CSCanada
Advances in Petroleum Exploration and Development
Vol. 9, No. 1, 2015, pp. 119-126
DOI:10.3968/6685

ISSN 1925-542X [Print]
ISSN 1925-5438 [Online]
www.cscanada.net
www.cscanada.org

Trajectory Control Technology of the Shallow Layer Cluster Horizontal Well in Western Margin of the Junggar Basin

YANG Chunxu[a], [b], *

[a] Shengli Petroleum Engineering Co. Ltd, Drilling Technology Research Institute, Donying, China.
[b] Petroleum Engineering College of China University of Petroleum, Qingdao, China.
* Corresponding author.

Received 8 February 2015; accepted 23 March 2015
Published online 30 March 2015

Abstract
The Pai 601 block of Shengli Oilfield in the western margin of the Junggar basin is the key block of capacity building in the Junggar basin, due to shallow kick-off points, strong anisotropy of oblique section of strata and the development of reservoir calcareous intercalation leads to very outstanding problem of Well trajectory control. Through using method of optimizing the KOP anddrilling well path design method which correct the dogleg that based on the steerable BHA and formation anisotropy, combiningbuildup section and horizontal landing phase of the BHA and drilling parameters optimization, which has solved the problem of shallow layer cluster horizontal well trajectory control in western margin of the Junggar basin. Through the technology applications of the 200 shallow horizontal wells, a set of shallow horizontal well trajectory control technology which was suitable to the west margin of in Junggar basin was formed.

Key words: Shallow layers; Junggar basin; Cluster horizontal wells; The drilling well trajectory design; Well trajectory control

Yang, C. X. (2015). Trajectory control technology of the shallow layer cluster horizontal well in western margin of the Junggar basin. *Advances in Petroleum Exploration and Development*, *9*(1), 119-126. Available from: URL: http://www.cscanada.net/index.php/aped/article/view/6685
DOI: http://dx.doi.org/10.3968/6685

INTRODUCTION
The degassed viscosity of the west margin of Junggar basin in Xinjiang 601 block crude oil is in 50,000 and 90,000 mPa·s which belongs to super heavy oil reservoir. In order to improve the comprehensive exploit effect, the block used the whole cluster horizontal well development technology, nearly 800,000 tons of production capacity construction goal has been achieved, become the western oil and gas development, especially the successful example of super heavy oil development, which has greatly promoted the development processing of the western new block exploration and development of Shengli oilfield. Because of generally shallow kick-off points, The characteristics of reservoir calcareous intercalation development is outstanding, which has put forward new requirements to cluster horizontal well trajectory control, the main technical problems including as follow:

(a) The vertical section is short, and the ratio of displacement than vertical depth is large, weight on bit (WOB) transfer difficulties. The block reservoir layer depth is 425-610 meters, and The ratio of displacement than vertical depth is close to or even more than 1, which is prone to the phenomenon that the upper section weight of drilling tools is unable to resist the well fraction, and lead to problem that difficult to transfer WOB in horizontal section during the drilling.

(b) Shallow kick off point, loose cementation of the stratum, difficult to build up during initial direction[1-2] .

(c) The three-dimensional well path design of shallow layer and the precision of well trajectory control are of high requirements. Because the block using cluster horizontal is well to exploit, the design of three-dimensional well path is inevitable, in addition shallow objective layer and limited adjustment space of well trajectory control of buildup interval. Therefore, the precision of trajectory control accuracy requires higher.

