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Determination of optimum drilling parameters using 8.5 inch tricone bits in olkaria geothermal steamfield, Kenya

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Abstract: *The performance of drilling bits has a direct influence on cost and increase in the rate of penetration translates significantly to cost and time saving. From a total sample of 56 wells, approximately 450 tri-cone bits were consumed at a cost of KSh 200Millions.*

The primary objective of this study is to analyze and optimize 8½" tricone bits which were used to drill the 8½" diameter hole at Olkaria geothermal field. The pads had three wells each with the intention of exploring t in order to determine resource availability for massive power production.

The exercise covered depth from 750m to 3000m using three rigs all with kelly drive systems. The data were compared in average between the daily and sectional drilling range for each well. Evaluation was on weight on bit, rev per minute and strokes in regard to their ROP.

Olkaria formation is mainly trachytic and rhyolite with pyroclastic on surface. Also, occasional minor syenitic and deleritic dyke intrusive on bottom with temperatures above 250degrees centigrade encountered at 3000m total depth.

From analysis the average parameters which suits olkaria formation are WOB of 11tonnes and RPM of 50 which accounts an average ROP of 5m/hr while maintaining average strokes of 75.

Finally, drill off test has been recommended in future so as to get in-depth parameters while maintaining constant geological section and setting

Key Words: *Geothermal, Tri-cone Bits, Drilling, Olkaria*

I. Introduction

A. Tricone Bits

The history of tri-cone drill bit development stretches back over 100 years. It may seem strange to think that such a precision piece of equipment from the present has roots dating back to 1908, but the road to the level of innovation in modern tri-cone bits is a long one. Before there was the tri-cone drill with its 3 interlocking rollers Howard R. Hughes Sr. invented a dual-cone rotary drill which revolutionized the oil drilling rigs of the time. When he founded the Hughes Tool Company in 1908 (then the Sharp-Hughes tool company until 1912) he had a patent for the first roller cutter drill ever made and had founded of one of America's most notable corporate dynasties. When he died in 1924, ownership of the company passed to his famous son, Howard Hughes jr. who had himself declared legally an adult so he could fend off relatives squabbling over his father's will and take full control of the company that would soon create the tri-cone drill bit. *Article Source: http://EzineArticles.com/7405636*

i. Tri-cone Bits Elements

Cones-They make up the cutting elements of the rock bit and comprises of carbide inserts, thrust, outer shell and bore.

Lugs-Coupled in three by120degree to form the bit body and the pin connection, the lugs are also machined to hold the nozzles and a journal bearing surface.

Nozzles-Used to create back-pressure in the bit to force air through the bearing airways and increase the air blast force to remove and flush cuttings from the bottom of the hole. Too large of a nozzle causes insufficient volumes of air to be delivered to the bearings, while too small of a nozzle will increase the back pressure above the compressor modulation setting is reached, it will then reduce its volume output causing decrease in volume going to the bit. (Hughes, 1998)

Inserts-It is the actual physical elements that spall and break the rock. Inserts are made from tungsten carbide powder and a cobalt binder material, which is pressed into the desired shape then sintered. Depending on the application, the tungsten carbide inserts in a given bit will have a shape and physical properties best suited for the rock being drilled. (IADC, 1992)

Figure 1.Tricone bit

ii. Bit Nomenclatures

The product uses the International Association of Drilling Contractors code along with the product line and added bit features to help describe the bit. The IADC code is a three numbered system to classify the hardness and type for all rollers cone rock bits. *First digit* identifies the bit type and major hardness inserts class where 1 represents soft and 8 hard formations. *Second digit* designates the formation hardness subclass and 4 is the hardest subclass. *Third digit* designates the bit's features in terms of cones design.

iii. Bit Type Selection

Soft formation bits-Are designed with long shim, strong teeth to permit deep penetration into the formation with comparatively light weight. Also, bit geometry is adjusted to give maximum desirable scraping action on-bottom. So specific, range of footage or penetration rates can be used as a yardstick for determining when to stop using this type bit due to wide valuation in weight, rotary speeds and formation variations encountered. However, if excessive tooth breakage occurs, you might safely assume that either the combination of weight and rotary speed is too great or formation is too hard for this type of bit (www.atlascopco.com/rotary products).

Medium hard formation bits-The design differs from the softer types principally in the progressive strengthening of the teeth and change in bit geometry to provide more chipping to crushing action. These bits have more closely spaced teeth with a large included angle and more gage surface to resist the wear in harder and amore abrasive formations (www.atlascopco.com/rotary products).

Hard formation bits- Compared with the soft and medium formation bits. This bit has higher capacity bearings and more closely spaced teeth with increased tooth angles to allow the use of heavier weights required to effectively drill hard formations. The geometry of this bit provides maximum chipping and crushing action with minimum scrapping action (www.atlascopco.com/rotary products).

B. Olkaria Geothermal Steam-field

Several geothermal prospect areas have been identified in Kenya and are mainly located within the Kenyan Rift system. Olkaria prospect was the first to be explored and developed and became Olkaria geothermal field, located 125 km North West of Nairobi .After extensive geo-scientific surveys in the early seventies, exploration drilling started in 1974 and continued through 1977. Following evaluation of the initial drilling results, a feasibility report was produced in 1977. The following year 1978, production drilling commenced and continued until 1983. Sufficient resource capacity was confirmed for installation of the first power plant of 45 MWe at Olkaria between 1981 and 1985.Further exploration continued in Olkaria and additional resource capacity was confirmed and the field size approximated to be about 80 km2. It was therefore found prudent to segment Olkaria geothermal field into seven sectors for ease of development. The sectors are namely, Olkaria East, Olkaria North East, Olkaria Central, Olkaria South West, Olkaria North West, Olkaria South East and Olkaria Domes (Ouma 2009).

As drilling continues, assignment covered three sectors within Olkaria which were put into commitments from year 2007 to 2012. Approximately 56wells were drilled and captured as a total sample though the assessment sampled only three pads from three field sectors. The 8.5" bits products consumed during these drilling practices projected to be roughly 450 bits at approximated costs of 200millions in Kenyan money.

These bits were used to drill production section from 750m to a total depth of 3000m with a correlated on bottom temperature of 300degrees centigrade.

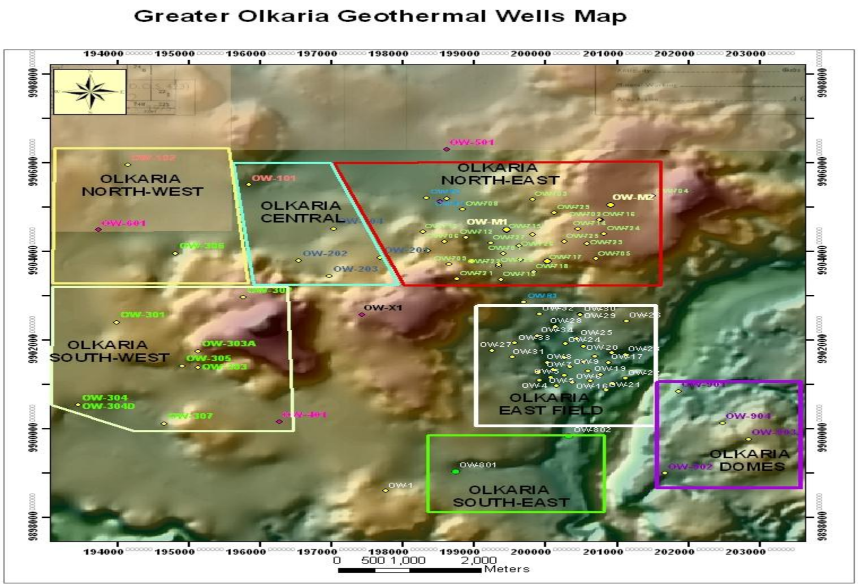

Figure 2. Olkaria Geothermal Steam-field.

II. Olkaria Geology

Olkaria geological formation was well captured in relation to four phases of drilling program as explained in sectional matrix below.

0-50m PyrocIastics; Loose soils/pyroclastic mainly made up of pumice, obsidian and lavalithic fragments. This zone is soft and may cave in.

50-300 m Rhyolite; The zone consists of relatively unaltered rhyolitic lava. At shallow depths within the zone blocky lavas are expected and major losses of circulations occur. Washouts and cave inns may also occur.

