyan wells the range is 30.87 (i.e. 60.15-37.01) and for Icelandic wells the range is 38.45 (i.e. 80.76-42.31).

The resultant normal distribution curve for the ADD/D is shown in Figures 2 and 3. For Kenyan wells the average depth drilled per day is about 48 m and for Icelandic wells it is about 56 m.

Tables 5 and 6 show various activities undertaken during drilling and the time spent to perform them. The data for Icelandic wells was adopted from the work of Sveinbjörnsson (2010). Figures 5 and 6 give graphical representations of how the total work time was consumed by various activities during drilling. In order to improve efficiency in drilling, it is important to reduce the time spent on activities other than actual drilling.

The graphical representation of overall time analysis for the various activities is shown in the Figures 4 and 5.

2.3 Time Analysis-Processed Data

To compare the time spent in each of the activities for the wells, the number of workdays must be normalized with respect to the reference well (Sveinbjörnsson, 2010). The reference well was found by getting the average of the parameters under study and using it as a standard. Table 7 shows the reference wells against which the other wells were normalised. The method of normalising is adapted from the previous work of Sveinbjörnsson (2010). This was done for both Kenyan and Icelandic wells.

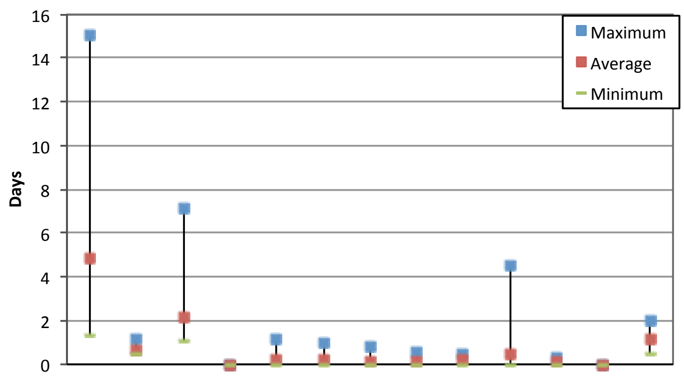

Figure 6. Step 1 time analyses for different activities for Kenyan wells.

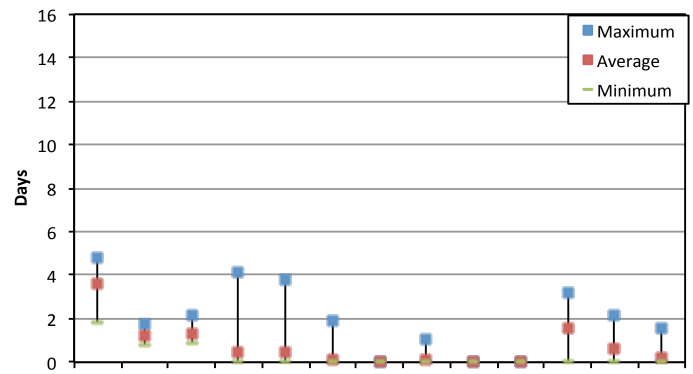

Figure 7. Step 1 time analyses for different activities for Icelandic wells.

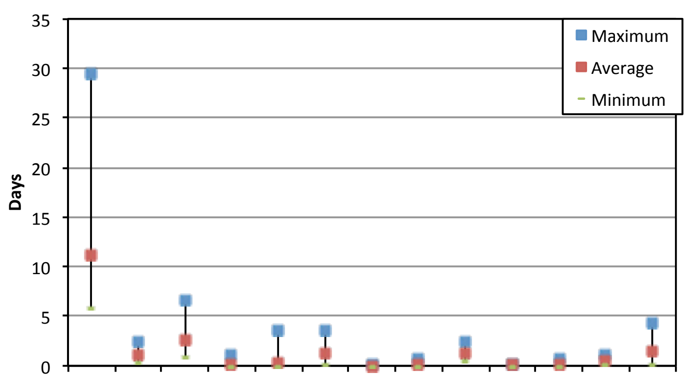

Figure 8. Step 2 time analyses for different activities for Kenyan wells.

