Low-cost Drilling Technology for Horizontal Wells with Atmospheric Shale Gas in the Outer Margin of Sichuan Basin

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Abstract. Shale gas reservoir at the outer edge of Sichuan basin belongs to normal pressure shale gas reservoir. In the analysis of the difference between the current and the pressure shale gas drilling, the technical measures to reduce the cost of drilling, the design of the well, the borehole trajectory, the drilling, the drilling fluid and the cementing process, the design of the three shafts, the design of the structure of the shaft, the design of the two dimensions of the well, the design of the two dimensions, the design of the orbital trajectory of the shafts, using the spin guide technology to control the orbital trajectories of the two shafts, the low-oil, and the optimal production of the concrete and the production of the drilling and the drilling costs, the technology and the measures, to provide the technical support for the economical and efficient development of the natural gas in the Sichuan basin.

1. Introduction
Shale gas is a highly valuable unconventional natural gas resource, which is a highly efficient and clean energy in the free and adsorption state of dark mud shale and tight sandstone in the stratum.

China's shale gas resources are characterized by wide distribution, low abundance, easy discovery and difficult exploitation. They are low-efficiency gas reservoirs with self-generated and self-storage, low porosity and low permeability, no gas-water interface and large area continuous accumulation. According to the statistics of shale gas completion drilling in south Sichuan, there are many uncertain factors in shale gas development, and the pressure and fluid properties are difficult to predict. Mud shale and tight sandstone are easy to hydrate and expand, easy to break, and unstable. The reservoir is easy to damage and the recovery rate is low. With slow drilling speed, long drilling cycle and big development technology difficulty, drilling cost is a high problem.

China has made great breakthroughs in shale gas development zones. Most shale gas blocks are located in Sichuan basin, such as the blocks of Qiaoshiba, Weiyuan, Fushun-yongchuan and Changning, etc. There are also many shale gas reservoirs in the outer edge of Sichuan basin, such as the Pengshui, Wulong and Huangping blocks. The tectonic transformation of the outer edge of the basin is relatively strong, and the pressure coefficient of shale gas reservoir is 0.90-1.2. It is an atmospheric shale gas reservoir with low gas production.

China's shale gas reservoirs are similar to those in the United States in geological conditions, but differ greatly in reservoir characteristics, and domestic shale gas development faces greater drilling difficulties and challenges. Most of the domestic shale gas enrichment blocks belong to piedmont structure with buried depth (1,500-3,500m), exposed old strata and poor drillability. The drilling method and process are limited, so it is difficult to copy the American drilling technology and the development model of batch drilling.
Domestic atmospheric shale gas development mainly adopts high-pressure shale gas development technology, and the development cost per unit of gas production is relatively high. Therefore, it is urgent to carry out low-cost drilling technology and stimulation technology. Among them, reducing drilling cost is more direct and important. Therefore, the author discussed how to reduce the drilling cost from the aspects of well body structure, well trajectory design, drilling fluid selection and cementing technology, so as to provide guidance for the economic and effective development of atmospheric shale gas in the outer margin of Sichuan basin.

In July 2012, well Penglin Hf-1 was awarded 2 in Pengshui block, southeast Chongqing 52×10^4m^3/d gas production, realizing the exploration breakthrough of silurian atmospheric shale gas in the outer edge of the basin.

2. The difference between normal pressure and high pressure shale gas drilling first, second, and third level headings

In Sichuan basin edge Wulong atmospheric shale gas blocks for example analysis of atmospheric shale gas drilling and high pressure differences of shale gas drilling. This block is located in ChuanDongNa lichuan - Wu Longfu southern syncline, shale gas reservoir buried depth 2,000-3,000m, drill the strata from top to bottom in turn is the fourth is a play, the Triassic Feixianguan age of jialing river group, the group, the integration of Permian Changxing group, the Wu Guping group, Mao kou, Qixia group of lower Permian Liangshan, the longmaxi group, the weifenggroup, LinXiang group, etc. According to the micro-pressure test results of LP-1HF well, the reservoir pressure coefficient is 1.05-1.10. It belongs to the atmospheric shale gas reservoir.