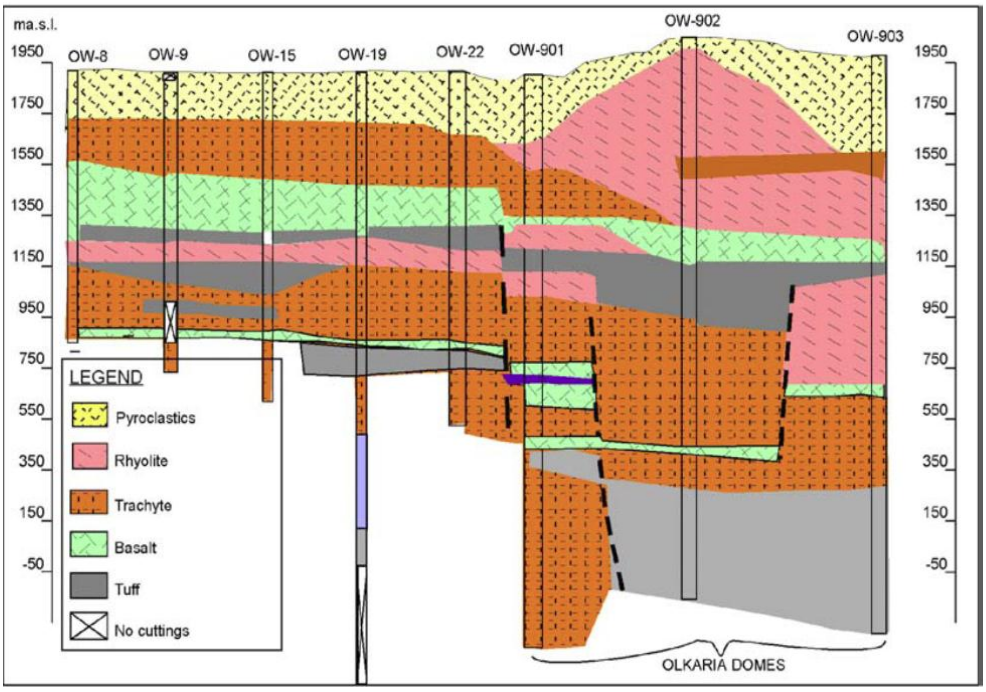

Figure 3. Olkaria Geological Formation

300-400m Trachyte and tuff; Soft and altered zone. The clays may swell and care should be taken to avoid clogging the bit.
400- 700m Rhyolite; The rock consists of mainly rhyolite with occasional trachyte Intercalations. The rock is medium hard to hard and competent. Minor losses may be experienced.
700 -1500 m Trachyte; The zone consists of mainly trachyte lava. The rock is competent and weakly altered. Minor or partial losses may be experienced at fracture zones. Casing may be set in this zone.
1500-2000m Trachyte and rhyolite; The zone consists of mainly Trachyte 1 with occasional rhyolite intercalations. The rock is competent and weakly altered
2000-2400m Rhyolite; The rock in this zone is mainly trachyte. It is hard and competent. Minor or partial losses may be experienced at fracture zones
2400- 3000m Trachyte; The zone consists of mainly trachyte and tuff intercalations with ccasional minor syenitic and doleritic dyke intrusives. The formation here is compact and is expected to have partial losses.

III. Drilling

a. Drilling Rigs

Three rigs were contracted to drill wells at OGS from year 2007 to 2012.During this down hole makeup practice, the directional well drilling subjected rigs to higher loading than that in vertical wells. The hoisting equipment and mast beared additional loads due to drag and fishing requirements for difficult directional drilling. The additional pressure drop in the bottom hole assembly due to directional down-hole motors and instruments being substantial. In order to deliver hydraulic power to the bit, pumps with higher pressure ratings were necessary. The rigs had to drill up to 3000m total depth within 55days.Three Great Wall Drilling Company rigs GW#120, GW#116 and GW#188 drilled 56wells which represented the total sample of this assessment. Two rigs had 2000hp electrically driven and one rated at 1500hp with mechanical drives. The static hook load was 450tons with 12 lines travelling block, two 9-P-100 triplex single acting slush pumps and a 5” drilling string. The average total hook load was 70tons and drag force 60tons with margin of over pull being 250 tons. The hoisting system was therefore adequately rated and pressure tabulated with circulation rate of 2500l/min of water (Gabolde and Nguyen, 1991).

Figure 4.Rig GW#116

2. Drilling Program and lithology

Drilling Phases

The drilling practices starts with pad inspection and measurement to accommodate drilling equipment’s in accordance with quality management certification. Drilling involves four phases with the guidance from drilling program.

First phase; drilling from 0-60M using 26” tri-cone bit with gel-lime/water on plyloclastics formation where the 20” casing is run-in and cemented.

Second phase; drilling using 17.5” bit from 60-300m with gel-water on rhyolite formation and 13.375”casing is run-in and cemented.

Third phase; drill using 12.25” bit from 300-750m with suff foam on rhyolite and trachyte formation and kick off point is done at 400m using directional tools with a buildup angle at about 3 degrees per 30 m (100ft) and 9.625” casing is run-in and cemented.

Fourth phase; the last phase which is production zone drilled using 8.5” bit from 750 to 3000m with water and aerated foam in Trachyte dominant and rhyolite minor formation. Run in liners.

Directional Well Profile

1.	Trajectory:	Type I (build angle and hold)
2.	Kick off Point:	400 m RKB
3.	Angle of Inclination:	20 degrees
4.	Rate of build:	About 3 degrees per 30 m (100ft)
5.	Single shot measurements:	The surveys will be done before kickoff, at KOP, every single drilled, then 30m, 60m, 90m and every 150m drilled.
6.	Desired measured depth:	3000m at a TVD of approximately 2800M
7.	Target Lateral displacement at TD.	800 m

Table 1.Inclination Data

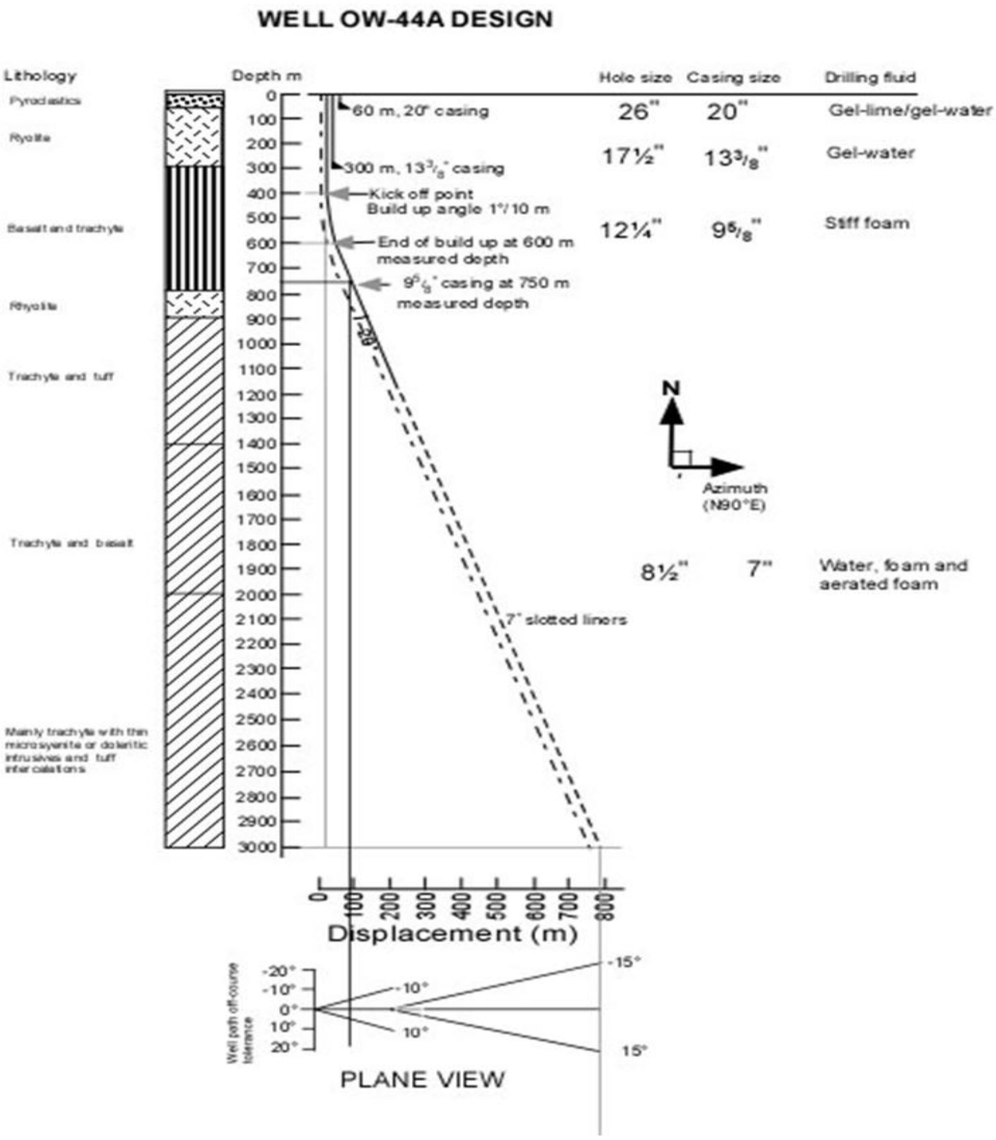

Figure 5.OW#44A Well Design

3. Bottom Hole Assembly

Olkaria East

The Bottom Hole Assembly used for Olkaria East wells was mainly stiff to maintain the deviation data as per drilling program and well design. In this case, fourteen 6.5" Drill collars were used in connection with 5" heavy weight drill pipes and a near bit stabilizer fixed to a ponny collar attached to the bit sub alongside nonmagnetic drill collar leading the series of drill collars.

The total weight of drill collars was 16.8tons though the maximum weight exerted on the bit was 13tons which translates to 80% of the total weight.

Well Name		***Hole Size***	***Kelly Length***			***Kelly Saver***	
OW-44B		**8 1/2"**	11.30			1	
			BHA	***DC***	***HWDP***	***KRB***	
Date	**7/28/2011**		282.44	140.92	139.97	0.42	
S/N	**Type**	**Length**	**Stand No.**	**Segment length**	**T-Length**	**Depth (W/*Kelly*)**	**Remark**
05985	8 1/2"Bit	0.23	637G	0.23	0.23	12.66	King-Dream
410x430	Bit sub	0.61		0.84	0.84		W/F
	Pony DC	2.87		3.71	3.71		
	STB	0.00		3.71	3.71		
410x410	6 1/2"NDC	8.81		12.52	12.52		
	X/O	0.69		13.21	13.21		
1	6 1/2"DC*14	9.07	5	140.92	140.92		
2	5" HWDP*15	9.15	5	139.97	139.97		

Table 2.BHA for Pad#44

Olkaria North East

The wells from Olkaria North East had low on-bottom temperatures compared to Domes and East sectors. The string BHA was designed to suit this kind of formation. Fourteen 6.5” drill collars were used and connected to fourteen 5” heavy weight drill pipes. Two ponny collars were fixed in between two stabilizers assembly.

The total weight of drill collars was 16.8tons though the maximum weight exerted on the bit was 13tons which translates to 80% of the total weight.

