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A New Method for Designing Casing Program of Horizontal Wells

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Abstract: Horizontal well has become an important technology for efficient oil and gas exploration at present, whose casing program design is mostly based on methods of vertical well and directional well. However, the influence of the dynamic pressure on the horizontal section is not taken into account. Therefore, leakage is likely to occur in the drilling process of horizontal section, which directly affects the efficiency and the cost of drilling. Considering the pressure characteristics and the force analysis of horizontal section when drilling, a new method for designing casing program of horizontal wells has developed after analyzing dynamic pressure and leakage on the horizontal section, which was based on the petroleum industry standard<SY/T 5431-2008 The design method of casing program>.Taking into account the influence of leakage, the drilling facts show that the method is safer, more efficient and more cost-saving than conventional design methods.

Keywords: *Profile; Calculation; Analysis; Application*

1. Introduction

Casing program design is the key thing when drilling horizontal wells, which is not only directly related to the drilling safety, but also to the drilling cost (Xu et al, 2007). At present, casing program design of horizontal wells mainly refers to the petroleum industry standard <SY/T 5431—2008 the design method of casing program>. Based on the two pressure profiles (formation pore pressure profile and formation fracture pressure profile), the six design parameters and the pressure balance relationship, the casing program design can be determined. Then, in order to prevent differential pressure sticking, leakage check at the upper casing shoe should be done under the condition of overflow well killing (Shao et al, 2008; QING et al, 2006). However, in the process of horizontal wells drilling, formation fracture pressure on horizontal section is basically stable. And as horizontal section drilling pushes forward, the annular dynamic pressure at the bottom is increasing, which is likely to result in well leakage in the horizontal section, and then do bad to the whole drilling (DOU,2013;LI et al, 2013).Therefore, considering the pressure characteristics and the force analysis of horizontal section when drilling, a new method for designing casing program of horizontal wells has developed after analyzing dynamic pressure and leakage on the horizontal section, based on the conventional design methods. Compared with conventional methods, the particularity of horizontal section drilling was taken into account in this method, which was safer, more efficient and more cost-saving.

2. Formation pore pressure profile

As drilling on the horizontal section pushes forward, formation pore pressure and formation fracture pressure are basically stable which is the pressure particularity of horizontal wells, compared with the conventional vertical wells and directional wells. On the pressure profile based on the vertical depth, the pressure value of the horizontal section is focused on one point; on the pressure profile based on the slant depth, the pressure value of the horizontal section is a vertical line.

Therefore, the pressure profile based on the vertical depth can be transformed into the pressure profile based on the slant depth by using data of vertical depth formation pore pressure profile and well trajectory, which is more convenient and intuitive. So formation pressure data of any point on the well trajectory can be found easily in this way. In addition, wellbore annular pressure drop can be calculated by slant depth, while wellbore hydrostatic pressure can be calculated by vertical depth transformed by slant depth. And the transformation can be accurate when using minimum curvature method.

3. Casing program design for horizontal wells

3.1. Calculation of dynamic pressure drop

Dynamic pressure drop of horizontal wells is mainly affected by mud density, viscosity, displacement, hole size, the size of the drill string and so on, the annulus dynamic pressure drop of any point can be calculated by the following formula (Chen and Guan, 2000).

$$P_f = \frac{0.57503\rho_m^{0.8}\mu_{pv}^{0.2}L_pQ^{1.8}}{(d_h - d_p)^3(d_h + d_p)^{1.8}} \quad (1)$$

The parameter declaration: P_f means the annulus dynamic pressure drop of any point(MPa); ρ_m means mud density (g/cm^3); μ_{pv} means mud Plastic viscosity (Pa·s); L_p means the length of drill string above the calculated point (m); Q means mud displacement(L/s);d_h means hole diameter(cm) ; d_p means Outer diameter of drill string(cm).

3.2. Analysis of dynamic leakage

An analysis method of dynamic leakage for horizontal wells has developed after deeply analyzing leakage characteristics, and the concept of "leakage critical point" is also proposed. Specific steps are as follows:

(1) To judge whether horizontal section leakage occurs.