LY-1HF well adopts the "pipe + triple open system" well body structure, which is similar to the high-pressure shale gas blocks such as fuling and Qingqiao. The first well is drilled with a 406.4mm drill bit, and 339.7mm surface casing is used to seal the upper Triassic and Permian easily leaky carbonate rocks and strata that may contain shallow gas. The second opening adopts 311.1mm drill bit to drill into the formation 50m of Longmaxi formation and 244.5mm technical casing to seal the strata of Hanjiadian formation and Xiaoheba formation of Permian and silurian. Triple tap 215.9mm bit drilling, equipped with near-bit MWD system, until the completion of drilling depth [2].

Drilling practice of LY-1HF well shows that, compared with high-pressure shale gas wells in fuling, Qingqiao, Changning-Weiyuan and other blocks, atmospheric shale gas wells have the following characteristics:

2.1 Low formation pressure coefficient
The formation pressure coefficient of shale gas reservoir in Wulong block is only 1.05-1.10, the density of drilling fluid used in drilling is lower than that of high-pressure shale gas wells, usually 1.10-1.35kg/L, there is a contradiction between the need to increase the density of drilling fluid to maintain the stability of shale formation and the need to reduce the density of drilling fluid to prevent well leakage.

2.2 Low free gas content
The free gas content in high-pressure shale gas reservoirs is usually between 60-75%, while the free gas content in atmospheric shale gas wells is low, which is between 30-40%. Therefore, the risk of drilling well control and cementing gas migration is relatively low.

2.3 Well structure has optimization space
From the drilling practice of 1HF well in LP-1HF and 4 horizontal Wells in the adjacent Pengshui block, it can be seen that the lower Silurian strata, such as Hanjiadian formation and Xiaoheba formation, are relatively stable with little risk of leakage [3]. LP-1HF well is used to seal the Xiaoheba formation and the strata above. The technical casing enters the formation 50m of Longmaxi formation,
resulting in a longer technical casing sealing and cementing section. Due to the low pressure of the atmospheric shale gas reservoir, there is room for the optimization of casing cementing.

2.4 Lower cost drilling requires higher requirements
Due to atmospheric pressure the strata and the main purpose of shale gas well layer shale gas well with high pressure, the current atmospheric shale gas well drilling, well logging, mud logging technology and adopted by the technical measures taken by the shale gas well with high pressure difference is very small \cite{4-5}, but low atmospheric pressure shale gas production of gas wells, therefore to achieve economic and effective development of atmospheric pressure shale gas, must reduce the drilling cost.

3. Key technology for low-cost drilling
According to the characteristics of normal pressure shale gas field and the actual situation of Wulong block in the outer margin of Sichuan basin, this paper discusses the low-cost drilling technology for normal pressure shale gas Wells in the outer margin of Sichuan basin from the aspects of borehole structure optimization, borehole trajectory control, drilling fluid, cementing process, and acceleration and efficiency improvement.

3.1 Well structure optimization
Well bore structure in drilling speed up effect and reduce the drilling cost has an important influence, in meet the demand of late drilling safety and fracturing operation, can be taken to reduce the large diameter borehole diameter, shorten the interval length and avoid in large diameter hole directional Angle gain or torsion, realize the drilling speed and reduce the drilling cost.

