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Research article

Transient dynamics study on casing deformation resulted from lost circulation in low-pressure formation in the Yuanba Gasfield, Sichuan Basin

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Abstract

In the course of completion of an ultra-deep well newly drilled in the Yuanba Gasfield, Sichuan Basin, long-section and large-scale deformation occurred in the heavy casing section and nickel base alloy casing section of the sealing Triassic limestone interval, so a new hole had to be sidetracked, which impels us to rediscover the applicability of conventional drilling and completion technology in ultra-deep wells. In this paper, based on the borehole condition and field operation data of this well, the borehole pressure field variation initiated by lost circulation in the low-pressure formation was analyzed from the perspective of dynamics, then, the variation pattern of differential pressure inside and outside the well bore at different time intervals was depicted, and the primary cause of such complication was theoretically revealed, i.e., the pressure wave generated by instant lost circulation in low-pressure formation would result in redistribution of pressure inside the downhole confined space, and then the crush of casing in the vicinity of local low-pressure areas. Pertinent proposals for avoiding these kinds of engineering complexities were put forward: ① when downhole sealing casing operation is conducted in open hole completion, liner completion or perforated hole, the potential damage of lost circulation to casing should be considered; ② the downhole sealing point and sealing mode should be selected cautiously: the sealing point had better be selected in the section with good cementing quality or as close to the casing shoe as possible, and the sealing mode can be either cement plug or mechanical bridge plug. This paper finally points out that good cementing quality plays an important role in preventing this type of casing deformation.
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Keywords: Sichuan Basin; Yuanba Gasfield; Ultra-deep well; Casing deformation; Lost circulation; Surge wave; Transient flow model

Casing deformation has very serious effect on drilling, completion and production of oil and gas wells and generally results in local or full abandonment of the wells, so attention has always been paid to the related mechanisms [1–6]. Based on currently used static or quasi-static pipe string mechanics verification methods, Wang Tao [7] and Ai Chi et al. [8,9] investigated casing damage status and rules in the Tarim Oilfield and analyzed several main reasons for casing damage, including plastic or high-permeability formations outside the casings and defective cementing quality. Zeng Yijin [10], Zhang Jincheng [11] and Song Shengli [12] evaluated the crushing stress exerted on the casings by studying the creeping rules of gypsum salt beds. Zhang Guangqing et al. [13] established creeping load and swelling stress model for mud shale formations and found out that swelling stress of mud shale formations could reach several to tens of times the far-field loads with the changing of formation swelling factors. As for the casing strength under the force of non-uniform external load induced by the creep of gypsum salt beds, Han Jianzeng et al. [14] pointed out that increasing wall thickness is more suitable for improving the casing collapsing strength under the force of non-uniform load than increasing steel grades. Deng Jingen et al. [15] described quantitatively the non-uniform external load on casings by using “equivalent breaking loads” and short-long axis ratio of elliptic loads and established casing strength design chart with non-uniform external loads, so as to detect the safety of running casing in

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rheological formations (e.g., salt beds) or conduct casing strength design with given casing external loads.

The Yuanba Gasfield in the Sichuan Basin is a typical ultra-deep "three-high" (high temperature, high pressure and high sulfur content) gas field, and its development well is characterized by TVD of 6900 m, formation temperature of 165 °C, formation pressure of over 70 MPa, average H_2S content of 5.14% and average CO_2 content of 7.5%. The development well is mainly in the configuration of five sections with liner completion in the reservoirs.

Multiple large-scale long deformations occurred in the fourth casing section below 5800 m in a newly drilled horizontal well when it was put into production in the Yuanba Gasfield, even though various adverse factors were taken into consideration and the casing strength index was designed by ensuring the values stipulated by the regulations. In this paper, analysis is performed on the change of borehole pressure fields induced by lost circulation in the low-pressure formation by considering the borehole condition and field operation data of this well. The variation patterns of differential pressure inside and outside the borehole at different time intervals are illustrated, and the primary cause of such complication is theoretically revealed. Then, some specific suggestions are provided on avoiding complication of similar engineering.

