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Research and Practice on Key Technology of Drilling Ultra-deep Horizontal Wells at Southeast Block in Gulf of Mexico

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Abstract: ***It is complicated for geologic condition at Southeast Block in the Gulf of Mexico, which has a serious impact on the scientificity of drilling design and pertinence and validity of drilling technical measures. Based on it, the paper explored the application of key techniques. For example, optimum design technique of deep wells and ultra-deep wells under complicated geologic condition, and oil base drilling fluid technique with high density, high temperature resistance and anti-pollution, and prevention and treatment techniques for complicated situation and accidents under wells. Another example cementing quality techniques of complicated formation intervals and small clearance, and special drilling techniques with advanced technical facilities. The series of techniques work very well at this block by resolving the drilling difficulties in complex situations (e.g. many pressure systems, long open whole, bad stability of well wall and high temperature and pressure during drilling, and bad possibility of drilling deep stratigraphic rock.) This research would be helpful for technical development of ultra-deep extended reach horizontal well at home and abroad.***

Keywords: Ultra-deep extended reach horizontal well, Rotary steering, Oil-based drilling fluid, Drilling Technique

1. Analysis of Difficulties in Drilling Technique

Uncertainties like heterogeneity of ground stress, state of formation and soil type, depth of formation with geologic layers and completion in Southeast Block in Gulf of Mexico gravely affect the of drilling design and pertinence and availability of drilling technical measurement. Therefore, they increase the difficulties in optimization of well structure, stability of borehole, controlling of well trajectory, improvement of mechanical drilling speed, and prevention and treatment of complicated situations and accidents. There are many occasions of sidetrack, stuck, lost circulation and deaeration and chock during drilling in recently construction of BAC-100， BAC-200， BAC-201， BAC202 and situations like repeatedly downhole collapse and blocking of oil passage during extracting oil. They prompted us to analyze technical difficulties during construction.

1.1. Large Friction and Torque, and Difficult Pressure Transmission for Drilling Tool

Horizontal section of ultra-deep extended reach horizontal well with high vertical depth ratio, thus the drilling tool is easy down to well wall with difficult cuttings return. In addition, the friction increases in proportion to the depth. In addition, the changes for wellbore trajectory of ultra-deep horizontal well greatly increase friction. Besides, long open hole section, long construction time and borehole immersion in drilling fluid in long term, mud rock is easy to hydration and swelling, which makes well wall unstable, collapsing, breaking and stuck are easily to happen[1].

1.2. Difficulties in Carrying Solid, Easy to Form Cutting Bed

Because of long maintain angle section and horizontal section, eccentricity of drilling tool, large annulus, difficulty in cutting returns, and low delivery speed, it is easy to be piled up at the bottom of well, and it forms cuttings bed, which increase friction between drilling tool and well wall, it is easy to cause down hole accidents[2].

1.3. Complicated Wellbore Trajectory in Actual Drilling

It is hard to control wellbore trajectory in actual drilling, and there are some errors of the actual trajectory compared to the original design. Lack of optimization for wellbore trajectory, it causes serious problems, such as large friction and torque, severely bending of dill stem, difficulties in putting out of and running in hole, difficult manipulation, which is easy to cause difficulties in stuck and running in completing casing string, and increases construction difficulty.

1.4. Complicated Situation Downhole

There are many pressure systems, because low-pressure layers and high pressure layers coexist, it is difficult to confirm the position thief zone. There are low-pressure thief zones at Southeast Block in Gulf of Mexico with uncertainty of it, and the upper non-reservoir contains low-pressure thief zone, and middle and lower reservoir contains low-pressure thief zone too. In addition, it shows the loss as high pressure of liquid column and returns of drilling fluid as decreasing pressure of liquid column, which makes plugging agent not stick in the thief zone, forms blocking layer of plugging agent and causes bad effect of blocking. Besides, because of uncertainty of thief zone, and long open hole section, it is difficult to achieve pressure bearing and lost circulation. When the depth is more than 4000m, oil production, asphalt production and sand production are serious, which cause over pull in running in hole and casing. Therefore, it must ream the hole repeatedly. However, it is slow to do it the hole and easier to generate the new hole. Taking BAC122 for an example, lithology analysis of well section is shown as figure 1 (from 4061m to 4858m , total 791m).

