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Experimental study on the mechanical responses of downhole tools in highly-deviated waterflooding well

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ABSTRACT

The complexity of the well structure of highly-deviated wells causes complicated and changeable mechanical response of the downhole tools under the operation conditions such as waterflooding, packer seating, circulation well cleanup and packer unlocking. To investigate the mechanical response mechanism of downhole tools in highly-deviated wells during different operation stages, a force test instrument is developed and used to test the axial forces of downhole tools in two typical highly-deviated wells in Jidong oil field in China. It has been found that reverse circulation well cleanup has little influence on the axial forces in downhole tools due to the small bulging effect caused by the pressure difference between the inner and outer of the tubing. Whereas, the packer seating operation has the biggest effect on the change of axial force in tubing string due to the piston effect. In case of no anchor, the maximum axial force imposed on the packer can reach 125 kN which is far more than the maximum static friction force (30 kN) that a packer can bear. In the waterflooding stage, due to the temperature effect, the tubing section close to the packer sustains compression force and is likely to produce sinusoidal buckling and helical buckling. Mechanical response analysis on the whole construction period also shows that the different combination scheme of downhole tools has great influence on the forces in them.

1. Introduction

Waterflooding wells are widely used for oil&gas production in many offshore oil fields to enhance oil recovery. Most of them are highly-deviated directional wells which consist of several well sections with different deviation angles and azimuthal angles, as shown in Fig. 1 (Liu et al., 2018). Tubing, packer and anchor are the most important downhole tools to ensure the success of the water injection operation. Under different waterflooding operation stages, such as circulation well cleanup, packer seating, waterflooding and packer unlocking, the mechanical responses of these tools in highly-deviated well are very complicated and changeable, which can easily lead to large force and deformation in the tubing string (shown in Fig. 2) and exacerbate the failure of downhole tools. Moreover, with the waterflooding technology developing towards to segmentation and deep direction, and with the waterflooding pressure and its differential between layers increasing dramatically, the mechanics responses of downhole tools tend to be more diversified and complicated. Therefore, to ensure the safety and efficiency of the waterflooding operation, it is very important to understand the mechanical response mechanism of downhole tools in highly-deviated waterflooding wells.

The deformation study of drilling string or tubing string in oil&gas wells can be traced back to the study of the buckling behavior of tubing string. Mitchell (2006) studied the buckling behavior of a tubing string under external connections and circumferential torque. Recently, the various loads and their weights in buckling problem of the tubing string were discussed by Hajianmaleki (Hajianmaleki and Jeremy, 2014). Gulyayev (Gulyayev and Shlyun, 2016, 2017; Gulyayev et al., 2009, 2015; Andrusenko et al., 2012) presented a load model for buckling analysis of tubing string under frictional force and discussed the influence of the friction and the borehole trajectory on the buckling of tubing string emphatically. Gao (Gao and Huang, 2015) summarized the research and development of tubing column buckling in the field of petroleum engineering, and gave the directions and emphases of the research on the buckling behavior of tubing columns. Huang (Huang et al., 2016) studied the buckling behavior of tubing column in vertical wells, focusing on the influence analysis of borehole wall and deadweight.

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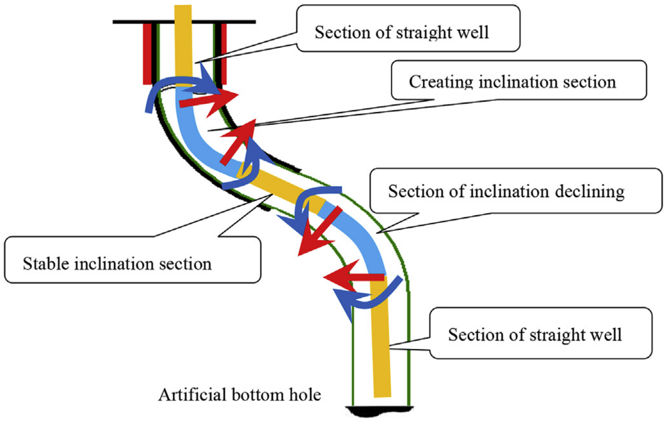


Fig. 1. Structure sketch of five-section highly-deviated well.

