M. Chen et al. (Eds.)

doi:10.3233/ATDE220526

Calculation and Analysis of Drag of Spoon-Shaped Well Strings

Yihan ZHANG [a], Baokui GAO [a,1], Xingwang CHEN [a] and Yanhuan ZHANG [a]
[a] College of Petroleum Engineering, China University of Petroleum (Beijing), 18 Fuxue Road, Changping District, Beijing, China

Abstract. In order to improve recovery ratio in “Well Factory” development model, spoon-shaped wells are introduced. Spoon-shaped wells need a reverse hole extension with deviate and azimuth change before forward drilling. The complicated well trajectory leads to larger drag on the working string during the string slacking off and pulling up. In order to analyze the friction characteristics of downhole string, software is developed. Case study shows that spoon-shaped hole section makes it more difficult for the working string to slack off and pull up than an ordinary horizontal well. The software calculates the axial force, and the in-depth analysis concludes that the contact force between string and borehole wall in the forward deviation-built section is very large, especially in the section that deviation and azimuth change; large target section deviation increases the contact force.

Keywords. Spoon-shaped well, string, axial force, drag

1. Introduction

In recent years, with the application of the "Well Factory" model in shale gas development, some problems have emerged [1]. One of them is that the oil beneath the drilling platform is difficult to extract, because a traditional horizontal well will leave horizontal displacement in front of target. To minimize the displacement, need large borehole curvature, which makes it difficult for the working string to slack off [2]. For this reason, a special type of horizontal well has been developed, which is referred to in engineering as a spoon-shaped horizontal well, a fishhook well, an under displacement well or a reverse displacement well and is here after referred to as a spoon-shaped well in this paper [3-7]. Spoon-shaped wells can extract the dead gas zone below the drilling platform, increasing reservoir mobilization and increasing production. In the design of the drilling platform, emphasis needs to be placed on anti-collision problem and the spoon-shaped well is indeed a 3D well [8,9].

A great deal of research has been done on the establishment and calculation of downhole string friction models. In 1984, Johancsik for the first time proposed a soft rod model for predicting whole string drag, which was mechanically analyzed for the micro-element section and calculated iteratively from the bottom [10]. In 1987, Sheppard et al. considered the effect of well trajectory on the torque and concluded that the torque of the string could be reduced by adjusting the well trajectory in the lower section [11]. In 1988, HS Ho et al. introduced the effect of stiffness into soft rod model to form the rigid rod

[1] Baokui Gao, Corresponding author, College of Petroleum Engineering, China University of Petroleum (Beijing), 18 Fuxue Road, Changping District, Beijing, China; E-mail: gaobaokui@126.com.

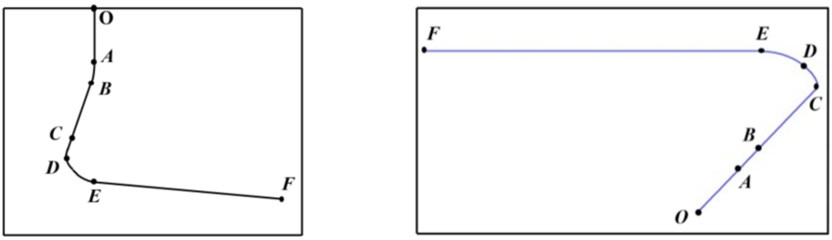
model based on large deformation theory [12]. In 1989, Zhang et al. considered the correlation between the drilling string tension increment and the lateral force to obtain a model for calculating the drag in directional wells [13]. In 1993, Han obtained 2D and 3D friction model [14]. In 2000, Gao et al. calculated string spiral buckling critical force in slant well section, the contact force distribution after buckling [15]. In 2011, Yan et al. adopted segmental calculation method to establish a three-dimensional drilling string drag model for horizontal wells to improve accuracy [16]. In 2017, Wang et al. conducted a computational analysis on string axial force in L-type wells. These works increased the understanding of string friction in complex well type [17]. In 2018, Zhu et al. calculated the torque problem of spoon-shaped wells based on the full drilling string dynamics model, and concluded that the contact force of the forward building up section is high [18] .

In the past studies, the modified soft rod model that considers the additional contact force caused by the string stiffness is generally used. The contact force of the special well section is high and the effect on string axial force is more complex. Therefore, it is necessary to analyze axial force distribution of the downhole string in spoon-shaped wells.