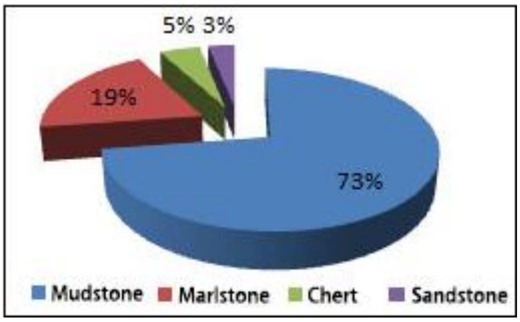

Figure 1: Analysis of Formation Lithology (formation lithology analysis from section 4061m to 4858m)

Mudstone and marlstone with strong water sensitivity are in the majority in the block. The formation section composed of mudstone and marlstone shares more than 90%, and chert and sandstone only shares 5% and 3%. The formation with large mudstone or marlstone has strong water sensitivity which is easy to absorb water for expansion and dispersion, and it causes extremely instability of well wall so that stuck and over pull with the risk of lost circulation and blow out, which has become the world-level difficulty in drilling.

2. Research and Practice on Core Technology

2.1 Optimization of Wellbore Configuration

2.1.1 Optimized Selection of Wellbore Configuration

During design of wellbore configuration, it needs to consider optimized selection in size of casing and drilling bit and coordination for casing and intervals between wellbores together. There are fully consideration and emergency plans for possible complicated downhole situations, thus providing effectively corresponding solution to specific situation. Not only ensure drilling by fast and safe way, but also provide reserved plans for different complicated situations. Adopt backward induction on design from the bottom up gradually to confirm setting position. Confirm the maximum loading capacity and minimum completion size in casing shoe, thus identifying hole size of wellbore and considering reserving sequence of primary or secondary casing for size adjustment at the same time; besides, it is possible to consider run in flush joint casing for changes of design in engineering geology and problems of running in big size casing. After confirmation of casing sequence, on the calculation basis of maximum density of drilling fluid and critical value of differential pressure and stuck, under precondition of stability of well wall, ensure an interval value of running depth for each casing layer (especially the main technical casing), so the interval can be adjusted according to formation and length of casing [3].

2.1.2 Confirm proper pre-target distance and build-up rate

Selection of pre-target distance and build-up rate is the key for design of wellbore trajectory. If pre-target distance is long, then the horizontal section is long. The length of build-up section and horizontal section increases, and the length of friction and torque increases. If pre-target distance is too short, then the corresponding build-up rate will be high. If the overall angle change rate is large, the drilling tool will be close to well wall, it is easy to have buckling and self-locking. Besides, torque and friction will increase. With proper pre-target distance, it can both easily decrease friction in ultra-long horizontal section and meet requirement of pre-target [4].

Kick off point usually shall be placed in formation with good diagenesis and stratum, in order to ensure that the wellbore is stable and to achieve the fast build-up. Under the permitted condition of stratum and loose selection range of build-up point, if build-up point is selected shallow, there is a bigger adjustment for deviated rate of deviated section and overall angle change rate. When smaller overall angel change rate is helpful for decreasing torque and friction and drilling in long horizontal section, but with long deviated section and pre-target distance. Conversely, if build-up point is selected deep, along with short deviated section and pre-target. However, there is smaller adjustment range for deviated rate and overall angel change rate, if overall angel change rate, torque and friction are big, it will not be helpful for drilling ahead. Generally, under permitted situation of formation, selection of shallow or mid-depth build-up point can both decrease torque and friction and make design of wellbore trajectory and overall angel change rate flexible, which is helpful for increasing drilling speed and drilling ahead in long horizontal section.