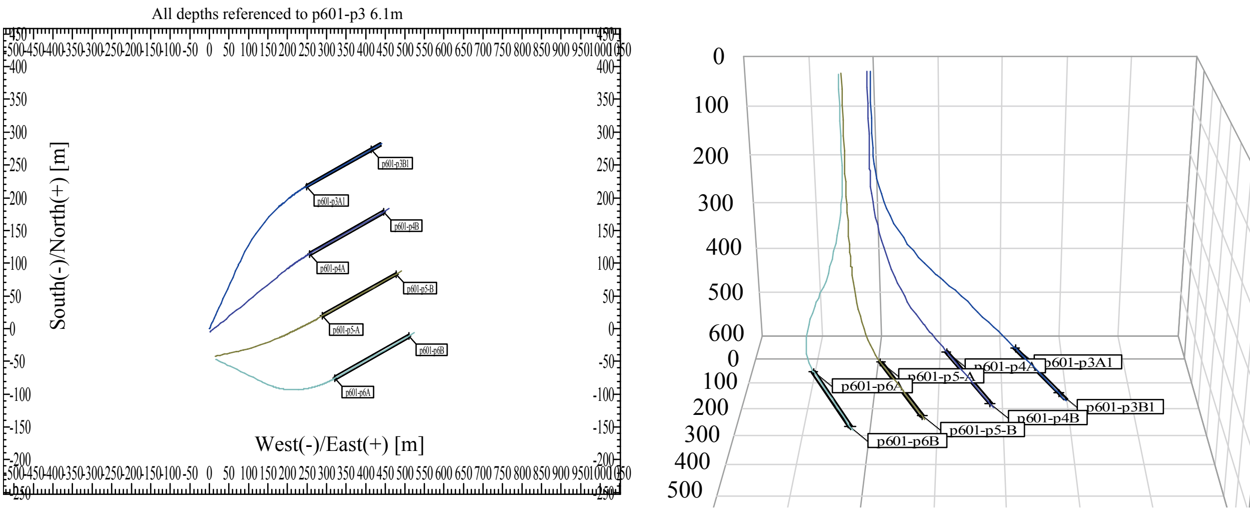

Figure 1
The Location Map Projection of 4 Wells in Same Platform

(d) Because of the development of conglomerate in the bottom of group Taxihe, big thickness and diameter of gravel layer, which is incompact and unbreakable and easy to form fragments, that result instability to the surface of oriental tools, which exert influences to the directional construction safety and the effectiveness of well trajectory control.

(e) The formation heterogeneity is serious, which give a great influence to the BHA's build up ability, and difficult to land for the horizontal section. The mainly problem to the construction of the horizontal well landing section in the block including two aspects: One is the cap rock of target stratum of Shawan group at the block developed a set of water-sand layer which has about 10meters thickness in vertical. Because those sand cementation heterogeneity is very serious, lead to large change of rate of overall angle change during the drilling and affected the well trajectory control seriously. Second is the uncertain cap rock thickness of mudstone lead to uncertain vertical depth of target stratum, greatly increase the difficulty of revised the trajectory design of landing section which based on thickness of mudstone. Third is the thickness of the bottom of mudstone is different from lime layer which developed from target stratum. Because of the great uncertainty control of the landing dogleg degree and into the oil on the top angle of inclination, the difficulty of controlling landing section further increased.

(f) The lithology in the horizontal section are of complex, it is difficult to control the well trajectory. The lithology of the target stratum in the block are complex. Some developed of conglomerate are very thick, a bouncing phenomenon is serious. Some mudstone are mix up with sandstone, the balling bit suppress pump. Some physical properties is good, and the drilling speed is very fast, the formation drill ability is low and easily broken, and there will have the phenomenon of low rate of build up even if with continuous buildup, some of them is high content of limestone, affected by the relationship of well shape and calcareous intercalation space, the rate of over all angle change is big.

1. THE WELLPATH OPTIMIZATION DESIGN TECHNOLOGY OF SHALLOW CLUSTER HORIZONTAL WELL

1.1 The Optimization Kick off Point (KOP)

The significant difference of conventional horizontal well and shallow horizontal well is the KOP is very shallow. Because of the loose formation cementation, the building up ability of guiding drilling tools is lower at the initial buildup section and the dogleg is always difficult to meet the demand of design. At the same time, as lack of the vertical space, it is impossible to low the KOP to solve the problem. Therefore, at the Pai 601 block, the optimization of KOP should follow the principle as below: If the depth of the design KOP is not less than 200 m, the KOP should be advanced 10 m, or if the depth of KOP more than 200 m, we can reduce the advance distance properly, this principle mainly based on the follow two factors:

(a) The KOP advanced can raise the vertical space between KOP and the target, and increase the tangent section length, slows down the low dogleg of initial building up section leaded to a problem that the dogleg must be higher at the later stage of building up section.

(b) If the initial dogleg reached the design requirements of engineering design, the tangent section will be last longer in the later stage of building up section, and we can obtain the initiative of construction in the landing period of horizontal well.

