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Achieving Drilling & Development Targets in Remote Areas of East Africa through Fit-For-Purpose Planning

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Abstract

East Africa is recognised for its undeveloped oil industry infrastructure. Exploration and development of fields in East Africa requires detailed planning and execution to minimize unforeseen events. An Operator in East Africa conducted comprehensive studies to prepare for their next campaign. Drilling in remote locations always presents multiple challenges; including - but not limited to - supply chain and geographical challenges, security and community issues and not withstanding technical problems such as wellsite selection, lost circulation, wellbore stability and other drilling-associated problems.

An in-depth review of previous wells was conducted to select the optimum drilling fluids package to have minimum impact on the wellbore. Detailed seismic and surface-topographical survey analyses were performed in order to select the prime drilling locations which would mitigate the consequences of major structural fault regimes to minimize wellbore instability and downhole losses. Nine wells were drilled in this campaign with excellent performance results. Minimum losses were encountered and wells were drilled faster and cheaper than planned.

Furthermore, despite significant security and community issues, no shortage of equipment or products was experienced. Fit-for-purpose technology proved successful in attaining these results. Alongside technology application, detailed logistics planning was a key factor in eliminating down-time due to equipment or chemicals delays. This paper details the activities in the planning phase which led to the marked improvements in this campaign

Background

Kenya is located in East Africa. It borders the Indian Ocean between Somalia and Tanzania. Other bordering countries are Uganda in the West, and Ethiopia and South Sudan in the North. Tullow acquired their first operated interests in the onshore rift basins of Kenya in 2010. Figure 1 shows the country location and operatorship regions. Tullow Oil spudded its first well in Q1 2011 in the Lokichar basin. Prior to Tullow Oil's entry into Kenya, only four wells had been drilled. Synonymous with most exploration projects worldwide, limited knowledge of, and high uncertainties in the subsurface geology presented an immense challenge to drilling operations in the country's remote rift basins. Associated mobilisation and operational costs were extremely high owing to unpredictable downhole conditions and infrastructure access associated costs. Despite increased knowledge of the subsurface structures as more wells were drilled, the geology remains highly variable even with wells drilled in close proximity and/or in the same field due to the compartmentalisation of the structure.

With no available alternative mode of transport for heavy loads, a 1200km road supply line routing from Mombasa (main port) to the Lokichar area (rig activity area) via the country's capital, Nairobi, exists. This main transport route to the oil field region (Mombasa-Nairobi-Nakuru-Eldoret-Kitale-Lokichar) has two major challenges. Firstly, the Mombasa Port to Eldoret section is a heavily congested route particularly in the town of Mombasa and the capital Nairobi. Truck and vehicular movement is challenging along the ~250km mountainous road section (known for its steep gradients and tight bends) between Kitale town and the rig activity area. The movement of heavy loads is challenging and requires careful planning. The road infrastructure of the ~900km bituminous road section from Mombasa to Eldoret is in a fairly reasonable condition. Whilst it is a heavily congested section, the ride quality is not as challenging as the subsequent 300km A1 from Eldoret to Lokichar basin which can add up to 24hrs travel time resulting in an overall 3 to 4 day journey. The Kainuk bridge, approximately 120km beyond Kitale town, is a major constraint to heavily loaded trucks as it has a weight limit as an axle load restriction. A temporary river crossing drift was created and installed by Tullow Oil as an alternative to the existing bridge and its constraints but is not usable during heavy rains. Poor road quality and an absence of river crossings had compromised the successful delivery of the exploration program to an appreciable extent.

With the limited amount of drilling and the variability of drilling hazards the exploratory wells proved difficult to plan.

To date, with over 40 wells drilled, the variation exhibited in existing wells sustains the difficulty of regionally mapping expected geological character. Every well is effectively a new well in terms of expected lithological features even in the appraisal phase. Correct pressure and fracture gradient predictions are essential to reduce the cost of the wells. It is critical to be able to reduce risk far enough to simplify well designs by eliminating casing strings and avoiding expensive advanced-cement slurries. Alternatively, a conservative well design would be used in order to reduce risk exposure thus increasing cost. The earliest wells suffered from wellbore instability which resulted in cavings, pack offs and severe losses. All of these mechanical weaknesses were controlled through a better understanding of the geological response and control of the high smectite content of the shale sections with all of these problems contributing to the initial cost of the wells.

These problems also resulted in poor quality wellbores, which were, in turn, challenging to cement satisfactorily and resulted in having to focus on pushing the cement design to meet well integrity requirements. As the operation matured, these well construction costs were considerably reduced; owing to optimised rig move planning, a number of technology initiatives, performance improvement, focused training of local crew and risk reduction in terms of geological uncertainty.

Fit-For Purpose Planning - Drilling Fluids Selection

Over the course of previous campaigns, the drilling fluids selection went through an evolutionary process resulting in a fluid type being used to optimise performance and the mud weight being corrected as per response of the wellbore and formation

Several Exploration and Appraisal wells in Tullow Kenya's South Lokichar Fields Development Project have experienced incidents of lost circulation that have been costly in terms of lost mud and materials and Non-Productive Time (NPT) exacerbated by the slow rate of mixing replacement-mud at the rig site. Besides the obvious benefits of maintaining circulation, preventing or curing mud losses is important to other drilling objectives such as obtaining good quality formation evaluation, minimising formation damage and achieving effective primary cement isolation, which is particularly important for the planned cased and perforated completions.

A study was launched to determine if mud related costs and NPT attributed to lost circulation could be reduced by the implementation of preventative measures or the application of effective LCM techniques when preventative measures fail. Previous wells drilled were analysed to determine the type and locations of losses

Surface Hole

Surface sections utilise water-based mud as standard, to ensure aquifer protection and mitigate the impact of potential shallow lost circulation zones in pre-fractured volcanoclastic. The elimination of one of the surface casings resulted in the top hole section being drilled with water based mud to cap rock depth. This section is challenging for its interbedded nature and length. The early use of a simple polymer fluid system controlled the costs and was environmentally sound. However, the poor inhibition attributes of this system resulted in instability of some shallow shales reacting to the fluid, which increased the drill-days for the section. The introduction of Potassium Silicate water based muds eliminated many of the problems previously faced but came at a significantly higher cost and interference of log data. At a slight reduction in performance and inhibition, without a noteworthy compromise of wellbore stability, Potassium Sulphate was introduced to replace Potassium Silicate as a cost saving alternative. Figure-2 shows the evolution of the drilling fluids used for the surface hole.