2.1.3 Selection of Wellbore Trajectory

Because of heterogeneous formation of Southeast Block in Gulf of Mexico, the upper formation lithology is mudstone, limestone, serpentinite, sandstone and chert mixed together. Suddenly angle building up and dropping off for wellbore trajectory caused by changes of formation often occurs, and there are errors of directional instruments, it is difficult to control precisely trajectory. In order to adopt formation changes and precisely targeting, optimized wellbore trajectory of BAC-124 is "vertical section-build-up deviated section-stable deviated section-build-up deviated section -horizontal section" (see table 1).

Table 1: Design of Bac-124 Wellbore Trajectory

Measured Depth m	Direction of deflection deg	Angle deg	Vertical m	South-north m	East-west m	Horizontal m	Overall Angle Change Rate deg/100m	Build-up Rate deg/100m	Remark
0	0	0	0	0	0	0	0	0	
1600	0	0	1600	0	0	0	0	0	
1800	10	98	1798.99	-2.42	17.24	0.98	5	5	
3267.31	10	98	3244	-37.88	269.55	15.33	0	0	

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3272.38	10	98	3249	-38.01	270.43	15.38	0	0	
3276.66	10.61	96.95	3253.21	-38.11	271.19	15.43	15	14.34	
3399.07	10.61	96.95	3373.52	-40.83	293.57	17.11	0	0	
3939.76	89.39	0	3717	297.15	356.77	360.93	16.77	14.57	
5439.85	89.39	0	3733	1797.15	356.77	1832.22	0	0	

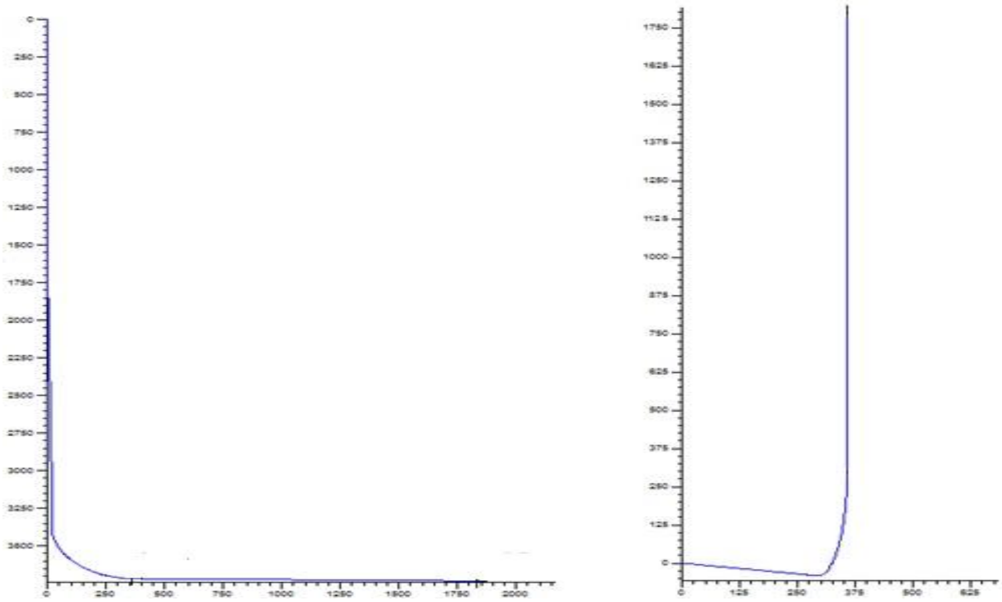

Figure 2: Cross-section Design of BAC-124

2.2 Rotary Steering Technology

Compared with traditional sliding steering, downhole tools work all the time under rotary status during running to hole by rotary steering drilling. Therefore it is better for purification with strong extended and reaching ability, which is more applicable for drilling special wells [5-6] with complicated configuration like ultra-deep extended reach well, horizontal well with long distance in oil & gas reservoirs [5-6].