2. Models for String Drag

2.1. Borehole Description

The trajectory of a typical spoon-shaped well is shown in figure 1, where OA - straight section; AB - reverse build up section; BC - hold on section; CD - drop off and azimuth change section; DE - forward build up section; EF - target section. This paper mainly analyses string force in curved section and target section. Basic assumption include: the hole is smooth; the string slides axially along borehole wall; the friction coefficients in cased section and bare-hole section are constant respectively.



(a) Vertical projection (b) Horizontal projection

Figure 1. Well trajectory of a spoon-shaped well.

2.2. String Force in Slant Section

An axial string segment, length dl, is taken and force analysis is shown in figure 2.

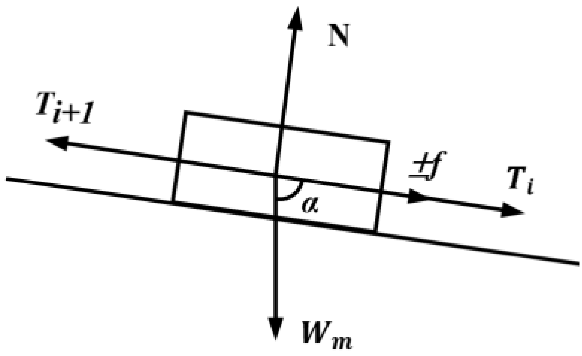


Figure 2. Force analysis of string element in slant section.

In figure 2: α – deviation angle; T_{i+1} - the axial force at the upper end of string element; T_i - the axial force at the lower end of string element; N - contact force between the string element and the borehole wall; W_m - effective weight of the string element.

Normal force:

$$N=W_m \times \sin\alpha \tag{1}$$

Axial force:

$$T_{i+1}=T_i+W_m \times \cos\alpha \pm f \tag{2}$$

Axial force:

$$T_{i+1}=T_i+W_m \times (\cos\alpha \pm \mu \sin\alpha) \tag{3}$$

2.3. String Force in Curved section

In the shale gas 'Well Factory' mode of exploitation, the design needs to consider anti-collision issues, the curved section of a spoon-shaped well is a three-dimensional section. When analyze string force, it is assumed that there is a difference in the contact position when slacking off and pulling up, and the curvature of the string is equal to the borehole. *Take a* micro-element section for force analysis, contact force between string and borehole is: [16]

$$N=\sqrt{(T_i\Delta\theta \sin\alpha)^2+(|T_i\Delta\alpha| \pm W_m \sin\alpha)^2} \tag{4}$$

Where: $\Delta\theta$ - azimuth angle increment; $\Delta\alpha$ - deviation increment.

Equation (4) can be used for two-dimensional well section when Δθ = 0, and further when Δα = 0, it becomes straight well equation.

Axial force:

$$T_{i+1}=T_i+W_m \cos\alpha \pm \mu N \tag{5}$$

3. Spoon-shaped Wells Axial Force Analysis

Based on the overall force analysis of the string, the software for calculating and analyzing the string drag was developed, and use the software to calculate the force of the string.

3.1. Case Studies

An example of a drilled spoon-shaped well in China is analyzed, its borehole parameters are shown in table 1.

Table 1. Borehole parameters.

Key points	Measure depth (m)	Deviation angle (°)	Azimuth angle (°)	Well section
Wellhead	0	0	-	-
A	750	0	-	Straight
B	985.44	23.54	43.86	Build up
C	2012.78	23.54	43.86	Hold on
D	2200.93	11	43.85	Drop off
E	2364	0	338.84	Drop off and azimuth change
F	2537.08	48.02	270.26	Build up and azimuth change
G	2654.81	48.02	270.26	Hold on
H	2829.73	83	270	Build up
I	4329.73	83	270	Object

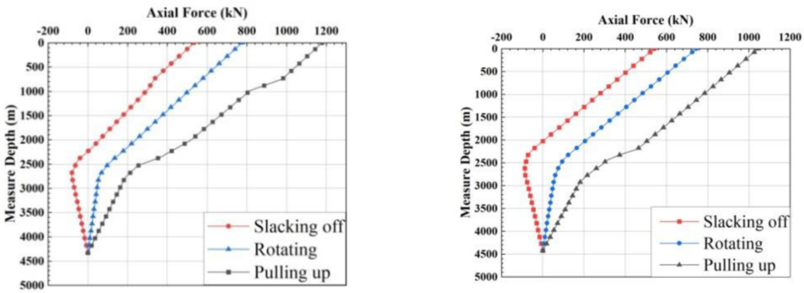
The well is previously cased with 339.7mm surface casing to the end of straight section (above 750m) and 244.5mm intermediate casing to the end of curved section (above 2829.73m). And production string will be lowed to hole bottom (4329m). Take friction coefficient is 0.25 in cased section and 0.30 in bare borehole. The following is an analysis of string drag during the production string trip in the hole.