1.2 The Drilling Well Path Optimization Design Technology

During the well path design, designer can only depend on the offset well drilling data and use the relatively fixed dogleg for the well path design. But in actual construction, the dogleg will be changed in a long span, therefore the core problem of horizontal well trajectory control is to how to handle the dogleg properly, make it as far as possible close to the design value or meet the requirement of landing.

In addition, not only the controllable factors such as the characteristic and parameters of the BHA, but also the uncontrollable factors such as situation of formation cementation, which is formation property[3]. In using the same set of steerable BHA, under the condition of the same drilling parameters, in different formation of the dogleg change is not the same. For example, the block used to use the BHA of single bent and stable with 1.75 degrees, which have a full building up dogleg above 45°/100 m in a dense cementation mudstone formation of the bottom of Shawan, and in the mudstone of the upper water sand formation to build up dogleg often only 25°/100 m or so, in the initial stage of directional unconsolidated formation, dogleg tend to be less than 20°/100 m.

Based on the above considerations, the author advocated a design theory that "Based on steerable BHA and formation anisotropy to correct the dogleg". According to the real drilling data, the statisticsaboutdogleg of steerable BHA drilling in different formation was completed. While design the drilling trajectory in later, we can confirm the mainly formation parameters according to the results of formation evaluation while drilling and combine the former statistical laws, to determine reasonable dogleg, and lay a foundation for forming controllable design of the drilling well path, that can solve the difficult of dogleg prediction a large extent due to different formation changes and the high risk of uncontrollable trajectory.

The Table 1 shows the statistics of build-up rate in the different vertical deep corresponding steerable BHA in the Pai 601 block, which can provide guidance for drilling well path design.

Table 1
The Steerable BHA's Build-up Rate in Different Vertical Depth in Pai 601 Block

Vertical depth (m)	Rock characteristics	Formation name	The build-up rate of 1.5° single bend steerable BHA angle building hole rate angle building hole rate (°/100 m)	The build-up rate of 1.75° single bend steerable BHA (°/100 m)
Wellhead -345	It consists of primarily mudstone, mixed up with sand conglomerate, sandstone thickness thin, majority of them are flow sand layer.	Xiyu formation Dushanzi formation	15-25	25-30
345-425	The conglomerate at the bottom of Taxihe, mainly for the gravel, with a large thickness, gravel size is big, it is of loose and unbreakable to fragment.	Taxihe formation	20-25	25-30
425-480	It consists primarily of mudstone, mixed up with sand conglomerate,	Shawan formation	20-25	25-35
480-490	Gravel sand layer water, fast in drilling speed	The bottom of Shawan formation	10-15	15-20
490-510	Mudstone, vertical thickness about 21.4m, slow in drilling speed, Easy to hold the pump, the mark layer	The cretaceous system	25-35	30-40
510-bottom of a well	Target layer, mixed up gravel with fine sands, oil & gas showing active, loose cementation and of a faster drilling speed	The cretaceous system	At the top of reservoir developed a set oflime layer, when drilling in the lime layer, the build-up rate of rotary drilling is of about 10 to 20°/100 m. But the thickness development of the lime layer is of irregular, some of them are of 2 m, the others less than 0.2 m, and rotary drilling shown a drop trend when drilling into oil reservoir, the single bend with 1.5° steerable BHA can reach about 10 to 20°/100 m while continuous building up, but the single bend with 1.75° steerable BHA can reach about 20 to 30°/100 m .	

It is not difficult to discover from the data of the table above, the building up ability of BHA influenced by lithology, layer thickness, the control well trajectory technology and rate of penetration obviously. So in actual operation, the above for drilling well path design ideas need specific implementation from following several aspects:

(a) The geological logging and the results of the logging while drilling were integrated. The single well formation evaluation and interpretation while drilling need to be strengthened.

(b) The sharing platform of engineering-geological data was established, which was used to real time contrast of real drilling profile and spatial relation to the drilling the formation and target formation. The contrast of drilling engineering data and geological data are to conduct and the drilling well path design for each single pipe. The drilling well path design of landing section was improved gradually in order to ensure vector target.

(c) The law of build-up about steerable BHA in limestone interlayer was analyzed based on the characteristics of the high response resistivity level of limestone formation[4].