Well Name		***Hole Size***	***Kelly Length***			***Kelly Saver***	
OW-733A		**8 1/2"**	11.30			1.16	
			BHA	***DC***	***HWDP***	***KRB***	
Date	**10/18/2011**		369.61	239.45	130.16	0.42	
S/N	**Type**	**Length**	**Stand No.**	**Segment length**	**T-Length**	**Depth (W/*Kelly*)**	**Remark**
05894	8 1/2"Bit	0.23		0.23	0.23	12.69	617G
	410x430/F	0.60		0.83	0.83		
	STB	1.64		2.47	2.47		
	Pony DC	2.86		5.33	5.33		
	Pony DC	1.37		6.70	6.70		
	STB	1.64		8.34	8.34		
	NDC	8.81		17.15	17.15		
	X/O	0.81		17.96	17.96		
1	6 1/2"DC*14	9.05	5	127.64	127.64		NC46
2	5" HWDP*14	9.30	4	130.16	130.16		NC50

Table 3.BHA for Pad#733

Olkaria Domes

This field is associated with high on bottom temperatures and string BHA suited its formation. The total collars” weight was 18tons with 80% needed for weight on bit application. Non magnetic collar was fixed in between two stabilizers to form a string BHA using fifteen 6.5” drill collars and 5” heavy weight drill pipes respectively.

Well Name		***Hole Size***	***Kelly Length***		***Kelly Saver***		
OW-915A		***8 1/2"***	11.3		1.25		
			BHA	***DC***	***HWDP***	***KRB***	
Date	**4/3/2010**		375.15	107.47	165.04	0.42	
S/N	**Type**	**Length**	**Stand No.**	**Segment length**	**T-Length**	**Depth (W/*Kelly in*)**	**Remark**
020	8.5"Bit	0.23	Chuanshi	0.23	0.23		617X
	Bit sub	0.61	1	0.84	0.84		430*410
	stab	1.69		2.53	2.53		410*411
	NDC	9.09		11.62	11.62		NC50
	stab	1.55		13.17	13.17		NC50
	X/O 4A10X411	0.81		13.98	13.98		
1	6.5"DC*6	8.92				12.78	NC46
	X/O 4A11X410	*0.25*					
2	6.5"DC*4	*8.91*	4	107.47	107.47		NC46
	X/O 4A11X410	*0.25*					
3	6.5"DC*5	*9.13*					NC46
4	5" HWDP*15	*8.80*	6	165.04	165.04		NC50

Table 4.BHA for Pad#915

Figure 5. Pad #915 hoisting three wells

4. Drilling Challenges.

a.Rotary Torque Management

Friction on drill pipes increases with the angle of inclination. Where 90degrees is approached, the string weight is converted from hook load to drag weight. As the string in directional wells lie on the lower side of the wellbore, friction increases resulting in increased torque. For 3000m well deflected at 40degrees, it is common to have 10 and 30tons of friction while tripping. Mud control is extremely important in decreasing the drag in a directional well (Ngugi 2002).

b.Drilling Hazards:

Trouble is a generic name for many sorts of unplanned events during drilling, ranging from minor small amounts of lost circulation to catastrophic BHA stuck in the hole and the drill string twisted-off. In some cases, experience in the same or similar reservoirs will give a hint that certain types of trouble are likely especially encountered at OW#915B where the drilling string got stuck and twisted off at a depth of 1734m, after back off the BHA left over had length of 166m.Therefore, KOP began at 1400m after plug job. Nevertheless, the BHA twisted off at 2842m though the fishing was successful the well was terminated at that point because drilling was behind schedule by 25days, drilling on hard formation hence non-porous and finally the on bottom temperatures had been achieved with outflow temperature of 54 degrees centigrade. Through multi-adoption the risks are reduced by at least 40% since drilling starts below casings.

Furthermore, in holes that exceed 35degrees inclination, there is a tendency for cuttings to form beds on the lower side of the bore, which increases drag risk of the pipe sticking and pipe failure. In addition, hole angle affects hole cleaning because cuttings removal depends on the vertical component of fluid velocity rather than calculated annular velocity (Ngugi 2002). Residual cuttings causing high back reaming not only to the reamer but also to the bit shirttail alongside the cutting angle of the cones design setting.

c. Bit walk or lateral draft

The tendency for the bit to drill a hole curved in the right hand direction is known as bit walk. The right hand rotation and increase in bit offset cause it. It may also contribute to the increase in the hole inclination. Evidence exists that increase in bit offset in a specific bit increases the tendency for the bit to walk towards the right and may also contribute to the increase in the hole inclination (Gabolde and Nguyen, 1991).

Bits with zero drift are said to check these deviation tendencies. A packed hole assembly is the best method of controlling inclination and direction caused by bit walk. Bit walk however not unique to directional drilling but is also experienced in vertical drilling.

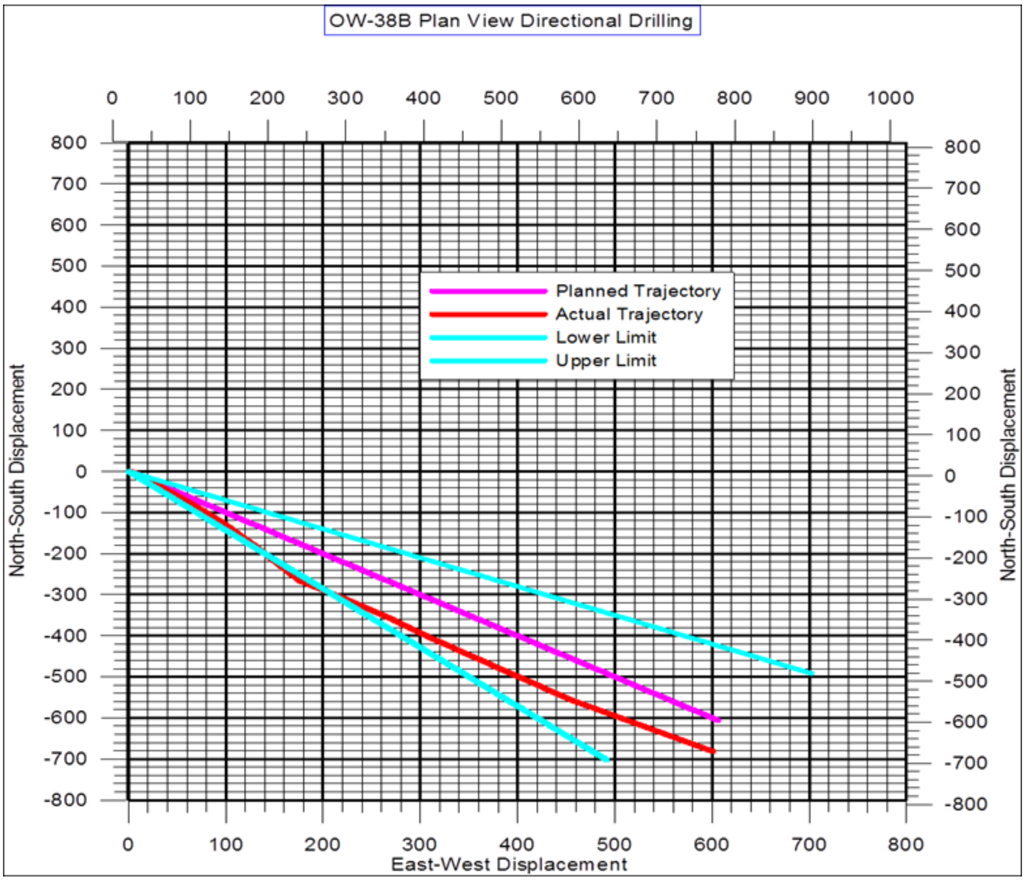

Figure 6. Well OW#38B plan view.

d. Weight on Bit variation and Vibrations.

Poses challenges especially on directional drilling, where only a fraction of drilling collars weight is transmitted to the bit. BHA drag due to gravity plus tendency of the tool joints ploughs the well bore hence decreases the weight. However for vertical cases the hole subjects the string to compressive forces that increases tendency of the string to fail (Ngugi 2002).

Design of a geothermal well is a bottom-up process that requires drilling tools reliability and safety. The graph below shows the depth run variations for OW#44A.It is clear that the vibration due to hard formation or lack of drilling shock subs contributes greatly to drilling lugs alongside wait on repair may also be sounded. The run gap in production zone shows less bit life due to high on bottom temperature causing many runs for bit change. Finally, loss of circulation confirms more use of cement and drilling fluid end hence more costs and time especially wait on cement to set. Multilateral application overcomes these challenges where the risk is equated only to bit life.

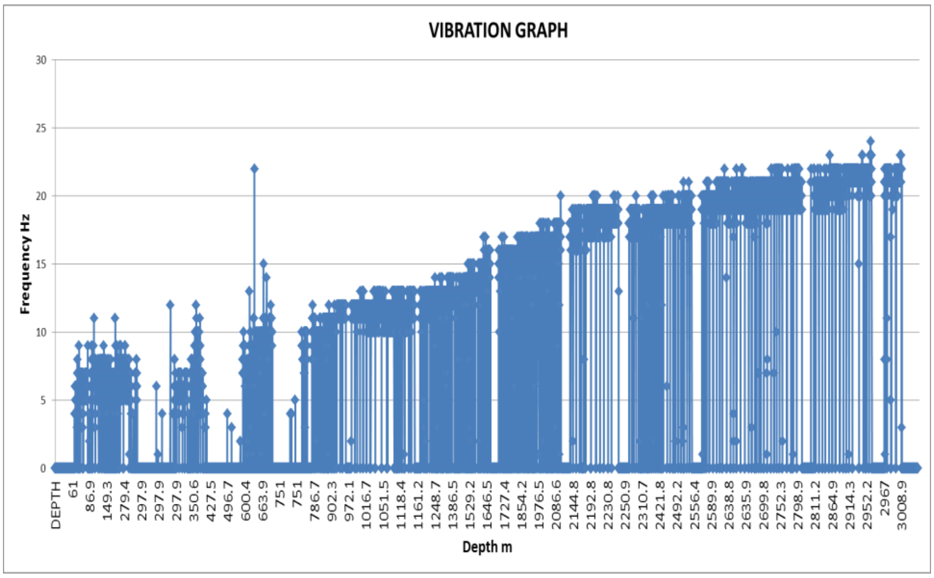

Figure 7. Vibration graph

e. Rate of penetration (ROP) (Time vs Depth)

Many of the costs attributed to drilling are time-dependent so it is clear that anything that speeds up the hole advance without compromising safety, hole stability, or directional path is beneficial (Millheim & Chenevert 1991). The curve shows how the drilling time is of paramount important when working on a geothermal well. Hard formation contributes to more torque and weight on bit to cut formation hence consuming more fuel and bits. Also, soft formation gives high ROP but increases drilling hazards. In the case of multi analysis this section which contributes to a third total depth the risks are zero.

