The Study of High-Building Rate Horizontal Downhole Casing and Drilling Fluid Technology for Deep Water Shallow Soft Strata of South China Sea Gas Hydrates

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Abstract. The development of horizontal wells is one of the important means to increase the production of natural gas hydrates in offshore areas and accelerate the commercial exploitation of natural gas hydrates. However, due to the characteristics of the natural gas hydrate reservoirs in the South China Sea, such as poor geological consolidation, small pressure gradient of formation fractures, and narrow safety windows, it is easy to cause problems such as leakage of target layers, formation collapse and key grooves, as well as secondary generation of hydrates during the construction of horizontal wells. The combination of downhole casing and drilling fluid technology is one of the important ways to solve the problems encountered during the process of horizontal well development. Based on the information from a deep water shallow high-building rate horizontal well in a certain area of the South China Sea, this study used the downhole casing method with riserless drilling technology for the first time in the deep water area. Taking into account the characteristics of shallow-buried formation, large inclination angle, and shallow burial depth of the inclined and horizontal sections at the wellbore during the drilling process, drilling fluid technology measures before casing are proposed, and the stress analysis and effect of two casing times in the horizontal well are compared. Combining with the stress characteristics of downhole casing in this well, the key technologies such as wellbore cleaning, lubricity, and wellbore stability in the highly inclined section and horizontal section are discussed respectively. By optimizing the drilling fluid technology during the downhole casing period, this study provides construction guidance and technical support for the development of shallow-soft mineral resources such as natural gas hydrates and deep-water shallow gas reservoirs in the South China Sea.

Keywords: Deep water shallow soft formations · High-building rate horizontal wells · Riserless drilling · Drilling fluids · Marine natural gas hydrates

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1 Introduction

As a new exploration and production technology, deepwater shallow horizontal wells have been widely used in the exploration of unconventional oil&gas such as coalbed methane and shale gas. Compared with traditional vertical wells, shallow horizontal wells have the advantages of better wellbore stability, smaller borehole diameter, and larger recoverable area, which can improve production efficiency and reduce production costs. In the process of natural gas hydrate exploitation, the application of horizontal wells can greatly increase the mining efficiency. At the same time, high-building rate horizontal wells can reduce the area occupancy of seabed, reduce the impact on the environment, has high application value. Therefore, it is of great significance to apply shallow horizontal well technology to the study on natural gas hydrate production. The deep water shallow strata in the South China Sea have poor cementation, low formation fracture pressure gradients, and a narrow density window. At the same time, hydrates are easily formed at the mudline [1]. In the exploration and exploitation of deep-water shallow soft strata in the South China Sea, high-building rate horizontal well technology is an effective exploration method, although there are some technical difficulties. Casing and drilling fluid technology are the two aspects that are most widely used. First of all, the casing technology is an important guarantee for the smooth progress of horizontal wells. Due to the special structure of horizontal wells, the casing needs to be used in unconventional methods and materials to ensure stability and sealing during drilling. Therefore, in the drilling and exploitation of natural gas hydrates in the South China Sea, the casing technology must be highly valued, otherwise it will bring great difficulties to the entire drilling work. At the same time, drilling fluid technology is also an indispensable component in the construction of horizontal wells. The type and ratio of drilling fluid need to be designed according to specific circumstances, taking into account factors such as reservoir pressure and temperature, to ensure the uniformity and controllability of drilling fluid mobility, inhibition ability, and density. The special conditions of the deep water shallow soft formation in the South China Sea make the drilling fluid technology very difficult. Therefore, it is necessary to conduct in-depth research on the properties and usage methods of drilling fluid to find the best formula and usage plan. During the drilling of deep water shallow layers, the main method is to add hydrate inhibitors to control the formation of hydrates [2, 3]. During the drilling of deep water surface layers, the first step is to use a conduit jet, and the second step is to use a riser to ensure drilling safety [4–6]. In order to solve the problem of leakage in shallow target layers, the first time in deep water, the whole well drilling fluid open-path drilling method was adopted, which effectively solved the drilling problem of leakage in deep water shallow horizontal wells. However, using this method will face the difficulty of running casing under the condition of high deflection rate without a water-resisting conduit. Attention should be paid to the problems of formation collapse and keyway in the shallow deflection section, and the performance of drilling fluid should be fully considered [7]. The drilling fluid needs to meet the requirements of inhibiting the secondary formation of hydrates, wellbore cleaning, wellbore stability, good lubricity, and safe and environmentally friendly [8–10].

