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Field Study of Drilling Horizontal Wells in Abu Rudies Field, Gulf Of Suez, Egypt

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Abstract

Drilling horizontal wells has a great role in maximizing recovery efficiency of reservoir energy by increasing drainage area at the wellbore and increasing the length of pay zone within the target reservoir rock unit so the main objective is to continue drilling more horizontal wells in order to increase the oil production from Abu Rudeis field with the lowest possible cost.

This research is focused on the study of the latest horizontal wells drilled in Abu Rudies Field in Gulf of Suez, optimization of best horizontal well design and introduction of horizontal wells landing challenge in Abu Rudies field starting from drilling pilot hole till finally introduction of reservoir mapping while drilling tool that was used for the first time in Egypt for landing top of unconformable surface in Nukhul Formation that results in avoiding drilling pilot hole and reducing the total well cost.

Keywords: *Abu Rudies Field; Horizontal Well; Nukhul Formation; Reservoir- Mapping- While Drilling.*

1. Introduction

Most of the oil production in Abu Rudeis field comes from Nukhul formation which resulted in the depletion of this zone that creates challenge for the drilling engineering to achieve better production rates by drilling more horizontal wells as compared to drilling deviated wells.

Recent field studies in Abu Rudeis Field suggested that drilling horizontal wells would result in better oil production rates in comparison to deviated wells and extra cost of drilling horizontal wells is usually recovered by increasing production from well.

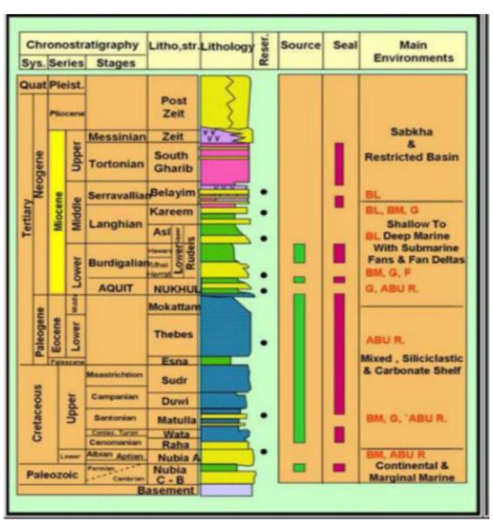

Figure 1. Stratigraphic column of Gulf of Suez

Different horizontal drilling systems and engineering solutions introduced in drilling the latest horizontal wells in Abu Rudies Field will be discussed illustrating well design philosophy of each well drilled in this field.

One of the most critical problems associated while drilling horizontal wells in Abu Rudies Field is the landing application on top of tansition Nukhul Formation in this Field.

Nukhul Formation in Abu Rudeis Field is a clastic depleted reservoir of Oligo-Miocene age underlying pressurized Miocene Shale of Rudeis Formation as illustrated in Figure (1).

It consists of three sandstone layers intercalated by shale. The thickness variations of Rudeis Shale and Transition Nukhul Formation (TNAF) increase the uncer- tainty of casing point detection and due to the difference in pore pressure between the depleted sand and the pressurized shale of Rudeis formation above it so Failure to set casing at the top of the reservoir sand would result in complete mud circulation losses if drilled Nukhul formation with heavy mud weight or if set casing point earlier in pressurized shale of Rudeis formation and continue drilling rest of it in the next phase with lighter mud weight will result in stuck pipe due to hole instability with this light mud weight.

The main objective is to identify the optimum horizontal well design to achieve the maximum profit with lowest total well cost and time to continue drilling more horizontal wells in order to increase the oil production from the field.

2. Geostopping technologies evaluation to detect top of transition zone in Nukhul Formation in Abu Rudeis Field

2.1. First scenario

Several horizontal wells were drilled in Abu Rudeis Field and beginning for all these wells; a pilot hole was drilled in order to determine the unconformable top of Nukhul Sand Formation, then The pilot holes were plugged and abandoned and side-tracks were drilled for a build-up section whose casing point selection was made based on the pilot hole data and due to operational cost and time lost in drilling pilot holes so another solution was needed.

2.2. Second scenario

The resistivity at bit tool was then implemented in other wells to detect the top of transition zone that was helpful in indicating the transition between different formations with resistivity contrast but this tool did not add value in the landing application on top of Nukhul Formation.

The main reason is that when the tool was able to determine the top transition of Nukhul Formation (TNAF), and due to the limited depth of investigation, the bit would have already entered in the depleted zone of Nukhul sand, causing complete losses.

2.3. Third scenario

Another technology that was considered in the landing application was the Seismic-While Drilling (SWD) but the main challenge in utilizing this technology in the Abu Rudeis Field is the high degree of seismic uncertainty associated with multiple reflections due to the presence of evaporites in the South Gharib and Zeit Formations above the Rudeis Shale [3].