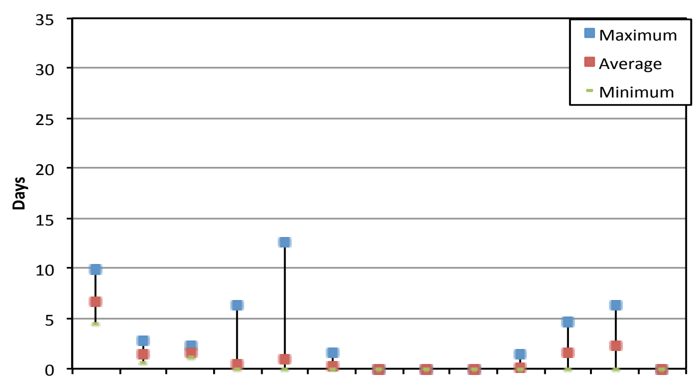

Figure 9. Step 2 time analyses for different activities for Icelandic wells.

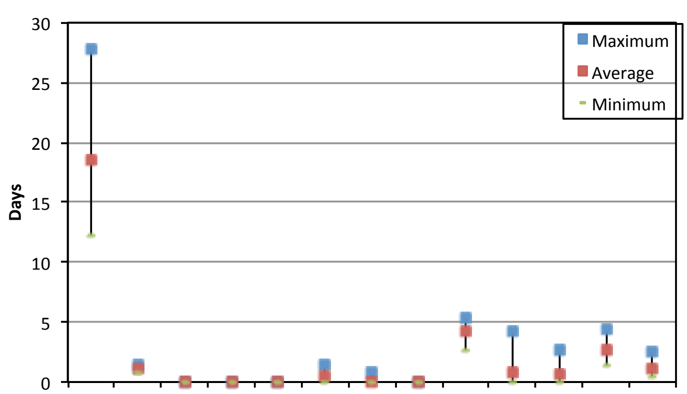

Figure 10. Step 3 time analyses for different activities for Kenyan wells.

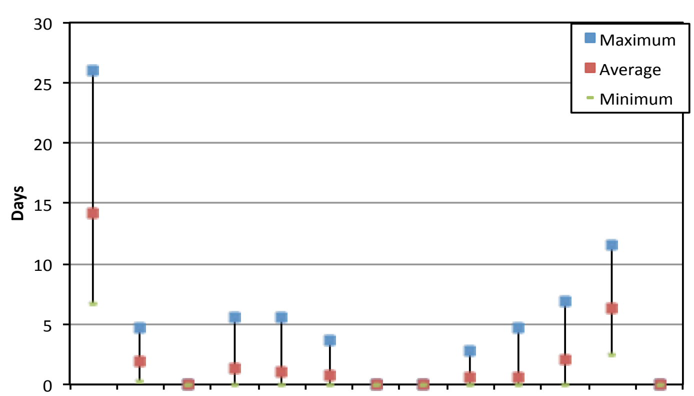

Figure 11. Step 3 time analyses for different activities for Icelandic wells.

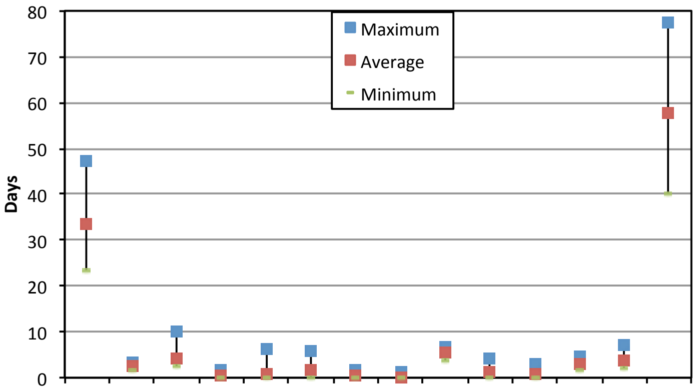

Figure 12. Overall time analyses for different activities for Kenyan wells.

