Research and Application of Drilling Technology of Extended-reach Horizontally-intersected Well Used to Extract Coalbed Methane

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Abstract

The extended-reach horizontally-intersected well used to extract coalbed methane (CBM) can increase reservoir contact area, extend the influence scope of drainage-pressure drop and the district of CBM desorption. Furthermore, the extended-reach horizontally-intersected well can enhance unit well output and create favorable conditions for future workover. With the support of Major Projects of National Science and Technology, the research on key technologies of extended-reach horizontally-intersected well is done through theoretical analysis and experiment, the concrete research content includes selection of target formation and design of casing program, choice of survey instruments, research on the bottom hole assembly design and technique of steering wellpath, research on drilling fluid and extended-reach horizontally-intersected technology. As engineering examples of popularization and application of extended-reach horizontally-intersected well, a “U” shape well group located in Sihe mine field of Qinshui Basin and a “V” shape cluster well group located in Dafosi coal mine of Binchang mining area have been constructed successfully by using the integrated technologies.

Keywords: Coalbed Methane; Extended-reach; Horizontally-intersected Well; Drilling Technique; Drilling Fluid

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1. Technology characteristics and application status of extended-reach horizontally-intersected well

Horizontally-intersected well is a well group that a horizontal well intersects with other wells underground. The drilling technology of horizontally-intersected well has been extensively applied in halogen salt mining, underground gasification of coal seam, oil and gas exploration, coalbed methane extraction, geothermal resource exploration, trenchless engineering and so on[1]. A extended-reach horizontally-intersected well used to extract CBM refers to a horizontal well which intersects with a vertical well in coal seams, and the distance between wellheads is usually greater than 500m. According to the geological conditions and engineering requirements, the horizontal well can be drilled continually forward and construct branches after accomplishing the intersection to increase the reservoir contact area of coalbed methane, improve the efficiency of ground coalbed methane extraction, enhance unit well output. The CBM extended-reach horizontally-intersected well drilling technology includes a number of advanced drilling technologies, such as the horizontal well drilling, the open hole cavity technique in coal seams, survey technology for precise intersection, sidetracking branch and geo-steering technology. So construction of CBM extended-reach horizontally-intersected well is a very difficult and highly specialized system engineering[2], which has a higher requirements for drilling equipment, drilling tools, survey instruments and drilling technique.

Abroad, especially in the United States, Australia and Canada, with the development of CBM industry, the drilling technology of extended-reach horizontally-intersected well has been improved gradually. The difficulties in technology and drilling depth have been overcome continually, and good development effectiveness and economic benefit have been produced [3,4]. In china, since the first horizontally-intersected well was designed and constructed in Jincheng city, Shanxi province in 2004 by Orion Energy International Inc, the extended-reach horizontally-intersected well has been used to develop CBM in medium hard to hard and stable coal seams in Shanxi, Shaanxi and Inner Mongolia by Petro China Company Limited, China CBM Company Limited, and Orion Energy International Inc. With the perfection of auxiliary equipments and improvement of drilling technique, the drilling technology of CBM extended-reach horizontally-intersected well has been increasingly recognized and developed rapidly.

2. Research on the key technologies of extended-reach horizontally-intersected well

2.1. Research on the selection of well location and target formation and casing program

2.1.1. Selection of well location and target formation

During the process of drilling geological design, the optimal selection of well location and target formation is very important, which is directly related to whether the construction of extended-reach horizontally-intersected well is successful. And the selection of well location and target formation should be based on the analysis of geographical and geological conditions [5,6]. The requirements of geographical conditions are relatively flat terrain, convenient traffic and beneficial to sustainable development of coal mining area. The requirements of geological conditions are simple strata structure in which the well trajectory is located, good hydrogeology conditions and higher exploration degree. As ideal target formation, the characteristics of coal seams are temperate buried depth, large thickness, stable horizontal distribution, moderate porosity and permeability, high gas content.

2.1.2. Casing program design

The basic principles of casing program design of extended-reach horizontally-intersected well are: (1) the hole size must firstly meet the requirement of measurement while drilling(MWD) tools and be beneficial to borehole wall stabilization; (2) down-hole safety and geological conditions of overlying strata should be paid more attention to [7]. The casing program with three sections is suitable for CBM
extended-reach horizontally-intersected well. The surface section is drilled into the stable bedrock about 10m after drilling through overburden layer, then surface casing is set and cemented to seal the loss zone and water-saturated strata, and the common size of wellbore and casing is φ311mm×φ244.5mm. Second section is drilled into stable strata above the landing point, then intermediate casing is set and cemented, and the common size of wellbore and casing is φ215.9mm×φ177.8mm. In coal seam, third section is openhole completion, and the size of wellbore may be φ152.4mm, φ149.2mm or φ117.8mm, according to the geological conditions and radius of curve section.