(d) According to preliminary statistical rules and requirements for drilling well path design to, the BHA & the drilling parameters and the drilling methods and penetration analysis was optimized.

(e) The model of real drilled formation distribution of the block was established. The reservoir design model was refined and modified for guiding subsequent horizontal well drilling engineering design.

2. WELL TRAJECTORY CONTROL TECHNOLOGY

The core problem of horizontal well trajectory control is how to control the change rate in a relative reasonable range. The same BHA and drilling parameters in different layer and block can show the different build-upcharacteristics. Therefore, the selection BHA properly can improve the control precision of well trajectory and reduce the lost caused by replace drilling tool, in the process of construction of the shallow heavy oil cluster well in Pai 601 block, the single bent steerable BHA with a stabilizer was used mainly.

According to the demand of dogleg design in different formation and the preliminary operation experience, the BHA program was recommended as bellow:

The first trip (Before logging while drilling system into well), BHA: Φ241.3 mm bit + Φ197 mm (1.5°) single bend PDM + Φ127 mm non-magnetic drill pipe + MWD + Φ127 mm heavy weight drill pipe + Φ127 mm drilling pipe.

The second trip (During logging while drilling system into well), BHA: Φ241.3 mm bit + Φ197 mm (1.75°) single bend PDM + LWD + Φ127 mm non-magnetic drill pipe + MWD + Φ127 mm drill pipe + Φ127 mm heavy weight drill pipe.

Before the logging while drilling (LWD) system into well, the design of build-up rate is low, has not yet been drilled in Shawan formation of water sand, so the selection of 1.5 degree motor completely meets the demand of design of dogleg. After running LWD system into well, in order to prevent low build-up rate from water sand layer of Shawan formation, at the same time considering the rotary drilling inclination will drop slightly in the reservoir at the same time, the larger degree 1.75°motor was selected to drill which can adjust inclination in horizontal section timely.

2.1 The Directional Drilling Section

The BHA (before logging while drilling system into well): Φ241.3 mm bit + Φ197 mm (1.5°) single bend PDM + Φ127 mm non-magnetic drill pipe + MWD + Φ127 mm heavy weight drill pipe + Φ127 mm drilling pipe.

Drilling parameters: WOB 30-80 kN, pump pressure 8-9 MPa, flow rate 28-33 L/s.

The depth of kick off point between 150 to 300 m in the block, given loose shallow layer, in the initial directional section (Inclination < 10 degree) , pump flow rate was controlled less than 28 L/s and effective weight on bit (WOB) was ensured under the premise of tool surface stability, generally the WOB was needed to control about 40 kN. When inclination greater than 10 degree, the flow rate can been increased to 33 L/s gradually and the WOB can been controlled between 40 and 80 kN. The slide drilling and rotary drilling were combined, well trajectory parameters were real time detected by wireless measuring while drilling (MWD) and revised the drilling well path design. The dogleg was control strictly in order to ensure effective control of well trajectory[5]. As inclination about 40 degrees, the MWD was needed to replace LWD according to the demand of engineering design.

Geo-steering BHA: Φ241.3 mm bit + Φ197 mm (1.75°) single bend PDM + LWD + Φ127 mm non-magnetic drill pipe + MWD + Φ127 mm drill pipe + Φ127 mm heavy weight drill pipe.

Drilling parameters: WOB 80-100 kN, pump pressure 10-12 MPa, flow rate 30-35 L/s.

The SLBF-LWD which was independently researched and developed by Shengli oilfield was used in the process of drilling operation, it can real time measure natural gamma and induction resistivity. In the process of drilling operation, according to the drilling geological parameters and the drilling time condition, the water layer location of the top of mudstone at Shawan formation was confirmed. As shown in Figure 2, drilling a well to depth of 583 m, the value of resistivity fell from 1.3 to 0.8 ohm·m and the value of gamma increased from 60 to 100-120 API, and the drilling time become fast, we can judge into water-sand layer. while drilling to the depth 593 m, the rate of penetration (ROP) become slow, the value of resistivity increased from 0.8 to 1 ohm·m, the value of gamma increased to 180API, while that depth of 587 m the resistivity peak to 2.0 ohm·m, and we can determine 593 m is the top of mudstone. So we can adjust the drilling well path design of the section as follows.