1. Brief introduction and preliminary cause analysis of casing deformation

When a well in the Yuanba Gasfield was drilled to the depth of 6580 m, the liner of 2482 m long (ø 206.4 mm BG 110TSS × 19.05 mm + ø 193.7 mm BG110TS × 12.7 mm + ø 193.7 mm BG 2532-125 × 12.7 mm) was run in for well cementing so as to isolate high-pressure gas reservoir of the Upper Triassic Xujiahe Formation from high-pressure water layers of the Lower Triassic Jialingjiang Formation. After the fifth drilling was completed, ø 127 mm liner was run in the pay zones. Sealing cement plugs were temporarily set at the depth of 5746−6005 m to isolate the low-pressure pay zones below, so as to tie the ø 193.7 mm casing back to the wellhead. After tieback of the casing, the whole borehole pressure test proved qualified and completion was finished in the whole well. The main lithologies of the lower formations are shown in Table 1.

Abnormal pressure occurred twice when liner cementing was conducted at the fourth casing section and when temporary sealing cement plugs were set. One time is during slurry displacement in liner cementing, the pump pressure rose abnormally and resulted in overflow, which was controlled by means of throttling circulation well-killing. Based on logging interpretation, the cementing was unqualified at the middle-upper interval of this casing section. The other time is when the standpipe pressure dropped slowly to 2.2 MPa from 3 MPa and then rose to 9.9 MPa after temporary sealed cement plugs were set for building pressure and waiting on cement. Based on interpretation, high-pressure formation fluids channeled and leaked into the borehole.

In the subsequent production operations, cement plugs were drilled to 5843 m by using three-cone bits. After the gas was blown off, the pump pressure dropped and no drilling fluids flowed back to the wellhead. After plugging operation was completed, the cement plugs were further drilled to 5946.85 m where touch sticking happened. When it was treated to the depth of 6200 m by using caliper log, milling, washing over and fishing, five deformed casing sections of 0.5−1.37 m long were totally washed over from carbon steel and nickel base alloy casing sections. The whole section below 6200 m was sealed due to casing damage, so it is decided that the treatment of the casing be abandoned and sidetracking be conducted to connect the pay zones.

It is concluded on the basis of drilling and completion operations that large-scale casing deformation took place after the setting of temporary sealing cement plugs. Moreover, it is indicated by the serious casing damage discovered at the nickel base alloy casing section (BG 2532-125) in limestone interval that high-pressure creep and high-acidity gas corrosion in gypsum salt beds are not the direct reasons for casing damage.

In this study, the reason for casing damage is preliminarily analyzed. High-pressure formation fluids break through the borehole before temporary sealing cement plugs are set. After the setting of cement plugs, the high-pressure fluids are sealed below cement plugs, so the pressure inside the casing below the cement plug rises gradually. The pressure coefficient is lower in Changxing Formation (Table 1), so lost circulation takes place and results in transient low pressure in the borehole below the temporary sealing cement plugs when borehole

Table 1
Geologic sequence of the lower formations.

Formation	Well depth of top boundary/m	Well depth of bottom boundary/m	Bottom boundary TVD/m	Pressure coefficient	Remarks
Lower Triassic Jialingjiang Formation	5362	6182	6146	1.50−2.03	Anhydrite rocks occur in Jia 2 and Jia 5 − Jia 4 Members, and limestones and dolomites are dominant in other intervals. High-pressure water layers appear in Jia 2 Member.
Lower Triassic Feixianguan Formation	6182	6624	6467	1.20−1.95	In Fei 4 Member, anhydrites are interbedded with gypsum dolomites, argillaceous dolomites and limy dolomites in the same thickness. Limestones are dominant in other intervals.
Upper Permian Changxing Formation	6624	7788	6551	1.01−1.12	As the principal pay zone, it is dominantly composed of limestones and dolomites. H_2S and CO_2 occur in natural gas.

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