2.2. Selection of survey instruments

During the construction process of extended-reach horizontally-intersected well, MWD technology and hitting target measurement technology are necessary for directional drilling and horizontal intersection. At present, the signal of MWD system extensively used in practice is transmitted by wireless way of drilling fluid pulse and electromagnetic wave[8]. The remarkable advantage of MWD system using drilling fluid pulse is that the communication information is reliable, and its disadvantage includes no function of two-way communication, slow transmission speed and strict requirement for drilling fluid(sand content of B less than 1% ~4%, gas content of H not more than 7%). Because of the strict requirement for gas content, the drilling fluid pulse can not be used in under-balance drilling without continuous liquid phase, such as air drilling, foam drilling. The advantages of electromagnetic measurement while drilling (EMWD) System is fast data transmission speed, in addition, the EMWD system can be used to transmit parameters of directional drilling and geological survey in laser drilling, air drilling, foam drilling, etc. The disadvantage of EMWD system is signal transmission affected greatly by formation resistivity. The electromagnetic wave can not pass through low-resistivity formation, so the distance of signal transmission is limited. The EMWD system is suitable for the stratum whose resistivity ranges from 3Ω to 1000Ω and the depth of well less than 3000m.

With the growth of CBM development, the horizontally-intersected well group has been used to extract coal bed methane recently, and the diameter of intersection target area is generally from 0.5m to 1.0m. By means of conventional MWD system, the parameters for directional drilling can be obtained in different logging environment, but accumulated discrepancy of azimuth and hole deviation parameters will generate during the drilling process. Therefore, when the diameter of intersection target area is not more than 1.0m, it difficult to guarantee hitting the target accurately only depending on MWD system, and the hitting target measurement technology must be used. At present, there are mainly two kinds of hitting target measurement technology, one is passive magnetic field ranging technology (Mag Trac) developed by Scientific Drilling Inc, the other is active magnetic field ranging technology developed by Vector Magnetics LLC[9]. An active magnetic beacon system is used in the active magnetic field ranging technology, and the magnetic signal of which can penetrate tens of meters thickness in strata. The ranging scope of the active magnetic beacon system is generally from 40m to 45m, sometimes, which can reach to about 70m, so the azimuth and drift angle of measuring point can be obtained in advance, then, the operations of deviation correction are done in time, which can ensure horizontally-intersected well drilled successfully.

2.3. Research on bottom-hole assembly design and wellpath control technology

2.3.1. Principle of bottom-hole assembly design

The drilling technique of extended-reach horizontally-intersected well is relatively complex, and the bottom-hole assembly will be charged constantly according to the casing program, so the principle of bottom-hole assembly design is simple and practical, easy change. The diameter of surface and second sections of extended-reach horizontally-intersected well is relatively large, and tri-cone bit is a better selection. The third section located in coal seam is suitable to use cone bit or PDC bit. According to
different requirements, the optimization of bottom-hole assembly is necessary, usually, when the surface section and second sections are drilled, collar is needed, and when the third section is drilled, weighted drill pipe is needed.

The angle of the bent sub of screw motor is selected based on formation characteristics and requirement of deviation curvature, for example, the screw motor with bent sub angle ranged from 0.5° to 1.0° can be used for deviation correction during second section drilling, and the screw motor with bent sub angle ranging from 1.25° to 1.5° can be used for deflecting drilling during second and third section drilling. The selection of drill pipe is very important, generally the \( \varphi 127 \text{mm} \) and \( \varphi 114 \text{mm} \) drill pipes are used to drill surface and second section. The \( \varphi 89 \text{mm} \) and \( \varphi 73 \text{mm} \) drill pipes are used to drill curve and horizontal section. According to above principles, the common bottom-hole assemblies used for CBM extended-reach horizontally-intersected well are listed as following.

**Surface section:**
\( \varphi 311.15 \text{mm} \) tri-cone bit + sub with both internal thread + \( \varphi 165 \text{mm} \) drill collar + \( \varphi 114 \text{mm} \) drill pipe.

**Second section:**
\( \varphi 215.90 \text{mm} \) tri-cone bit + sub with both internal thread + \( \varphi 165 \text{mm} \) drill collar + \( \varphi 114 \text{mm} \) drill pipe.