2 Drilling Information

Well SXXX is located in a certain area of the South China Sea, with a water depth over 1,200 m. Three suction anchors were pre-installed as the foundation for the wellbore. Jetting conductor to 61m below mud line. Directional drilling 18–1/8″ hole and kick off at 77 m, with an average deviation rate 13°/30 m and a maximum deviation rate 15°/30 m. Directional drilling 12–1/4″ hole to horizontal section at 580m, with a well inclination 86° and a maximum dogleg 9.38°/30 m. The total depth is 930 m, with TVD 290 m and horizontal section length of 350 m. HD/VD is 1.19, with maximum inclination 92.2°.

The drilling fluids were performed as follows: Seawater bentonite for spud in, and low temperature polymer for 18–1/8″ hole, and low temperature dual-inhibition water based drilling fluid for 12–1/4″ hole.

3 Stress Analysis for Running Casing

With a drilling mechanics analysis software WELLPLAN, a depth-friction curve for horizontal hole casing running is simulated basing on a modeling established by well structure, string combination, and various hydrodynamic parameters. A depth-hook load curve for the casing running process was derived through inverse calculation. The curves were then fitted with actual hook load data from the two casing running operations (Fig. 1 and Fig. 2). Based on these fitting results, stress analysis on strings was conducted.

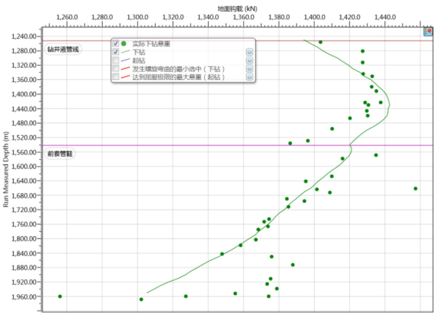

Fig. 1. Depth-Hook load simulation and fitting for the 1st casing run

As shown in the figures above, the actual hook load on the 2nd casing run is well fitted with the simulated curve. However, there are two major deviations of sections between the actual hook load and the simulated curve for the 1st casing run: The upper casing section from 100 m below KOP to casing shoe, where the actual hook load is less than the simulated, and the difference gradually increases with depth; The horizontal hole, where the actual hook load is higher than the simulated, but close to that of the 2nd casing run.

Based on the data above, the analysis is as follows:

(1) The actual data of 2nd casing run are highly consistent with the simulated, indicating that the simulated curve can accurately reflect the stress conditions of the pipe string under ideal conditions;

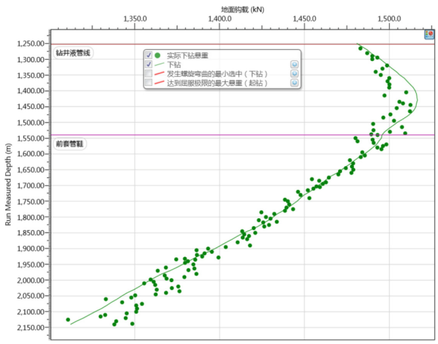

Fig. 2. Depth-Hook load simulation and fitting for the 2st casing run

(2) After casing run into the high-inclination section, the friction inside the upper casing increases significantly with depth, while after casing entering the open hole section, the friction increases relatively steadily;
(3) The casing strings of the twice run are basically the same in structure. Through the comparison of the actual hook load (Fig. 3), the twice data are close after the casing enters the horizontal section, indicating that the string friction returns to normal after the 1st casing run into the horizontal section.

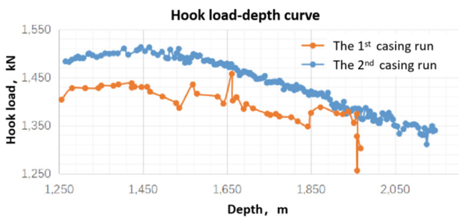

Fig. 3. Hook load comparison for twice casing run

Conclusion can be drawn from the analysis above: Before the casing string entering the horizontal section, the friction is mainly caused by "iron-iron" friction between the pipe string and the upper casing; After the casing string entering the horizontal section, the friction is mainly the resistance between the string and wellbore.

