Optimization of Deviated and Horizontal Wells Trajectories and Profiles in Rumaila Oilfield

تحسين تصاميم ومسارات الأبار المائلة والأفقيه في حقل الرميلة النفطي

Hussein Saeed Almalikee[*], Fahad M. Al-Najm[**]
[*]Fields division, Basrah oil company, Basrah, Iraq
[**]Geology Department, College of Science, University of Basrah, Basrah, Iraq
Corresponding Autor E-mail: hussein.almalikee@gmail.com

Abstract

Directional and horizontal wellbore profiles and optimization of trajectory to minimize borehole problems are considered the most important part in well planning and design. This study introduces four types of directional and horizontal wells trajectory plans for Rumaila oilfield by selecting the suitable kick off point (KOP), build section, drop section and horizontal profile. In addition to the optimized inclination and orientation which was selected based on Rumaila oilfield geomechanics and wellbore stability analysis so that the optimum trajectory could be drilled with minimum wellbore instability problems. The four recommended types of deviated wellbore trajectories include: Type I (also called Build and Hold Trajectory or L shape) which target shallow to medium reservoirs with low inclination (20^o) and less than 500m step out, Type II (S shape) that can be used to penetrate far off reservoir vertically, Type III (also called Deep Kick off wells or J shape) these wells are similar to the L shape profile except the kickoff point is at a deeper depth, and design to reach far-off targets (>500m step out) with more than 30^o inclination, and finally Type IV (horizontal) that penetrates the reservoir horizontally at 90^o. The study also recommended the suitable drilling mud density that can control wellbore failure for the four types of wellbore trajectory.

Keywords: Horizontal well, drilling, wellbore stability, Rumaila.

Introduction

Horizontal and highly deviated wells became an important strategy in modern oil and gas industry because this type of wells offer great economic profits by higher production rates and recovery factors and lower development costs.

Generally, there are two primary kinds of trajectory for the borehole [1]:

1. Straight or vertical.
2. Directional, which include horizontal and deviated borehole trajectory.

The vertical borehole also termed a straight borehole hole. Nevertheless, naturally, a slight deviancy from vertical regularly happens that is associated with the features of the formation like stiffness and dip angle due to the drilling influences, (borehole assembly, bit type, and weight on bit) [2].

Determination of suitable drilling mud density using rock failure analysis is a necessary step to gain control on wellbore instability in both vertical and deviated wells [3]. According to the mud properties, the analysis results for successful drilling recommended to sustain the lowest possible mud density in order to reduce contamination of the producing formations. However, the pressure of drilling mud (the hydrostatic pressure) would not be possibly sufficient to maintain borehole stability if the mud density is too low [4].

Values of shear failure pressure in Rumaila oilfield that are measured in pound per square inch (psi) can be converted to shear failure equivalent mud weight (EMW) in gram per square centimeter (gm/cm^3) by using conversion equation (2) which is a derivation of equation (1) as follows: [5].

$$EMW(ppg) = \frac{Pressure\ (psi)}{0.052 * True\ vertical\ depth\ (ft)} \qquad (1)$$

Considering: 1 ppg (pound per gallon) = 0.1198 gm/cm^3.

1 ft = 0.3048 m. That leads to:

$$Shear\ Failure\ EMW\left(\frac{gm}{cm^3}\right) = 0.703\frac{Shear\ failure\ pressure\ (psi)}{True\ vertical\ depth\ (m)} \qquad (2)$$

Table (1) demonstrate the average shear failure pressure and its equivalent mud weight (EMW) predicted from five wells in Rumaila oilfield (R-527, R-518, R-523, Ru-385 and

Ru-382) [6]. The red flagged EMW values in the table points to high shear failure EMW that exceeds 1.2 gm/cm^3 (which is the mud weight regularly used to drill the same set of formations). The observed correspondent lithology for that high EMW was shale.

Shale is a fine-grained sedimentary rock that has a low permeability. Therefore, the redistribution of stress took longer time until a new hole is being drilled, leading to a possible failure in the borehole even after a few days of drilling. This is because the pore pressure in low permeable formations is very high prior to drilling compared to high permeable formations due to pore pressure not able to dissipate freely when in contact with the drilling mud [7].

Table (1) Average values of shear failure pressure with their equivalent mud weight [6]

Formation		Minimum shear failure pressure (psi)	Average depth (m)	EMW (gm/cm^3)
Sadi		2618.70	2000	0.92
Tanuma		3907.75	2162	1.27
Khasib		3229.38	2203	1.03
Mishrif		2563.48	2280	0.79
Rumaila		3205.40	2396	0.94
Ahmadi	Ahmadi (Shale1)	4323.70	2450	1.24
	Ahmadi	3470.60	2514	0.97
	Ahmadi (Shale2)	4573.83	2571	1.25
Mauddud		3608.34	2641	0.96
Nahr Umr	NahrUmr Shale1	4862.03	2733	1.25
	NahrUmr Shale2	5015.69	2797	1.26
	NahrUmr Sandstone1	4563.92	2889	1.11
	NahrUmrSandstone2	5445.04	2943	1.30
Shuaiba		4323.81	3008	1.01
Zubair	Upper Shale	5608.58	3103	1.27
	Upper Sandstone	4294.38	3210	0.94
	Middle Shale	6148.79	3298	1.31