The assumption has been made that the majority of losses seen in this interval (to be 12¼" in development wells) is to a Mid-Miocene volcanoclastic sequence containing open and connected fractures. There appears to be considerable variation in lithology through this interval ranging from basalt to volcanic tuffs. The volcanics also vary in depth from field to field as shown in table-1.

Losses to volcanics do not occur in every well but when they do occur loss volumes can be significant. All Field-1 wells, with the exception of Well-8 had losses in the volcanics. No losses to volcanics have been reported in Field-3 and Field-4 with only minor losses being seen in Field-2, possibly to unconsolidated sediments above the volcanics. There were significant losses on Field-5 but they were controlled with conventional granular LCM (marble) and again the losses may have been to sediments above the volcanics. Table-2 summarises the losses encountered in the top sections of the different fields.

Reservoir Interval

Inhibited water based mud was initially used in the production hole sections for all wells. The first phase used a High Performance WBM system of another Fluids provider, which could not adequately prevent chemical wellbore instability and resulted in a side-track at a significant unplanned cost. Following this Potassium Silicate WBM was introduced to allow for better inhibition and subsequent wellbore stability. However, it was found that the nature of the mud gave a filter-cake that essentially gauge-plated the wellbore and interfered with data acquisition during wire-line logging. Furthermore, K-Silicate WBM was found to be unstable at the elevated temperatures experienced at depth in the northern-most wells drilled.

The objectives for exploration and appraisal wells continued to be the priority for data acquisition, hence this interference and instability proved unacceptable. Synthetic oil based mud (SOBM) was considered and selected for its favourable impact on wellbore quality, it demonstrated superior inhibition and gave thermal stability. It also proved to be cost-competitive compared to the high performance water based muds, despite the required maintenance and associated waste management costs as it could be reused to drill multiple wells.

This campaign required more demanding trajectories and tighter performance goals which synthetic based mud enabled Tullow to achieve by improving ROP and wellbore quality significantly. The consequent improved data acquisition guaranteed well objectives were achieved and allowed casing strings to be run on depth, without incident and significantly reduced well construction costs. Figure-3 shows the evolution of drilling fluids used in the reservoir sections and their pros & cons.

It can be seen from table-3 that losses have occurred, to a greater or lesser extent, in the reservoir intervals in all fields and almost all wells. The problems in this interval are similar to the surface section, associated with drilling fractured and faulted lithologies but with mud overbalance pressures required to maintain wellbore stability; with inevitable losses unless adequate bridging or blocking can be achieved.

South Lokichar Loss Mechanism Identification

To reduce the potential for lengthy NPT associated with lost circulation incidents on future wells the mechanism(s) that could lead to the losses was considered in detail and the conclusions related to mud losses from their work are summarised here:

1. In surface sections losses occur most frequently in the Miocene Volcanic interval, where fractured formation is encountered, combined with a low water table[2] level. A result of the well being drilled overbalanced and conductive, open fractures being encountered.

2. The low water table means that even when using unweighted drilling fluid losses will occur unless fracture bridging can be achieved and maintained.

3. In reservoir sections losses occur most frequently in the Auwerwer and Lokone formations, where open fractures and possibly faults are encountered, when drilling with overbalance mud weights.

4. It appears that losses have only rarely been induced by exceeding the fracture gradient. One example was in the Auwerwer Formation in Well-7, Field-1 (12¼" section) during a pack-off event. However, increases in mud weight may be required to manage well bore stability in the deviated development wells. If this is the case ECDs may exceed SFG in some intervals and this must be considered in the planning of these wells. It may be possible to apply wellbore strengthening techniques in such cases to avoid major mud losses when ECD or casing surge pressure exceeds minimum horizontal stress.

The study concluded that the primary loss mechanism in these wells is to open fractures, both in the Miocene volcanics and in the reservoir interval. The conclusions propose the use of mud systems, which, by nature of their specific rheologies, will reduce the potential for mud losses to open (natural) fractures. When losses occur to open fractures due to drilling with significant overbalance, specific remedial LCM treatments are required.

The following recommendations as shown in Table-4 were suggested as preventative and remedial techniques to prevent or cure downhole mud losses.

Fit-For Purpose Planning - Drilling Fluids recommendations

Mixed Metal Oxides (MMO – WBM)

MMO muds potentially offer an elegant solution to losses in the fractured volcanic interval. While drilling, a thin stationary layer of MMO fluid forms adjacent to the wellbore to reduce seepage losses, stabilize unconsolidated formations and significantly reduce washouts. Under static conditions, MMO fluid gels rapidly to produce high, but flat, gel strengths, which are not only desirable for rapid support of cuttings, but can reduce and even eliminate whole mud losses into highly porous and fractured formations. There are, however, some concerns regarding the level of inhibition that can be achieved with this system. The MMO system is also sensitive to solids so high dilution rates may be required when drilling with very coarse shaker screens or bypassed shakers.

Low clay SOBM

To reduce surge and swab pressures and to reduce pump start-up pressures it was recommended that a move be made towards a low-clay, constant-rheology, system. Oil based muds solely viscosified with organo-clays produce gel strengths that even when low and flat when measured on a V-G meter can still develop a fluid environment which contributes to annular pressure increases caused by pipe surges or pump start up. Oil based mud systems that use polymeric viscosifiers develop gels which may look very similar to clay based systems on the V-G meter but are in fact very fragile. The fragile gels reduce hydraulic transients.