**Third section:**
\( \varphi 152.40 \text{mm} \) or \( \varphi 149.2 \text{mm} \) tri-cone bit or PDC bit + \( \varphi 120 \text{mm} \) screw motor (bent sub angle 1.25° or 1.5°) + sub + \( \varphi 95 \text{mm} \) nonmagnetic drill pipe + MWD + \( \varphi 89 \text{mm} \) weighted drill pipe or \( \varphi 117.80 \text{mm} \) one-cone bit or PDC bit + \( \varphi 95 \text{mm} \) screw motor (bent sub angle 1.25° or 1.5°) + sub + \( \varphi 89 \text{mm} \) nonmagnetic drill pipe + \( \varphi 89 \text{mm} \) weighted drill pipe + MWD + \( \varphi 73 \text{mm} \) weighted drill pipe.

**Horizontally-butted section:**
Third section: \( \varphi 152.40 \text{mm} \) or \( \varphi 149.2 \text{mm} \) tri-cone bit or PDC bit + magnetic bit sub + \( \varphi 120 \text{mm} \) screw motor (bent sub angle 1.25° or 1.5°) + sub + \( \varphi 95 \text{mm} \) nonmagnetic drill pipe + MWD + \( \varphi 89 \text{mm} \) weighted drill pipe or \( \varphi 117.80 \text{mm} \) one-cone bit or PDC bit + magnetic bit sub + \( \varphi 95 \text{mm} \) screw motor (bent sub angle 1.25° or 1.5°) + sub + \( \varphi 89 \text{mm} \) nonmagnetic drill pipe + \( \varphi 89 \text{mm} \) weighted drill pipe + MWD + \( \varphi 73 \text{mm} \) weighted drill pipe.

**2.3.2. Wellpath control technology**

The following factors are considered when designing well trajectory: geological conditions, size and depth of different wellbore section, radius of curvature, ratio of horizontal displacement and vertical depth. And the design of well trajectory should be conducive to the wellpath control, which can ensure accurate landing in the target seam. And the horizontal section of horizontally-intersected well should be drilled forward as far as possible in the middle and the upper of coal seam. In order to reduce the friction and enhance the extension capacity of wellbore, the horizontal section should be as smooth as possible[10,11].

The wellpath control of extended-reach horizontally-intersected well can be divided into four sections: the vertical section, curve section, horizontal section and horizontally-intersected section. Considering the characteristics of extended-reach horizontally-intersected well, an overall scheme of wellpath control should be made, and the basic requirements are: (1) the parameters of curve section for hitting the target area must meet the geological and engineering requirements; (2) the wellpath control of horizontal section should be done precisely in order to ensure effective extension of wellbore and success of horizontal intersection.

The characteristics of extended-reach horizontally-intersected wellpath are short radius of curve section, shallow vertical depth, large ratio of horizontal displacement and vertical depth. Considering the research contents and the geological conditions of testing field, the well trajectory composed five sections, which is vertical section + angle buildup section + angle hold section + angle buildup section + horizontal section, is designed for extended-reach horizontally-intersected well.

**2.4. Drilling fluid technology**
Coal seam is easy to be polluted, and during the construction process of CBM well, the reservoir protection is very difficult, so the drilling fluid design for CBM production well should be able to not only ensure drilling safely, but also effectively protect the coalbed reservoir [12]. Since the radius of curve section of extended-reach horizontally-intersected wellpath is relatively small and the displacement of horizontal section is relatively long, the drilling construction of CBM extended-reach horizontally-intersected well has higher requirements on safety drilling and reservoir protection. Firstly, it’s very important to ensure drilling safety during construction of horizontal section in the target coal seam, because downhole drilling trouble will affect the intersection between horizontal well and vertical well, and reservoir will be damaged during the treatment process of downhole drilling trouble. Secondly, reservoir protection must be attached to great importance during drilling in the target coal seam, otherwise the CBM extraction by water drainage will be greatly influenced, even the aim of CBM production can’t be achieved sometimes.

Combining with performance of coal reservoir and drilling technology characteristics of extended-reach horizontally-intersected well, the basic principle for drilling fluid design is different type of drilling fluid for different wellbore section. The drilling fluid scheme is: (1) normal drilling fluid systems are used in the strata which are above the target coal seam; (2) solids free polymer drilling fluid system is used in target coal seam to ensure the drilling safety, and a kind of complex treatment is used to adjust the performances of drilling fluid. After finishing drilling, in order to reduce or eliminate the reservoir damage and increase the connectivity of the reservoir to the wellbore, a special kind chemical grout whose performance matches the components of drilling fluid system is used to clear drilling skin and achieve plug-removal.