Optimization of drilling mud weight for vertical wells in Rumaila oilfield for the sake of gaining wellbore stability requires raising the drilling mud weight more than 1.27 gm/cm^3 starting from the bottom of Sadi Formation to the well total depth (bottom of Zubair Formation). This mud weight can help to decrease and minimize most of the breakout intervals except Nahr Umr sand2 and Middle shale where these zones require higher mud weight (more than 1.31 gm/cm^3). However, reaching such high mud weight may create induced fractures in the weak zones, which could lead to severe lost circulation; also, it may possibly cause reservoir damage as the mud solids penetrate deeply into the reservoir [8].

Figure (1) demonstrates the mud weight window (MWW) deduced from the margin between lowest value of average EMW of the Minimum Horizontal Stress (S_{hmin}) and highest average shear failure EMW at a vertical well in Rumaila oilfield. $S_{hmin,}$ which is also termed Fracture pressure or Tensile Failure is the pressure that fractures formations, when the minimum compressive stress and tensile strength that exceeds the formation pore pressure [6]. The lowest values of MWW are preferred and marked in green color [9].

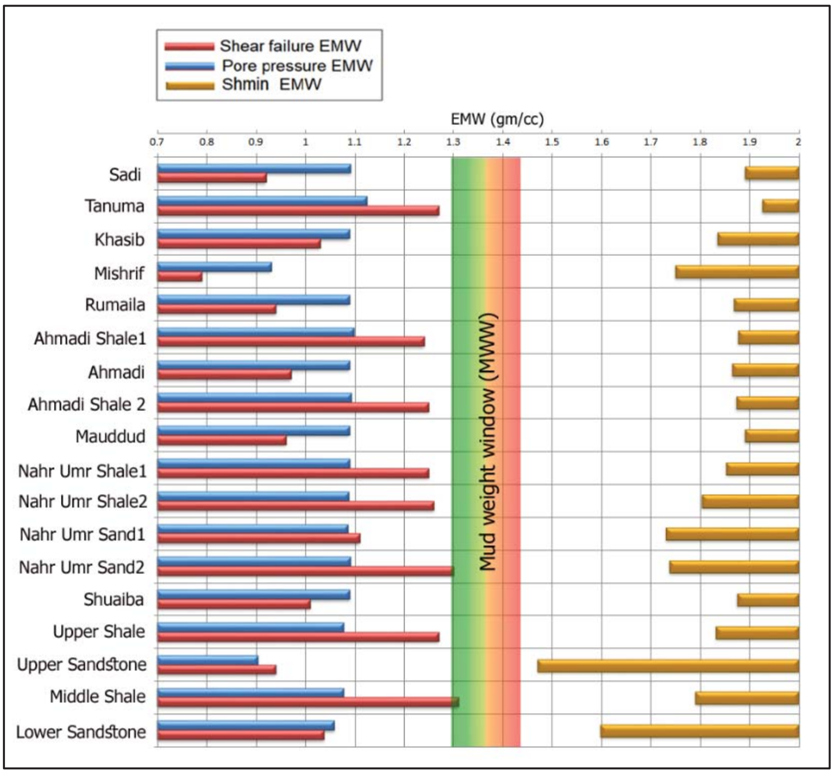

Fig. (1) EMW values for Pore pressure, Shmin and Shear failure with possible mud weight window for different formations (modified after [9]).

Directional and high angle wells optimization:

Directional drilling is a broad term that concerns all required activities for design and drill a wellbore to reach a reservoir target, or number of targets, is located at some horizontal distance from top of the hole. In other words, the purpose of directional drilling is to connect the surface location with oil or gas reservoirs . Also the directional drilling can be the solution in the event of the drill pipe becoming stuck in the hole by simply drill around it or plug back the well to drill to a replacement target [10]. It was concluded from previous Geomechanically studies that the optimized direction to drill deviated wells in Rumaila oilfield is NE or SW (parallel to the maximum horizontal stress) [6].
Four primary types of well shape are considered during planning a deviated well [11]:

Type I wells:

This kind of well profile is composed of a kicking off position, single build-up segment and a contiguous segment. This type is also titled Build and Hold Trajectory or L Profile Wells; which is drilled vertically from the top to shallow depth kicking off point (KOP). The well starting from the KOP is progressively deviated till reaching the desired direction and angle (Build section). Additionally, the established direction and angle are sustained (Hold section) during drill operation till the objective as presented in Figure (2). This technique is typically used while planning to drill wells with a one shallow producing reservoir [11].