When LP-1HF well drilled to the upper strata of Jialingjiang formation, recurrent leakage occurred. The shallow and easily leaky strata were sealed with a conduit, which provided conditions for the smooth construction and well control safety at the lower part. When drilling into the strata of Longtan formation, the fractured and lost formation was encountered again, and the lost drilling fluid was 300m$^3$. When drilling into the Qixia formation, Maokou formation, Changxing formation and other formations, the gas measurement showed abnormalities, while drilling into the strata of Hanjiadian formation and Xiaoheba formation of Silurian did not occur. The X -1 well in the adjacent block did not sidestep the horizontal well in time after drilling the guide hole well. The open hole guide hole was soaked in water-based drilling fluid for about 4 months, and no borehole wall collapse occurred, indicating that the Silurian Hanjiadian formation, Xiaoheba formation and other formations in this block have good stability and are not prone to collapse \cite{6}. Therefore, when drilling into the strata of Xanjiadian formation, the upper leaky strata and shallow gas strata should be sealed.

According to the actual drilling situation of longging1hf well, the section with great potential for speed increase is 311.1mm. The drilled strata in this section are mainly Maokou formation, Qixia formation, Liangshan formation, Hanjiadian formation and Xiaoheba formation. The formation thickness of Hanjiadian formation and Xiaoheba formation is 800-900m, mainly silty mudstone and arry siltstone, with poor drillability and slow mechanical drilling speed, which can be accelerated by reducing the hole diameter of this section and avoiding or reducing the directional or torsional orientation in this section.

Based on the above analysis, the well structure was optimized, and the "pipe + three-open system" well structure was optimized into the "pipe + two-open system" well structure. The structure of the "pipe + triple open" well before optimization is as follows: the pipe is drilled to the depth of 60m with a 609.6mm drill bit and 60m with a 473.1mm casing. The first bit was drilled to a depth of 1,648m and with 339.7 mm casing to the depth of 1,646m. Second opening using 311.1mm drill bit drilling to the depth of 3078m, 244.5mm casing down to the depth of 3,076m. Triple tap 215.9mm drill to depth of 5,176m, 139.7mm casing to 5170m depth.

The optimized "pipe + two open" well body structure is as follows,406.4mm drill bit is used to drill to the depth of 60m and 339.7mm casing down to 60m depth. In the first operation, the drill bit with a diameter of 311.1mm was used to drill to a depth of 2,600m, and the casing with a diameter of
244.5mm was used to drill to a depth of 2,598m to seal off the leaky formation and shallow gas formation in the upper part of the hanjiadian formation. With 215.9 mm drill bit, the hole was drilled to depth of 5,176m and 139.7mm casing to 5,170m depth. Compared with the pre-optimization period, the hole diameter of the tubing, primary and secondary segments is reduced, the secondary drilling depth is increased, and a layer of technical casing is saved, which can realize the purpose of improving the drilling rate, shortening the drilling cycle and reducing the drilling cost.

| The serial number | Rail type           | Build point/m | slope | TD/m | Torsion bearing / (°) | Maximum sliding friction/kN |
|-------------------|---------------------|---------------|-------|------|-----------------------|---------------------------|
| 1                 | Five section of the system | 2200          | 4570  | 76   | 214                   |                           |
| 2                 | Six section of the system   | 2060          | 4585  | 92   | 235                   |                           |
| 3                 | Pairs of two-dimensional  | 1200          | 4540  | 0    | 221.5                 |                           |

### 3.2 Well track optimization design

Conventional two-dimensional horizontal Wells are usually used in the shale gas exploration stage at the outer edge of Sichuan basin. In the drilling process, only the deviation is increased and the azimuth Angle remains unchanged. Therefore, the difficulty in design and construction is relatively low. In the development stage, cluster Wells are generally deployed, and most of them are three-dimensional horizontal Wells. In the drilling process, both deviation and twist orientation should be increased, and problems such as preventing collision with adjacent Wells and deviation capacity and friction resistance of the drill string assembly in the three-dimensional well segment should also be considered, making the design and construction more difficult [7-9].

In order to speed up drilling in the formations with poor drillability such as the hanjiadian formation and xiaoheba formation, it is necessary to avoid torsional bearing at a large Angle in the well track design. Therefore, a "two-dimensional" model is adopted for well trajectory design. The "two-dimensional" model can transform the three-dimensional horizontal well trajectory into two-dimensional borehole orbits, and the torsional orientation is not required in the drilling process, which can greatly reduce the workload caused by the torsional orientation.