According to the requirements of safety drilling and reservoir protection, the performance index of drilling fluid used in target coal seams need to meet the following basic conditions: (1) reasonable density, that is, the drilling fluid density window is confirmed reasonably, and the hydrostatic fluid column pressure in the well is maintained properly and as far as possible to keep the hole stress in coal seam balance; (2) strong sealing ability and better wall building property, that is, drilling fluid can effectively fill nearly sidewall within the scope of the fracture, form filter cake, and then prevent the filtrate from penetrating the internal coal; (3) better rheological properties, meaning that the drilling fluid not only satisfies the requirements of carrying cuttings, but also could reduce the adverse effect on the wellbore stability; (4) strong inhibitory, as restraining hydration after the filtrate into coal rock fracture and avoiding inflation or swelling of clay components, that helps to maintain the stress balance; (5) better lubricity, which can reduce the frictional resistance between the boring tools and hole wall, and can prevent downhole troubles while enhancing the ability of horizontal section extending; (6) appropriate pH value, which can ensure effective dissolution and utilization of the drilling fluid additive, and can reduce or avoid the damage to coal reservoir.

2.5 Horizontal intersection technology

Rotating magnetic ranging system (RMRS) is extensively used in horizontally-intersected operation [13,14], whose equipment includes magnetic bit sub, receiving probe and auxiliary ground equipments. When executing horizontal intersection, the bottom hole assembly used in horizontal well is drill bit+ magnetic bit sub+ screw motor + non magnetic drill pipe+ MWD+ drill pipe. The survey instrument used in vertical well is receiving probe+ communication cable. The ground equipments include pulley system, indicator etc. The construction procedures are as follows: (1) in the vertical well, a cavity whose diameter is no less than 500mm should be made in target coal seam, and the height of cavity is equal to coal seam; (2) when the intersection distance between horizontal well and vertical well is about 100m left, the magnetic bit sub needs to be assembled between drill bit and motor for drilling horizontal well; (3) in vertical well, the receiving probe should be placed above the cavity, and the distance between
them is form 1.0m to 1.5m; (4) after the drilling string is set into horizontal well again and drilling continues, the rotary magnetic signal can be received initially while intersection distance approaches 70m, and the offset distance between drill bit and cavity can be calculated precisely by RMRS survey data when survey distance ranges from 30m to 50m. The wellpath of horizontal well can be controlled to drill toward vertical well and realize intersection by adjusting toolface of screw motor to steering drilling.

Due to long horizontal section, large displacement and negative influence of geomagnetic field, the accumulated discrepancy of azimuth of actual wellpath is relatively big sometimes. During the process of horizontal intersection, when the survey distance of RMRS is about 60m, the directional drilling should be stopped if the azimuth offset is greater than 10°, and a suitable sidetrack point should be selected to drill a lateral branch and carry out the second intersection after correcting azimuth offset.

3. Field application

3.1. "U" shaped well group located in Sihe mine field of Qinshui basin

The drilling construction of a "U" shaped well group named SH-U2/U3 has been finished successfully by using the drilling technique of extended-reach horizontally-intersected well in Sihe mine field of Qinshui basin. The "U" shaped well group is composed of two wells: horizontal well (SH-U3) and vertical well (SH-U2).

3.1.1. Geology overview

The target formation of the “V” shaped well group was coal seam No. 3. And the strata drilling encountered include Quaternary, Shiqianfeng Formation, Upper Shihezi Formation, Lower Shihezi Formation and Shanxi Formation. As the mainly mined coal seam, coal seam No.3 was from 4.45m to 8.75m thick, the average thickness was 5.89m, and the number of rock parting in the seam was from 0 to 5. The bottom of the seam was soft coal, about 0.8m thick. The distance between the seam and overlying sandstone K8 was about 30m, and the distance between the seam and underlying seam No.9 was about 48m. The upper floor of coal seam No.3 was sandy mudstone or siltstone, and fake floor such as thin carbonaceous mudstone or shale commonly existed. The lower floor of coal seam No.3 was black mudstone, sandy mudstone, siltstone, fine-grained sandstone locally.