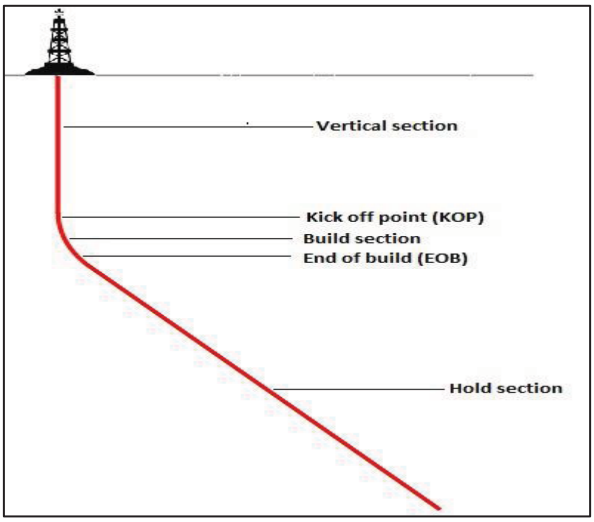

Fig. (2) Type I well directional plan

Type II wells:

Wells of this type are composed of a straight segment, a KOP, a section of buildup, a tangential segment, a drop-off segment and a hold segment till reaching the objective as illustrated in Figure (3). They are also termed (S shape wells). Type II are likewise Type I, where wells are vertically drilled from ground till KOP at a reasonably low depth, then the wellbore is gradually deflected efficiently till the wanted path and max angle are reached (Build section). The path and angle are continued till reaching definite depth (Hold section). Next, progressively and smoothly drop the angle (Drop section) till the well becomes nearly vertical. The well starting from the KOP is progressively dropped down till it becomes nearly vertical.

Lastly, the direction and the angle are continued until reaching objective depth as illustrated in Figure (3). Type II disadvantage is it may cause additional drag and torque for the deviated segment (especially between build and drop sections). Typically, this technique is utilized for penetrating several reservoirs or inclination reduction in the pay zone or to bypass fault regions or drill sidetrack wellbore due to drilling issues in the original wellbore [10].

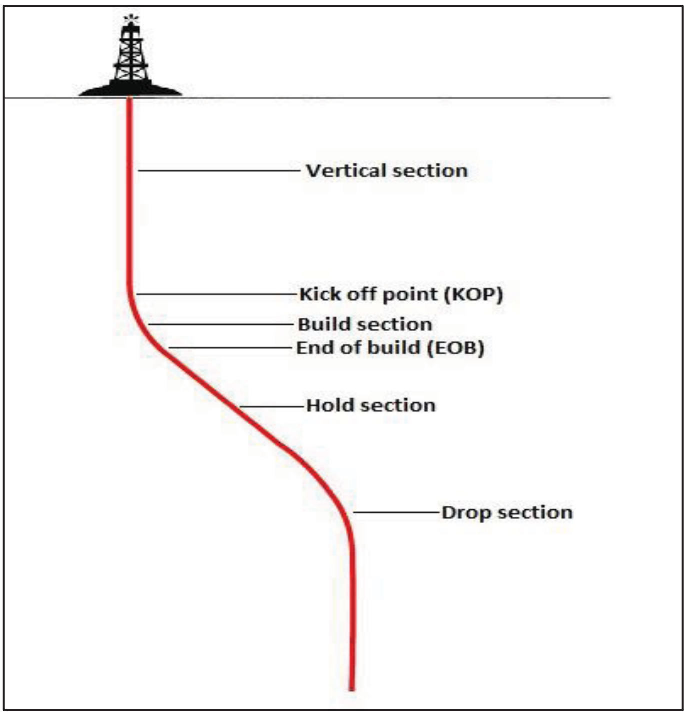

Fig. (3) Type II well directional plan

Type III wells:

The deep Kick off wells or J Profile wells (called Type III) includes a vertical segment, a deep KOP and a build-up to the objective depth. Wells from this kind are similar to type I apart from the KOP exists at a deeper depth and the last section is continuous build whereas in Type I the last section is Hold section. On the KOP the well is diverted, and deviation is made continuously along the interval of the objective (Build) as demonstrated in Figure (4). This kind of trajectories is usually implied in penetrating multiple zones of sand, faults, and Salt anticlines [12].

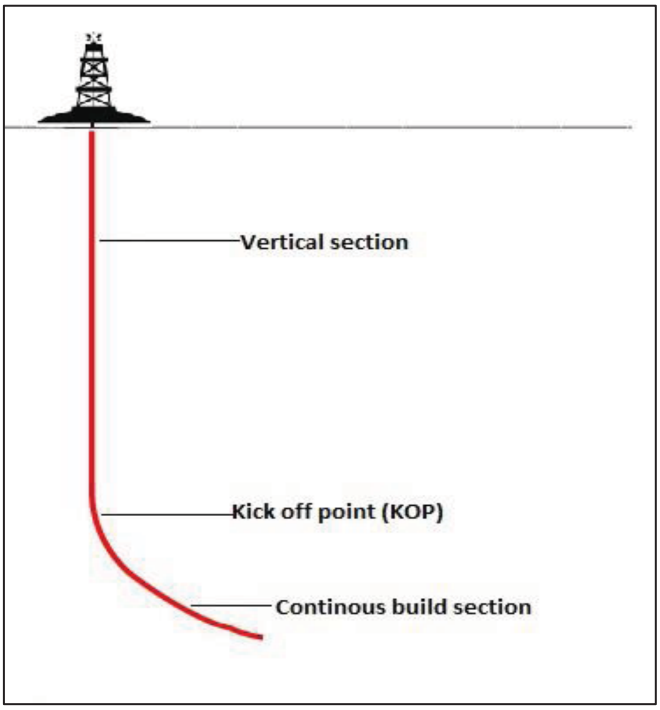

Fig. (4) Type III well directional plan

Type IV wells:

