Effect of Sand Production on Casing Integrity

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Abstract

This paper documents a case study about the effect of sand production on casing damage. Many wells were converted from production to water injection. Formation of precipitates across the injection interval required frequent well washing which inadvertently involved reducing the well pressure rapidly. Consequently, solids were released from the formation into the wells. The well washing and associated solids production went unnoticed for an unknown length of time until significant casing deformation was encountered during a recent workover. The significant solids production caused casing buckling near the perforation interval. It also activated a weak plane in the overburden, causing further casing damage. This paper will present relevant field data and engineering analyses to support the above conclusions. Field measures to improve the casing's resistance against the buckling are also described.

Introduction

This paper is concerned with casing integrity in conventional onshore reservoir production in the Niuzhuang area of the Shengli Oilfield in China. Worldwide experience shows that origins of casing failure are complex. Reservoir geology, drilling and cement practices, production drawdown schemes and casing hardware can all influence casing integrity. Nevertheless, major casing damage mechanisms can be summarized as follows: 1) chemical corrosion(1, 2); 2) shear deformation along re-activated weak planes(3-8); 3) significant reservoir compaction(9-11); and, 4) excessive sand production(12-16).

Chemical corrosion is a major casing damage mechanism in the NiuZhuang field. In a total of six wells being investigated, damage to five of those wells was caused by corrosion(17). However, this paper describes another casing failure mechanism; unintended excessive sand production. The following description will first present relevant field data. Mathematical analyses are then carried out to quantify the damage mechanisms. Finally, field measures are proposed to correct the problem.

Reservoir Geology and Rock Mechanical Properties

Production in the NiuZhuang field mainly comes from two sand bodies at a depth of approximately 3,200 m. The reservoir is structurally simple with only a small normal fault at an offset of 10 m. The original reservoir pressure is abnormally high at 1.68 SG. Average reservoir permeability based on core analysis is 24.5 mD and porosity is 18.2%. Porosity is the major fluid conduit and storage. Natural fractures are not developed. Initial well production rate is very high, but the productivity decreases rapidly. Full production started in 1993. Water injection was needed in late 1994. The effect was seen at the production wells usually four to six months after water injection started at the surrounding wells.

No rock mechanical tests were done on our target reservoir rocks. Instead, rock mechanical properties were calculated from well logs and petrophysical data using Baker Hughes' LMP (Log of Mechanical Properties)(11). Table 1 lists the average properties calculated at reservoir pressures equal to the peak injection pressure (70 MPa) or the minimum pressure reached during well washing (35 MPa). Table 1 also includes a set of lab-measured mechanical properties on a similar stratum in an adjacent oil field.

Well History and Casing Damage

Well N42 experienced significant casing deformation. It was completed in November 1990 and converted from production to injection four years later. Casing failure was encountered in early 2002; 11 years after its completion. Workover tools, and then production tubing, could not pass through the damaged interval due to dramatic multiple doglegs formed therein. Repeated efforts over 75 days could not free the tubing out of the casing. Locations of significant casing deformations are shown in Figure 1a. The failure occurred in two zones, all of which were below the cement return height. One interval is approximately 6 m long, shortly (about 5 m) above the perforation interval. As shown in Figure 1b, six doglegs over this 6 m interval were felt during the workover. The other zone of significant casing deformation is located over a 9 m interval at approximately 300 m above the perforation interval.

Injection pressure at N42 was mostly at 70 MPa. However, to remove precipitates formed across the injection interval, the well was frequently washed via rapidly bleeding off the injection pressure by opening the wellhead to the atmosphere. This meant a rapid pressure drop of 35 to 40 MPa across the perforations during the well washing process. Note that the injection pressure was 70 MPa and the hydrostatic pressure at the perforation depth was 30 to 35 MPa. Rock fragments, including cement, were seen at the wellhead. Four production tubing strings were buried in rock solids downhole when the casing failure was noticed. Therefore, it is reasonable to hypothesize that the near-wellbore rock around the perforation interval was aggressively disturbed. The rock is mechanically weakened and then structurally loosened. The injected waste water likely reduced the rock strength due to swelling of the clay fines upon exposure to the freshwater. As a result, significant amounts of rock solids were produced over time. Open cavities were likely formed behind the casing, weakening or eliminating its lateral support. The casing is prone to buckle when the reservoir subsides in response to the pressure drops during the well washing.

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TABLE 1: Representative rock mechanical properties for the target reservoir.

	p0 = 35 MPa	p0 = 70 MPa	Lab Test Results
Young's modulus, GPa	7.2000	5.2584	8.0000
Poisson's ratio	0.2300	0.2555	0.2000
Bulk compressibility, 1/GPa	0.2250	0.2790	0.2250