Table 2
The Design of Drilling Well Path

MD (m)	Inc (°)	Azi (°)	TVD (m)	NS (m)	EW (m)	V. Sec (m)	Dogleg (°/100 m)	T. Face (°)	Target
593	65.76	59.17	529.58	92.9	134.01	154.11	0	0	
606.85	70.27	58.32	534.76	99.56	144.99	166.48	33	-10	
616.35	72.45	58.32	537.8	104.29	152.65	175.13	23	0	
693.88	84	62.5	553.5	141.65	218.55	248.67	15.8	20	
796.74	90	74.34	559	179.32	313.87	350.62	12.89	63.5	A
990.04	90	74.34	559	231.49	499.99	543.92	0	0	B

Table 3
Original Well Path Design

MD (m)	Inc (°)	Azi (°)	TVD (m)	NS (m)	EW (m)	V. Sec (m)	Dogleg (°/100 m)	T. Face (°)	Target
0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	
276.66	0.00	0	276.66	0.00	0.00	0.00	0.00	0.00	
600.27	71.20	55.73	523.19	176.49	99.37	145.85	22.00	0.00	
620.84	71.20	55.73	529.82	195.95	110.33	161.94	0.00	0.00	
784.68	90.00	74.34	556.70	354.90	177.28	307.45	16.00	43.13	A
984.70	90.00	74.34	556.70	550.95	231.28	500.05	0.00	0.00	B

According to the drilling data, the depth of mudstone roof is 593 m, and vertical depth is 529.5 m, combining with development of mudstone in the block, the thickness is about 24 m. Therefore, we forecast the vertical depth of oil roof is 553.5 m, the oil thickness of the block is about 8m. According to the offset well data, according to the process requirement of heavy oil exploitation, the well trajectory of horizontal section travel in the lower part of the reservoir is more conducive to heavy oil thermal recovery. So the vertical depth of target A is 559 m after revised, the whole mudstone section of well depth from 616.35 to 693.5 m need dogleg of 15.8°/100 m, the steerable BHA can completely meet the demand and enlarge proportion of rotary drilling section, which can improve the ROP. After drilling into reservoir, as the loose cementation is of 693.88 to 796.94 m, the steerable BHA have a low build-up ability. However, the dogleg must reach to 12.89°/100 m after revised, according to the statistics law of the drilling build-up rate also satisfy the correction of the design requirements, to ensure the later operation can accomplished smoothly.

According to the top of drilling mudstone and thickness of mudstone of offset wells to predict the depth of oil top and prepare for landing. Short tripping should been conducted before landing, which can destroy the cutting bed timely, clear the borehole, ensure smooth borehole rules, prevent new wellbore emerge when running in,and ensure safety of the following operation. Besides, by inversion the drilling tools, the heavy weight drill pipewere put in the section of vertical andinclination that less than 30 degrees section. It isadvantageousto transferthe WOB and achieve the aim of improving build-up rate.