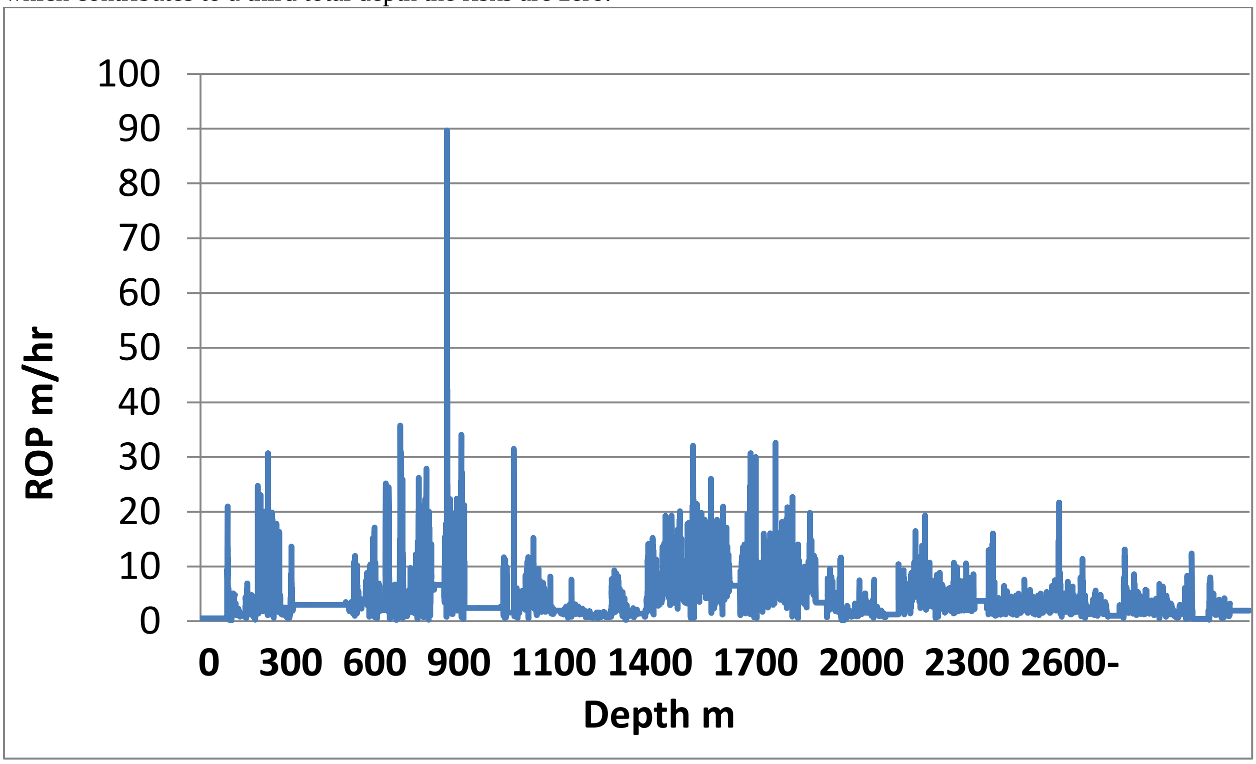

Figure 8. Rate of penetration graph

f. Stand Pipe Pressure

One of the most important aspects of drilling design is to identify the abnormal pore pressure zone against stand pipe pressure which is usually drawn in to lift cuttings. The graph shows a pressure variation curve from spud in to well completion of a directional well OW#44A.In the case of multilateral the challenges caused by this factor are overcomed since drilling starts below production casing reducing the risk by 40%.(Ngugi 2002).The gaps shows the frequent of bit change after reaching its life span end.Also, shows the pressure on formation was uniform to accomadate under balancind drilling and better hole cleaning.

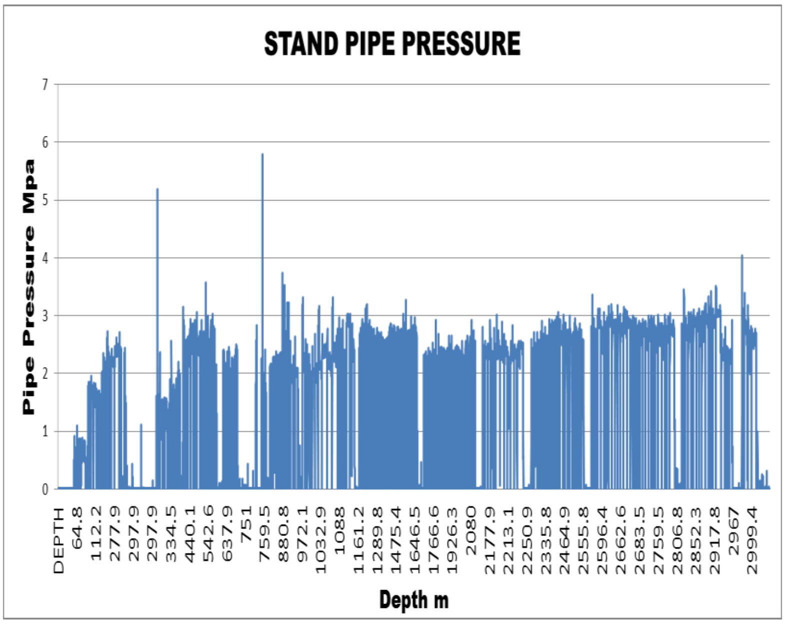

Figure 9. Stand pipe pressure graph

IV. Dull Grading

The dull grade was done for bits which were used to drill nine wells within three pads;pad#915,pad # 44 and pad#733 covered within three field sectors of olkaria. A total of 68 8.5" tricone bits were dull graded in terms of inserts wear, the gage, cones effectiveness/interference, rerunability factor and other factors. From the dull matrix 65bits had its teeth worn and all cones failed proving not good for redrilling alongside pulled out of hole due to low penetration rate. Two bits had all cones effective and active insert ratio for reuse though the bits had been out of hole after reaching the total depth before life optimization. Finally, only one bit out of the sampled figure could not be dull graded because it was left on bottom after string shearing off at 1436m in well OW#915B.

Bits	Dull Grade I	Dull Grade O	Dull Grade MD	Dull Grade LOC	Dull Grade B	Dull Grade G	Dull Grade OD	Dull Grade RP	Dull Grade RR	Nozzle Summary
65	5	5	WT	A	FFF	1	CI, CD,LT,JD,SD	PR	NO	Open
2	3	2	WT	A	EEE	1	SD	TD	YES	Open
1	N	N	N	N	N	N	N	LO	NO	Open

Table 5. Dull grading data

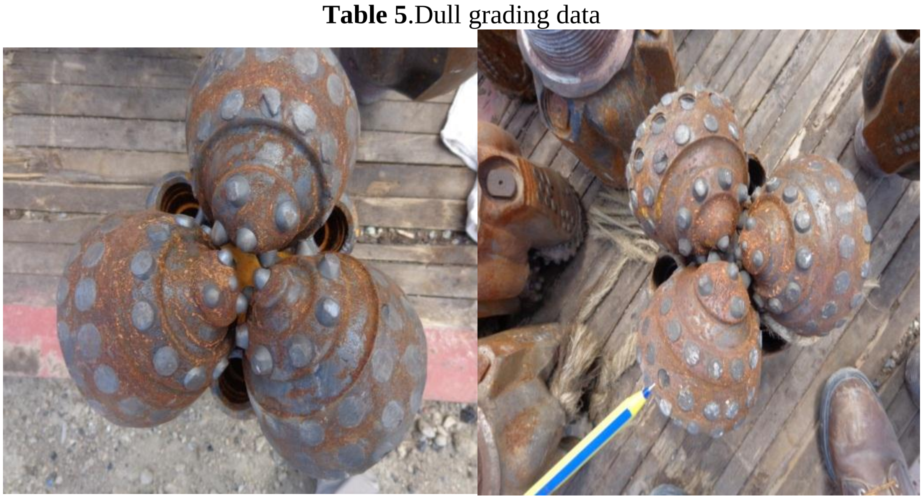

Figure 10. Olkaria domes and North East bits

Figure 11. Olkaria East and Teared down bits

The pie chart below shows that 96% of the bits were pulled out of hole due to low penetration rate, 3% after reaching total depth and 1% represents the number of bits left in the hole after string shear off or back off after sticking.