Wells from this type are composed of any one of previous trajectories in addition to a horizontal segment along the pay zone. This type is also termed Horizontal wells as shown in Figure (5). The horizontal segment is typically penetrated at 90^o and consequently the contributory additional calculations are straightforward as the required is the horizontal segment length so that the whole measured depth and entire departure of well can be elaborated [2].

Drilling horizontally can be implemented in production from thin zones of oil with gas or water cone issues leading to increase productivity of pay zones that are not been effectively depleted by vertical wells, also connection of the productive segments from the pay zones and raise production in low permeable pay zones by escalating the extent of formation exposed to the wellbore [9]. The cost of horizontal well could range from 20% up to 300% and it can enhance the production 2 to 10 times compared to a vertical well. Hence, a reduced wells number are needed for the field development [13].

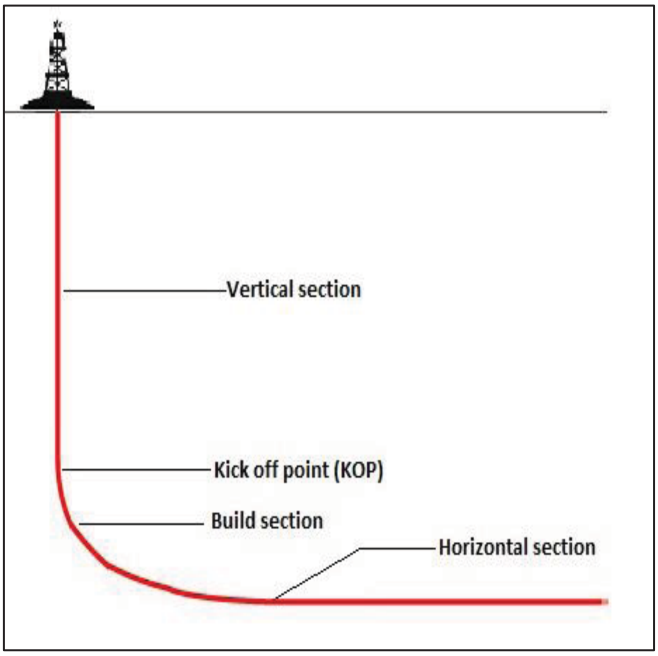

Fig. (5) Type IV well directional plan

Results And Discussion

Directional well proposals for Rumaila oilfield.

The four directional well profiles can be proposed for application in Rumaila oilfield, taking into account the field Geomechanically characteristics [6]. Also, the limitation of the volume of alteration in deviation and/or azimuth of the wellbore (Dogleg severity) commonly dogleg severity is stated in degrees for every 30 meters of path length [2]. The directional trajectory calculations can be made using the Minimum Curvature Method in excel spreadsheet [14].

1- Type I well trajectory:

As this trajectory is suitable to target reservoirs at medium depths which is suitable to penetrate Mishrif reservoir (2200-2400m depth). The proposed trajectory is displayed in Figure (6) and Table (2). The kickoff point was selected in Umm Er Radhuma Formation because its composed of thick homogenous Dolomite and also was not recommended to kick off in the Dammam Formation where drilling encounter mud losses issues. Furthermore, the Anhydrite lithology such as present in Rus Formation is not suitable for buildup.

The anticipated breakouts zone in this type of profile is the shale layers in Tanuma Formation only, where the estimated shear failure EMW is 1.23 gm/cm^3 at 20^o inclination, taking into account the preferred azimuth to drill is 50^o or 230^o (parallel to max horizontal stress direction) [9].