Table 1 shows the design of deviation point, completion depth, Angle of twist bearing and maximum sliding friction of X horizontal well using three track models of "two-dimension", "space five-segment system (side increasing hypotenuse twist bearing)" and "space six-segment system (pure twist bearing)". X well A target depth of 2,800m, 300m offset, closed from 430m, level 1,500m, azimuth 36.86 angle. As we can be seen from table 1, the well depths of the designed whipstock of the three track models are quite different, but the differences in the designed drilling depths are relatively small. The maximum sliding friction of the six-stage system is the largest, with the "two-dimension" in the middle. "Double two-dimensional model was adopted to design borehole trajectory can be in the upper section on low slope (2-3°)/30m directional offset, avoid in the lower part of poor drillability of directional twist bearing strata, compared with other two directional deflecting orbit model can greatly reduce the lower workload, and is more advantageous in shallow strata directional cluster Wells in the process of drilling hole crash-proof.

### 3.3 Optimization of wellbore trajectory control mode

At present, the common well trajectory control methods for horizontal Wells include constant LWD, near-bit measurement system and rotary guide. The features of the tools used in the three control modes are as follows:

1) Different measurement of zero length.
The zero length of conventional LWD measurement is relatively long, ranging from 16-20m. The nearest measuring point of the near-bit measuring system is only about 1.10m. The zero length measured by the rotary guide tool is 2-3.5m. Near-bit measurement systems and rotation-guided tools are superior to conventional LWDS in trajectory prediction and control, reducing the number of hole trajectory adjustments and improving drilling efficiency.

2) Different directional drilling methods.

The conventional LWD and near-bit measurement systems use fixed-face sliding drilling for orienting, while the rotation-guided tools use full rotary drilling for orienting. When drilling in highly deviated, torsional and horizontal sections, rotation-guided tools can not only improve directional drilling efficiency and time, but also improve hole cleaning, reduce friction and torque, improve well quality and achieve safe drilling.

3) Different comprehensive costs.

Based on the calculation of the actual average drilling index of shale gas horizontal Wells in the adjacent Qingqiao block, the comprehensive cost of the three borehole trajectory control methods was analyzed. The second opening section of shale gas horizontal Wells in Wulong block is generally about 2,200m long. The drilling assistance cost is calculated according to the daily drilling rig fee. Taking the 50ZJ type drilling rig as an example, the comprehensive cost of three well trajectory control methods is calculated assuming other influencing factors are all the same.

| Trajectory control mode | ROH/ (m³h⁻¹) | length/m | Cycle/d | Unit price/(104 ¥·d⁻¹) | Instrument service cost/10⁴ ¥ | Comprehensive cost/10⁴ ¥ | Measure zero length/m | Combined drilling rate, % | Hole smoothness |
|-------------------------|--------------|----------|---------|-------------------------|-----------------------------|-------------------------|----------------------|------------------------|----------------|
| LWD                     | 6.1          | 2200     | 32      | 3.9                     | 118                         | 342                     | 16-20                | 30-40                  | LOW           |
| near-bit                | 7.1          | 2200     | 24.8    | 7.2                     | 186                         | 360                     | 1-1.5                | 40-60                  | LOW           |
| Rotary steering         | 9.6          | 2200     | 17.7    | 12                      | 2112                        | 336                     | 2-3.5                | 100                    | HIGH          |

We can see from table 2, the single from the instruments of service costs, near-bit measurement system and the rotary steering tool is higher than conventional LWD, but because the rotary steering tool with composite way into all the way, speed up effect is good, two spudding well cycle is much shorter than conventional LWD and near-bit measurement system, the comprehensive cost reduced. At the same time, the hole smoothness under the rotary steering trajectory control is the best of the three control methods, which is beneficial to the later completion operation. Therefore, based on the comprehensive analysis of the above three factors, it is recommended to use rotary steering tools to control the well trajectory in order to achieve efficient, high-quality and low-cost drilling of shale gas horizontal wells.