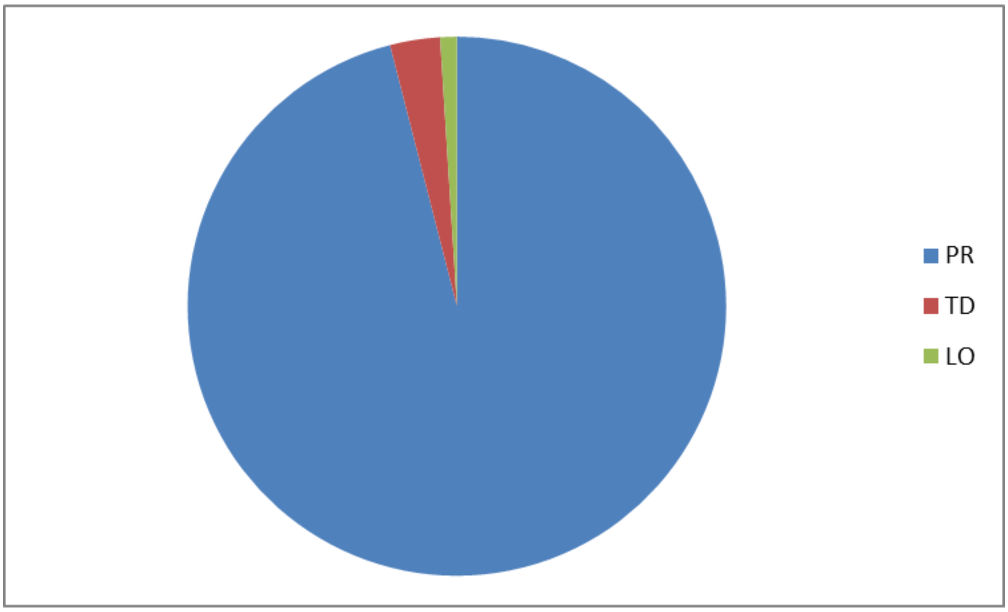

Figure 12. Percentage of bits dull graded in terms of pull out of hole.

V. Parameters

a. Olkaria Domes

From the assessment, at least 28bits were used to drill three wells in pad#915.Drilled 8.5" diameter hole range from 800m to 3010m with maximum parameters of weight on bit 13.9tons, revolution per minute 58 and strokes per minute of 97.The highest sectional rate of penetration was of 6m/hr.

RIG - GWDC-120			FIELD-OLKARIA DOMES				WELL- OW#915B			
BIT S/N	IADC CODE	DAILY AVERAGE				SECTION AVERAGE				SECTION (m)
		Highest ROP	WOB	RPM	SPM	Highest ROP	WOB	RPM	SPM	
5919	617G	4	9	45	70	6	9.5	53	70	803-830
5992	637G	5.4	10	45	97	4	5	40	70	830-1044
6048	637G	6.3	10	47	55	6	11	45	70	1044-1451
6021	627G	2.1	14	58	64	3	13.7	45	65	1451-1482
6051	637G	1.3	4	48	64	2	6	50	65	DOC
5892	637G	2.8	4	46	65	3	7	53	70	1512-1770
5853	617G	3.78	9.1	51	70	3	8	40	70	1776-2321
6017	617G	4	14	41	70	4.4	13.9	47	65	2321-2714
6060	637G	4	13.3	50	70	4.5	12.5	47	65	2714-2842
RIG - GWDC-116			FIELD-OLKARIA DOMES				WELL- OW#915A			
BIT S/N	IADC CODE	DAILY AVERAGE				SECTION AVERAGE				SECTION (m)
		Highest ROP	WOB	RPM	SPM	Highest ROP	WOB	RPM	SPM	
19	617X	5	8	50	92	6	9.5	53	80	1040-1329
60	617X	5.5	8	50	80	4	5	40	85	1329-1617
61	617X	4.4	4.4	50	80	6	11	45	85	1617-2070
18	617X	7.2	13.6	48	83	3	13.7	45	80	2070-2313
26	617X	2.6	14	50	83	2	13	50	80	2313-2530
69	617X	4.4	16	50	80	3	15	53	87	2530-2801
20	617X	3.78	15	50	80	3	15	40	90	2801-2971
22	617X	2.5	14	50	80	3	15	40	90	2971-3010
RIG - GWDC-188			FIELD-OLKARIA DOMES				WELL- OW#915			
BIT S/N	IADC CODE	DAILY AVERAGE				SECTION AVERAGE				SECTION (m)
		Highest ROP	WOB	RPM	SPM	Highest ROP	WOB	RPM	SPM	
116	627G	4	7.5	49	96	5	7	52	90	808-833
16373	617G	2.9	6.5	49	96	3	8	48	88	833-1264
16353	617G	3	7.5	48	90	2.5	8	45	90	1264-1570
16333	617Y	3.2	8	48	96	3	8	45	97	1570-1732
112	617G	3.1	6.7	50	96	3.2	5	50	96	1732-2022
16383	637G	3.8	7.7	50	96	4	4	51	96	2022-2273
16388	637G	1.5	8.7	50	90	2	3	40	90	2273-2500
16384	637G	2.8	8	50	92	3	3	40	90	2500-2557
16400	637G	2.64	8.8	48	90	2	3	49	90	2557-2716
16382	637Y	1.8	8	49	88	2	6	51	90	2716-2879
107	627Y	2	9.6	49	88	2	9	49	90	2879-3010

Table 6. Parameters for Olkaria Domes

b. Olkaria East

In this specific field, 24bits were consumed while drilling three wells in pad#44. Drilled 8.5" diameter hole from 800m to 3010m with maximum parameters of weight on bit 15tons, revolution per minute 62 and strokes per minute of 96.The parameters gave highest rate of penetration of 6m/hr. The data shows, as the depth increases the short the drilling section per bit because the temperatures increased with depth.

RIG - GWDC-188			FIELD-OLKARIA EAST				WELL- OW#44			
BIT S/N	IADC CODE	DAILY AVERAGE				SECTION AVERAGE				SECTION (m)
		Highest ROP	WOB	RPM	SPM	Highest ROP	WOB	RPM	SPM	
33	627Y	2.5	7	50	96	3	7	52	90	827-1205
47	627Y	2.04	8	50	96	2	8	48	88	1205-1547
16372	617G	2.91	8	50	90	2.5	8	45	90	1547-1773
21801	637G	3.5	8	50	96	3	8	45	97	1773-2101
24799	637G	3.7	8	50	96	3.2	8	50	96	2101-2360
21820	637G	4.2	8.8	50	96	4	8	51	96	2360-2659
22851	637G	2	8.8	50	90	3	9	40	90	2659-2931
21784	637G	4.2	8.8	50	92	4	7	40	90	2931-3000
RIG - GWDC-116			FIELD-OLKARIA EAST				WELL- OW#44A			
BIT S/N	IADC CODE	DAILY AVERAGE				SECTION AVERAGE				SECTION (m)
		Highest ROP	WOB	RPM	SPM	Highest ROP	WOB	RPM	SPM	
52	627Y	2.5	9.7	49	55	3	8	50	60	781-1164
23206	627G	5.7	9.3	51	88	6	9	50	59	1164-1674
23203	627G	5.8	13	57	80	5	12	45	60	1674-2134
21788	637G	2.1	12	51	80	3	12	50	80	2134-2594
21791	637G	2.37	12	52	88	2	13	55	75	2594-2807
21786	637G	2.6	11	52	76	3	10	51	75	2807-2967
21788	637G	2	16	50	79	2	14	45	80	2967-3010
RIG - GWDC-116			FIELD-OLKARIA EAST				WELL- OW#44B			
BIT S/N	IADC CODE	DAILY AVERAGE				SECTION AVERAGE				SECTION (m)
		Highest ROP	WOB	RPM	SPM	Highest ROP	WOB	RPM	SPM	
74	637X	6.4	16	52	90	6	8	52	58	771-1419
16338	627Y	5	17	45	81	5.3	8	48	60	1419-2089
67	617G	4.7	17	50	82	5	9	50	60	2089-2486
16374	617X	5.7	14	62	71	6	12	45	77	2486-2690
16332	617G	2	14	58	96	2.5	12	43	80	2690-2789
16405	617G	2.5	15	50	92	3	10	53	80	2789-2889
16407	637G	3.6	14	50	80	4	13	45	75	2889-3000

Table 7. Parameters for Olkaria Domes

c. Olkaria North East

In this field, 18bits were used to drill three wells in pad#733.Drilled 8.5" diameter hole from 750m to 3000m with maximum parameters of weight on bit 14.9tons, revolution per minute 67 and strokes per minute of 88.Also, the highest rate of penetration gained was 6m/hr.

RIG - GWDC-120		FIELD-OLKARIA N.EAST				WELL- OW#732				
BIT S/N	IADC CODE	DAILY AVERAGE				SECTION AVERAGE				SECTION (m)
		Highest ROP	WOB	RPM	SPM	Highest ROP	WOB	RPM	SPM	
16340	617G	1.2	11.5	52	54	2	10	52	55	784-1275
16354	617G	3.3	12.4	51	65	3	11	52	55	1275-1734
16336	617G	3.7	12.4	51	65	4	12	49	67	1734-2323
23042	627G	4	12	52	65	4	7	50	68	2323-2783
21798	627G	4	13	55	70	3	9	55	68	2783-3000
RIG - GWDC-116		FIELD-OLKARIA N.EAST				WELL- OW#733A				
BIT S/N	IADC CODE	DAILY AVERAGE				SECTION AVERAGE				SECTION (m)
		Highest ROP	WOB	RPM	SPM	Highest ROP	WOB	RPM	SPM	
5855	617G	4.9	11	41	78	4	10	52	77	781-1305
5845	617G	2.6	11	54	70	3	10	41	70	1305-1620
5852	617G	2.2	8	50	80	2	7	45	88	1620-1805
5814	617G	5.2	13	54	90	5	13	55	88	1805-2486
5898	617G	3.3	14	54	70	3	14	50	80	2486-2795
5997	637G	2.8	8.6	55	87	3	8	55	85	2795-2806
5853	617G	2.7	14.9	67	87	3	14	40	85	2806-2887
5986	637G	2.1	13	56	80	2	12	55	88	2887-3000
RIG - GWDC-188		FIELD-OLKARIA N.EAST				WELL- OW#732A				
BIT S/N	IADC CODE	DAILY AVERAGE				SECTION AVERAGE				SECTION (m)
		Highest ROP	WOB	RPM	SPM	Highest ROP	WOB	RPM	SPM	
5998	637G	4.4	8.8	51	80	4	8	52	80	759-1440
6004	637G	3	7.8	59	83	4.4	7	51	88	1440-1634
6003	637G	4.4	12	56	83	3	11	52	88	1634-2154
5856	617G	5.6	9.8	56	88	6	11	55	85	2154-2616
6001	637G	4.4	11	56	88	3	11	56	85	2616-3000

Table 8. Parameters for Olkaria Domes

VI. Data Analysis and Discussion

a. Olkaria North East

An evaluation of the eighteen bits that were used to drill three wells at pad# 733 indicates that, seventeen bits were pulled out of hole as a result of poor penetration rate after total depth. The low rates of penetration ranged between 1.10-2.0m/h. The data shows all parameters were uniform with depth increase and also confirms the formation strength was almost linear. Penetration rate remains key when determining the bit life cycle when on bottom. The graph shows slight decrease in ROP when WOB is reduced with increase in RPM. That reflects little weight to exert the inserts of the bit in the formation lacking enough cutting weight to the formation. Also, high SPM with low WOB confirms better ROP since the mud hydraulics are able to lift the cutting with no regrinding lugs.