Figure 3: BHA (Bottom Hole Assembly) Optimization

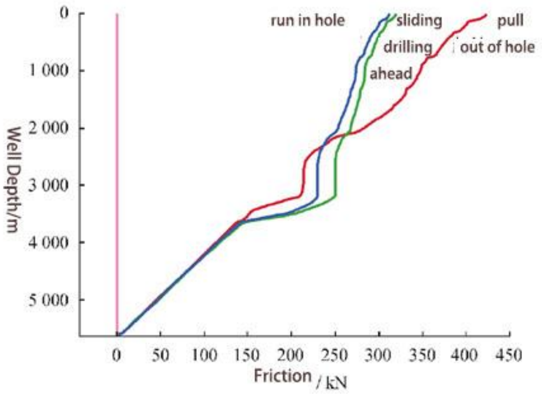

Figure 4: Friction Diagram of stimulated work for sliding directional BHA

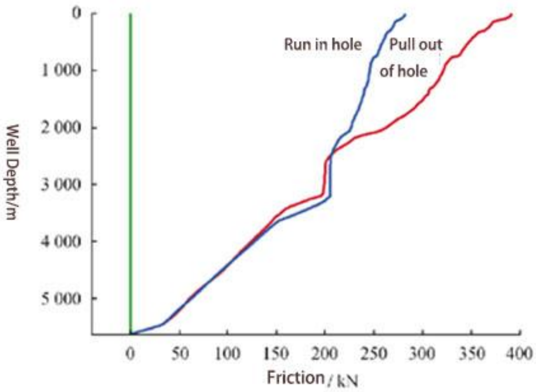

Figure 5: Friction Diagram of stimulated work for rotary steering BHA

The rotary steering technique becomes necessary for drilling ultra-deep horizontal wells at Southeast Block in Gulf of Mexico. Based on it, in the BAC202 well section of correction run at secondary drilling with large directional workload and heavy drag of directional construction, Schlumberger Rotary Steering System is selected to use. It turns out that the mechanical drilling speed of the well has increased 120% and solves the problem of directional drag [7-8].

2.3 Use Proper Oil-based Mud

This block is major formation of mud rock with manifesting as mixing of mud rock, composite sandstone and conglomerate with bands of thin siltstone and marlstone, and there are radiolarian rock and mudstone at the bottom. There are limitations to use KCL (potassium chloride) polymer and water base drilling fluid type, which cannot suppress efficiently hydration swelling and hole shrinkage of mud rock with strong water sensitivity, resulting in fast hydration dispersion of mud rock entering into drilling fluid and making it difficult to adjust performance of mud. Practice of drilling indicates that oil base drilling fluid is the best choice in this block for several years, and that is also the best mud type to reduce failure rate of extended reach well.

It can stabilize borehole because of strong inhibition of oil base drilling fluid; it can reduce drag and torque with excellent lubricity; it has good temperature tolerance with stable performance; unpolluted formation protection works well with high permeability recovery. Oil base mud has stable performance with good sand carrying; the maintenance of drilling fluid supplements new mud oriented with supplementing water evaporation with sea or fresh water, which can solve on-site complicated problems very well and improve drilling security and working efficiency[9].

2.4 Adopt new technical tools

2.4.3 Cuttings Bed Destructor

Cuttings destructor plays a destructive role to sand bridge often existed in the extended reach ultra-deep well, and reduces accidents of stuck of sand bridge. The application of these new technologies improves extremely work efficiency and provides powerful guarantee for downhole works. BAC202 uses cutting bed destructor, and then improves efficiency extremely with average mechanical drilling speed at 9.2 m/h which is maximum average mechanical drilling speed in the local. Besides, work efficiency has increased 12.4%, saving drill cycle 36 days with increasing speed by 9.5%.