The data of intermediate casing and production string to be run in are shown in table 2.

Table 2. Downhole string data.

String type	Outer diameter (mm)	Inner diameter (mm)	Wire weight (kg/m)
Intermediate casing	244.5	222.41	64.74
Production string	139.7	115.44	34.22

The axial force of string when reaching well bottom is shown in figure 3(a), and for comparison, similar axial force for an ordinary horizontal well with the same hole configuration, azimuth change and target section is shown in figure 3(b).



(a) Spoon-shaped well (b) Ordinary horizontal well

Figure 3. Axial force distribution.

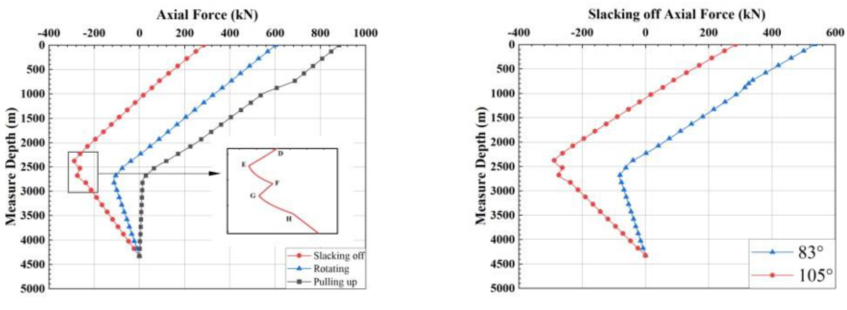
Figure 3 (a) shows that, the hook load is 535kN when slacking off, 776kN when rotating and 1179kN when pulling up, the difference between the hook load when pulling up and rotating is dF1=1179-776=403kN, the difference between the hook load when slacking off and rotating is dF2=776-535=241kN. This indicates that drag when pulling up is higher. Analysis of the axial force calculation using the software and Landmark yielded results within 5% difference.

Comparing figures 3(a) with (b), it is found that strings in spoon-shaped well are more difficult to slack off and pull up than in ordinary horizontal well.

3.2. Effect of Target Section on Axial Forces

3.2.1. Axial Force Distribution

For the above actually drilled well, change its deviation angle of target section, and string axial forces are shown in figure 4.



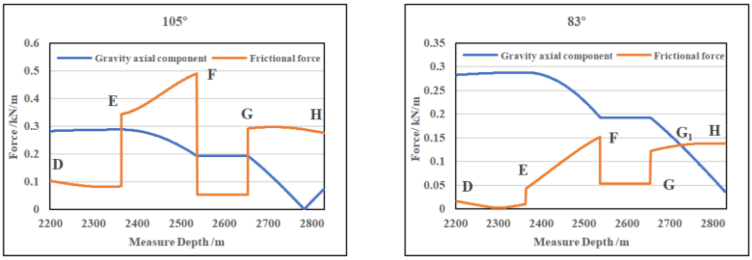
(a) Target section deviation 105° (b) Target section deviation 83° to 105°

Figure 4. Effect of target section deviation on string axial forces.

Figure 4 shows that as deviation angle of target section increases, spoon-shaped well is more difficult to slack off and easier to pull up. In addition, when the deviation angle increases, slacking off axial force appears uncommon change in curved section, and this phenomenon becomes more obvious as the deviation increases.

3.2.2. Axial Force Component

The friction and the axial component of the gravity of string in curved section for target section deviation 105° and 83° are shown in figure 5.



(a) 105° (b) 83°

Figure 5. Axial force component fortarget section deviation 105° and 83°

Figure 5 (a) shows that gravity axial component is greater than frictional force in segment DE and FG in the well with target section deviation 105°, axial force decreases; the opposite is true for the segment EF and GH, axial force increases. Resulting in axial force in curved section appears uncommon change. However, figure 5(b) shows that the well with target section deviation 83° has a greater gravity axial component in segment DG_1, axial force decreases; the segment G_1H has a greater frictional force, axial force increases. Axial force shows normal trend above the G_1 point.