Drilling Fluids Formulations Design & Lab Tests

MMO mud was selected to drill the top interval to mitigate the losses encountered in the Volcanics and fractured zones. Lab tests were carried out to determine the optimum products concentrations to produce characteristics that met field requirements.

The Synthetic Base mud was formulated using Saraline 185v base oil, a premium-quality product. It is classified as a synthetic base fluid as it is synthesized from natural gas in the GTL process. Saraline 185v readily biodegrades in an aerobic environment and has a low viscosity, a low pour point and relatively high flash point making it ideal for onshore use.

In lab tests a polymeric viscosifier supplemented by an organo-clay was used to deliver the required rheological profile under downhole conditions. The Polymeric viscosifier contributes to low shear viscosity (even at high temperatures), reinforcing the suspension properties of the mud and also gives a shear thinning rheological profile to the mud. A liquid fluid loss reducer was also used to minimize solids content and reduce downhole-circulating pressures.

Advanced Hydraulics software was used to simulate drilling conditions. The Hydraulics software is based on a solid foundation of sound engineering principles and fundamental physical models, and combines practical drilling fluid considerations with fluid-flow modeling. Hydraulics analyses were made to simulate downhole pressures using the anticipated fluids properties.

The selected fluids were stress-tested using simulated drill solids to check on actual performance under the field conditions. These formulations are shown in table-5.

Products / Equipment Logistics Planning & Management

A detailed mobilisation logistics schedule and plan was prepared on award of contract to ensure all products and equipment were available on location prior to spud of the first well. Drilling fluids chemicals, equipment and spare parts were procured and imported from around the globe to support this campaign.

Imports had variable lead times and shipping schedules and Kenyan government regulations dictated that all imports had to be inspected by third-party agencies in country of origin before loading for transport to Kenya. All sea freight was shipped to Mombasa, port of entry, to be customs cleared prior to trucking to the field location around 800-km away. Kenya roads and infrastructure are challenging, as mentioned in the preamble, so detailed planning and execution was required to avoid issues and ensure that materials arrived safely to the field of operations.

A logistics tracking template was developed to monitor the geographic position of every item imported. The log was updated daily and monitored progress real-time every step of the way, from placement of order to delivery at the field warehouse and eventually the rig. This tool was shared between all involved parties in Kenya, the UK and UAE, and updated as needed.

This process planning and management ensured that chemicals, equipment and personnel were on location prior spudding the first well.

First well results

The first well of the 2nd campaign was spudded in December 2016. The MMO mud system was used to drill the 17 ½” top hole. The system performed adequately, no losses were encountered except when running the casing, but some difficulties controlling excessive rheology were experienced due incorporation of reactive clays and lack of system inhibition.

Although the Operator was satisfied with MMO’s performance the contractor was requested to investigate ways of improving the inhibitive properties of the system. A study was launched with the MMO manufacturer to identify additional inhibitor(s) that can be added to the system without jeopardizing its characteristics and performance. This study is in progress at time of writing. The Operator reverted to the Potassium Sulphate WBM system to drill surface sections on subsequent wells, pending study results.

Following reservoir intervals (12 ¼” and 8 ½”) were drilled with Low-Clay SOBM as per the formulation shown in table-5. The mud was conditioned as required and hydraulics simulations were performed daily to predict and monitor downhole rheology and pressures. Mud parameters were maintained as per the program and adjusted based on hole conditions. Figure-4 illustrates the snapshots taken daily to monitor drilling progress, downhole pressures, hole cleaning, etc.

Proprietary hydraulics software was also used during pre-planning casing/liner running, to calculate the running speed limits to avoid exceeding the fracture gradient and possible fluid losses. This plan was calculated for every string run in the hole and followed by the crew. Figure-5 shows an example of such calculations and how far or close we are to the fracture gradient. Slight losses were encountered when drilling the 17½” and running the 13 3/8” casing. No losses were encountered when drilling the 12¼” hole section with the SBM, but seepage losses were encountered when drilling the 8½” interval, mainly when running casing and P&A the well.

Drilling Performance/Efficiency on the subsequent eight wells drilled

All the material changes discussed above would be meaningless without focusing on the resultant drilling performance and operational efficiency. Clear areas were identified as part of Tullow’s Technical Limit approach for performance improvement and the application effectiveness was clearly visible in the recently concluded campaign.

Eight additional wells were drilled in this campaign covering different fields and formations with excellent performance; lessons learned were highlighted after each well drilled and implemented on future wells.

Potassium Sulfate mud was used on all these wells with acceptable results; some bit balling occurred on a couple of wells but was managed with the addition of an encapsulator to improve the system's inhibition. Some losses were encountered when drilling these top holes, mainly seepage, without affecting the operations.

The Synthetic base mud was stored and re-used on the appraisal wells, but for the exploratory ones, fresh SOBM was mixed for data acquisition and formation evaluation purposes. Significant losses were not encountered while drilling the reservoir sections; most of the losses were while running casing and/or cementing. The last well suffered excessive rheology due to solids and ultrafine build-up associated with the re-use of the stock SBM over several wells. Dilution, along with the use of the centrifuge was used to bring back the mud rheology within the recommended range. Table-6 summarises the main wells information, losses encountered, total depths, etc.

Materials management was carefully monitored, especially when local community security incidents occurred close to the fields' location and roads were blocked for some time. To mitigate this materials and equipment were mobilized in convoy, with armed security guards, to avoid deterioration of issues with the local communities.

Despite all the logistical and social issues, no shortage of any chemicals, base oil, personnel or equipment was experienced during this campaign; thanks to the strict monitoring and follow-up of all orders. A total of 11 orders were placed during this campaign where each order was discussed, planned and agreed between all parties then tracked on a daily basis as explained earlier.

Conclusions

- The fit-for-purpose fluids designs were very successful in mitigating problems encountered on the previous campaign, where no hole instability problems, stuck pipe or severe losses were experienced on these nine wells.
- The use of Potassium Sulfate system with an encapsulator was successful in stabilizing the top hole sections and eliminate downtime related to hole instability
- Constant rheology SBM performed well in reducing losses while drilling, though some more work need to be done to eliminate losses while cementing.
- The use of the advanced hydraulics software was key in planning and monitoring drilling performance and was a major contributor to the success of this project.