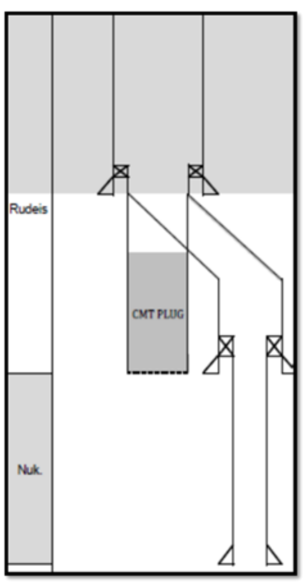

Figure 2. Pilot Hole Drilling Schematic

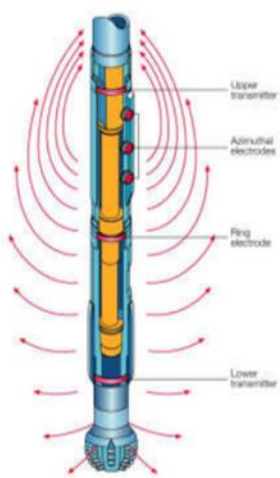

Figure 3. Resistivity at bit tool schematic

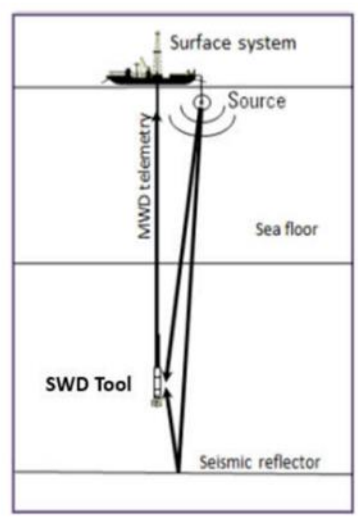

Figure 4. Seismic-While-Drilling Schematic

2.4. Optimum and best scenario

Finally the reservoir mapping while drilling tool was used for the first time in Egypt for landing applications in horizontal wells to detect the top of target reservoir rock to set the casing point exactly at the top of depleted zones such as Nukhul formation in Abu Rudies field [1,4,5].

This service employs an array of multiple subs in the bottomhole assembly to transmit deep directional resistivity measurements that map multiple reservoir layers with resistivity contrasts in real time.

The multi-spaced receiver array extends the radial depth of investigation to 100 ft from the tool, revealing subsurface bedding and fluid-contact details at a true reservoir scale [4].

Dupuis *et al.* [5], describes the mode of operation of this tool and the advantages that contributed in the ultra-deep depth of investigation. Three main changes were introduced to the service's design to allow the extended depth of investigation.

2.4.1.Tool design.

The reservoir mapping while drilling tool is a modular tool which consists of one transmitter and multiple receivers, up to 3 receivers (Figure 5). The choice of the number of receivers and the transmitter-receiver spacings are part of the pre-job planning phase and it depends on the client's challenge and the objective of the service.

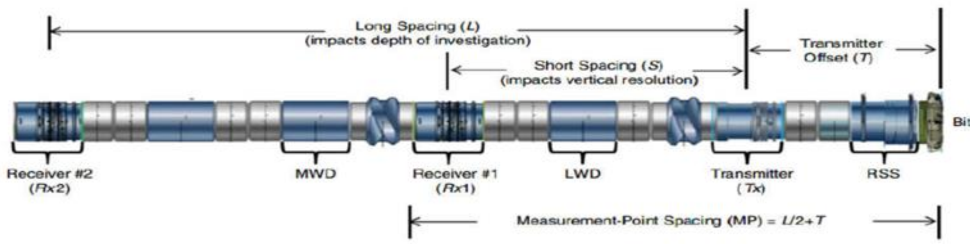

Figure 5. Reservoir mapping-While-Drilling bottom hole assembly overview

The reservoir mapping while drilling tool generates directional electromagnetic waves that are transmitted over a broad band of frequencies from the transmitter to the receiver.
The relationship between the frequency utilization and the depth of investigation is explained using equation (1) which implies that the skin depth is inversely proportional to frequency and therefore the lower the frequency used, the deeper the depth of investigation.

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \qquad (1)$$

where: δ is the skin depth in meters; σ the resistivity in ohm.m; ω the angular frequency equal to 2π times the signal frequency; μ the magnetic permeability, considered constant in this application.

2.4.2. Inversion software capabilties

The software utilizes the large array of deep directional data from the multi-spacing and broad frequency ranges to invert for the best fit model which Includes, but not limited to, information like:

- ✓ Formation resistivity map
- ✓ Formation dip information
- ✓ Associated uncertainties

The software is fully automatic and it does not require any users' input to the inversion. The inversion runs continuously in real-time as long as the tool is transmitting data. The large amount of data transmission was made possible using the compressed data transmission system from the new telemetry-while-drilling system utilized in new generation of the measurement-while-drilling tools [5].

3. Horizontal wells design summary evaluation in Abu Rudeis Field and the proposed best horizontal well design in the future.

3.1. Case Study #1 (Well# XH) (Drilling Pilot Hole To Detect Top Of Nukhul Formation)

3.1.1. Well objective

The well#XH was drilled to make a new drainage section in Nukhul Formation in the Abu Rudeis Field. The aim of this well was to maximize the drainage interval in the layers Nukhul A, Nukhul B and adding also layer Nukhul C that never put in production with a horizontal well.

Well #XH was planned to be drilled with a total depth of 4000 m MD and a maximum inclination of 90 degree. The total time and costs for both drilling and completion of the well is estimated to be 100 days and 8.2 M$.