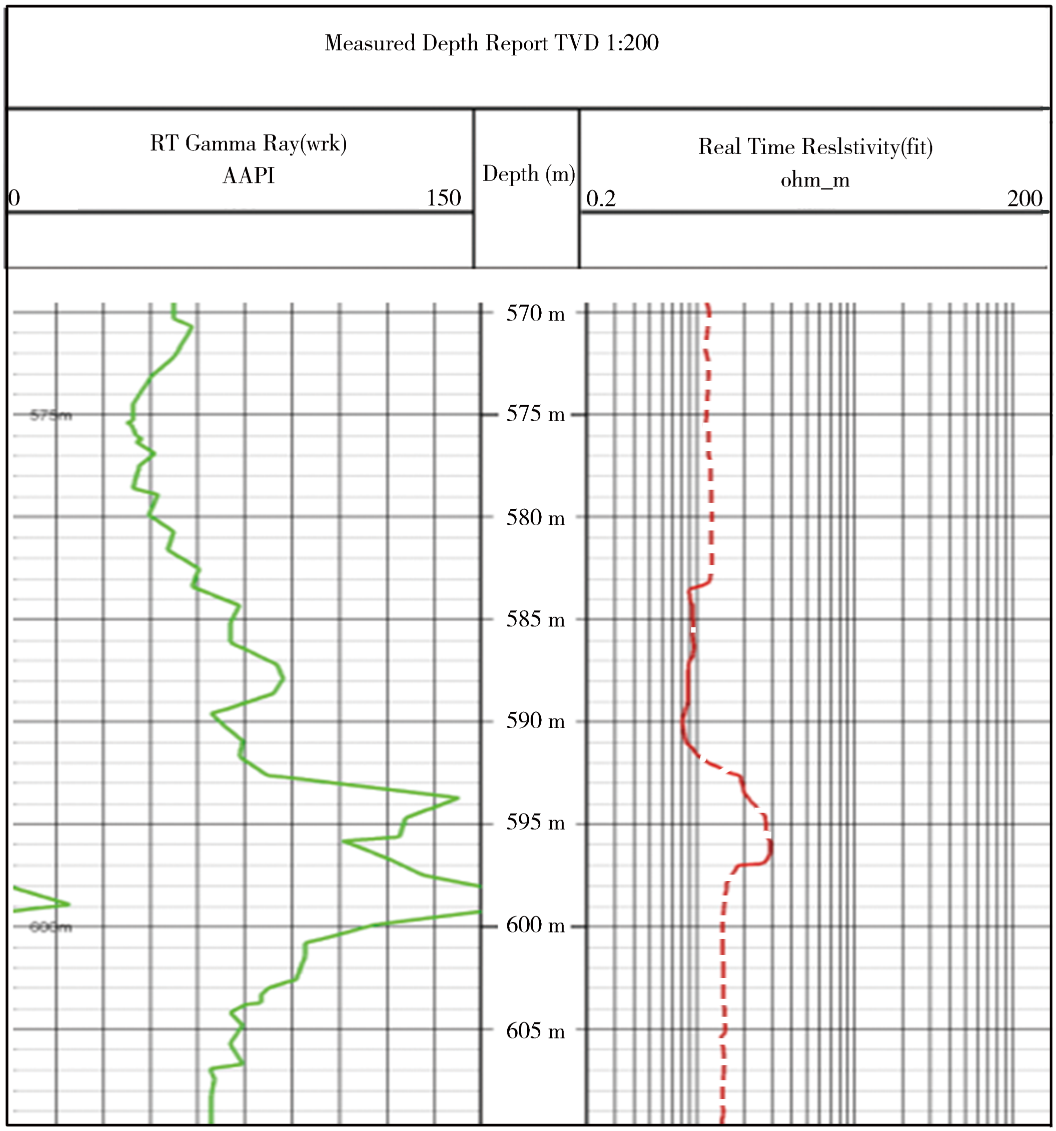

Figure 1
The Comparison Diagram of Water Layer of Gamma and Electrical Resistivity

2.2 The Landing and Horizontal Section

Geo-steering BHA: Φ241.3 mm bit + Φ197 mm (1.75°) single bend PDM + LWD + Φ127 mm non-magnetic drill pipe + MWD + Φ127 mm drill pipe + Φ127 mm heavy weight drill pipe.

Drilling parameters: WOB 80-100 kN, pump pressure10-12 MPa, flow rate 30-35 L/s.

Landing section: The value of resistivity and gamma should been strengthened the monitoring while drilling nearthe oil top. Based on drilling time curve and total hydrocarbon show and sand sample to analysis of the oil top position comprehensively, so as to achieve purpose of accurate landing.

(a) On the basis of actual drilled vertical depth of mudstone top and the drilled offset datato confirm the thickness of mudstone, predict the vertical depth of oil top.

(b) On the basis of expected oil drop deep to determine the target A deep, according to the actual drilling data to optimize the landing profile.

(c) The inclination into the top of the oil was optimized based on the current depth measured well trajectory parameters data, comprehensive considering the build-up rate when steerable BHA drilling in lime layer and the thickness of lime layerΔh1.

(d) Drilling through lime layer with the inclination (as shown in Figure 3), when drilling encounter a faster ROP, the combination of total hydrocarbon values and value of resistivity and gamma value with drilling, the inclination should been increased to about 90 degrees at a right opportunity in horizontal section drilling.