3.4 Drilling fluid and cementing process optimization

In order to quickly drill through the shallow leakage layer, clean water is used for the upper part of the pipe section and a straight section, and KCl polymer drilling fluid is used for the lower part. The first is to reduce the cost of drilling fluid, and the second is to realize green drilling. The silurian formation encountered in the second open-hole section is the mud shale formation with strong water sensitivity. Currently, oil-based drilling fluids and high-performance water-based drilling fluids are mainly used in high-pressure shale gas blocks to drill into silurian strata. Oil-based drilling fluids are widely used due to their strong inhibition, high reuse rate, well stability and good lubricity, etc. but their costs are high and are not conducive to environmental protection [10-12]. In order to reduce the cost of oil-based drilling fluid, on the basis of the mature oil-based drilling fluid, the cost of oil-based drilling fluid can be reduced by more than 10% per unit volume by selecting domestic low-price and high-quality
treatment agent and reducing the oil-water ratio of oil-water ratio (the oil-water ratio should be controlled at 75/25 ~ 60/40).

High-performance water-based drilling fluid is currently in test phase, CQH-M1 and water-based drilling fluid in Sichuan Changning DRHPW-1 Weiyuan block certain progress has been made: Weiyuan block application CQH - M1 high-performance water-based drilling fluid deepest to 5,250 m depth, shale formation speed of up to 2,238 m, the highest temperature of 130℃; The application of drhpw-1 high-performance water-based drilling fluid in Changning block has created many records, such as horizontal penetration through shale formation and drilling fluid immersion time. High-performance water-based drilling fluid provides a new technical approach to solve the problems of high cost and high environmental pressure of oil-based drilling fluid [13-15]. In order to meet the requirements of low cost and environmental protection in the development of atmospheric shale gas and improve the overall development efficiency, the environment-friendly treating agent can be further optimized and compatible materials with abundant sources and low price can be used in the atmospheric shale gas block in combination with the test results of high-performance water-based drilling fluid in the early stage.

The cementing industry standard for shale gas Wells requires the cement slurry return to be 300m above the formation deviation point, and the length of sealing upper casing should be no less than 300m to meet the fracturing requirements. Therefore, the production casing cement slurry return height can be optimized, and the original return to the surface is optimized to 500m above the surface casing shoe.

In order to reduce the cost of natural gas Wells, the foamed cement slurry with a density of 1.2-1.5kg/L is prepared by using nitrogen, foaming agent and nitrogen-filled foaming device according to the principle of mechanical foaming. The foamed cement slurry has the properties of expandable and anti-gas channeling, which is suitable for sealing the low pressure shallow gas in Longtan formation and maokou formation. The cost of cementing can be reduced by more than 9% by partially replacing the lightening agent with foamed cement slurry [16-17].

3.5 Technical measures for raising speed and lowering cost

1) Optimization of efficient drill bits.

Wulong block is a limestone stratum containing siltstone, siliceous strip and flint lump. PDC bit has poor adaptability to it. When drilling with PDC bit, mechanical drilling speed is low and single bit penetration is short. Comprehensive consideration of formation lithology and rock mechanics parameters, optimizing bit type:

a) Permian Wu Guping and Mao group formation recommend using PDC bit, with a bit transition, in order to get higher rate of penetration, such as using S1665FGA, KMD1652ADGR PDC bit and HJT617GL cone

b) Silurian Hanjiadian formation and Xiaoheba formation are recommended as MDSI616 type PDC bit and alliance 1633dst cone -PDC hybrid bit.

2) Adopt domestic drilling tools.