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Acronyms

Acronym	Meaning	Comment
BHCT	Bottom Hole Circulating Temperature	The temperature of the drilling fluid at TD when the mud is being circulated
BHST	Bottom Hole Static Temperature	The temperature of the drilling fluid at TD when the mud is static. With time this will approximate to formation temperature
ECD	Equivalent Circulating Density	Surface MW + circulating pressure losses and variations due to downhole temperature and pressure
ESD	Equivalent Static Density	Surface MW + variations due to downhole temperature and pressure
FROBM	Constant/Flat Rheology Oil Based Mud	Oil based mud that exhibits only small variations (typically no more than 10%) in YP, Yz and gel strengths over the temperature range prevalent in the well.
FLT	Flowline Temperature	Temperature measure at the flow line representing the temperature of the fluid returning from wellbore
HGS	High Gravity Solids	Weighting agent, usually barite
K Silicate	Potassium Silicate	
LCM	Lost Circulation Material	
LGS	Low Gravity Solids	Drilled solids and mud chemicals included in the total solids in the drilling fluid.
MMO	Mixed Metal Oxide	Bentonite based drilling fluid with unique fragile gel structure
MW	Mud Weight	
NPT	None productive Time	Time lost due to unplanned incidents on the well
PP	Pore Pressure	
PSD	Particle Size Distribution	This defines the range of sizes of particles (solids) present in the drilling fluid.
PV	Plastic Viscosity	
SOBM	Synthetic-Oil Based Mud	
SC	Safe-Carb	Sized marble LCM
SCE	Solids Control Equipment	Includes shale shakers (primary SCE), desanders, desilters, mud cleaners and centrifuges (secondary SCE).
SFG	Sand Fracture Gradient	
TD	Total Depth	Can refer to the final drilled depth of a specific interval or the whole well
TOR	Top of Reservoir	
TOV	Top of Volcanics	
WBM	Water Based Mud	

WPS	Water Phase Salinity	Concentration of salts in the brine phase of OBM or SBM. Measured in mg/L or gm/L
YP	Yield Point	
Yz	Yield Stress	A measure of the drilling fluid behaviour at low shear rates. Derived from V-G meter as ((2*Ø3)- Ø6)

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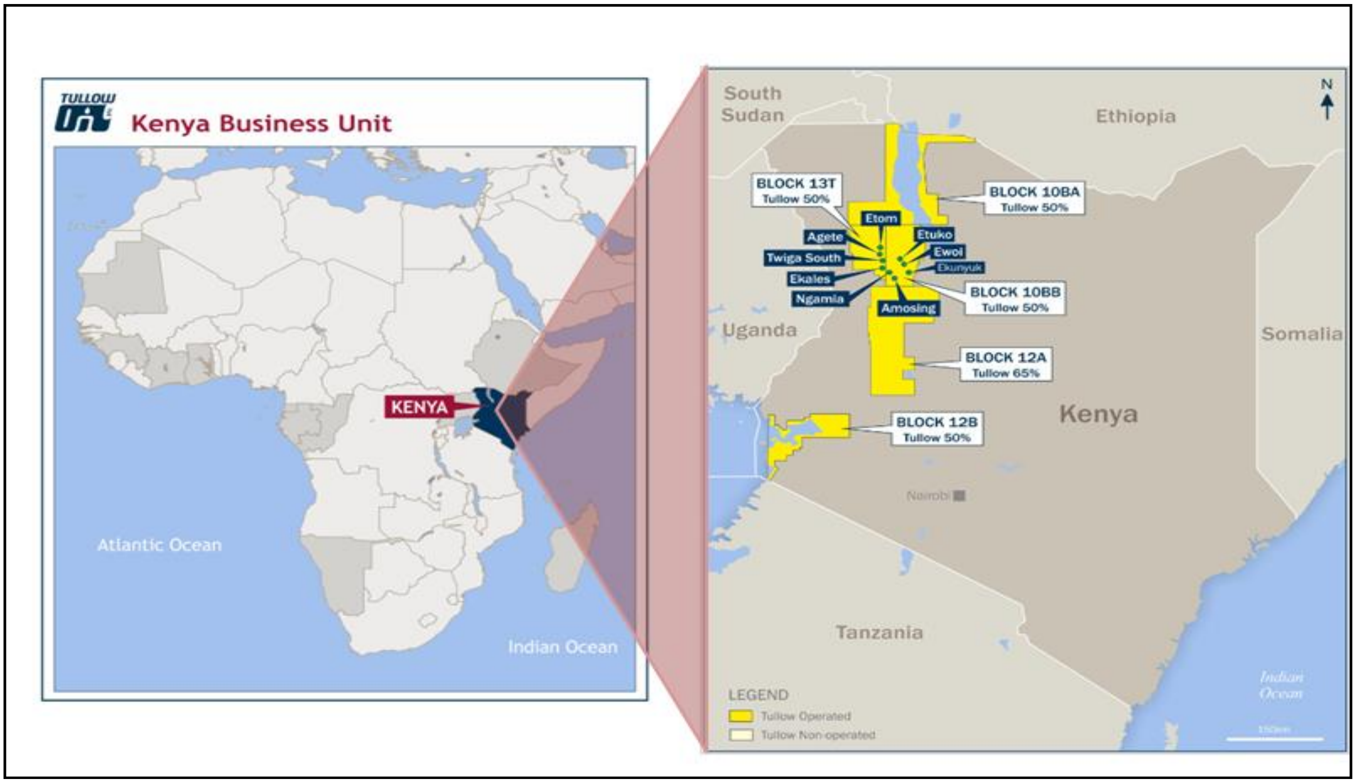