2.4.4 Hydro-oscillator

In order to solve the problem of directional back-pressure, it matches with hydro-oscillator. The hydro-oscillator can transfer energy of drilling fluid into energy of mechanical vibration, which makes drilling column produce cycle vibration inspiration and brings axial vibration of drilling column. It transfers static friction into dynamic friction, in order to reduce friction and torque and deliver the drilling pressure easily. With controllability and better stability of tool face, reduce drilling ahead time and improve drilling ahead efficiency. From 2016 to 2018, we used hydro-oscillator in seven wells with heavy directional back-pressure, and tool life is up to above 100h, and average mechanical drilling speed increases above 9% comparing with the adjacent wells. Besides, it obviously eases back-pressure during sliding drilling ahead with smooth setting of tool face, which has no any harmful impact on regular drilling.

2.4.5 Technique of Flush Joint Casing

Use floating casing technology to low into flush joint casing. The flush joint casing has good sealing performance with strong torque resistance, and threaded connection is at the same height as pipe that it is convenient for casing to place in the oil and gas well. Usually buckle type is VAMSLIJ-II nearly to design of flush type and the same height of threaded connection as pipe, which optimize annular clearance and has characteristics of stretching, compressing and good air tightness. It can solve the problems of difficulty in lowing in casing caused by small annular clearance and bad quality of cementing well for deep well, ultra-deep well and extended reach well. The key of floating casing is to determine location and position of floating coupling. Taking borehole trajectory of GB0-260 extended reach well at Southeast Block in the Gulf of Mexico for example, use software Landmark to make analog calculation of casing friction, in order to check whether the floating casing technology is needed, and placement of floating coupling. Figure 6 is the vertical section of well with horizontal displacement 4090m, vertical depth 1935m and vertical depth ratio 2:1.

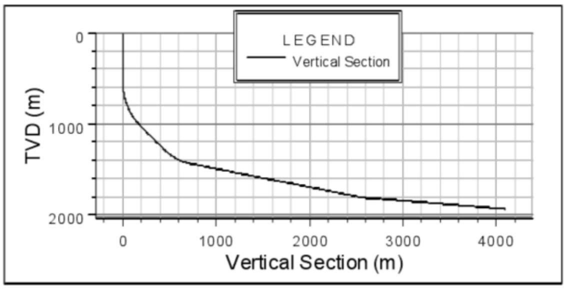

Figure 6: Vertical Section of GB0-260

(1) Check whether it needs to install floating coupling

Use software of Landmark to make stimulated calculation on wellhead load of casing, as shown in Figure 7.

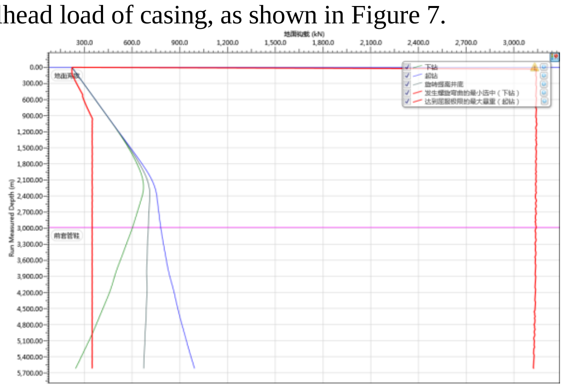

Figure 7: Wellhead Load Curve of Regular Running in Casing

As 244.5mm casing is run down to well depth of 4977m, the casing is buckled. There is impossible to run in casing to the bottom of well if use regular running in casing, so it needs to use running in floating casing technology.

(2) Calculate Placement of Floating Coupling

A. Calculate the initial placement

After ensuring piping structure of floating casing, it needs to calculate placement of floating collar, which minimizes the friction as running in floating casing. As ensuring placement of floating collar by running in floating casing, optimize and analyze by method of calculation. Initial calculated point of placement for floating collar is selected in the critical resistance angle of extended reach horizontal well.

