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Research article

Problems in the wellbore integrity of a shale gas horizontal well and corresponding countermeasures

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Abstract

In the Changning–Weiyuan national shale gas demonstration area, SW Sichuan Basin, the wellbore integrity damage occurs in some shale gas wells and has direct effect on the gas production rate of single shale gas horizontal well. After statistics analysis was performed on the problems related with wellbore integrity, such as casing damage, casing running difficulty and cement sheath blow-by, the multi-factor coupling casing stress calculation and evaluation mode laws established. Then study was conducted on the influential mechanism of multi-factor coupling (temperature effect, casing bending and axial pressure) on casing damage. The shale slip mechanism and its relationship with casing sheared formation were analyzed by using the Mohr–Coulomb criterion. Inversion analysis was performed on the main controlling factors of casing friction by using the developed casing hook load prediction and friction analysis software. And finally, based on the characteristics of shale gas horizontal wells, wellbore integrity control measures were proposed in terms of design and construction process, so as to improve the drilling quality (DQ). More specifically, shale gas well casing design calculation method and check standard were modified, well structure and full bore hole trajectory design were optimized, drilling quality was improved, cement properties were optimized and cement sealing integrity during fracturing process was checked. These research findings are significant in the design and management of future shale gas borehole integrity.

Keywords: Shale gas; Wellbore integrity; Casing damage; Shale slip; Drilling quality (DQ); Sichuan Basin; Changning–Weiyuan; National shale gas demonstration area

As a core index [1] in drilling and completion of horizontal wells in the development of shale gas, wellbore integrity may play an important role in ensuring the safety of shale gas wells during the entire service period. In addition, wellbore integrity is a key attribute to protecting the hole from structural damages and maintaining desirable performances. Wellbore integrity may also ensure downhole safety and promote productivity of individual wells in shale gas development. In recent years, studies have been performed on wellbore integrity from different perspectives. As far as engineering is concerned, wellbore integrity include two key components: drilling quality (DQ) and completion quality (CQ) [2,3].

The Changning–Weiyuan national shale gas demonstration area in southwestern Sichuan Basin suffered some problems related to wellbore integrity of some shale gas wells since its exploration and development in 2013. Such problems include difficulties in tripping in casings in horizontal well intervals, cement sheath blow-by and severe casing damage. It is especially worth mentioning that casing damages may lead to difficulties in the installation of bridge plugs and the milling of such bridge plugs by coiled tubing. In extreme cases, fracturing operations were forced to be abandoned in certain intervals. All such problems may negatively affect enhancements in productivity in individual shale gas horizontal wells.

With regard to wellbore integrity in horizontal shale gas wells, Adams and Sugden et al. [4,5] analyzed major factors that may affect the generation of abnormal loads on production

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casings in shale gas wells of the United States. They proposed, for the first time, the concept of irreducible fluid contraction in annular spaces during fracturing. In addition, they reviewed hazards in casing design of shale gas wells. With consideration to the present situations and the specific features of wellbore integrity in horizontal shale gas wells, CNPC Drilling Research Institute conducted researches on correlation between pressures and temperatures of irreducible fluids in annular spaces, impacts of shale slip on casing damage and major controlling factors for difficulties during casing installation. During the course, models for assessments and calculation of casing damages induced by multiple causes have been constructed to reveal mechanisms and patterns of casing damages, shale slip, difficulties in casing installation and other aspects. Relevant researches may provide valuable guidelines for design and management of wellbore integrity during shale gas development.

1. Wellbore integrity problems in horizontal shale gas wells

1.1. Frequent occurrence of casing damage

Statistics show that 13 wells out of 33 wells with large-scale hydraulic fracturing operations before 2015 in the Changning−Weiyuan area suffered casing damages or deformations of various degrees. In the Changning Block, 9 wells out of the 14 horizontal wells with fracturing operations experienced abnormal conditions. It can be seen that wellbore integrity is a prominent problem (See Fig. 1). Analysis results show that these casing damages may have three specific features. First, majority of casing damages are concentrated around Point A (Landing point) in the horizontal well. To be more specific, 62.5% casing damages are distributed around the point, whereas the remaining 37.5% may be distributed in other areas. Second, all casing damages occur during hydraulic fracturing. Third, certain casing damage points are distributed around the contacts of different formations, or around the faults identified through logging data interpretation. With significant changes in lithologic features, these formations have high heterogeneity in both geomechanics and crustal stress.

1.2. Difficulties in casing installation

Difficulties in casing installation can be frequently encountered during production casing installation in shale gas wells in the Changning−Weiyuan area. For example, in Well HJBH6-8, the hook disengaged from the production casing at the well depth of approximately 3500 m. Difficulties in the lowering of the production casing were encountered at approximately 3757 m. So it is necessary to move the casing up and down with amplitudes of 2−3 m to install the production casing properly. From the depth of 3772 m, amplitudes of such movements were increased to 5−6 m. Further down to the depths of 4185−4208 m, more severe difficulties were encountered. So it is necessary to enhance wellhead pressures, or even "bump in" (Fig. 2) to install the production casing. Upon installation of the ⌀127 mm production casing in Well CNH2-1 (at well depth of 4177.95 m), joints on female screw of the casing were found to be deformed. Great difficulties were also encountered during the installation of the ⌀127 mm production casing in Well CNH2-3 at the depth of 3060 m. The casing was moved up and down repeatedly for about 1 h before proper installation.

1.3. Difficulties in maintaining cement sheath integrity

In the shale gas demonstration area, cement sheath integrity is subject to impacts of high-density oil-based drilling fluids which are difficult to be flushed or displaced, difficulties in centralization of casing, high formation pressure coefficients in shale, high pressures and low temperatures during fracturing. Consequently, severe problems may be encountered, especially in long horizontal intervals.

2. Analysis on the wellbore integrity of horizontal shale gas wells

2.1. Mechanisms of casing damage based on multi-factor coupling

In view of temperature effects, pressure effects, bending effects and other factors may affect performances of casing, assessment and calculation models for casing damages

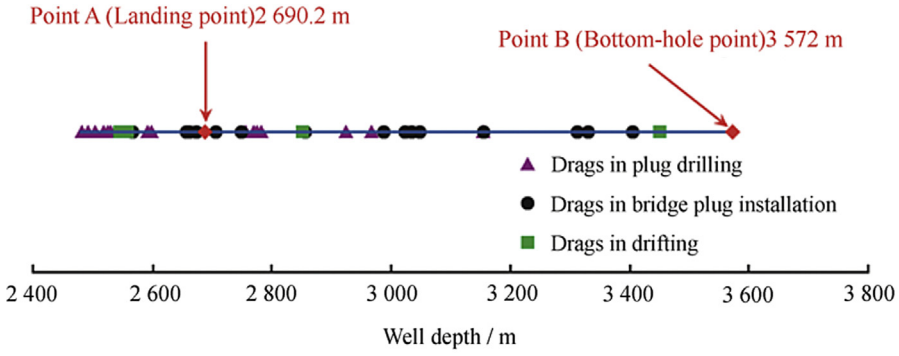

Fig. 1. Statistics on points with casing damages at different well depths in the Changning−Weiyuan Area.