Fig. 2. Deformation of downhole tubing string.

The mechanics analysis of tubing column in inclined waterflooding wells has been carried out by some studies. A model was used by Bernt (Aadnøy et al., 2003) to study the mechanical behavior of tubing column in inclined well, aimed at the tubing stuck. Focusing on the mechanical behavior analysis of downhole tubing under test condition, Li (Li, 2012; Li et al., 2017) summarized the development course of oil& gas well tubing mechanics systematically, and put forward the key problems of tubing mechanics and its main research direction at present. Elgibaly (Ahmed et al., 2016) presented a friction factor model for the tubing string in directional well. Mohiuddin (Mohiuddin et al., 2007) used field measured data to investigate the borehole stability of vertical wells, directional wells and horizontal wells. Lian (Lian et al., 2015) established a mechanical model of tubing string in horizontal wells in multi stage fracturing operation.

Although many studies (Luo (Luo et al., 2009), Ju (Ju et al., 2012), Wang (Wang et al., 2011a), Chen (Chen et al., 2009), Wei (Wei et al., 2014), Cheng (Cheng et al., 2015) and Liu (Liu et al., 2015)) have discussed the application of different waterflooding technology in oil field, the mechanical response research of the downhole tools under waterflooding operation are still very limited. Wang (Wang et al., 2011b) studied the damage mechanism of the casing in injection well in Tarim Oilfield in China and put forward the corresponding preventive measures. A theoretical analysis of wellbore pressure field and temperature field during waterflooding operation was carried out by Xu (Xu and Liu, 2015), Nian (Nian et al., 2016). Tian (2016), Qiao (Qiao et al., 2015) to study the mechanical behavior of downhole tubing string during waterflooding.

The influence mechanism of packer in highly-deviated waterflooding well and horizontal well on hydraulic crack was investigated by Li (Li et al., 1997). A packer and an anchor used for waterflooding operation of highly-deviated well was developed by Wang (Wang et al., 2011c), Wang (Wang et al., 2013). Zhang (Zhang et al., 2014a, 2014b) studied the force response in tubing string in deep inclined well under the condition of dropping and reverse circulation well cleanup. Liao (Liao et al., 2012) investigated the influence of downhole packer on the mechanical behavior of downhole tubing string.

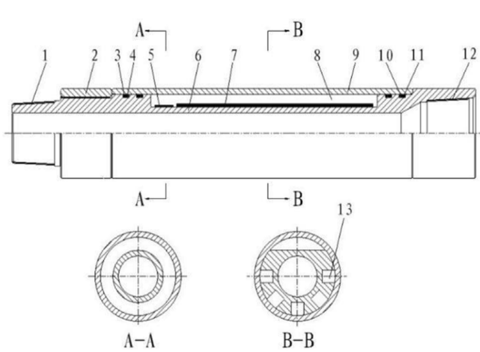
Despite the above significant studies, at present, the understanding of the mechanical response mechanism of the tubing column in the whole waterflooding construction period is far from enough. Sufficient field experimental verification is also needed in the existing theoretical studies.

The purpose of this paper is to develop a force testing instrument to measure the force in downhole tools in highly-deviated waterflooding well. On this basis, the mechanical response mechanism of downhole tools under different operation stage is investigated, aimed at providing theoretical support for waterflooding operation of highly-deviated well.

2. Experimental equipment and method

2.1. Experimental equipment

A force test instrument is developed to measure the axial force of the downhole tools, as well as the pressure and temperature of the annulus in highly-deviated well during waterflooding operation. The force test instrument, whose structure schematic and physical graph are shown in Fig. 3 and Fig. 4 respectively, is composed of strain gauge sensor, data acquisition circuit board, power supply module and force test sub section which is used for the installation and fixation of other parts.



1—External thread joint; 2—Tubular end stops; 3, 11—O-ring; 4, 10—Sealing hubcap 5—Strain gauge sensor; 6—Inner cylinder; 7—Data acquisition circuit board; 8—Sealed cabin; 9—Outer cylinder; 12—Internal thread joint; 13—Battery pack slot

Fig. 3. Structure schematic of force testing instrument.