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Research Article

Deformation mechanism of horizontal shale gas well production casing and its engineering solution: A case study on the Huangjinba Block of the Zhaotong National Shale Gas Demonstration Zone

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Abstract

In the Huangjinba Block of the Zhaotong National Shale Gas Demonstration Zone in the periphery of the Sichuan Basin, two horizontal shale gas wells suffer severe casing deformation. In this paper, the geological and engineering characteristics of the strata around the deformed casing interval were analyzed based on the 24-arm caliper measurement of casing deformation, open-hole caliper, electrical resistivity, drilling time and gas logging, cementing CBL＼VDL and CBL imaging. Then, 24-arm caliper measurement data were analyzed and 3D imaged by 3D imaging analysis software, to figure out the morphologic characteristics of deformed casing. It is shown that severe casing deformation tends to occur where structural fractures are developed. Besides, casing deformation is mainly in the form of "S"-shape bending vertically. The severely deformed casing is also characterized by obviously transverse shear deformation caused by the high-angle sliding compression of rocks. Therefore, some suggestions were proposed correspondingly. First, the countermeasures in this block shall focus on shear casing deformation caused by the sliding of rocks along the fracture face. Wellbore trajectory shall be designed based on the structural contours map of pay zones to bypass the "ridge" and "valley bottom" area in the local high and steep structural zones. Second, the distribution information of fractured zones shall be predicted based on the ant-tracking attribute volume distribution map of pay zones, so that the wellbore trajectory can run along the strike of fractured zone. And third, it is recommended to use plug-drilling free big bore bridge plug or full-bore infinite stage completion technique, so that the conventional bridge plug milling operation after fracturing can be omitted and each fractured layer can be put into production after fracturing.

Keywords: Sichuan Basin; Periphery; Zhaotong National Shale Gas Demonstration Zone; 24-arm caliper measurement; Shale gas well; Casing deformation; Natural fracture; Shear deformation; Sliding of rocks; Engineering solution

0. Introduction

For the production wells in the Huangjinba Block of the Zhaotong National Shale Gas Demonstration Zone undertaken by PetroChina Zhejiang Oilfield Company, the three-spud-in horizontal well casing program is adopted, with Ø139.7 mm casing as the production casing. The inner diameter of the casing is 115 mm, while the outer diameter of the bridge plug for pumping in multi-layer fracturing is 108 mm. After the pumping of the bridge plug between two fracturing stages or the completion of full-hole fracturing, the working tools may be stuck due to casing deformation during the mill-out of the bridge plug in some wells, which has brought great risks and difficulties to the operations. For example, the operation cycle and complex processing costs are greatly increased, and even in serious cases the well production capacity is damaged.

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A lot of analysis and research have been performed on the causes or the mechanism of casing damage of conventional oil and gas wells and water injection wells in oilfield blocks [1−9]. In order to further reveal the mechanism of casing damage, many scholars regard casing-cement sheath-formation as a system and consider the uniform in-situ stress, non-uniform in-situ stress, centering and bending of casing, cement sheath distribution and cementing quality, in-tube pressure and other variable conditions, to make casing stress and deformation analysis under various simulation conditions, and realize the quantitative or qualitative interpretation of the causes of casing damage [10−20]. Although conventional oil and gas well casing damage assessment and analysis model theory and method are still applicable to shale gas wells, the casing in shale gas wells face more severe stress conditions, more complicated geological conditions and more widespread damage with its own characteristics. In recent years, with the increase of shale gas wells and the continuous emergence of casing damage, the research on the causes and mechanism of casing damage in shale gas wells is being strengthened.