It was planned to drill 8 ½′′ pilot hole and hit Nukhul formation with 75° @ ± 3530 m MD, keep drilling till maximum 10 m MD inside Nukhul formation to confirm the clean sand of level "A" then Plug back the pilot hole and finally drill 8 1/2" open hole Side-track to the same impact point of Nukhul formation at +/- 3530 m MD but Don't enter Nukhul formation and drill 6" hole inside Nukhul building the angle to 90° down to well TD at +/- 4000 m MD.

3.1.2. Well design summary

The 23" hole section was drilled vertically to 200 m MD due to the short distance between offshore line and well location to avoid any hole washout of the loose sand below the cellar. this phase was drilled with spud mud with mud weight range was 1.04–1.06 kg/lit then the 18 5/8" casing was run and cemented via inner string technique to allow the use of the diverter system for the drilling of the 16" hole section.

After installing the diverter system the 16" hole section was drilled directionally to section TD at 1278 m MD inside zeit formation, the purpose of drilling this phase was to set 13 3/8" casing to cover all unconsolidated sand of post miocene & zeit formations, shallow water zones, build up section and attain fracture gradient beneath surface casing sufficient for rising mud weight for the next phase.

This section was drilled with milled teeth rock bit on steerable assembly with MWD to 1278 m MD using Spud / KCL Poly. Mud with mud weight range is (1.06 – 1.13 kg/lit) then 13 3/8" casing was run and cemented in one stage and two slurries up to at 500 m MD RKB to allow installing casing head housing and blow out preventer before drilling 12 ¼′′ hole section.

After installing the wellhead and the BOP, 12 ¼" hole section was drilled inside rest of Zeit, South Gharib, Belayiem, Kareem and Rudeis formations to 3302 m MD.

The goal of this phase was to set 9 5/8 x 9 6/8 x 9 7/8" casing in Rudeis Formation to cover all the salt beds of S.GH with high collapse grade casing.

This section was drilled with 12 ¼′′ PDC on rotary steerable system with motor and MWD using oil base mud with mud weight 1.75 kg/lit then 9 5/8′′ x 9 6/8′′ x 9 7/8" casing was run and cemented in one stage and one slurry up to 800 m MD RKB.

8 ½′′ pilot hole section was drilled through Rudeis formation down to the well casing Point @ 3606 m MD RKB (2574 TVD) on the top of transition zone of Nukhul formation (TNAF).

This section was drilled with 8 1/2′′ PDC bit on rotary steerable system, MWD/LWD to detect top of Nukhul Formation using oil base mud with mud weight 1.75 kg/lit then the pilot hole was plugged back and 8 ½′′ side track hole was drilled to 7′′ liner casing point @ 3562 m, 7′′ liner was run on 5′′ DPs to 3549 M, set 7′′ liner hanger @ 3234 m and cemented in one stage and one slurry.

6′′ hole section was drilled through Nukhul formation down to the final well casing Point @ 3724 m MD RKB (2595 m TVD), this section was drilled with 6′′ PDC on rotary steerable system and MWD/LWD using oil base mud with mud weight (0.93-1.05 kg/lit), the 5′′ liner was run on (3 ½′′ and 5′′ DPs) to 3716 M, set 5′′ liner hanger @ 3486 m and cemented in one stage and one slurry.

7′′ scab Liner was run to top of 7′′ liner @ 3234 m, performed cement job in one stage then complete sting in previous 7′′ liner and 7′′ scab liner hanger was set @ 1387 m.

Well was displaced with completion fluid (7% KCl Brine, 1.04 Kg/L) and completed The Well as an ESP Producer from Nukhul Formation. Table.1 illustrate the planned total time, cost analysis, actual total time and cost analysis for well#XH.

Table.1 Planned total time, cost analysis, actual total time and cost analysis for Well #XH

Planned total time and cost analysis			Actual total time and cost analysis		
Cumulative time (days)	Cum cost (US$)	Total depth (m)	Cumulative time (days)	Cum cost (US$)	Total depth (m)
105	8,164,472	4005	90	7,050,373	3724