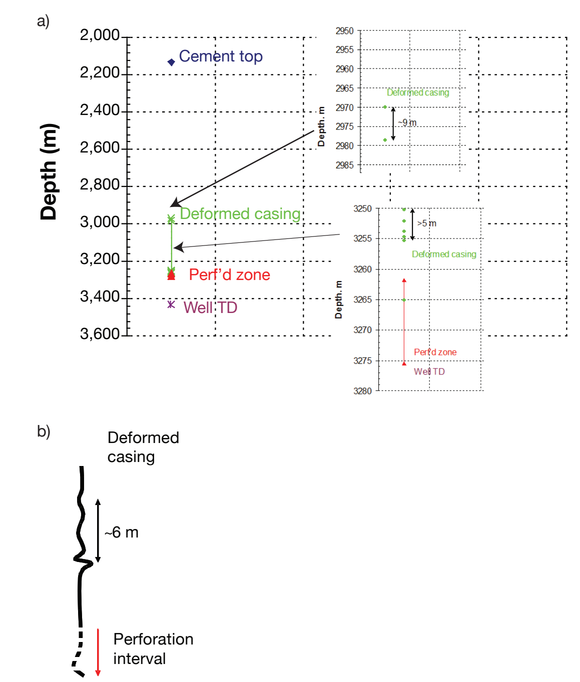

FIGURE 1: a) Relative vertical positions of casing deformation, cement return heights, perforation interval and well depth at well N42; b) Multiple doglegs formed at N42. Relative position and severity of the doglegs are based on the field data; but their absolute severity is for illustration purposes only.

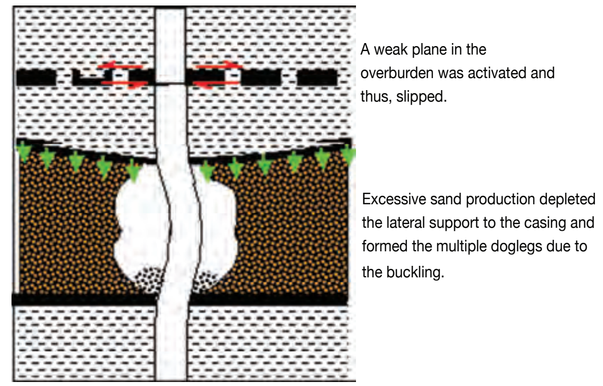

FIGURE 2: A schematic summarizing the casing damage mechanisms at N42.

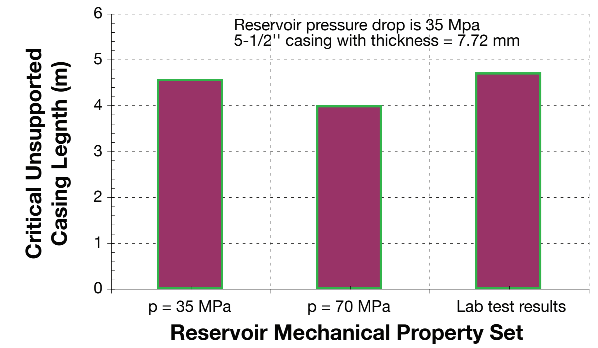

FIGURE 3: Maximum safe unsupported casing length during the well washing at N42. The x-axis denotes different sets of material properties whose details are listed in Table 1.

In fact, the multiple doglegs, formed near the perforation interval at N42, bear the hallmark of casing buckling. Moreover, formation of the open cavity and reservoir compaction during the well washing may have activated weak planes in the overburden, causing the casing failure at 300 m above the perforation interval. The above-described mechanisms are schematically shown in Figure 2. The following mathematical analysis will verify these hypotheses.

Mathematical Analysis of Casing Buckling and Activation of Weak Planes in the Overburden

Two key variables are affected if a casing buckles. One is the axial compressive load on the casing imposed by the reservoir compaction. The vertical compaction strain, ε_{zz}, and subsidence, Δu_z, can be calculated using the following formula[11]:

$$\varepsilon_{zz} = -\left(\frac{\eta}{G}\right)\Delta p$$

$$\Delta u_z = -\left(\frac{\eta}{G}\right)\Delta ph \quad \text{...(1)}$$

The other key variable that determines if a casing buckles is its unsupported interval. A longer unsupported casing interval is more prone to buckle. Therefore, the concept 'maximum safe unsupported casing length' is defined. If the casing is not supported over an interval larger than this critical length, the casing will buckle. In general, a buckled casing interval observed in the field should be equal to or longer than the theoretical maximum safe unsupported casing length. Figure 3 shows that at N42, the theoretical maximum safe length after a 35 MPa pressure drop is 4 to 5 m. The buckled casing length observed in the field is approximately 6 m as shown in Figure 1. Therefore, the casing buckling mechanism mathematically explains the observed casing failure interval in the field.

The casing buckling explains the multiple severe doglegs formed near the perforation interval at N42. The same casing buckling mode cannot explain the other damaged casing interval at N42, which is about 300 m above the perforation interval. It is unlikely that the buckling mode would extend over a 300 m interval. Reactivation of weak planes at this depth can explain the casing damage. Figure 4 plots the distribution of effective shear stress along a horizontal weak plane at 300 m above the subsiding reservoir payzone. The effective shear stress is defined as the shear stress acting on a weak plane minus its friction resistance. Thus, a larger-than-zero effective shear stress denotes that the shear stress exceeds its friction strength and the plane is prone to slip. Figure 4 shows that a portion of the weak plane in our discussion indeed meets this criterion and thus, will activate to slip. This requires the following conditions to be met or uses the following input parameters:

1. The weak plane is horizontal and 300 m above the top boundary of the subsiding reservoir. This is a conservative assumption for the reservoir subsid plane. First, the 300 m vertical dis plane and the reservoir top may be a closer proximity from the weak pla voir makes it easier to slide. Second, an inclined weak plane