Figure-1 Tullow Oil Kenya Business Unit - Location and Operatorship

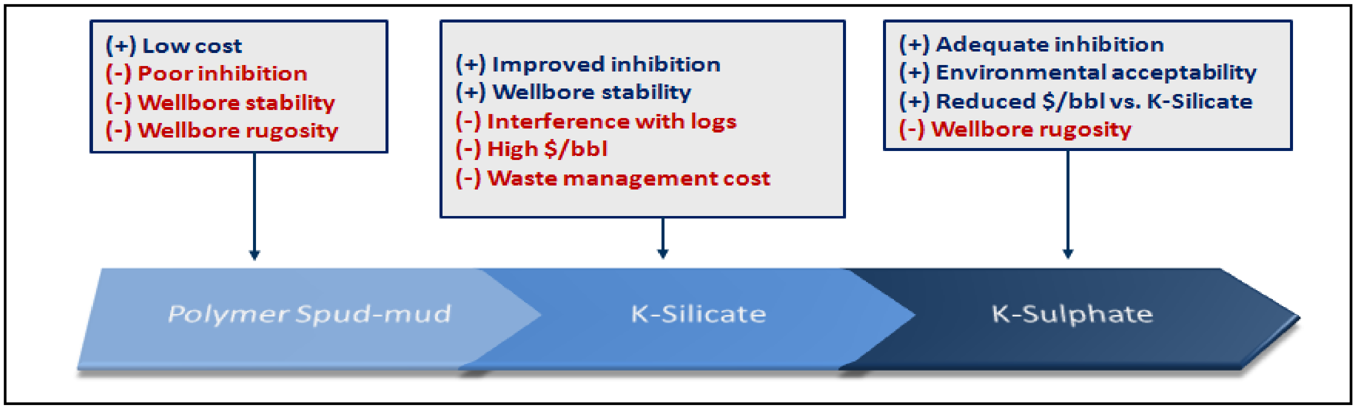


Figure-2: Evolution of Drilling Fluids for Surface Hole Drilling

Table-1: Volcanics depths for the different fields

Prognosed Miocene Volcanics Depth Range (m-TVD)		
Field-1	140	270
Field-2	40	140
Field-3	400	500
Field-4	550	630
Field-5	320	360

Table-2: Losses encountered in top hole sections of the different fields

Losses to Miocene Volcanics									
	Field-1								
Well	1	2	3	4	5	6	7	8	9
Mud Type	Gel-Poly WBM Kla-Shield	WBM K. Silicate	SOBM	SOBM	SOBM	WBM K. Silicate	WBM K. Silicate	WBM K. sulphate	WBM K. sulphate
Losses @ m	203	350	78		202	103 to TD	456 (pack-off)		100-245, 464, 715
Hole Size "	17½	17½	12¼	12¼	17½	12¼	12¼	17½	12¼
Losses bbls	471	429	639	110	2581	1369	303	0	3381
Cured	yes	partial	partial	yes	No	No			no
Comment	0-30bph. Cured with Kwikseal.	Below volcanics	Total loss @ 78m Controlled with conventional LCM	seepage	5 pills (including one FAB) Drilled to TD with losses.	Base volcanics 276m 15bph. LCM added directly to active. No pill pumped.	No losses while drilling volcanics @ 276m. No losses on cement job		Drilled blind through 2 faults. Conventional LCM reduced losses to 20-60bph. 100ppb blend of LCM worked best. Minimal cement returns.

	Field-2			Field-3			Field-4		Field-5	
Well	**1**	**2**	**3**	**1**	**2**	**2-A**	**1**	**2**	**1**	**2**
Mud Type	WBM polymer	WBM K. Silicate	WBM K. Silicate	Gel-Poly WBM Kla-Shield	WBM K. Silicate	SOBM	WBM K. Silicate	WBM K. Silicate	WBM K. Silicate	WBM K. Silicate
Losses @ m						250 and 400			295	
Hole Size "	26	12¼	12¼	26 / 17½	17½	12¼	17½	17½	12¼ (pilot) / 17½	17½
Losses bbls	0	0	0	0	0	321	0	0	1257 / 602	0
Cured						yes			Partial	
Comment						Seepage possibly above volcanics 10 bph reduced to 4bph with 8ppb SC.			Possibly above volcanics	