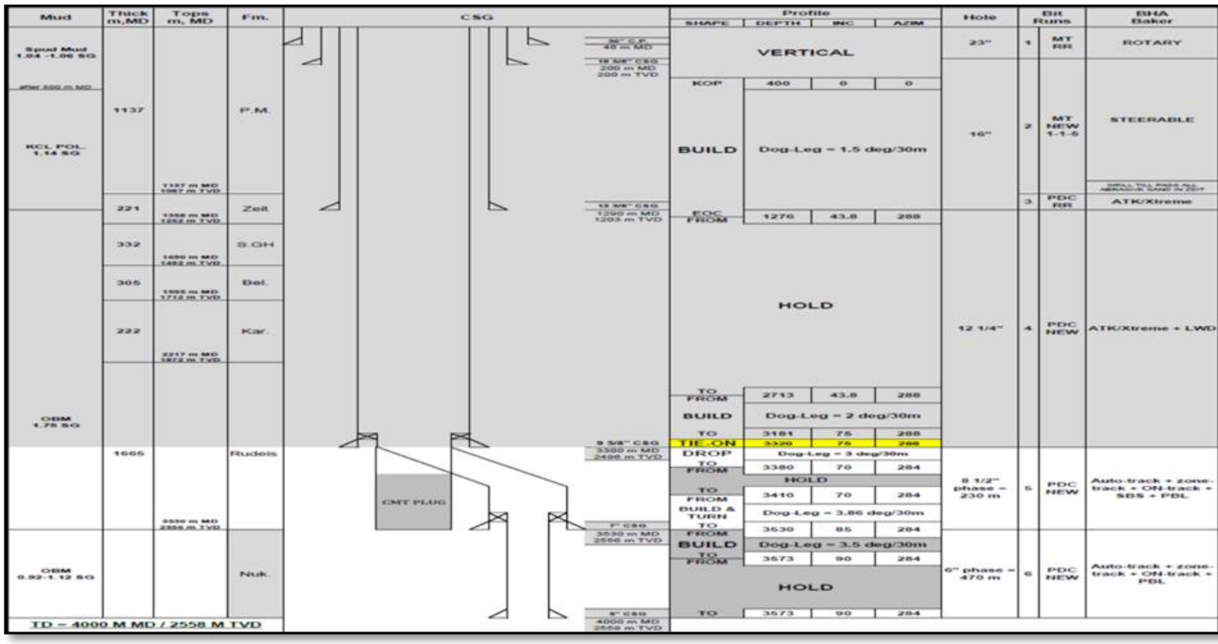

Figure 6. Planned Well# XH design schematic

Table.2 Actual Well# XH design summary

Hole size	Mud type & M_{Wt}.	BHA	Formations	Casing Size
23″ hole to 200 m	Spud Mud (1.04-1.06 Kg/L).	Rotary Stabilized.	Post Miocene	18 5/8″ casing.
16″ hole to 1278 M after installing 21 ¼″ diverter	Spud/ KCL Poly Mud (1.06-1.13 kg/L).	Steerable BHA + MWD.	Post Miocene & Zeit	13 3/8″ casing.
12 ¼″ hole to 3302 m using 13 5/8″ BOP stack & 13 5/8″ WELL HEAD.	OBM (1.75 kg/L)	Motorized Rotary steerable system + LWD	Zeit + S.Gharib + belayiem + kareem + Rudies.	9 5/8″ x 9 6/8″x 9 7/8″ casing
8 ½″ pilot hole to 3606 m MD RKB (2574 TVD).	OBM (1.75 kg/L)	Rotary steerable system + LWD.	Rudies & Nukhul	Plug back & side track.
8 ½″ sidetrack hole to 3562 m MD.	OBM (1.75 kg/L)	Rotary steerable system + LWD.	Rudies & Nukhul	7″ liner
6″ hole to 3724 m MD RKB (2595 m TVD)	OBM (0.92 – 1.05 kg/L)	Rotary steerable system + LWD.	Nukhul (A & B)	5″ liner

3.1.3. Problems encountered and results

1. While drilling 8 ½'' pilot hole, had complete loss after hitting Nukhul Formation, to secure losses then plug back hole and sidetracked the hole lost 8 days & 0.41 M $ over the planed cost and time till drill 8 ½'' side track hole to top of Nukhul formation.
2. While drilling 6'' hole through Nukhul A, B & C, after drilled Nukhul A & B with M_{wt}= 0.94 Kg/lit (without losses) and due to existence of shale layer before drilling Nukhul C that was not stable with this mud weight so had to increase mud weight up to 1.05 kg/lit till this shale layer was stable but unfortunately caused severe & complete losses in Nukhul A & B that lost NPT and cost till secured losses.
   So it was planned to find another design to minimize well cost and maximize the profit.

3.2. Case study #2 (Well# YH)(using reservoir mapping while drilling tool to detect top of Nukhul Formation)

3.2.1. Well objective

The proposed well#YH was drilled to make a new drainage section in Nukhul Formation in Abu Rudeis Field. The aim of this well was to maximize the drainage interval in the layers Nukhul A, Nukhul B and adding also layer Nukhul C that never put in production with a horizontal well. Well #YH was planned to be drilled with a total depth of 4111 m MD and a maximum inclination of 85 degree.

The total time and costs for both drilling and completion of the well is estimated to be 90 days and 6.8 M$. The expected initial rate and the final reserves are respectively: 300 m^3/d and 1.73 MM STB of oil. In this well, the reservoir mapping while drilling technology was used for casing point selection for detection top of transition zone (TNAF) in Nukhul Formation instead of drilling pilot hole.

The reservoir mapping while drilling service was able to successfully land at the desired geo-stopping point and inclination, the geo-stopping point was 13 m TVD deeper than the prognoses, which further solidified the significance of using the reservoir mapping while drilling service in order to proactively adjust the well trajectory to land at the desired inclination.

The reservoir mapping while drilling service was also able to accurately map the apparent formation dip, which was 8 degrees towards the well trajectory.

3.2.2. Well design summary

The 26" hole section was drilled vertically to 158 m MD, This phase was drilled with spud mud with mud weight range was 1.04–1.06 kg/L then the 20" casing was run and cemented via inner string technique. After installing the diverter system the 16" hole section was drilled directionally to section TD at 1438 m MD inside Zeit formation to set 13 3/8" casing to cover all unconsolidated sand of post Miocene & Zeit formations, shallow water zones, build up section and attain fracture gradient beneath surface casing sufficient for rising mud weight for the next phase.