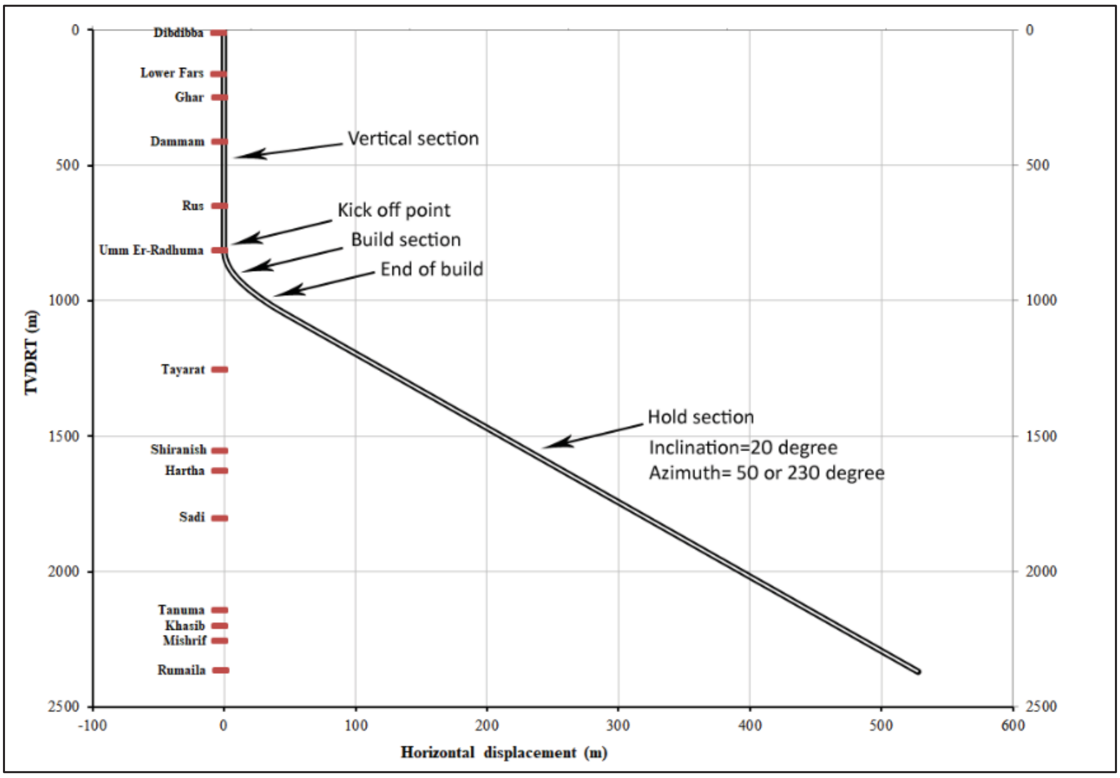

Fig. (6) Type I trajectory plan at 20^o inclination and 50^o azimuth targeting Mishrif Fm.

Table (2) Proposed trajectory profile (Type I) targeting Mishrif Fm.

Directional drilling segment	MD (m)	Formation	Inclination (deg)	Azimuth (deg)	TVD (m)	Horizontal displacement (m)	DLS (deg/30m)
Vertical section	0 - 810	Dibdibba - Umm Er Radhuma	0	0	0 - 810	0	0
Kick off point	810	Umm Er Radhuma	0	0	810	0	0
Build section	810 - 1050	Umm Er Radhuma	20	50 or 230	810 - 1044	0 - 42	2.5
End of build	1050	Umm Er Radhuma	20	50 or 230	1044	42	2.5
Hold section	1050 - 2460	Tayarat - Rumaila	20	50 or 230	2370	523	0

2- Type II well trajectory:

This type (S shape profile) can be recommended when the reservoir is required to be penetrated vertically to avoid deviated water coning and other reservoir depletion issues, or there is no available space on the surface to drill the well vertically. Kick off point (KOP) is the same as Type I profile except that the hold section inclination is higher (30^o instead of 20^o) for the sake of reaching the same horizontal displacement (≈500m) as shown in Figure (7) and described in Table (3). The Drop section was selected in Sadi Formation to avoid directional drop work in the deeper Tanuma Formation which has problematic shale breakouts. The disadvantage of this trajectory is all the predicted breakout zones in the well can be penetrated vertically and requires a higher mud weight to prevent breakouts as compared to inclined wellbores.