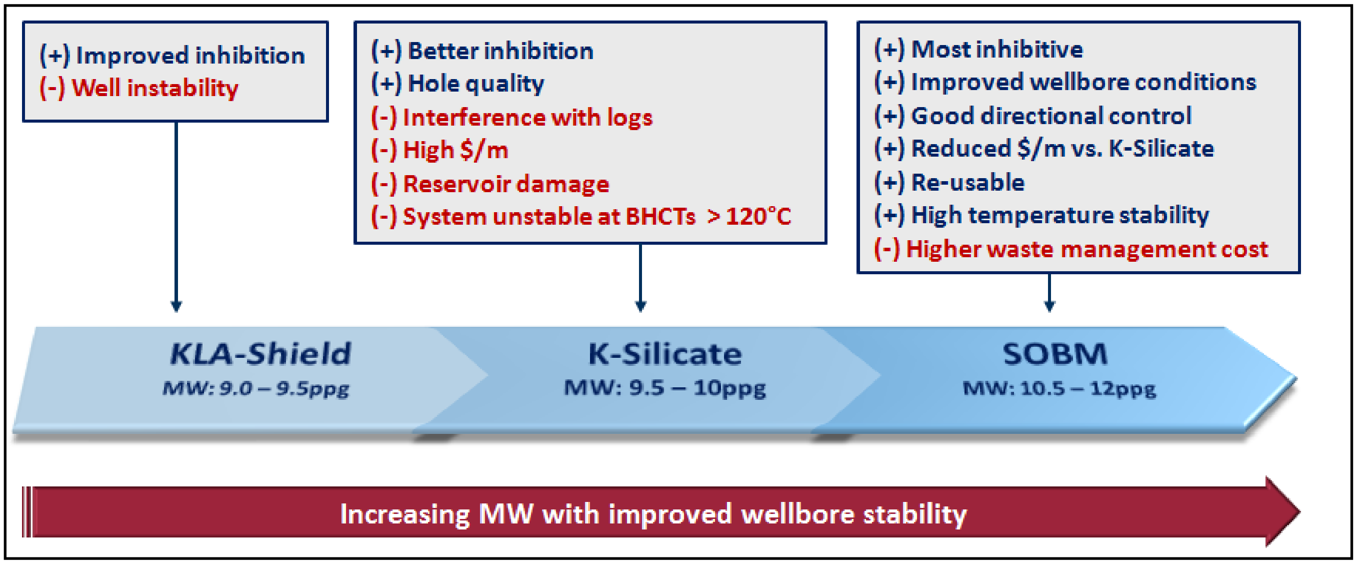


Figure-3: Evolution of Fluids for Production Hole Drilling

Table-3: Losses encountered in reservoirs sections of the different fields

Losses In Reservoir Interval									
Field-1									
Well	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Reservoir									
Mud Type	HPWBM Kla-Shield	SOBM	SOBM	SOBM	SOBM	SOBM	SOBM	SOBM	SOBM
Losses @ m		910-1009		867-983		Whole interval	2913 - 2924		
Hole Size “	8.5	12¼	8 ½	8 ½	12¼	8 ½	8 ½	12¼	8 ½
Volume bbls	0	183	920	146	168	274	1911	33	1195
Cured			Partial	yes	Yes	Yes	cement	slowed	
Comment		Minor seepage in Auwerwer	Includes 254 on cement job	Cured with Safe Carb 40µ additions	Seepage added 3-4ppb Safe Carb 40µ	While cementing. Ballooning. Reduced gpm-ok	Loss rate varied with extent of pack-off	Seepage - added Safe Carb 40µ	Stuck pipe and pack-off. Losses when circulating casing and cementing

Losses In Reservoir Interval										
	Field-2				Field-3			Field-4		Field-5	
Well	**1**	**2**	**2A**	**3**	**1**	**2**	**2-A**	**1**	**2**	**1**	**2**
Reservoir										A	A
Mud Type	WBM K. Silicate	SOBM	SOBM	SOBM	HPWBM Kla-Shield	SOBM	SOBM	WBM K. Silicate	SOBM	WBM K. Silicate	WBM K. Silicate
Losses @ m					2051 and 2111		2800		3651		1120
Hole Size “	8 ½	8 ½	8 ½	8 ½	8 ½	12¼	8 ½	12¼ / 17½	8 ½	12¼	12¼
Volume bbls	0	855	512	338		0	1027	0	525	42	240
Cured		partial			partial		Partial				
Comment		Seepage up to 4bph after coring	No detail in EOWR	Includes 254bbls on cement job	Seepage 5-10bph treated with Safe Carb 20, 40, 250 @ 4-6ppb	Core point not found Set Whipstock	2-4bph reduced with 44ppb Safe Carb 40µ. No cementing losses		Pack-off –1st incident at 3651		Losses while working stuck pipe

Table-4: Study recommendations and suggested systems/techniques

Interval	Mud System Selection	Preventative LCM	Remedial LCM
Surface section (Field-1)	MMO WBM	Prior to reaching volcanics Pre-treat with fibrous LCM	Magnesia cement, HSHF pill or X-linked polymer pill
Reservoir Interval (all wells)	Constant/Flat Rheology Low Clay SOBM	Pre-treat with marble bridging material	Magnesia cement, HSHF pill or X-linked polymer pill Treat with fibrous LCM

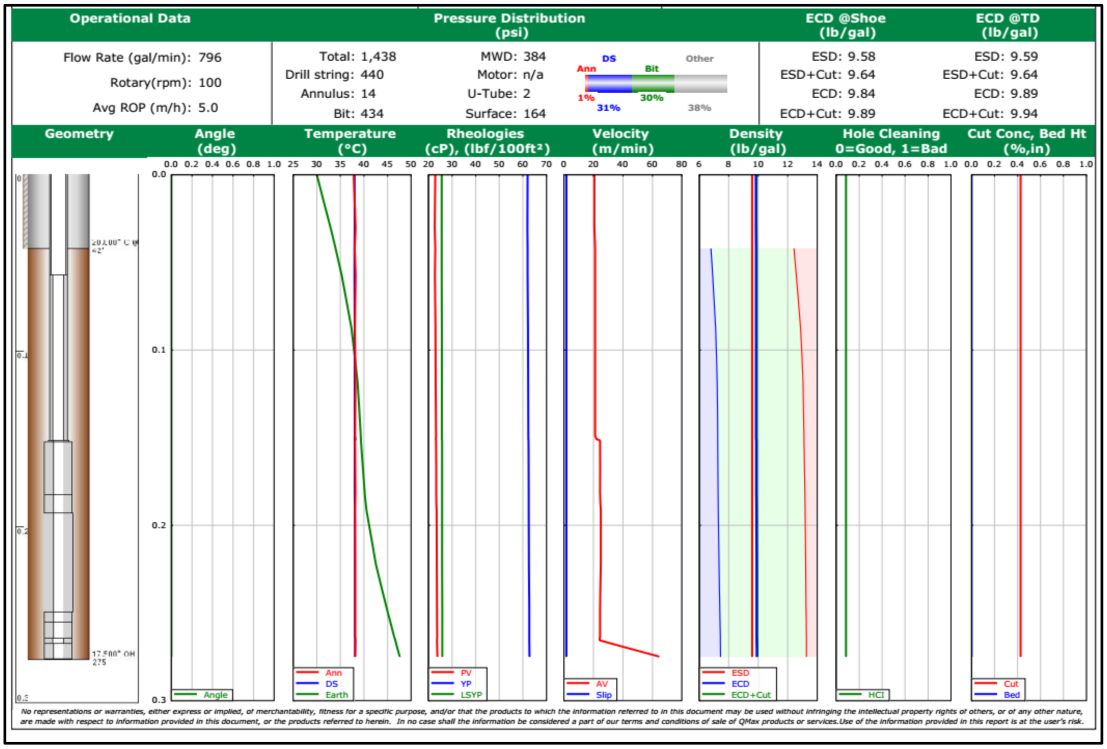
Table-5: Recommended MMO and SBM Formulations