This section was drilled with hybrid bit on steerable Assembly with MWD to 1438 m MD using Spud/ KCL Poly. Mud with mud weight range was (1.06 – 1.14 kg/L) then 13 3/8" casing was run and cemented in one stage and two slurries up to at 500 m MD RKB to allow installing casing head housing and blow out preventer before drilling 12 ¼'' hole section.

After installing the wellhead and the BOP, 12 ¼" hole section was drilled inside rest of Zeit, South Gharib, Belayim, Kareem and Rudeis formations to 3213 m MD. The goal of this phase was to set 9 5/8 x 9 6/8 x 9 7/8" casing in Rudeis Formation to cover all the salt beds of S.GH with high collapse grade casing.

This section was drilled with 12 ¼'' PDC on rotary steerable system with motor and MWD using oil base mud with mud weight 1.75 kg/lit then 9 5/8'' x 9 6/8 x 9 7/8" casing was run and cemented in one stage and one slurry up to 2070 m MD RKB. 8 ½'' hole section was drilled through Rudeis formation down to the well casing Point @ 3660 m MD RKB (2565 TVD) on the top of transition zone of Nukhul formation (TNAF).

This section was drilled with 8 1/2'' PDC bit on rotary steerable system, MWD/LWD and Reservoir mapping while drilling tool were used to detect top of Nukhul Formation using oil base mud with mud weight 1.75 kg/L then the 7″ liner was run on 5″ DPs to bottom @ 3660 M, set 7″ liner hanger @ 3152 m and cemented in one stage and one slurry. 6″ hole section was drilled through Nukhul formation down to the final well casing Point @ 3962 m MD RKB (2593 m TVD).

This section was drilled with 6″ PDC on rotary steerable system and MWD/LWD using oil base mud with mud weight 0.92 kg/L. The 5″ liner was run on (3 ½″ and 5″ DPs) to TD @ 3943 M, set 5″ liner hanger @ 3578 m and cemented in one stage and one slurry.

7″ polishing Assembly was run to T.O.7″ liner @ 3152 m, Polished and dressed top of 7″ LNR. 7″ scab Liner was run to top of 7″ liner @ 3152 m, performed cement job in one stage then complete sting in previous 7″ liner and 7″ scab liner hanger was set @ 1577 m. Table.3 illustrate the planned total time, cost analysis, actual total time and cost analysis for well# YH.

Table.3 Planned total time, cost analysis, actual total time and cost analysis for Well# YH.

Planned total time and cost analysis			Actual total time and cost analysis		
Cumulative time (days)	Cum cost (US$)	Total depth (m)	Cumulative time (days)	Cum cost (US$)	Total depth (m)
90	6,834,859	4111	84	5,121,977	3935