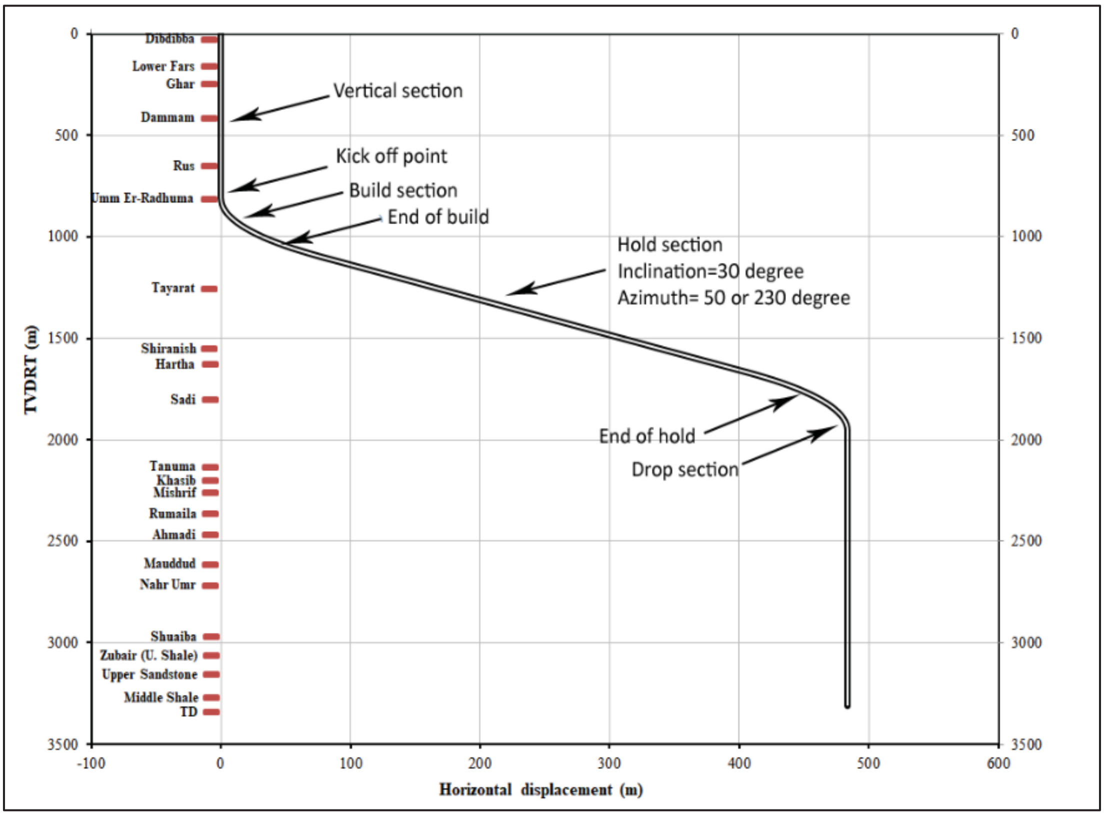

Fig. (7) Type II trajectory plan (S shape) targeting Zubair Fm.

Table (3) Proposed trajectory profile (Type II) targeting Zubair Fm.

Directional drilling segment	MD (m)	Formation	Inclination (deg)	Azimuth (deg)	TVD (m)	Horizontal displacement (m)	DLS (deg/30m)
Vertical section	0 - 810	Dibdibba - Umm Er Radhuma	0	0	0 - 810	0	0
Kick off point	810	Umm Er Radhuma	0	0	810	0	0
Build section	810 - 1110	Umm Er Radhuma	30	50 or 230	850 - 1096	0 - 77	3
End of build	1110	Umm Er Radhuma	30	50 or 230	1096	77	3
Hold section	1110 - 1770	Tayarat - Sadi	30	50 or 230	1096 - 1668	77 - 407	0
End of hold	1770	Sadi	30	50 or 230	1668	407	0
Drop section	1770 - 2070	Sadi	0	0	1668 - 1954	407 - 483	3
Deep vertical section	2070 - 3430	Sadi - Zubair	0	0	1954 - 3310	483	0

3- Type III well trajectory:

The well profile from this type is suitable for far-off targets (>500m horizontal displacement) targeting one or multi reservoirs directionally. In this type the well profile starts with vertical section from surface till the top of Sadi Formation, then the buildup section starts and ends within Sadi Formation which is deeper than Type I and II as presented in Figure (8) and clarified in Table (4). The buildup section was chosen to be in Sadi Formation because the shale layers in Tanuma Formation are not competent to undertake the buildup activities which can cause severe hole collapse. However, the thickness of Sadi Formation in decreasing in North Rumaila which require to set the KOP shallower (for example bottom of Hartha Formation).