4 Discussions on Measures of Drilling Fluids

Considering the stress characteristics during casing running in this well, a comparative discussion is carried out on the drilling fluid measures between the twice casing runs in terms of hole cleaning, lubricity, and hole stability.

4.1 Hole Cleaning

Sand bed is liable to form in directional & horizontal wells, and the effectiveness of cuttings bed removal directly impacts casing running operations. Based on the analysis of cuttings deposition and transport in highly deviated horizontal wells, calculations of viscosity and flow rate effects on cuttings beds show that increasing viscosity can reduce the height of cuttings beds, while increasing flow rate can remove cuttings beds. When changing flow rate is difficult to achieve, for example the pump rate is limited, rotary drilling plays a major role in hole cleaning [11]. During sliding drilling, drilling fluid rheological properties were maintained at somewhere FV between 50 s to 60 s and φ3 reading at 8 and φ6 at 10. Meanwhile, regular sweep with gel mud (FV $>$ 100 s) were carried out to assist hole cleaning. During composite drilling, the top drive speed was increased as much as possible to prevent cuttings bed from piling up.

Similar measures for drilling fluid rheology were taken before the twice casing runs, that gel muds with viscosity over 60 s were spotted to enhance the capacity of cuttings suspending during the static period. The wiper trip before the 2nd casing run shows that the tripping was smooth and there was no obvious accumulation of cutting beds, indicating that dual-inhibition drilling fluid meets the requirements for high deviated horizontal hole cleaning and works well.

4.2 Lubricity

The lubricity of drilling fluid plays a crucial role in casing running. Comparing the measures taken before the twice casing runs, the treating measures in open hole were similar, both adopting dual-inhibition drilling fluid and adding 3% high-efficiency lubricant. Solid lubricants were not added in the open hole considering reservoir protection. Inside the upper casing, 3% high efficiency lubricant was added for the 1st treatment, while 1% plastic balls, 1% friction reducer, and 3% high-efficiency lubricant were applied for the 2nd treatment.

Comparing with the 1st casing run, the string friction in the upper casing during the 2nd run was reduced by 90 KN maximum, and 50 KN average, indicating that the addition of solid lubricants has a significant effect on reducing the "iron-iron" friction between the casing string and upper casing. After entering the horizontal section, the friction of the two casing runs (before casing set weight) were relatively similar and was within expectations. The lubricity of drilling fluid meets the conditions for smooth casing running operations.

4.3 Wellbore Stability

Considering the characteristics of the formation in this well, which is mainly composed of argillaceous siltstone with shallow burial depth, insufficient compaction, poor diagenesis, high permeability, complex geomechanical parameters, and strong heterogeneity, the following drilling fluid measures should be taken before running casing to ensure wellbore stability:

Control water loss of drilling fluid to improve the quality of mud cake. During horizontal drilling, the API filtration loss was kept below 8.0ml to maintain suitable wall-building properties of the drilling fluid, and reduce excessive soaking of the wellbore by the drilling fluid. Thin, tough, and structurally dense mud cake formed on the wellbore wall can reduce the contact area between pipe string and the wall, thereby lowering the sliding resistance.

Shale-inhibiting drilling fluid was used to prevent hydration instability of clay. By adding 1% polyamine inhibitor and 5% KCl, the hydration of clay could be effectively suppressed, the invasion depth of water into the formation could be reduced, and the strength of clay could be increased, which is benefit to wellbore stability.

Appropriately increase the mud weight to provide mechanical support for the wellbore wall. Before the 1st casing run, MW 1.05 g/cm^3 inhibiting drilling fluid was used for pumping out of hole while MW 1.15 g/cm^3 padding mud for spotting the upper casing. After wiper trip, the entire well was padded with MW 1.20 g/cm^3 drilling fluid. Increasing mud weight could balance the lateral stress on the wellbore wall and be benefit to delay decomposition of gas hydrate formation.

5 Drilling Fluid Measures Before Run Casing

5.1 Measures for Horizontal Drilling

Drilling fluid formula: seawater + caustic soda + soda ash + bentonite + low-temperature viscosifier + low-temperature fluid loss agent + high efficiency lubricant + polyamine inhibitor + KCl + hydrate inhibitor.