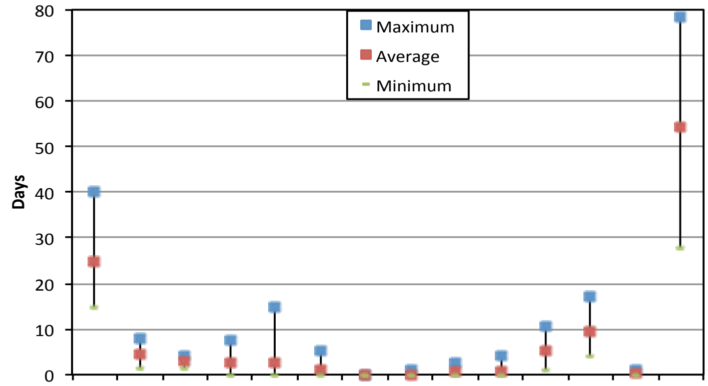

Figure 13. Overall time analyses for different activities for Icelandic wells.

Table 7. Drilling phases.

Reference Kenya Well		Reference Iceland Well	
Steps	**Depths (m)**	**Steps**	**Depths (m)**
1	314.09	1	309.40
2	1073.89	2	854.90
3	2829.64	3	2377.90

In order to normalize the work days for each activity in each phase interpolation is carried out using Equation 4 (Sveinbjörnsson, 2010). This was done for both Kenyan and Icelandic wells.

$$T_i = \frac{Drilled\ reference\ depth}{Actual\ drilled\ depth} \times t_i \quad (4)$$

Where: Ti = is the normalized number of workdays for item i
ti = is the actual number of days spent on item i

Finally in order to compare Kenyan wells with Icelandic wells, Icelandic wells were normalized into Kenyan wells using the Kenyan well in Table 7 as the reference well. Because there are so many tables generated in the process, the resultant graphs for each phase will be the basis of comparison as shown in Figures 6-13.

2.4 Discussion

Table 8 shows the percentage of the work time taken by the different activities during drilling. The wells have been normalised so that a direct comparison can be made.

Based on the time analyses, the following general deductions can be made from the study:

- The study of 12 Kenyan wells and 14 Icelandic wells shows that about 58% of the work time for Kenyan wells and 45% of the work time for Icelandic wells is spent on the actual drilling.
- The rest of the time is spent on other activities that make actual drilling possible like cementing and also activities that hamper drilling like stuck drill string or casing.
- Minimizing the time spent on other activities other than drilling will improve the efficiency of drilling time and eventually lower the drilling cost per well.
- The average drilling time and well depth are 41 days and 2379 m for Iceland and 57 days and 2830 m for Kenya. Note that the drilling time excludes step 0 (Kenya) and pre-drilling time (Iceland).
- ADD/D for Kenya it is about 48 m per day and for Iceland it is about 56 m per day as shown in Figures 2 and 3 respectively.
- Figures 6 to 13 shows graphs generated after normalizing all the wells with the reference wells. Each step can be compared with the other for similar activities because they have been put on the same bases as much as possible. Here below, the areas of large disparities for similar activities undertaken in drilling for Kenya and Iceland will be discussed.

(i) Bit or BHA Change: Kenya spends ten times more time on a bit/BHA change as Iceland. Most of this time is spent during tripping out to change worn out bits or to run in angle correction BHA. The possible cause could be in the types of bits used. Using long life bits may save on time spent to trip out of the hole in order to change the bit frequently. Tripping to change the angle correction BHA is another possible cause. Adopting measurement-while-drilling technology (MWD) and using mud motor for a longer time after finishing angle build up will greatly reduce the need to trip out in order to run in angle correction BHA. In Iceland drilling is done using the mud motor for a large portion of the trajectory (until a total loss of circulation is encountered) after building the inclination to the required angle. In Kenya after building up the

Table 8. Percentage of total time taken by each activity.