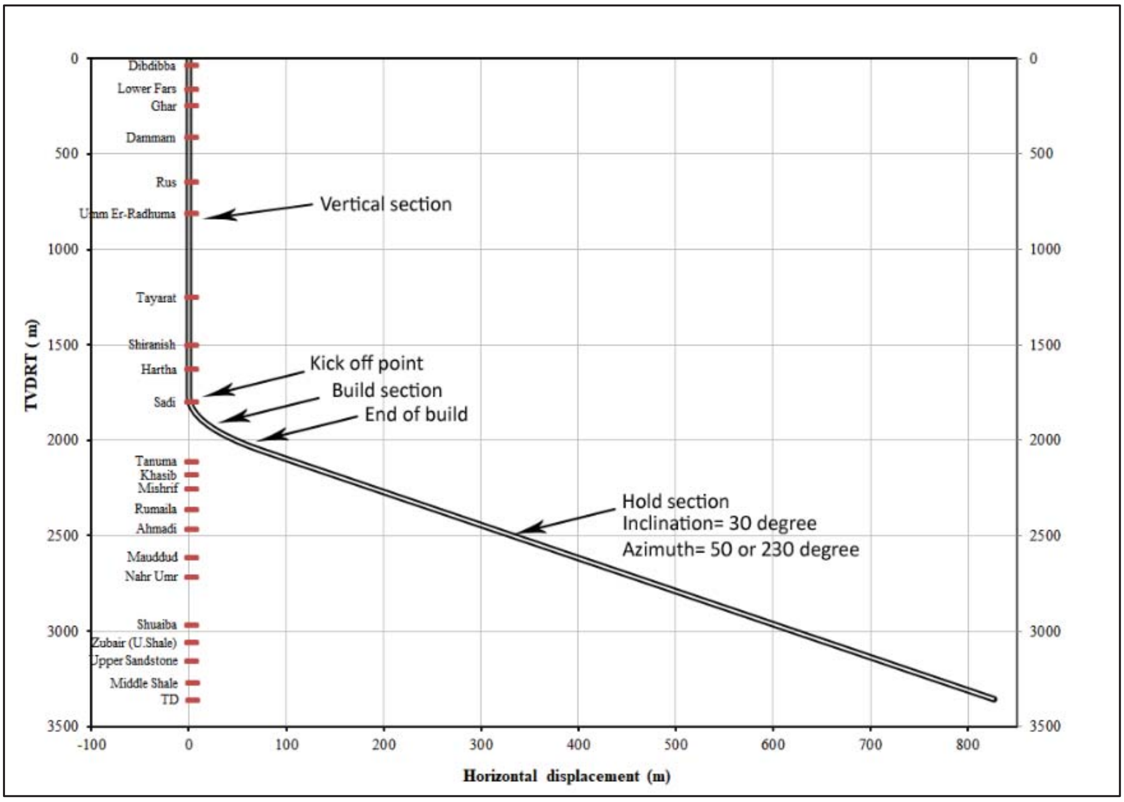

Fig. (8) Type III trajectory plan (30^o inclination and 50^o azimuth) targeting Zubair Fm.

Table (4) Proposed trajectory profile (Type III) targeting Zubair Fm.

Directional drilling segment	MD (m)	Formation	Inclination (deg)	Azimuth (deg)	TVD (m)	Horizontal displacement (m)	DLS (deg/30m)
Vertical section	0 - 1770	Dibdibba - Sadi	0	0	0 - 1770	0	0
Kick off point	1770	Sadi	0	0	1770	0	0
Build section	1770 - 2070	Sadi	30	50 or 230	1770 - 2056	0 - 50	3
End of build	2070	Sadi	30	50 or 230	2056	50	3
Hold section	2070 - 3525	Sadi - Zubair	30	50 or 230	2056 - 3316	50 - 521	0

4- Type IV well trajectory:

Drilling horizontal wells in Rumaila oilfield can play a vital role in raising oil production rates significantly because horizontal well exposure length to the reservoir is much higher than vertical or deviated exposure (can reach more than 1 km length); beside that the horizontal drilling cuts down the cost of drilling many vertical wells , processing time and equipment needed on the surface. Other advantage of horizontal well profile is that it is ideal to access and penetrate thin reservoir beds such as sandstone beds in the upper shale and upper sandstone Members in Zubair Formation. A suggestive trajectory plan is displayed in Figure (9) and explained in Table (5). The kick off point is as same as Type III (in Sadi Formation) towards maximum horizontal stress directions. However, the buildup inclination is higher (45^o). The hold section penetrates most of the predicted breakout zones with that angle; the deep build section was selected in Shuaiba Formation where inclination is increased gradually till reaching 90^o in Upper sandstone reservoir.