MMO Formulation

PRODUCT	SG	
SAMPLE COMPOSITION		**PPB**
Water	1.00	325.42
Soda Ash	2.50	0.25
Special Non-trreated Bentonite	2.60	8.00
MMO	2.70	0.80
Caustic Soda	2.13	0.25
Modified Starch	1.50	5.00
Sized Carbonate	2.70	20.00
Barite	4.20	39.00
Anionic Suppressant	1.12	0.2
Properties		
PERIOD AGED	Hours	16
TEMPERATURE	ºF	225
DYNAMIC / STATIC	**D**	**AHR**
Mud Weight	ppg	**9.5**
RHEOLOGY TEMP:	120	
600 RPM		96
300 RPM		78
200 RPM		64
100 RPM		54
6 RPM		43
3 RPM		30
GELS 10"	lbs/100ft2	32
GELS 10'	lbs/100ft2	33
GELS 30'	lbs/100ft2	34
APPARENT VISC.	cP	**48**
PLASTIC VISC.	cP	**18**
YIELD POINT	lbs/100ft2	**60**
API Filtrate		8.8
pH		10.2
Comments	Bentonite prehydrated for 6 hours	

SBM Formulation

PRODUCT	**SG**	
SAMPLE COMPOSITION		**PPB**
Base Oil	0.78	148.5
Primary Emulsifier	0.94	8
Polymeric Viscosifier	1	5
LIME	2.2	10
WATER		81.4
SODIUM FORMATE	1.92	23
Organo-Clay	1.8	2
Fluid Loss Reducer	1.01	3
Secondary Emulsifier	0.97	1
CALCIUM CARBONATE FINE	2.7	30
BARITE	4.1	127.8
Rheology Modifier	0.88	0.5
Properties		
PERIOD AGED	Hours	16Hrs
TEMPERATURE	ºF	250
DYNAMIC/STATIC	**D**	**AHR**
Mud Weight	ppg	**10.5**
RHEOLOGY:	TEMP. ºF	**120**
600 RPM		83
300 RPM		51
200 RPM		39
100 RPM		27
6 RPM		12
3 RPM		10
GELS 10"	lb/100ft2	13
GELS 10'	lb/100ft2	20
GELS 30'	lb/100ft2	22
APPARENT VISC.	cP	41.5
PLASTIC VISC.	cP	32
YIELD POINT	lb/100ft2	19
HT-HP FILTRATION		
Temperature	ºF	250
Delta Pressure	PSI	500
HT-HP Fluid Loss, @250F/500PSI	ml	4.8
Water in Filtrate	ml	0
ELECTRICAL STABILITY	VOLTS	460
Oil / Water Ratio		70/30



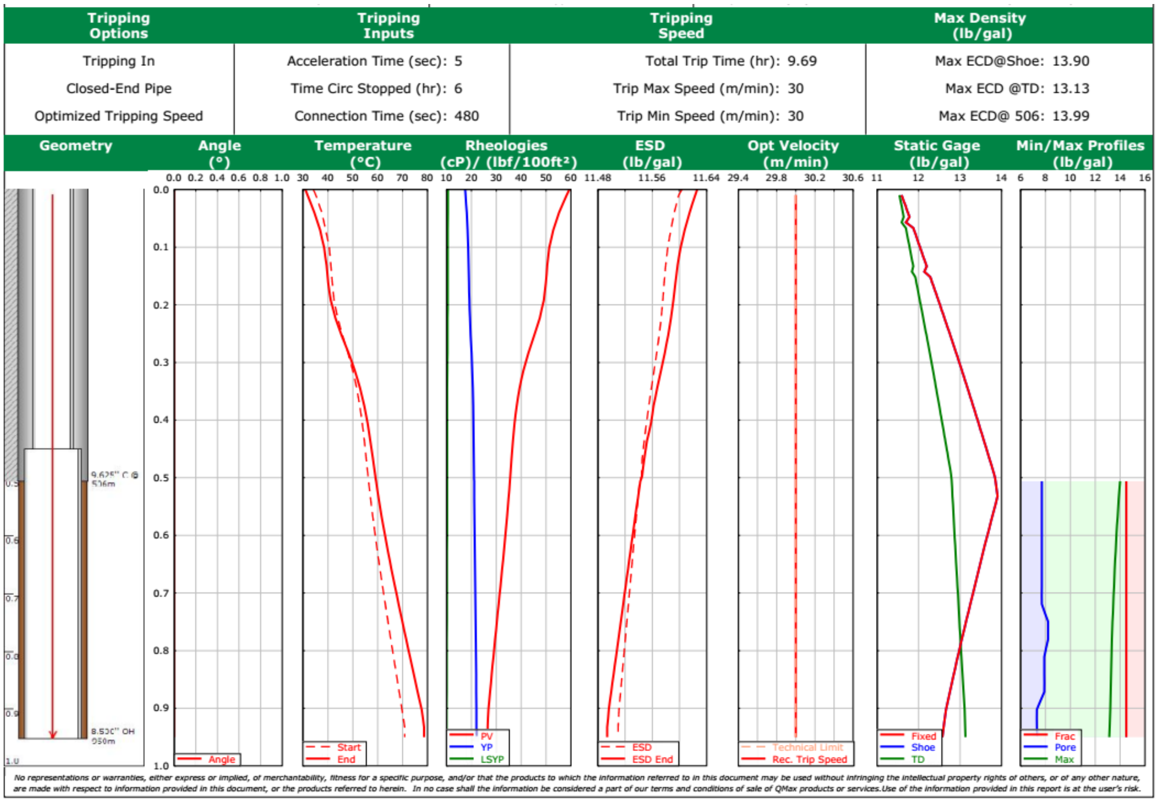
Operational Data
Flow Rate (gal/min): 796
Rotary(rpm): 100
Avg ROP (m/h): 5.0