The dual-inhibiting drilling fluid applied in horizontal drilling can effectively inhibit decomposition and secondary formation of hydrates, while meeting environmental requirements, with excellent low-temperature rheological properties and lubricity [11]. During drilling, the viscosity was maintained between 45 s to 55 s to ensure the requirements for directional section hole cleaning. Regularly use 8 m^3 polymer sweap mud to assist sand carrying, minimizing sand beds piling up. During horizontal drilling, further hole cleaning measures was carried out, increasing readings of φ3 at 8 and φ6 at 10, while increasing the drilling speed as much as possible during composite drilling to strengthen the disturbance and stirring effect on the sand beds. No coating agents were used due to limited flow rate; Control API water loss less than 10.0 ml, reducing the soaking effort on the wellbore. Use 5% potassium chloride with 1% polyamine inhibitor to inhibit the hydration of clay to prevent the instability of the wellbore. 1% high-efficiency lubricant was added to enhance lubricity.

5.2 Measures Before the 1st Casing Run

During pumping out of hole after drilling, adjust funnel viscosity above 55 s for improving hole cleaning. Control the API water loss less than 8.0ml and the mud cake thickness less than 0.5 mm, thus forming a thin and tough mud cake to further reduce the soaking of the wellbore. Add 3% high-efficiency lubricant to enhance the lubrication performance of the drilling fluid and reduce the drag of casing. Improve the pH value of the system to ensure that the drilling fluid will not deteriorate for a long time. After trip out the upper casing, spot MW 1.15 g/cm^3 padding mud in place of the upper casing to provide mechanical support for the wellbore.

5.3 Measures Before the 2nd Casing Run

The 9–5/8″casing set weight at 1960 m for the 1st run, then a wiper trip was carried out. During the circ, the funnel viscosity maintained above 55 s. Before POOH, spot open hole with MW 1.20 g/cm^3 padding drilling fluid, and upper casing with MW 1.20 g/cm^3 lubricating drilling fluid, in which 1% plastic pellets, 1% friction reducer, and 3% high-efficiency lubricant were added.

From drilling finished to the wiper trip, the drilling fluid remained static in the wellbore for over 50 h, and the wellbore soaked for a longer period of time. However, no wellbore instability occurred during this period, indicating that the drilling fluid had well compatibility with the formation with stable and reliable performance. The wellbore stabilization measures was verified (Table 1).

Table 1. Drilling Fluid Properties for Twice Casing Run

Properties	MW g/cm^3	FV s	PV mPa·s	YP Pa	Gel (10′/10″) Pa	API Fl mL
Horizontal Drilling	1.04	55	17	12	3.5/4.5	9.9
1st Casing Run (Open Hole)	1.05	60	17	13	4/5	9.8
1st Casing Run (Upper CSG)	1.15	65	25	13.5	4/5	9.0
2nd Casing Run	1.20	63	22	14.5	5/6	7.8

6 Conclusion and Suggestion

1) For deepwater casing running without risers, plastic bending of the casing is most likely to occur when the running tool approaches the wellbore. The key to successful casing running lies in the quality of the wellbore and the lubricating performance of the drilling fluid, which becomes even more critical as the horizontal section length increases.
2) The wellbore trajectory has a significant impact on casing running. The problems encountered in 1st casing run is directly related to the horizontal section trajectory. Therefore, it is necessary to design additional wellbore trimming measures before running casing.
3) The low-temperature dual-inhibiting drilling fluid is successful applied in deepwater shallow high-building rate horizontal wells in a certain area of the South China Sea. The drilling fluid has good performance in hole cleaning, wellbore stability, lubricity, and inhibition of hydrate decomposition and secondary formation, assisting in the first successful casing run in deepwater shallow high-building rate horizontal well of China.
4) Compared to conventional wells, special attention should be paid to reducing the "iron-iron" friction inner upper casing during casing running in deepwater shallow high-building rate horizontal wells. Practical experiences has proven that solid lubricants are much more effective than liquid lubricants.

5) Due to the reservoir protection, the types of lubricants used in open-hole sections are limited, so optimization on lubricants that take reservoir protection into account requires further research.
6) The casing running method and drilling fluid technology optimization scheme for high building rate horizontal wells for deep water shallow Strata analyzed in this article provide a construction basis and technical support for the development of mineral resources in shallow strata such as natural gas hydrates and deep water shallow gas reservoirs in the South China Sea.

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