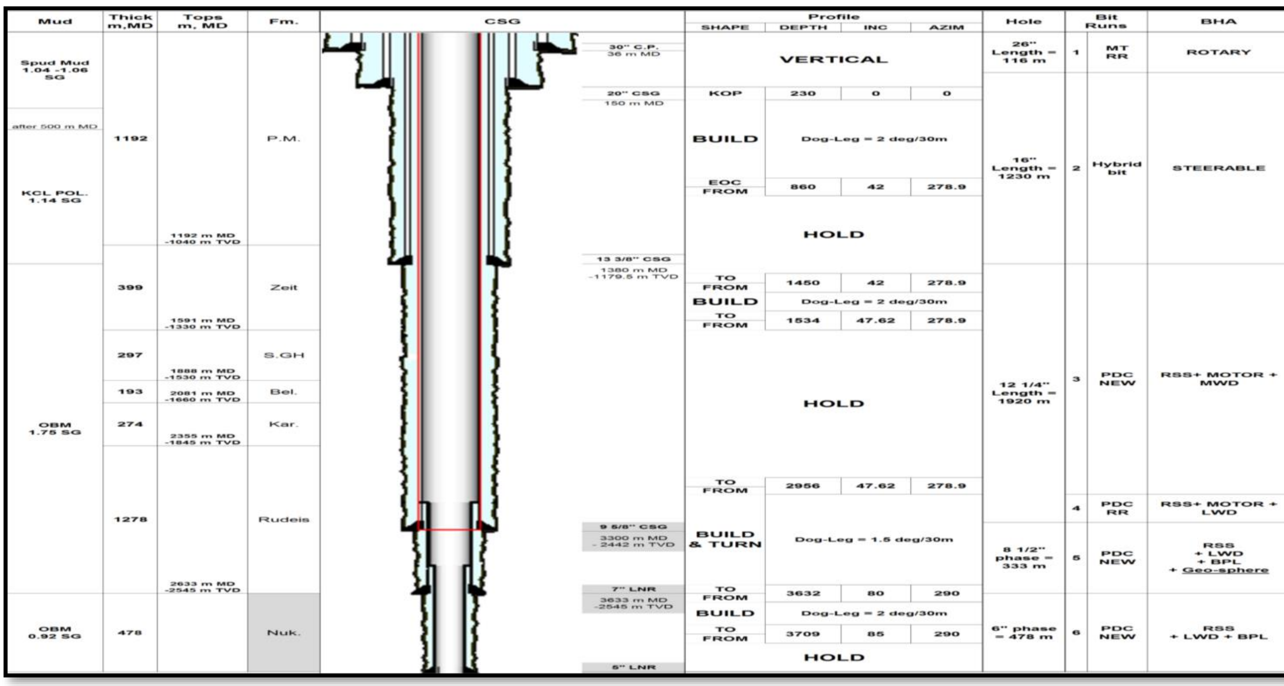

Figure 7. Planned Well# YH design schematic

3.2.3. Problems encountered and results

Regarding the actual well cost and time in comparison with the planned well cost and time, there is a great success as the final well cost and time were less than plan but regarding the proposed final reserve was less than expected as while drilling 6″ hole through Nukhul Formation with mud weight (0.92 kg/L) (Avg losses 3-5 BPH), after passing Nukhul B, the shale layer before Nukhul c was not stable as hole had high tendency to pack off so the plan to continue drilling to pass Nukhul c was cancelled so another design had to be planned.

Table 4. Actual Well #YH design summary

Hole size	Mud Type & M_{Wt}.	BHA	Formations	Casing Size
26'' hole to 158 m	Spud Mud (1.04-1.06 Kg/L).	Rotary Stabilized.	Post Miocene	20'' casing.
16'' hole to 1438 M after installing 21 ¼'' diverter	Spud/ KCL Poly Mud (1.06-1.14 kg/lit).	Steerable BHA + MWD.	Post Miocene & Zeit	13 3/8'' casing.
12 ¼'' hole to 3213 m using 13 5/8'' BOP stack & 13 5/8'' WELL HEAD.	OBM (1.75 kg/L)	Motorized Rotary steerable system + MWD + LWD "last 200 m".	Zeit + S.Gharib + belayiem + kareem + rudies.	9 5/8'' x 97/8'' casing
8 ½'' hole till detect top of transition zone of Nukhul Fm @ 3660 m.	OBM (1.75 kg/L)	Rotary steerable system + LWD + reservoir mapping while drilling tool.	Rudies & Nukhul	7'' liner.
6'' hole to TD @ 3962 m MD RKB (2593 m TVD).	OBM (0.92 kg/L)	Rotary steerable system + LWD.	Nukhul (A & B)	5'' Liner

3.3. Case study #3 (Well #ZH) (using reservoir mapping while drilling tool to detect top of Nukhul Formation Formation)

3.3.1 Well objective

The proposed well was to maximize the drainage interval in the layers Nukhul A, Nukhul B and adding also layer Nukhul C that never put in production with a horizontal well. It was planned to be drilled with a total depth of 3842 m MD and a maximum inclination of 85 degree.

The total time and costs for both drilling and completion of the well were estimated to be 85 days and 7.35 M$. The expected initial rate and the final reserves were respectively: 300m3/d and 1.73 MM STB of oil. In this well, the reservoir mapping while drilling technology was used for casing point selection for detection top of transition zone (TNAF) in Nukhul Formation instead of drilling pilot hole.

The reservoir mapping while drilling service was able to successfully land on top of Nukhul formation as The landing point was around 3 m TVD shallower than the planned landing point and the formation dip angle was around 5 degrees higher than prognosed.

3.3.2. Well design summary

The 26" hole section was drilled vertically to 150 m MD, This phase was drilled with spud mud with mud weight range was 1.04–1.06 kg/L then the 20" casing was run and cemented via inner string technique. After installing the diverter system the 16" hole section was drilled directionally to section TD at 1436 m MD inside Zeit formation to set 13 3/8" casing.

This section was drilled with hybrid bit on steerable Assembly with MWD to 1438 m MD using Spud KCL Poly. Mud with mud weight range is (1.06 – 1.16 kg/lit) then 13 3/8" casing was run and cemented in one stage and two slurries up to at 500 m MD RKB to allow installing casing head housing and blow out preventer before drilling 12 ¼'' hole section. After installing the wellhead and the BOP, 12 ¼" hole section was drilled inside rest of Zeit, South Gharib, Belayim, Kareem and Rudeis formations to 3270 m MD.

The goal of this phase was to set 9 5/8 x 9 6/8 x 9 7/8" casing in Rudeis Formation to cover all the salt beds of S.GH with high collapse grade casing.This section was drilled with 12 ¼'' PDC on rotary steerable system with motor and MWD using oil base mud with mud weight 1.75 kg/L then 9 5/8'' x 9 6/8 x 9 7/8" casing was run and cemented in one stage and one slurry up to 1540 m MD RKB.

8 ½'' hole section was drilled through Rudeis formation down to the well casing Point @ 3480 m MD RKB (2543 TVD) on the top of transition zone of Nukhul formation (TNAF). This section was drilled with 8 1/2'' PDC bit on rotary steerable system, MWD/LWD and Reservoir mapping while drilling tool were used to detect top of Nukhul Formation using oil base mud

with mud weight 1.75 kg/L then the 7″ liner was run on 5″ DPs to bottom @ 3480 M, set 7″ liner hanger @ 3193 m and cemented in one stage and one slurry.