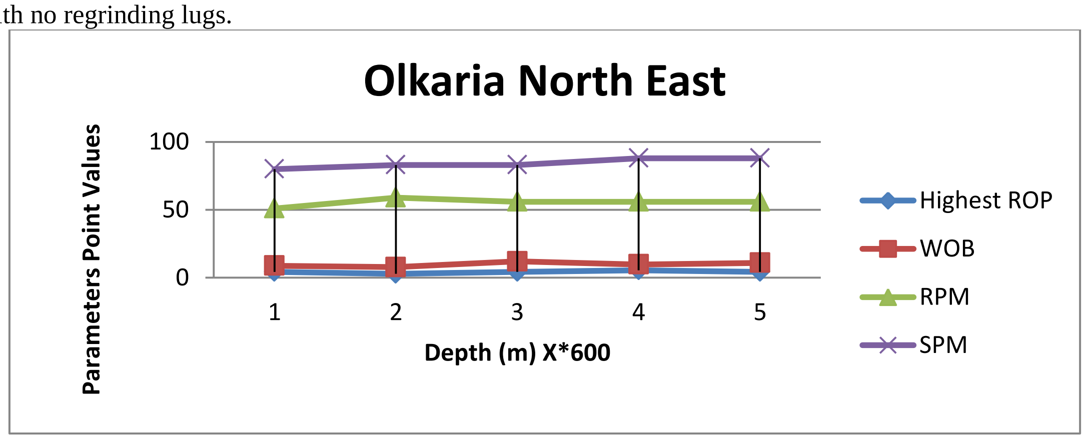

Figure 13. Olkaria North East parameters graph

The graph below justifies the cause of bit failure which was increase in bottom temperature as the depth progresses. This analysis shows that, as the depth increases the temperature increases hence increase in formation pressure .This formation gives better hole cleaning by lifting cutting though the bit life is diminished by high on bottom temperatures (Profile from appendix 3).

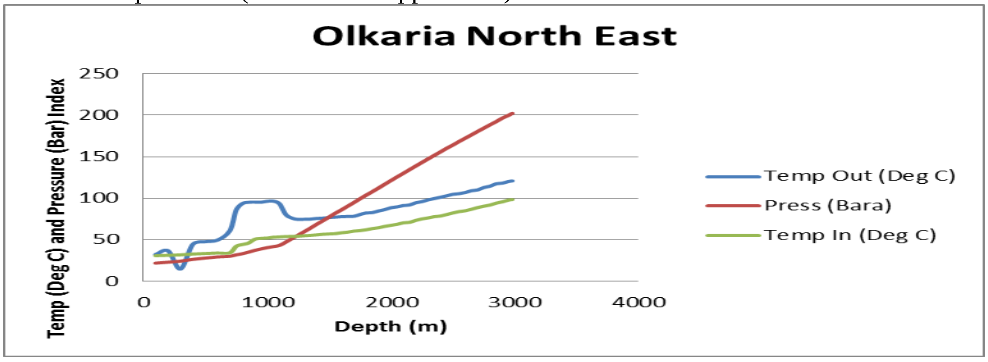

Figure 14. Olkaria North East temperature graph

b. Olkaria East

Pad# 44 indicates that, twenty four bits were pulled out of hole as a result of poor penetration rate. Though three bits were pulled out because of having reached the target depth but had low rate of penetration all together ranged between 1.0 -2.0m/hr. Penetration rate remained key when determining the bit life cycle when on bottom. The graph shows highest ROP is achieved through increase in RPM with decrease WOB while maintaining average SPM to have better cuttings lift. The data lacked flow uniformity especially SPM and PRM to correlate formation strength.

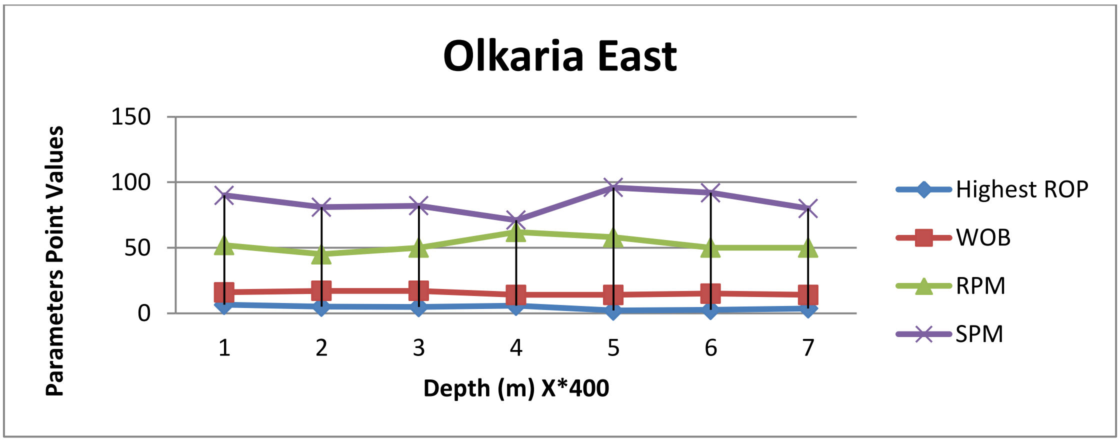

Figure 15. Olkaria East parameters graph

This field confirms to have high on bottom formation pressure hence better hole cleaning as depth increases. Also, the temperature on bottom reduces the bit life and tends to have low cutting criterion as the drilling bit time increases (Profile from appendix 2).

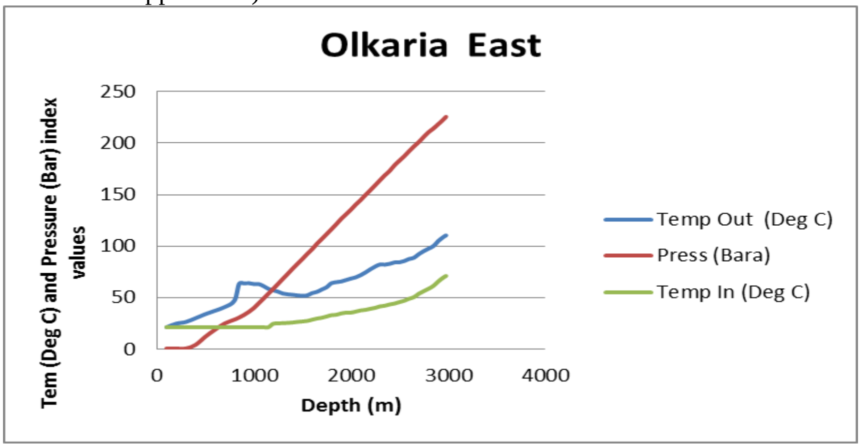

Figure 16. Olkaria East temperature graph

c. Olkaria Domes

Twenty eight bits were used to drill three wells at pad# 915, twenty six pulled out of hole as a result of poor penetration rate. Only one bit was pulled out because of having reached the target depth while the other was left on bottom as a fish. The low rates of penetration were ranging between 1.15-2.0m/h. The data shows all parameters were uniform with in depth increases and also confirms the formation strength was almost linear. Penetration rate remains key when determining the bit life cycle when on bottom. The graph shows slight decrease in ROP when WOB is reduced hence, sounding low weight for tearing formation. Better ROP can be gained if all parameters were held constant.