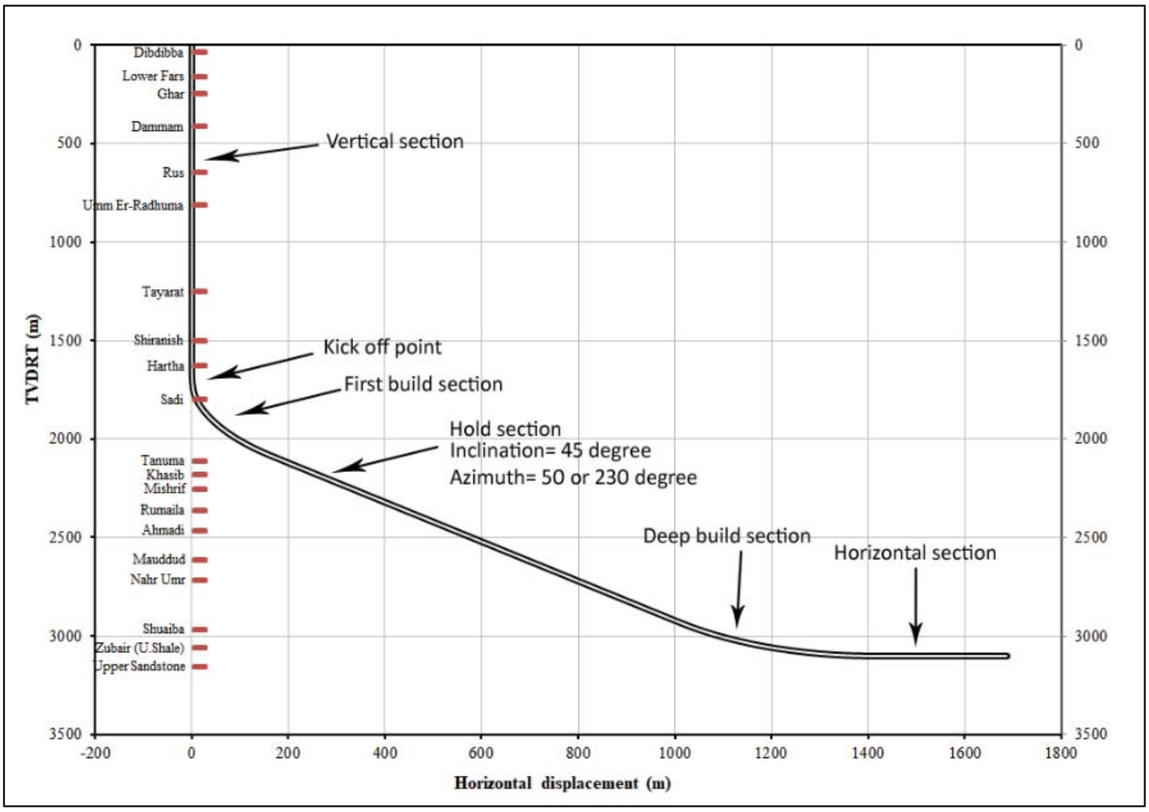

Fig. (9) Type IV trajectory plan for horizontal well targeting Zubair Fm.

Table (5) Proposed trajectory profile (Type IV) targeting Zubair Fm.

Directional drilling segment	MD (m)	Formation	Inclination (deg)	Azimuth (deg)	TVD (m)	Horizontal displacement (m)	DLS (deg/30m)
Vertical section	0 - 1680	Dibdibba - Hartha	0	0	0 - 1680	0	0
Kick off point	1680	Hartha	0	0	1680	0	0
First build section	1680 - 2130	Hartha - Sadi	0 - 45	50 or 230	1680 - 2085	0 -121	1 - 3
End of build	2130	Sadi	45	50 or 230	2085	121	3
Hold section	2130- 3330	Sadi - Shuaiba	45	50 or 230	2085- 2933	121 - 1013	0
End of hold	3330	Shuaiba	45	50 or 230	2933	1013	0
Deep build section	3330 - 3780	Shuaiba - Zubair	45 - 90	50 or 230	2933 - 3102	1013 - 1418	3
Horizontal section	3780 - 4050	Zubair Upper Shale	90	50 or 230	3102	1418 - 1688	0

Values of the shear failure equivalent mud weight (EMW) for each breakout zone in the proposed four well trajectory types are summarized in Table (6). As before, the equivalent mud weight (EMW) for shear failure is decreased when drilling deviated wells in the direction of S_{Hmax}, significant decrease in EMW will have positive effect on wellbore stability where a lower mud weight can be sufficient to maintain wellbore in stable condition.

Table (6) Shear failure EMW for each breakout zone in the four well types

Well profile type	Directional drilling segment	Inclination (deg)	Azimuth (deg)	Shear failure EMW in each breakout zone (gm/cm^3)							
				Tanuma	Ahmadi Shae1	Ahmadi Shae2	Nahr Umr Shale1	Nahr Umr Shale2	Nahr Umr Sand2	Upper Shale	Middle Shale
Type I	Hold section	20	50 or 230	1.26	Not reached						
			140 or 320	1.27							
Type II	Deep vertical section	0	0.00	1.27	1.24	1.25	1.25	1.26	1.30	1.27	1.31
Type III	Hold section	30	50 or 230	1.23	1.20	1.21	1.23	1.24	1.29	1.25	1.28
			140 or 320	1.27	1.22	1.23	1.24	1.25	1.30	1.26	1.29
Type IV	Hold section	45	50 or 230	1.18	1.16	1.18	1.19	1.20	1.25		
			140 or 320	1.26	1.20	1.22	1.22	1.23	1.27		
	Deep build section	70	50 or 230							1.17	
			140 or 320							1.21	
	Horizontal section	90	50 or 230								1.20
			140 or 320								1.26

Conclusions and Recommendations:

1- Four-deviated wellbore trajectory were suggested for implementation in Rumaila oilfield bychoosing the optimal trajectory depend on the target location and recommendation to penetrate it vertically or in certain angle.

2- The recommended kick off point in L and S shape wells in Rumaila oilfield should be in Umm Er Radhuma Formation due to limited drilling issues in that Formation, also it is not recommended to kick off in the shallower Formations such as Dammam Formation where mud losses events were encountered during drilling.

3- Horizontal well trajectory design requires two build up sections: 45^o inclination in Sadi Formation Section, and 90^o in Zubair Formation Section.

4- Dog leg severity (DLS) in deviated wells should not exceed 3 deg/30m to prevent drill pipe stuck and allow safe passage for the electric submersible pumps (ESP) during well completion.

5- It is recommended to avoid performing any build up or drop in the formations that cause drilling problems such as Dammam or Tanuma Formations because there is mud losses issue in Dammam and wellbore instability due to presence of Shale in Tanuma Formation.

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