6″ hole section was drilled through Nukhul formation down to the final well casing Point @ 3691 m MD RKB (2562 m TVD). This section was drilled with 6″ PDC on rotary steerable system and MWD/LWD using oil base mud with mud weight 0.92-0.96 kg/L.

The 5″ liner was run on (3 ½″ and 5″ DPs) to TD @ 3686 M, set 5″ liner hanger @ 3388 m and cemented in one stage and one slurry.

7″ polishing Assembly was run to T.O.7″ liner @ 3193 m, Polished and dressed top of 7″ LNR. 7″ scab Liner was run to top of 7″ liner @ 3193 m, performed cement job in one stage then complete sting in previous 7″ liner and 7″ scab liner hanger was set @ 1611 m.

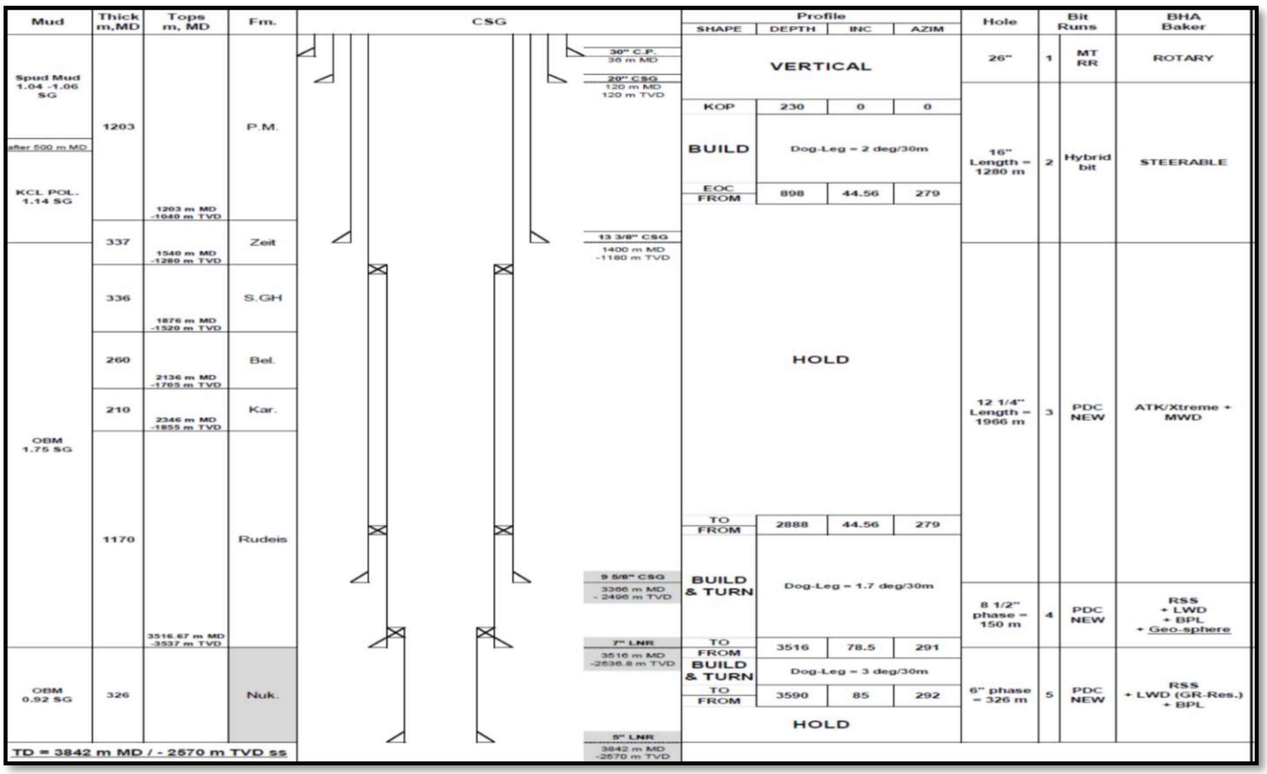

Figure 8. Planned Well# ZH design schematic

Table 4. Actual Well #YH design summary

Hole size	Mud Type & Mwt.	BHA	Formations	Casing Size
26″ hole to 120 m	Spud Mud (1.04-1.06 Kg/L).	Rotary Stabilized.	Post Miocene	20″ casing.
16″ hole to 1400 M after installing 21 ¼″ diverter	Spud/ KCL Poly Mud (1.06-1.14 kg/L)	Steerable BHA + MWD.	Post Miocene & Zeit	13 3/8″ casing.
12 ¼″ hole to 3366 m using 13 5/8″ BOP stack & 13 5/8″ WELL HEAD.	OBM (1.75 kg/L)	Motorized Rotary steerable system + MWD + LWD " last 200 m″.	Zeit + S.Gharib + belayiem + kareem + rudies.	9 5/8″ x 97/8″ casing
8 ½″ hole till detect top of transition zone of Nukhul Fm.	OBM (1.75 kg/L)	Rotary steerable system + LWD + reservoir mapping while drilling tool.	Rudies & Nukhul	7″ liner.
6″ hole to TD	OBM (0.92 kg/L)	Rotary steerable system + LWD.	Nukhul (A,B &C)	5″ Liner

3.3.3. Problems encountered and results

Regarding the actual well cost and time in comparison with the planned well cost and time, the total actual depth was shallower than plan with 151 m, as couldn't pass Nukhul C and cummulative actual time was greater than plan with 8 days as illustrated in the Table.6.