4. Conclusions

By calculating the axial force and analyzing contact force between string and borehole of spoon-shaped well, the following conclusions are drawn.

(1) In spoon-shaped well, it is more difficult for the working string to slack off and pull up than in an ordinary horizontal well, and drag when pulling up is higher than drag when slacking off.

(2) The contact force between string and borehole of forward deviation-built section is obviously higher than that of other sections.

(3) Large target section drag will increase the friction of curved section, and string axial force will appear uncommon change in curved section when slacking off.

Acknowledgement

This research was financially supported by the Grand National Science-Technology Project (2017ZX05009-003).

References

[1] Gong DZ. Shale gas "Well Factory" development mode and horizontal well trajectory control technology. Industrial Technology Innovation. 2021 Jun; 8(3):104-110.

[2] Meng BQ, Zhou BN, Fu Z, Gu CL, Yang Q. Application of spoon - Shaped horizontal wells for development of shale gas in Changning, Sichuan. Special Oil and Gas Reservoirs. 2017 Oct; 24(5): 165-169.
[3] Liu XS, Zhang HS. A design method of under-displacement horizontal wells. Natural Gas Industry. 2008 Oct; 28(10): 61-63.
[4] Zhao MJ. Derivation of design equations for under-displacement horizontal wells. Petroleum Geology and Engineering. 2010 Jul; 24(4): 80-81.
[5] Wang ZG, Li XX, Wang LB, Tong YJ, Yang J. L-shape well trajectory optimization and control in well Leng41-Ping14. Petroleum Drilling Techniques. 2006 Mar; 34(2): 72-74.
[6] Wang F. Drilling and completion technique of short displacement, shallow vertical depth horizontal well with reversed-tick type well trajectory. Oil Drilling & Production Technology. 2005 Jun; 27(3): 5-7.
[7] Liu MS, Fu JH, Bai J. Optimization of Shale Gas Dual - 2D Horizontal - Well trajectories and its application. Special Oil and Gas Reservoirs. 2016 Apr; 23(2): 147-150.
[8] Hummes O, Bond P, Jones A, Wayne S, Manitou B, Andrew S, Sergei P. Using advanced drilling technology to enable well factory concept in the Marcellus shale. IADC/SPE Drilling Conference and Exhibition; 2012 Mar 6-8; San Diego, California, USA.
[9] Poedjono B, Zabaldano J, Shevchenko I, Kuntz R, James A. Case studies in the application of pad design drilling in the Marcellus shale. SPE Eastern Regional Meeting; 2010 Oct 13-15; Morgantown, West Virginia, USA.
[10] Johancsik CA, Friesen DB, Dawson R. Torque and drag in directional wells-prediction and measurement. Journal of Petroleum technology. 1984 Jun;36(06): 987-992.
[11] Sheppard MC, Wick C, Burgess T. Designing well paths to reduce drag and torque. SPE Drilling Engineering. 1987 Dec;2(04): 344-350.
[12] Ho HS. An improved modeling program for computing the torque and drag in directional and deep wells. SPE Annual Technical Conference and Exhibition; 1988 Oct 2-5; Houston, Texas.
[13] Zhang JQ, Sun XZ, Zhao JP. A preliminary study of frictional drag model and its application to directional wells. Journal of DaQing Petroleum Institute. 1989 Jun;13(4): 23-28.
[14] Han ZY. 3D and 2D model for torque and drag of drillstring in the borehole. Journal of the University of Petroleum China (Edition of Natural Science). 1993;17(A00): 44-49.
[15] Gao DL, Gao BK. Effects of tubular buckling on torque and drag in horizontal well. Journal of the University of Petroleum China (Edition of Natural Science). 2000 Apr;24(2): 1-3.
[16] Yan T, Li QM, Wang Y, Li JH, Bi XL. Segmental calculation model for torque and drag of drillstring in horizontal wells. Journal of DaQing Petroleum Institute. 2011 Oct;35(5): 69-72.
[17] Wang LS, Gao BK, Gao L. Working string axial force in l-shaped oil well. IOP Conference Series: Materials Science and Engineering. 2017; 281(1): 012056.
[18] Zhu XH, Li K, An JW. Calculation and analysis of dynamic drag and torque of horizontal well strings. Natural Gas Industry. 2018 Aug;38(8): 75-82.