	Drilling	Casing	Cem.	Plug	Stuck	Ream.	Fish	WOW	bit/BHA	Repair	Cleaning	Meas.	Other
Kenya	57.94	4.42	7.40	0.47	1.26	3.22	0.42	0.37	9.55	2.02	1.66	4.93	6.35
Iceland	45.31	8.33	5.29	4.45	4.99	2.16	0	0.12	0.95	1.16	9.43	17.52	0.28

angle the mud motor is changed and there are cases where it is run in for angle correction. This takes a lot of time.

(ii) Well Logging: Takes the second largest work time after drilling in Iceland. Iceland spends almost four times as much time for well logging as Kenya. Mostly Kenya does measurements for direction and inclination during drilling and temperature and pressure logs on completion of the well, whereas, Iceland does several temperature and pressure logs during drilling, calliper logging before cementing, cement bond logging (CBL) after cementing and a full set of lithological logs made in the open hole before running each casing string. Such measurements helps get information to better understand the subsurface conditions. In Iceland several gyroscopic surveys have to be made to confirm the MWD readings due to reversals in polarity of the basalt lavas from different ages.

(iii)Cementing: Cementing wells in Kenya takes almost 1½ times as much time as cementing in Iceland. A possible cause of delay is the many number of backfill cementing (remedial jobs) done in Kenya when the primary cementing did not fill the annulus space to the surface. Unlike in Iceland, where plugging of major loss zones is done, Kenya continues to drill blind ahead of major loss zones which eventually takes longer during cementing to fill up. Another possible cause is in the cementing programe. In Kenya no calliper logging is done to ascertain accurately the capacity of the annulus. Usually the capacity of cement to be pumped into the hole is calculated with the assumption that the hole is uniform and then an excess of between 50% and 100% is factored in depending on the extent of lose zones encountered during drilling.

(iv) Running the casings: The analysis indicates that Iceland takes almost two times longer to run casings in than Kenya.

(v) Stuck: The analysis indicates that the drill string/casing gets stuck more often or longer in Iceland than Kenya. There could be a close correlation with the time Iceland spends in cleaning the hole possibly to avoid getting stuck.

(vi) Hole cleaning: Iceland takes almost five times longer for hole cleaning than Kenya. This may be because of many downhole formation problems encountered in Iceland than in Kenya.

(vii) Other activities: This section covers activities that arise to delay the progress of drilling such as accidents, presence of H2S, installing well heads and BOPs etc. Kenya takes much longer time in installing the well head and the blow out preventers (BOP) when changing from drilling in one step to another.

2.5 Suggested Improvements

Areas of improvements for Kenya include investing in better quality bits to reduce tripping time needed to change the bits. Also an investment in MWD equipment would reduce the time for checking the direction and inclination of the well. Kenya should reduce cementing time by doing calliper logs to help generate a more accurate cementing programe. Besides drilling, the activity that takes the longest time for Iceland to accomplish is well logging. Iceland carries out more sets of different well logs than Kenya. Taking the right set of logs that are sufficient to understand the geology and reservoir properties, may reduce time spent in logging. Optimising the time spent in taking logs to increase overall knowledge will improve the time spent in acquiring it.

3. Special Problems in Directional Drilling

Generally there are many problems encountered while drilling vertical wells, but drilling directional wells is more difficult. This is because everything routinely done in vertical drilling becomes more complex when the well has to be drilled directionally. Problems encountered in directional drilling are related to factors such as well profile and the reduced axial component of gravity acting along the drill string. The proportion of these difficulties in drilling a well is usually reflected in the time taken to complete the well which has a direct effect on the cost of the well. Vieira (2009) identifies five special problems that occur in directional drilling as:

(i) More hoisting capacity is often needed to raise and lower the drill string.
(ii) Greater rotary torque is needed to overcome friction.
(iii) Mud and hydraulic system requirements are more critical.
(iv) Stuck pipe and equipment failures are more common.
(v) Casing is harder to run and cement.