Table 6. Planned total time, cost analysis, actual total time and cost analysis For Well# ZH

Planned total time and cost analysis			Actual total time and cost analysis		
Cumulative time (days)	Cum cost (US$)	Total depth (m)	Cumulative time (days)	Cum cost (US$)	Total depth (m)
85	7,355,391	3842	93	6,078,222	3691

But regarding the proposed final reserve was less than expected as while drilling 6'' hole through Nukhul Formation with mud weight (0.96 kg/lit) (Avg losses 18-25 BPH), after passing Nukhul B, the shale layer before Nukhul c was not stable as hole had high tendency to pack off so the plan to continue drilling to pass Nukhul c was cancelled so another design had to be planned.

4. New proposed horizontal Well design (Well# VH)

The new proposed horizontal well# VH will be drilled to make a new drainage section in Nukhul Formation (Nukhul A, B & C) in Abu Rudeis Field. The aim of this well is to maximize the drainage interval in the layers Nukhul A, Nukhul B and adding also layer Nukhul C that never put in production with a horizontal well.

Nukhul formation (Nukhul A & Nukhul B) will be drilled in 8.5'' hole then Nukhul C will be drilled in 6'' hole to avoid what happened in previous horizontal wells before drilling Nukhul C, there is pressurized shale layer that is balanced when drilling with Mwt=1.05 Kg/lit so 8.5'' hole will be planned to be drilled with OBM (Mwt=0.92 Kg/L) to bottom of Nukhul B then 7'' liner will be Run to bottom and cemented in one stage. 6'' hole will be drilled through Nukhul C with OBM (Mwt=1.05 Kg/L) then 5'' liner will be Run to Bottom and cemented in one stage.

Well design is summarized below as follow:-

- The 26" hole section will be drilled to +/- 1000 m MD using 29 ½'' diverter system, This phase will be drilled with spud/ KCL POLY mud with mud weight range is 1.04–1.10 kg/L then the 18 5/8" casing will be run and cemented via inner string technique then 20 ¾'' x 3k Psi well head will be used to allow using 20 ¾'' x 3K psi BOP stack for next phase.
- After installing the 20 ¾'' x 3K psi BOP stack system and test same, the 16" hole section will be drilled directionally to top of South Gharib formation, the purpose of drilling this phase was to set 13 3/8" x 13 5/8'' casing to cover all unconsolidated sand of post Miocene, Zeit formations, shallow water zones, build up section and attain fracture gradient beneath surface casing sufficient for rising mud weight for the next phase.
- This section was drilled with hybrid bit on steerable Assembly with using Spud KCl Poly/ S.Saturated KCL Poly. Mud with mud weight range is (1.04 – 1.18 kg/L) then 13 3/8" x 13 5/8'' casing will be run and cemented in one stage and two slurries up to at 500 m MD.
- 12 ¼" hole section will be drilled inside South Gharib, Belayim, Kareem and Rudeis formations till top transition of Nukhul formation using Reservoir mapping while drilling tool.
- The goal of this phase is to set 9 5/8 x 10 ¾" casing to cover all the salt beds of S.GH with high collapse grade casing.
- This section will be drilled with 12 ¼'' PDC on rotary steerable system with motor, MWD and LWD using oil base mud with mud weight 1.75 kg/lit then 9 5/8'' x 10 3/4" casing will be run and cemented.
- 8 ½'' hole section will be drilled through Nukhul formation (A & B) down to the well casing Point
- This section will be drilled with 8 1/2'' PDC bit on rotary steerable system, MWD/LWD using oil base mud with mud weight (0.92 kg/L) then the 7'' liner will be run on 5'' DPs to bottom, and cemented in one stage and one slurry.
- 6'' hole section will be drilled through Nukhul formation C down to the final well casing Point
- This section will be drilled with 6'' PDC on rotary steerable system and MWD/LWD using oil base mud with mud weight 1.05 kg/lit.

- The 5′′ liner will be run on (3 ½′′ and 5′′ DPs) to TD and cemented in one stage and one slurry.

5. Conclusions

The positive results of identifying the optimum horizontal well design including mud program design, optimum solution to identify the top of reservoir rock using reservoir mapping while drilling tool, casing design, drill string design, optimum drilling parameters, optimum horizontal well cementing design with best centralization program,well logging program and optimum completion design resulted in saving an average of 1.8 million $/well as the analysis of the nonproductive time including the pilot hole cost, the sticking pipe risk and the possible oil based mud losses ranged +/- 1.8 M$.

Other positive results of optimum horizontal well design are the early production of the wells and encouragement of drilling more horizontal wells for optimum field development.

Nomenclature

A	*Azimuth angle, degree*	*OBM*	*Oil Based Mud*
BHA	*Bottom hole assembly*	*RSS*	*Rotary Steerable System*
CSG	*Casing*	*TD*	*Total depth (measured depth), ft*
I	*Inclination Angle, degree*	*TVD*	*True vertical depth, ft*
MD	*Measured depth of any point, ft*	*WBM*	*Water Based Mud*
MWT	*Mud weight, ppg*		

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