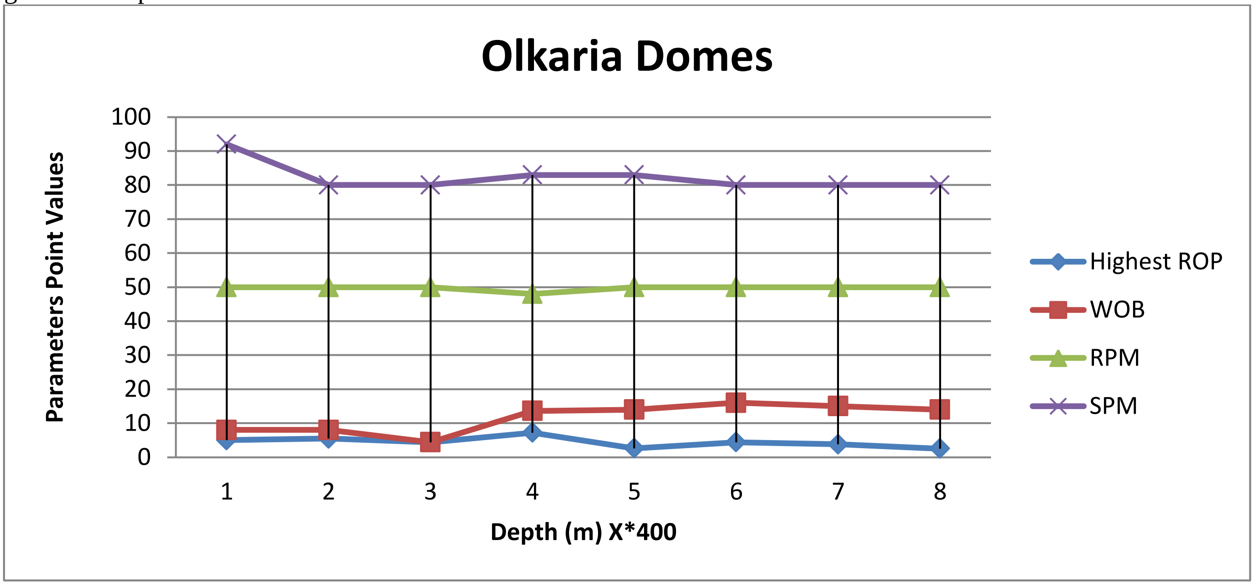

Figure 17. Olkaria Domes parameters graph

This field sector confirms to have the highest on bottom temperature within Olkaria. Drilling on this field needed a lot of care to avoid formation collapsing by applying under balancing drilling. This temperature raises the pressures and gives better hole cleaning. The main disadvantage is that, the bit doesn't survive long on bottom with high temperatures. The well kicks are commonly pronounced as deep drilling progresses (Profile from appendix 1).

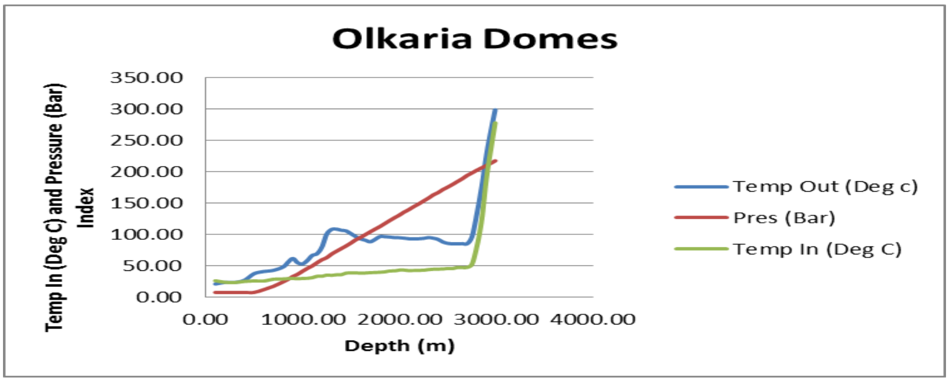

Figure 18. Olkaria Domes temperature graph

VII. Conclusion

From data analysis which covered the overall olkaria geological formation the optimal parameters for the 8.5" bit IADC 627,637 and 617 has been achieved. The WOB should range from minimum 9tons and maximum 13tons with a minimum PRM of 45 and maximum 55 that gives a high ROP of 2.5m/h to 5m/h maintaining average strokes/minute of 75, hence suits olkaria geological formation. The evaluated and analyzed optimal data if adhered to will lead to better bit utilization and hence overall reduction cost alongside safe drilling operation. The main cause of reduction in bit life was mainly high on bottom temperature which increased with increase in depth. Though the temperature denatured the tool life they give better hole cleaning by increasing cutting lifting pressures while on under balancing drilling application.

VIII. Recommendation

Improvement in technology and approach to scientific investigations has contributed to the high drilling success rate for exploration wells (Ouma 2009). Since the drilling parameters may not have been optimal for these bits, improvement on the dull of the cutting structure which will improve rate of penetration and prolong the bearing life. The diaphragm material strength and seal should be improved to suit on bottom temperature. Also, drill offset run test practice should remain key in all bits test for better optimization.

Acknowledgement

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Appendix 1.Pad#915 temperatures and pressure profile

OW-915												
Pre-Injection profile			Injection Profile		9 hour heating profile		15 days heating profile				37 days heating profile	
	28.10.2010		29.10.2010		30.10.2010		14.11.2010				6.12.2010	
Depth(m)	Temp (Deg c	Pres (Bar)	Temp (Deg C)	Pres (Bar)	Temp (Deg C)	Pres (Bar)	Depth(ft)	Depth(m)	Temp (Deg c)	Pres (Bara)	Temp(Deg c)	Pres (Bar)
100.00	21.10	7.70	26.30	0.80	22.90	3.90	300.00	91.46	34.10	0.80	36.10	10.60
200.00	23.70	7.70	23.90	0.80	27.40	3.90	600.00	182.93	43.00	0.80	39.90	9.41
300.00	23.70	7.70	23.50	0.80	38.50	3.90	900.00	274.39	78.90	0.80	45.80	7.96
400.00	27.00	7.70	25.30	0.80	58.60	3.90	1200.00	365.85	114.50	3.20	97.30	7.71
500.00	37.60	7.70	26.10	0.80	71.30	3.90	1500.00	457.32	120.70	11.00	141.60	15.82
600.00	41.10	12.10	25.90	7.80	81.40	8.40	1800.00	548.78	135.30	18.40	182.30	24.03
700.00	42.90	17.50	28.80	18.00	85.10	13.80	2100.00	640.24	169.90	27.20	203.00	31.76
800.00	48.30	24.60	29.20	27.00	96.00	20.10	2400.00	731.71	184.10	30.20	216.70	39.17
850.00	55.80	28.50	29.80	32.00	104.20	24.50	2700.00	823.17	192.00	35.30	227.70	46.63
900.00	61.90	33.20	30.00	37.00	111.30	29.20	2850.00	868.90	194.90	39.10	235.30	50.18
950.00	55.00	36.70	29.60	41.90	107.30	32.90	3000.00	914.63	197.50	42.10	243.70	53.74
1000.00	53.20	41.50	30.00	46.50	106.10	37.60	3150.00	960.37	199.70	47.00	249.60	57.30
1050.00	58.60	46.00	30.20	51.20	109.50	41.80	3300.00	1006.10	202.60	51.20	254.70	60.34
1100.00	66.70	50.00	31.20	56.20	116.30	45.80	3450.00	1051.83	203.20	55.10	259.10	63.81
1150.00	69.50	55.00	33.40	61.20	123.00	50.30	3600.00	1097.56	203.70	59.00	263.50	67.42
1200.00	80.00	59.80	33.40	66.90	130.70	55.30	3750.00	1143.29	204.80	62.90	266.60	70.78
1250.00	100.60	63.10	35.40	70.80	143.40	59.50	3900.00	1189.02	208.10	66.80	269.10	74.14
1300.00	108.10	68.90	35.00	75.20	149.80	63.50	4050.00	1234.76	211.00	70.90	271.70	77.51
1350.00	108.70	73.30	35.80	80.60	151.30	68.30	4200.00	1280.49	213.90	74.70	273.90	81.14
1400.00	106.90	77.60	36.00	85.30	151.90	72.70	4350.00	1326.22	216.00	78.40	275.40	84.25
1450.00	105.90	81.80	38.50	89.90	152.90	76.80	4500.00	1371.95	218.00	82.00	276.50	87.75
1500.00	101.40	86.50	38.90	94.30	152.90	81.40	4650.00	1417.68	221.10	86.10	278.30	91.13
1550.00	96.80	91.60	38.90	99.40	151.70	86.30	4800.00	1463.42	224.00	89.80	279.90	94.77
1600.00	93.10	95.50	38.50	104.60	151.30	90.90	4950.00	1509.15	225.50	93.60	280.70	97.89
1650.00	90.90	100.00	38.70	108.80	150.70	95.20	5100.00	1554.88	227.30	97.30	281.20	101.39
1700.00	88.50	104.40	39.30	114.10	149.60	99.40	5250.00	1600.61	228.60	101.20	282.10	104.51
1750.00	92.30	108.70	39.50	118.70	153.30	104.60	5400.00	1646.34	230.40	105.20	283.00	108.02
1800.00	96.80	112.80	39.90	123.80	156.90	109.50	5550.00	1692.07	234.20	108.60	283.80	111.54
1850.00	96.60	117.60	40.50	128.20	155.90	113.70	5700.00	1737.81	239.00	112.10	282.90	114.77
1900.00	96.00	122.30	41.90	132.60	151.30	118.50	5850.00	1783.54	241.00	116.50	284.30	118.03
1950.00	95.20	126.80	42.10	138.20	151.10	122.50	6000.00	1829.27	241.70	119.80	286.00	129.30
2000.00	95.00	131.00	43.30	142.80	150.90	126.80	6150.00	1875.00	241.40	124.00	287.40	124.79
2050.00	94.20	135.90	43.30	147.60	150.30	131.50	6300.00	1920.73	241.50	127.20	289.10	128.22
2100.00	93.30	139.90	42.50	151.90	149.40	135.40	6450.00	1966.46	241.90	131.30	291.50	131.23
2150.00	93.10	144.60	42.70	157.00	148.40	140.00	6600.00	2012.20	242.30	134.60	293.50	134.64
2200.00	93.30	148.80	42.90	161.60	146.60	144.10	6750.00	2057.93	243.20	138.40	296.20	138.19
2250.00	93.90	153.50	43.10	166.20	146.00	148.50	6900.00	2103.66	243.90	142.10	298.20	141.08
2300.00	95.20	158.10	44.10	171.30	145.80	152.50	7050.00	2149.39	244.80	145.60	296.20	144.44
2350.00	94.20	163.20	44.70	176.30	144.20	157.10	7200.00	2195.12	245.00	149.50	295.10	147.68
2400.00	92.30	166.90	44.90	180.70	138.30	161.40	7350.00	2240.85	247.20	153.60	298.40	151.12
2450.00	88.10	171.80	45.10	185.50	131.70	166.20	7500.00	2286.59	247.90	156.70	275.50	153.59
2500.00	85.90	175.70	45.90	190.20	127.60	171.80	7650.00	2332.32	247.90	160.60	264.80	156.39
2550.00	85.10	179.90	45.70	195.10	126.00	176.40	7800.00	2378.05	239.30	163.80	244.30	161.58
2600.00	85.10	184.50	47.50	199.50	125.00	181.30	7950.00	2423.78	224.20	167.30	235.30	164.64
2650.00	85.50	189.00	47.30	204.60	125.60	185.30	8100.00	2469.51	220.30	170.70	235.00	167.68
2700.00	85.30	194.20	47.70	209.20	124.80	190.60	8250.00	2515.24	218.70	174.00	239.50	171.57
2750.00	96.20	198.30	52.40	213.90	132.10	194.80	8400.00	2560.98	218.90	177.80	242.50	175.32
2800.00	132.30	202.50	80.40	218.30	156.70	199.00	8550.00	2606.71	219.40	181.50	244.80	179.19
2850.00	175.50	206.40	122.00	222.30	190.40	204.40	8700.00	2652.44	220.50	185.20	247.20	182.94
2900.00	227.30	210.20	189.60	227.20	226.50	208.20	8850.00	2698.17	225.30	188.90	254.90	184.21
2950.00	268.90	214.10	240.50	231.50	239.90	212.10	9000.00	2743.90	235.90	193.60	264.90	188.33
2990.00	299.00	217.70	278.20	234.60	282.00	214.50	9150.00	2789.63	252.10	198.30	278.10	192.29