These problems are caused by several factors encountered during drilling. These factors are discussed below.

3.1 Tortuosity

An abrupt rate of change in wellbore trajectory is the cause of many problems in directional drilling. Inclination and direction should be changed gradually and be evenly distributed throughout the length of the trajectory. Severe dog legs should be avoided because they may cause key-seating and increase torque and drag. If the drill string has to pass through a severe dog leg, the pipe will make contact with the side of the hole. As the drill string rotates, a small diameter groove in the side of the borehole wall will result. A problem will result during tripping because the large diameter drill collars will get stuck at the key-seat. To free the drill string the key-seat must be reamed out by a stabilizer or key-seat wiper which is usually installed on top of the drill collars. It is good practice to install a key-seat wiper in the BHA when drilling directional wells in which dog-legs can be expected.

3.2 Formation Effect

Different types of formations are encountered when drilling. Some formations become unstable either during drilling or sometime later. This may cause fragments of the formation to fall into the hole and around the drill collars or the bit. Borehole instability may result from such conditions as the presence of high percentages of swelling clays (sodium montmorillonite), presence of steeply dipping or fractured formations, over pressured shale zones and turbulent flow of drilling fluids in the annulus can cause washouts in soft formations. Most of the problems can be related to shale zones. Most shales will absorb water to some extent, lowering the compressive strength of the rock and allowing it to expand.

Sometimes the formation deflects the bit. Controlling the direction of the trajectory becomes more difficult when drilling through laminar or thin layer formations that are not level. When the formation's angle off the horizontal plane (dip) is less than 45°, the bit tends to drill perpendicular to the layers. If the angle is more than 45° the bit drills parallel to the layers. To overcome this problem a stiff BHA must be used.

The drill bit tends to deviate horizontally parallel to tilted formation strata. This effect is called wandering. Even where strata are horizontal, the right-rotating bit tends to walk to the right in inclined holes. This is called bit walk. Stiff BHA may not solve this problem and a more effective way is to use a steering system. If the driller anticipates this problem, he can offset the bit in the opposite direction to compensate for bit wandering and bit walk and then let the bit walk to the final target.

3.3 Differential Sticking

To prevent flow of formation fluids into the well bore, the hydrostatic mud pressure in the borehole must balance or exceed the pore pressure. In a permeable zone, a natural filtration process will take place where the fluid content of the mud will invade the formation while the solids build up on the wall of the borehole to form a filter cake. If the filter cake becomes thick, the drill collars may come into contact with it and become embedded. If the positive pressure differential is large (about 1000 psi) it may be difficult to free the pipe. The risk of differential sticking is increased if the pipe is allowed to stay static for a period of time (Inglis, 1987).

4. Conclusion and Recommendations

The two case histories presented here are intended to illustrate what can be learned. Results from other fields are likely to differ, but early identification of the peculiarity of each resource and the identification of the appropriate technology are keys to success. If such time/cost and well output data were more widely available for analysis it could be used to identify good drilling practices and assess the benefits obtained by simulation.

Closely analysing time taken for various activities during drilling can result in valuable insights on how improvement can be made. This will moreover lead to more accurate estimates of time and be an aid in the planning process. Kenya should invest in long life bits to reduce the time taken for tripping in and out to change bits and also consider drilling with a mud motor after building up the angle in order to reduce angle correction re-runs.

Acknowledgement

I am indebted to the Icelandic government, United Nations University and Geothermal Development Company Limited who financially made this study possible while undertaking an advanced diploma in drilling technology.

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