Pressure Distribution (psi)
Total: 1,438
Drill string: 440
Annulus: 14
Bit: 434
MWD: 384
Motor: n/a
U-Tube: 2
Surface: 164

ECD @Shoe (lb/gal)
ESD: 9.58
ESD+Cut: 9.64
ECD: 9.84
ECD+Cut: 9.89

ECD @TD (lb/gal)
ESD: 9.59
ESD+Cut: 9.64
ECD: 9.89
ECD+Cut: 9.94

Figure-4: Hydraulics Snapshot – Drilling Operations



Tripping Options	Tripping Inputs	Tripping Speed	Max Density (lb/gal)
Tripping In	Acceleration Time (sec): 5	Total Trip Time (hr): 9.69	Max ECD@Shoe: 13.90
Closed-End Pipe	Time Circ Stopped (hr): 6	Trip Max Speed (m/min): 30	Max ECD @TD: 13.13
Optimized Tripping Speed	Connection Time (sec): 480	Trip Min Speed (m/min): 30	Max ECD@ 506: 13.99

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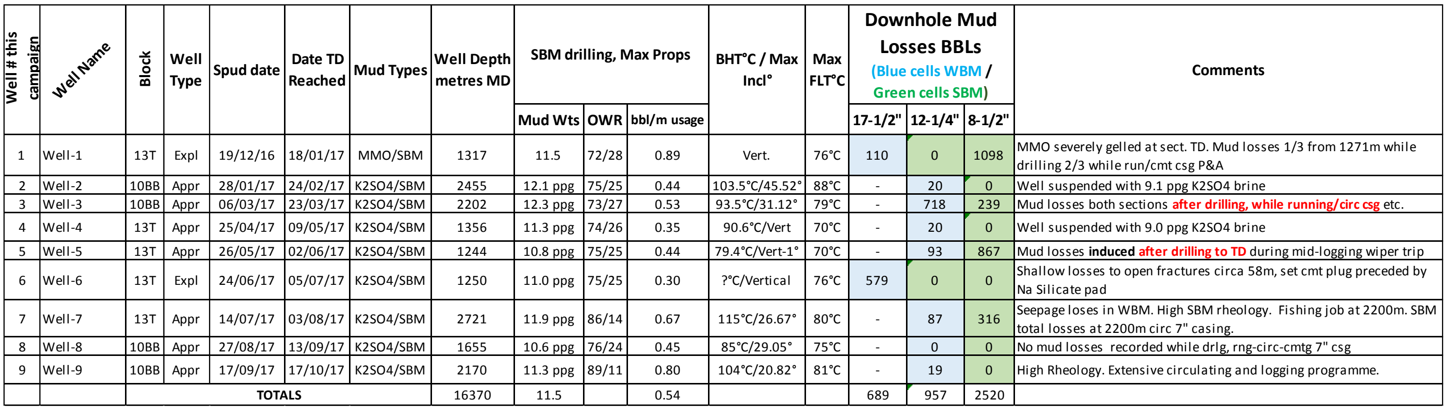
Figure-5: Hydraulics Snapshot – Tripping/Running Casing Operations

Table-6: Wells summary database and basic information



Well # this campaign	Well Name	Block	Well Type	Spud date	Date TD Reached	Mud Types	Well Depth metres MD	SBM drilling, Max Props			BHT°C / Max Incl°	Max FLT°C	Downhole Mud Losses BBLs (Blue cells WBM / Green cells SBM)			Comments
								Mud Wts	OWR	bbl/m usage			17-1/2"	12-1/4"	8-1/2"	
1	Well-1	13T	Expl	19/12/16	18/01/17	MMO/SBM	1317	11.5	72/28	0.89	Vert.	76°C	110	0	1098	MMO severely gelled at sect. TD. Mud losses 1/3 from 1271m while drilling 2/3 while run/cmt csg P&A
2	Well-2	10BB	Appr	28/01/17	24/02/17	K2SO4/SBM	2455	12.1 ppg	75/25	0.44	103.5°C/45.52°	88°C	-	20	0	Well suspended with 9.1 ppg K2SO4 brine
3	Well-3	10BB	Appr	06/03/17	23/03/17	K2SO4/SBM	2202	12.3 ppg	73/27	0.53	93.5°C/31.12°	79°C	-	718	239	Mud losses both sections **after drilling, while running/circ csg** etc.
4	Well-4	13T	Appr	25/04/17	09/05/17	K2SO4/SBM	1356	11.3 ppg	74/26	0.35	90.6°C/Vert	70°C	-	20	0	Well suspended with 9.0 ppg K2SO4 brine
5	Well-5	13T	Appr	26/05/17	02/06/17	K2SO4/SBM	1244	10.8 ppg	75/25	0.44	79.4°C/Vert-1°	70°C	-	93	867	Mud losses **induced after drilling to TD** during mid-logging wiper trip
6	Well-6	13T	Expl	24/06/17	05/07/17	K2SO4/SBM	1250	11.0 ppg	75/25	0.30	?°C/Vertical	76°C	579	0	0	Shallow losses to open fractures circa 58m, set cmt plug preceded by Na Silicate pad
7	Well-7	13T	Appr	14/07/17	03/08/17	K2SO4/SBM	2721	11.9 ppg	86/14	0.67	115°C/26.67°	80°C	-	87	316	Seepage loses in WBM. High SBM rheology. Fishing job at 2200m. SBM total losses at 2200m circ 7" casing.
8	Well-8	10BB	Appr	27/08/17	13/09/17	K2SO4/SBM	1655	10.6 ppg	76/24	0.45	85°C/29.05°	75°C	-	0	0	No mud losses recorded while drlg, rng-circ-cmtg 7" csg
9	Well-9	10BB	Appr	17/09/17	17/10/17	K2SO4/SBM	2170	11.3 ppg	89/11	0.80	104°C/20.82°	81°C	-	19	0	High Rheology. Extensive circulating and logging programme.
		TOTALS					16370	11.5		0.54			689	957	2520	