Appendix 2.Pad#44 temperatures and pressure profile

ow-44

Pre-Injection 18.02.2011			Injection 19.02.2011		9 Hrs Heat up 20.02.2011		23 Days heating	
Depth (m)	Temp Out (Deg C)	Press (Bara)	Temp In (Deg C)	Press (Bara)	Temp (Deg	Press (Bara)	Temp (Deg C)	Press (Bara)
100	21.4	0.8	21.4	0.8	40	6.9	63.7	43.05
200	24.9	0.8	21.4	0.8	52.1	8.6	82.9	42.46
300	26.5	0.8	21.4	0.8	59.4	10.1	95.1	33.51
400	30.2	4.3	21.4	0.8	72.3	12.2	157.1	33.18
500	34.1	12.2	21.4	7.6	83.7	14.7	250.9	34.05
600	37.4	19	21.4	17.2	95	16.8	267.9	34.5
700	41	25.1	21.4	26.3	108.5	18.1	272.6	35.48
800	47.2	28.8	21.4	35.9	117.3	23.2	274.6	36.63
850	63.7	30.9	21.4	40.7	142.6	26.9	275.6	37.2
900	63.9	33.4	21.4	45.6	134.4	31.6	276	38.22
950	64.1	36.4	21.4	50.6	132.2	36.1	277.2	38.79
1000	63.3	40	21.4	55.3	131.5	40.4	277.4	39.8
1050	63.3	44.6	21.4	60.7	129.7	45.2	278.9	40.37
1100	61.3	49.2	21.4	65.3	124.6	49.9	279.2	40.97
1150	58.6	54	21.4	70.2	121.7	54.4	280.5	41.09
1200	57.2	58.6	24.8	75.3	118.5	59.3	280.9	41.52
1250	55.9	63.5	25.2	80.4	114.2	63.8	281.3	41.81
1300	54.1	68.4	25.4	85.3	110.3	68.4	281.9	42.53
1350	53.3	73.3	25.6	89.8	108	73.2	282.5	42.81
1400	52.9	78.2	26	94.8	105	78.1	283.5	43.53
1450	52.3	82.9	26.6	99.6	103.6	83.1	283.9	44.4
1500	51.9	87.6	27	104.8	103.1	87.4	283.7	45
1550	52.3	92.5	27.5	109.4	104.2	92.3	284.7	45.7
1600	54.5	97	28.7	114.5	107.2	96.6	285.3	46.57
1650	55.7	102.3	29.8	119.1	109.3	101.5	286.5	47.29
1700	58	107	30.6	124.4	110.9	106.1	287.1	48.01
1750	60.2	111.7	31.8	129.4	112.8	110.8	288.1	48.87
1800	64.1	116.5	33.1	134.6	114.8	115.7	289.4	49.73
1850	65.1	121.4	33.5	138.8	115.8	120.1	289.6	50.6
1900	65.8	126.5	34.8	144.5	115	124.5	290	51.32
1950	67.2	130.9	35.6	148.5	114	129.4	290.8	52.33
2000	68.6	135.4	35.6	153.6	115.6	134.2	292	53.2
2050	69.8	140.4	36.6	158.1	118	138.4	292	54.35
2100	71.9	144.7	37.7	162.9	122.6	142.5	293	55.07
2150	74.5	149.6	38.3	167.8	126.9	147.6	293.8	56.08
2200	77.6	154.3	39.3	172.6	132	151.7	295	56.94
2250	80.3	159.1	40.2	177.5	135.4	155.9	295.6	57.95
2300	82.3	164	41.6	182.1	131.5	160.3	296.4	58.96
2350	82.1	168.8	42.3	186.7	123.6	165.3	297.6	59.96
2400	82.9	173.1	43.5	191.8	121.9	170.3	298.2	61.41
2450	84.3	178.5	44.4	196.7	121.5	174.6	299.3	62.55
2500	84.4	182.9	45.8	201.1	121.9	178.8	299.3	63.86
2550	85.6	187.3	47.1	206	123.6	183.8	301.1	66.25
2600	87.6	192.2	49.1	211.1	125.8	188.2	302.5	67.71
2650	88.8	196.8	50.6	215.6	127.9	192.4	303.1	68.88
2700	92.3	201	53.9	220.3	132.4	196.5	304.1	70.2
2750	95.2	206	56.4	224.8	136	200.9	305.7	71.67
2800	97.6	210.6	58.7	230.1	139.5	204.9	306.1	72.84
2850	100.1	214.1	61.5	234.1	142	209.2	308.1	74.6
2900	105	218.4	65.8	239.5	146.9	213.1	308.8	76.36
2950	108.7	222.6	69.4	244	151.8	221.5	309.8	77.97
2980	110.5	225.5	71.2	246.4	154	224.1	311	79.87

Appendix 3.Pad#732 temperatures and pressure profile

			ow-732			
	Pre-Injection 6.6.2011		Injection 7.6.2011		9 Hrs Heat up 7.6.2011	
Depth (m)	Temp (Deg C)	Press (Bara)	Temp (Deg C)	Press (Bara)	Temp (Deg C)	Press (Bara)
100	32.3	21.9	30.8	0.8	65.9	33.99
200	36.8	23	31.3	0.8	53.1	32.19
300	14.7	24.3	31.9	0.8	58	31.08
400	44.5	26.4	32.9	0.8	66.7	29.97
500	47.6	28	33.5	0.8	80.8	28.72
600	49.6	29.4	34.1	9.8	96.1	28.16
700	61	30.2	34.3	17.5	118.6	27.88
750	85.7	31.9	42.1	22.2	129.4	26.77
800	93.5	33.2	44.3	26.5	128	26.08
850	95.1	35.1	46.1	30.4	122	25.66
900	95.3	37.2	50.6	34	113.7	25.66
950	95.1	38.9	51.7	38	115.3	25.33
1000	96.3	40.5	52.1	41.8	118.2	24.83
1050	96.5	41.8	53.1	46.1	116.5	26.63
1100	93.3	43.2	53.5	49	102.9	30.25
1150	80.6	47.1	53.9	53.7	94.7	34.83
1200	76.1	51.4	54.1	57.9	91.4	39.27
1250	74.5	55.5	54.3	62.3	89.6	43.44
1300	74.7	59.8	54.9	66.5	89.2	47.88
1350	74.9	64	55.3	70.8	88.6	52.19
1400	75.7	68.6	55.9	75.1	89	56.36
1450	76.1	72.9	56.6	79.6	89.4	60.52
1500	76.8	77.2	57	83.9	90.2	64.96
1550	77.2	81.9	57.4	88.6	90.4	69.27
1600	77.8	85.9	58.4	92.7	91.4	73.86
1650	78	90.4	59.2	97.3	92.2	78.3
1700	78.2	94.7	60.4	101.8	93.1	82.47
1750	80.4	99.3	61	106.1	94.1	86.63
1800	82.3	103.7	62.1	110.7	96.3	90.94
1850	82.7	107.9	63.5	115.1	97.6	95.52
1900	84.7	112.3	64.5	119.1	99.8	99.55
1950	86.3	116.8	66.1	123.9	101.4	103.99
2000	88.6	121.3	67.4	128.4	103.7	108.16
2050	89.6	125.7	68.6	132.9	105.5	112.33
2100	91.2	130	70.4	136.9	107.6	116.63
2150	91.9	134.4	71	141.8	109.4	120.56
2200	94.5	138.7	73.3	145.9	111.4	125.11
2250	95.9	143	75.1	150.1	112.9	129.13
2300	98	147.3	76.3	154.7	115.3	133.02
2350	99.6	151.6	77.8	159.1	117.3	136.63
2400	101.2	155.8	78.6	163.2	118.4	141.08
2450	102.9	160.1	80.4	167.6	120.4	145.52
2500	104.7	164	82.3	172.1	122	149.83
2550	105.5	168.2	83.9	176.4	123.7	153.86
2600	106.9	172.2	84.9	180.4	124.9	158.16
2650	109	176.2	86.7	184.3	127.3	161.92
2700	110	180.4	88.8	188.3	129	165.38
2750	112.9	184.3	90.4	192.9	131.2	169.41
2800	114.5	188.4	91.8	196.9	132.4	173.44
2850	117.4	192.2	94.1	201.2	134.7	177.47
2900	118.2	196.5	95.7	205	136.9	180.66
2950	120.2	199.8	97.8	208.9	138.6	185.11
2980	120.8	202.2	98.4	211.6	140.2	186.63