3.1.2. Casing program

The casing program of actual drilling of SH-U3 well is listed in Table 1 as follows:

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Bit Size (mm)</th>
<th>Casing Size (mm)</th>
<th>Casing set depth (m)</th>
<th>Top of Cementing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Section</td>
<td>46.04</td>
<td>311.15</td>
<td>244.5</td>
<td>33.60</td>
</tr>
<tr>
<td>Second Section</td>
<td>58.50</td>
<td>215.9</td>
<td>177.8</td>
<td>57.77</td>
</tr>
<tr>
<td>Third Section</td>
<td>1027.37</td>
<td>117.8</td>
<td>/</td>
<td>/</td>
</tr>
</tbody>
</table>

The wellpath of SH-U3 well and the SH-U2 well is shown in Figure 1. The wellpath of horizontal well (SH-U3) was drilled into target coal seam at 394m, and successfully interested with the vertical well (SH-U2) at 727.01m[15].
3.1.3. Actual drilling results

The total footage of horizontal well (SH-U3) is 1304.33m, and the reservoir-encountered ratio of horizontal section is 100%. Drainage and CBM extraction of the well group began on February 24, 2011. Daily output curve until 1-June is shown in Figure 2. Until 25-June, the maximum daily output is more than $2.1 \times 10^4 \text{m}^3$, and the cumulative output exceeds $110 \times 10^4 \text{m}^3$. The CBM output prospect of the “U” shaped well group is considerable.

3.2 “V” shaped cluster well group located in Dafosi coal mine of Binchang mining area

Using the drilling technology of extended-reach horizontally-intersected well, a ”V” shaped cluster well group named DFS-C04 has been finished in Dafosi coal mine of Binchang mining area, which was composed of two Horizontal wells (DFS-C04-H1 and DFS-C04-H2) and one vertical well(DFS-C04-V1).

3.2.1. Geology overview

The target formation of the “V” shaped cluster well group was coal seam No.4. And the strata drilling encountered include Quaternary, Tertiary, Luohe Formation and Yijun Formation of Lower Cretaceous, Anding Formation and Zhiluo Formation of Middle Jurassic, Yan'an Formation of Lower Jurassic. The seam was about 10m thick, whose distribution was stable all over the mine field.
3.2.2. Casing program

The casing program of actual drilling of DFS-C04 well group is listed in Table 2 as follows, and the three-dimensional wellpath is shown in Figure 3.

DFS-C04-H1 well was drilled to intersect DFS-C04-V1 well at the footage of 1412.73m, and the horizontal displacement between these two wellheads is 1064.57m. DFS-C04-H2 well was drilled to intersect DFS-C04-V1 well at the footage of 1398.50m.

Table 2: Casing program of DFS-C04 well group

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Surface Section</th>
<th>Second Section</th>
<th>Third Section</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depth (m)</td>
<td>Bit Size (mm)</td>
<td>Casing Size (mm)</td>
</tr>
<tr>
<td>DFS-C04-H1</td>
<td>159.49</td>
<td>311.15</td>
<td>244.50</td>
</tr>
<tr>
<td>DFS-C04-H2</td>
<td>179.22</td>
<td>311.15</td>
<td>244.50</td>
</tr>
<tr>
<td>DFS-C04-V1</td>
<td>180.00</td>
<td>311.15</td>
<td>244.50</td>
</tr>
</tbody>
</table>

Figure 3. DFS-C04 well group three-dimensional track diagram

The horizontal displacement between these two wellheads was 983.94m.

At present, the drainage and gas extraction of DFS-C04 cluster wells have not began, and are under preparation now.

4. Conclusions and suggestions

(1) The extended-reach horizontally-intersected well is a new alternative scheme for CBM extraction from the surface in coal mining field, is characterized by single well output, convenient future workover, low integrated construction cost.

(2) The drilling technique of CBM extended-reach horizontally-intersected well contains a number of advanced technologies, such as vertical well drilling, horizontal well drilling, openhole cavity construction in target coal seam; precisely horizontally-intersected construction, multilateral and geo-
steering drilling, and coordinated use of all these technologies is favorable to provide better service for CBM extraction.

3. The successful drilling construction of extended-reach horizontally-intersected well needs the steering support provided by advanced instruments and equipment, including wireless MWD system, rotating magnetic ranging system, positive displacement motor with low rotary speed and large torque.

4. Under favorable reservoir geologic conditions and reasonable technique parameters, the drilling fluid scheme that a kind of solid-free polymer drilling fluid is used to drill target coal seams and a kind of water solution of a special chemical additive is used to avoid drilling skin, which can realize both safety drilling and reservoir protection.

5. Due to the narrow annular space between drill string and wellbore, the annular pressure loss varies rapidly with the increase of well depth, which limits the size of the drilling fluid density window, so the further study on optimization of BHA and casing program is necessary.

6. To realize the goal of effective utilization of CBM extended-reach horizontally-intersected well, it is suggested that research on drainage and gas extraction technique should be strengthened while studying the drilling and completion technique.

References