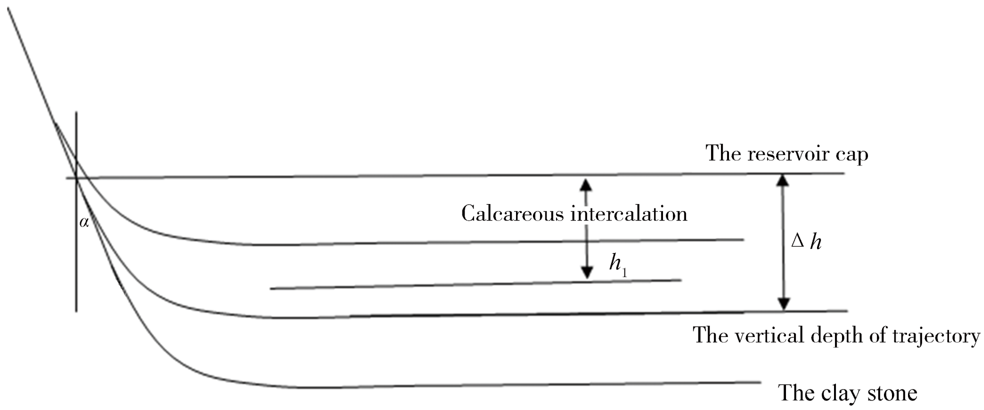

Figure 5
The Horizontal Well Landing Control

Horizontal section: By using the LWD geo-steering technology, strengthening the monitor of the value of resistivity and gamma, combining with drilling time curve and the show of total hydrocarbon and the condition of drilling mud cuttings to analyze the location of well trajectory in the reservoir layer,consists primarily ofrotary drilling,and slide drilling must confirm a principle that adjust subtly and diligently, control the dogleg strictly, achieve an effective well trajectory control of vertical depth and horizontal shake[6] and the realization the aim of geo-steering, to make the rate of drilling encounter reservoir of the trajectory reach maximum.

3. THE EFFECT OF TECHNOLOGY APPLICATION

As of 2014 December, by using the shallow layer horizontal well trajectory control technology more than 200 shallow layer horizontal wells have been completed at Pai 601 block of Jungar basin of Xinjiang, all of those wells have been achieved a precise target and the rate of drilling encounter reservoirhave been up to 98%, which have been met the demand of reservoir exploitation and achieved a good effect (as shown in Table 3).

Table 4
Partially Well Completion Condition in Block Pai 601

No.	Well No.	The KOP (m)	Well depth (m)	TVD (m)	Horizontal displacement (m)	The rate of drilling encounter reservoir (%)
1	Pai601-Ping62	175	908	513.07	504.85	100%
2	Pai601- Ping 63	208	886	516.67	493.4	100%
3	Pai601- Ping 64	248	900	520.52	494.34	100%
4	Pai 601- Ping 65	193	916	521.24	513.21	98.8%
5	Pai 601- Ping 22	150	902	470.04	551.55	100%
6	Pai 601- Ping 23	190	848	470.74	495.5	100%
7	Pai 601- Ping 24	207.2	860	475.66	495.85	99%
8	Pai 601- Ping 25	158	867	477.45	508.08	100%
9	Pai 601- Ping 26	179.9	874	476.61	510.23	100%
10	Pai 601- Ping 27	192	856	484.19	489.23	100%

CONCLUSION

(a) By analyzing the single bent sliding steerable BHA's building up characteristics of drilling in different formation at the block Pai 601, the BHA's dogleg was counted in different formation while drilling, and gave a well path design method of "Based on steerable BHA and formation anisotropy to correct the dogleg", using the method can reduce the difficulty of well trajectory control and improve the control effect of horizontal well trajectory.

(b) The landing section control and horizontal section control is the key to the horizontal well trajectory control. Therefore, the selection of the steerable BHA and the confirmation of the dogleg, optimization of theinto the oil on the top angle of inclination, the real-time monitor and calculation of parameters of well trajectory, the real-time monitor of the value of the resistivity and gamma (LWD), are the important technique of horizontal well trajectory control.

(c) The drilling well path design technology and well trajectory control technology in different lithology were discussed and applied by using the statistical method. Technical effect has been revealed preliminarily. But not yet discuss the factors for other application methods which affect the well trajectory such as lithology, thickness of formation, hole space form, evaluation of formation anisotropy, therefore, so it is necessary for well trajectory influence factors in a systematic and quantitative discussion.

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