According to equation 1, in the critical resistance angle, casing just goes by gravity and resistance inside of well, along with trend of non-downward sliding; according to equation 2, the critical resistance angle is just a function of friction coefficient by casing inside of well and well wall. Therefore, as optimization of placement of floating collar as running in floating casing, this position is set as initial calculation point.

$$W\cos\theta_c = \mu W\sin\theta_c \qquad (1)$$

$$\theta_c = \tan^{-1}\left(\frac{1}{\mu}\right) \qquad (2)$$

In the equation: W –Self-weight of casing - N;

θ_c - Critical resistance angle^0;

μ -Friction coefficient by casing inside of well and well wall

B. Optimize and select the installation position of floating coupling by trial method

After confirmation of initial point, use Landmark to analyze and calculate the simulated extended reach -well, and the calculated result see Figure 8.

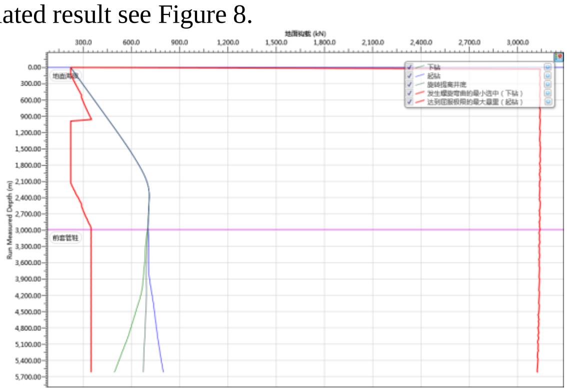

Figure 8: Load Curve of Wellhead

In theory, floating coupling is set in the initial position with the longest floating section, and the resistance is smallest as running in casing. However, along with running in air section casing, the wellhead load is smaller and smaller, so that air section cannot be run in hole. Therefore, the wellhead load needs to meet both requirements of air section and residual load of wellhead as the casing is run down to bottom. The residual load is too small to meet the requirements of handling accidents. It turns out that floating coupling is set at 3000m with length of floating casing 2600m and can run in casing successfully after our stimulated calculation.

Use the half floating casing with low density mud of 1.15g/cm3 inside of casing and annular density mud of 1.55g/cm3 at the first time during running in casing. Successfully run in flush joint casing of 298.5mm down to 5005m in the fourth borehole of 312.2mm, hanging over upper casing of 339.7mm at 2235.4m(technical casing shoe 3521m), and the top height of cement ring 2235.4 in cementing construction, and the length of cementing 2769.6m and the length of open hole 1484m. The top height of cement ring has achieved design requirement from test result, and 2440m outstanding well sections in the well shares 88.1%, and 191m excellent well sections in the well shares 6.9%, and overall cementing excellent quality is up to 95%.

3. Summary and Suggestions

The geological structure is complicated at Southeast Block of the Gulf of the Mexico; even adjacent blocks have big differences. For technical difficulties during construction in big changes of lithology, great adjustment of target A, high difficulty of medium target, big changes of formation dip in horizontal section and frequent adjustment of borehole trajectory caused by complicated geological structure of Cuba, fault development and big formation dip inside of block, the following specific and detailed suggestions are put forward:

1) Design proper well structure with considering complicated situation by separating lowercasing seal and reserving the first and the second casing, and consider running in flush joint casing if the horizontal section is too long.
2) Suggest to optimizing and adjusting position of Kick off point of horizontal well. Select build-up rate, well profile type, BHA and drilling ahead parameters, and reduce working effort of correction run if possible, and improve efficiency of directional construction.
3) Bring rotary steering drilling technology and near-bit FEWD, and reinforce controlling ability of borehole trajectory, and improve drilling catching rate in superior reservoirs and drilling speed, and reduce accidents and drilling costs.
4) Use oil-based drilling fluids system. Adjust proper performance of drilling fluids to assure ability of sand carrying based on specific situations and formation features.
5) Use technologies like hydro-oscillator and cuttings bed destructor to ensure the construction safe and smooth.

In view of a series of key drilling technical problems like deep wells and ultra-deep wells under complicated geological conditions, this research carries out some innovative onsite thinking and practice on it and which have been proved with good effect. Therefore, this research is helpful for the development of ultra-deep extended reach horizontal wells at home and abroad.

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