Relatively mature drilling tools such as jet impacter [18], hydraulic oscillator and directional instrument have appeared in China. On the premise of meeting drilling requirements, domestic drilling tools should be selected as far as possible. For example, the successful application of the 172mm hydraulic oscillator developed by the petroleum engineering technology research institute of sinopec in the coking stone dam block shortens the drilling cycle by about 5days and the tool surface adjustment time by about 30% compared with the conventional guided drilling tool assembly, and the cost is also relatively low, which can replace similar foreign drilling tools.

3) Shallow crack hole leakage, clean water and strong drilling.

In case of malignant leakage, quick-setting cement slurry, highly consolidated plugging slurry and controllable gel are adopted. Leakage leakage using high concentration composite bridge plugging slurry for static plugging or pressure plugging, or supporting downhole bypass valve for drilling with
plugging, so can not be drilling in the case of many times for high concentration, large particles plugging construction.

4) Reduce drilling costs

As the development cost of atmospheric shale gas should be controlled, the "well factory" drilling mode is more suitable for the development stage \[19\]. "Well factory" drilling mode is a platform layout of 5-6 wells, using the assembly line operation mode, through the cross operation, shorten the auxiliary working time, improve drilling efficiency, reduce drilling cost. According to the two-opening well body structure adopted in the horizontal well of atmospheric shale gas in Wulong block and the principle of consistent drilling method and drilling fluid in the same well section, the construction procedure can be divided into three steps: pipe and surface section operation, two-opening section operation and completion operation. At the same time, the casing depth and operation content of adjacent Wells can be further optimized according to the gas and water display and well leakage during the first drilling pipe section of the platform and the first drilling, so as to speed up and reduce the drilling cost. Using the "well plant" drilling model can also realize the reuse of drilling fluid in different drilling operations and further reduce drilling costs.

5) Optimized logging project

Different logging projects of pre-exploration well and development well should be optimized to reduce logging cost. In the aspect of logging, pre-exploration Wells acquire main geological parameters by comprehensive logging in the whole well section for the purpose of obtaining all data. In the development well, only gas logging is carried out from the second opening section, with stuck layer and optimized target window as the main methods. In the aspect of well logging, the first and second opening are used for standard logging, and the first and second opening are used for cementing quality logging after each cementing, and only the first and second opening are used for cementing quality logging in the development wells. At the same time, in principle, the development wells of the same platform only admit the data of one well, other wells will not be repeated admission; Logging is the information that can be obtained without logging. By optimizing logging project, logging cost can be reduced by more than 40%.

6) Detailed management.

Strengthen production organization and coordination, give full play to the advantages of technical regional integration management, organize the expert team to follow up the whole process of speeding up and improving efficiency, timely solve the problems in the drilling process, and provide all-round technical support. In addition, power supply from power grid and water supply pipeline can be unified, which can not only satisfy drilling construction, but also be used for subsequent fracturing and gas extraction.

4. Conclusions and Suggestions

1) Although Wulong normal pressure shale gas block in the outer margin of sichuan basin is basically the same as the stratum system drilled in fuling, Changning-Weiuyan and other high pressure shale gas blocks in the basin, the drilling technology used is different due to the influence of formation pressure coefficient and gas-bearing quality, and the requirements for low-cost drilling are higher.

2) In view of the Sichuan basin outer atmospheric shale gas blocks geological characteristics and the characteristics of drilling, will open three well bore structure optimization for the open hole structure, using "double two-dimensional" model design, borehole trajectory, using rotary steering technology to control the open borehole trajectory, and the use of low water-oil ratio oil-base drilling fluid and optimizing the production casing cement slurry return higher technical measures to reduce drilling cost and scheme.

3) Shale gas drilling has great investment and high risk. When taking technical measures to reduce the drilling cost, the drilling safety and well quality should be guaranteed first. It is suggested to conduct field tests of low-cost drilling technology in Wulong block to verify the feasibility of low-cost drilling technology.
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