Based on elasto-plastic mechanics, Liu Kui et al. [21] analyzed the mechanical behaviors of the casing-cement sheath-formation system in the horizontal segment during the fracturing of shale gas wells by means of complex function and stress field decomposition. Chen Zhaowei et al. [22] analyzed the correlation between casing deformation and faults, fractures, shale bedding and hydraulic fracturing in the Changning−Weiyuan shale gas demonstration area. In addition, based on the mechanical conditions of sliding faults, they proposed casing damage mechanism, that is, as the fracturing fluid enters the natural fractures along a certain channel to increase the pore pressure in the fractures, when the pore pressure reaches a critical value, natural fracture sliding will be stimulated to cause the casing deformation.

In this paper, in view of the problem of casing deformation which results in the sticking of working tools and affects the production during the well completion fracturing and the drilling and milling of bridge plug before production in horizontal wells (H1-2 and H6-7), data of drilling and logging, conventional logging, multi-armed caliper log of casing and well cementing quality evaluation were integrated to carry out a study on the casing deformation location rules and deformation characteristics, so as to reveal the location characteristics of casing deformation, the sources of power and the main factors that affect the shaping of the casing.

1. Positions with casing deformation

1.1. Serious casing deformation occurs in the associated fracture zone or natural fracture zone in the fault fracture zone

According to the operation records, the casing drift diameter was 112 mm (with inner diameter of 115 mm) before casing deformation at 2887 m in Well H1-2 of a platform and was less than 92 mm after deformation and less than 73 mm at 3007 m. The drift diameter of casing at 3441 m in Well H6-7 of another platform after deformation was less than 76 mm. Casing deformations at these positions are extremely severe, posing great difficulties to subsequent wellbore operations.

1.1.1. Well H1-2

The electrical logging and mud logging curves of the Ø215.9 mm borehole of Well H1-2 in the third spud-in (Fig. 1) show that fault fracture zone was encountered in the well at 2780−2820 m and 2900−2945 m. The point with extremely serious casing deformation in this well was at 2887 m near the fault plane, belonging to the associated fracture development zone, where the formation of fracture resulted in the release of stratum stress and regular borehole diameter.

Multi-armed caliper log shows that vertical rock dislocation occurred at this position and the adjacent intervals. A point with very serious casing deformation at 3007 m is located in the relative development zone (2945−3035 m) of secondary fractures adjacent to the fault fracture zone at 2900−2945 m. Due to the partial development of fractures, stratum stress was released to some extent in this area, the degree of formation breaking somewhat slowed down, and diameter expansion was seen in the borehole. Due to the existence of cracks, the show of crack gas was active. Compared with the interval of 3035−3400 m, this interval is characterized by low resistivity under the same characteristics of high gas logging value. This indicates that the gas content of the shale matrix in this interval is not high and the shale gas entering the wellbore during drilling is mainly crack gas. The point at 3007 m has a very low resistivity and the highest gas logging value, showing that cracks are most developed there.

Casing deformation was found in Well H1-2 when the 18th-stage cable bridge plug and perforating tool string were pumped to the point at 2887 m. Even though the casing deformation occurred during the 17th-stage fracturing, the Ø108 mm bridge plug was able to rush through the deformation point, showing that the initial casing deformation was not serious and the deformation was aggravating with the increase of time. After the entire fracturing was completed at 3007 m in Well H1-2, the Ø98 mm milling shoes could freely pass the position on the 82th day, and the Ø73 mm tubing body had been unable to pass the position on the 201th day, showing that the casing deformation increased with time.

Fault fracture zones are also clearly shown on the CBL and VDL curves of the cementing quality evaluation and the 8-slice CBL sound-amplitude imaging (Fig. 1). Due to the serious expansion of drilled hole caused by a fault rupture zone, channeling occurred in this interval during cementing and the cementing quality was poor.

1.1.2. Well H6-7

After the full-hole fracturing was completed in Well H6-7, the pumping of bridge plug was smooth, showing that the serious casing deformation at 3441 m did not occur during the volumetric fracturing. Therefore, casing deformation at 2887 m and 3007 m in Well H1-2 and at 3441 m in Well H6-7 cannot be explained by the mechanism of casing damage