①To calculate maximum allowable pressure increment on the condition that leakage doesn't happen at the bottom hole (ΔP_f).

$$\Delta P_f = 0.00981\times(\rho_f - \Delta\rho_f - \rho_m)\times H_{\text{bottom}} \quad (2)$$

The parameter declaration: ΔP_f means maximum allowable pressure increment on the condition that leakage did not occur at the bottom hole (MPa); ρ_f means formation fracture pressure equivalent density (g/cm^3); $\Delta\rho_f$ means margin of formation fracture pressure equivalent density (g/cm^3); ρ_m means mud density (g/cm^3); H_{bottom} means vertical depth at the bottom hole (m).

②If annular pressure drop at the bottom hole($\Delta P_{bottom1}$) calculated by formula (1) is less than or equal to ΔP_f , then it indicates that leakage will not happen on the section; If $\Delta P_{bottom1}$ is more than ΔP_f , then it indicates that leakage will happen on the section, so further leakage check needs to be done.

(2) To judge whether casing is needed when leakage happens

Preliminary check showed that if leakage happens on the horizontal section, decreasing mud density will be a good way to avoid accidents by decreasing wellbore pressure.

①To calculate maximum allowable pressure drop on the condition that well kick doesn't happen at the bottom hole after decreasing mud density(ΔP_m)

$$\Delta P_m = 0.00981\times(\rho_m - \rho_p - \Delta\rho_m)\times H_{\text{bottom}} \quad (3)$$

The parameter declaration: ΔP_m means maximum allowable pressure drop on the condition that well kick doesn't happen at the bottom hole after decreasing mud density (MPa); ρ_m means mud density (g/cm^3); ρ_p means formation pore pressure equivalent density (g/cm^3); $\Delta\rho_m$ means added value of mud density (g/cm^3).

Besides decreasing mud density, applying new drilling tools, new drilling technology and other measures can also reduce or prevent leakage under the premise of avoiding well kick, which is cost-saving without running casing. If measures above still can't reduce or prevent leakage, then times of drilling should be increased.

(3) To calculate the depth of leakage critical point and casing setting depth

If annular pressure drop at the bottom hole ($\Delta P_{bottom2}$) calculated by adjusted mud density ($\rho_{m2}=\rho_p+\Delta\rho_m$) and property is less than or equal to ΔP_m, then it indicates that drilling can be completed safely without running casing; If $\Delta P_{bottom2}$ is more than ΔP_m , then it indicates that running casing is needed.

When $\Delta P_{bottom2}$ is more than ΔP_m , there must be a point on the horizontal section whose annular pressure drop is equal to decreased hydrostatic pressure after reducing mud density, and the point is the depth of leakage critical point, namely casing setting depth. Iterative calculation by computer will be a good way to get the depth with consideration of complexity of computation.

(4)Redo leakage check after increasing times of drilling

Followed by step(3), borehole and casing sizes need to be redefined and annular dynamic pressure calculation also changes after increasing times of drilling. Therefore, leakage check needs to be redone following step (1), step (2) and step (3) until meeting the demands.

3.3. A new design method of casing program

When designing casing program for horizontal wells by experience or pressure balance relationship, the influence of dynamic leakage on the horizontal section is not considered. Based on the petroleum industry standard <SY/T 5431-2008 The design method of casing program>, a new design method of casing program for horizontal wells has developed with consideration of the geological setting position, dynamic leakage on the horizontal section and other factors. The design flow chart is shown in Figure 1.

4. Engineering application

Based on the proposed casing program designing method for Horizontal Wells above, a casing program designing software for horizontal wells has developed by C# programming language, which was tested and verified by the data of a horizontal well in the Guang2 block of Jianghan Oil Field.

The engineering parameters are as follows, well depth is 3600m, formation pore pressure coefficient is 1.05, formation leakage pressure coefficient is 1.37, bit diameter of the first spud is 444.5mm, casing diameter of the first spud is 339.7mm, bit diameter of the second spud is 311.2mm, casing diameter of the second spud is 244.5mm, bit diameter of the third spud is 215.9mm, casing diameter of the third spud is 139.7mm, length of horizontal section is 946.2m,outside diameter of drill pipe is 127mm, outside diameter of drill collar is 177.8mm.

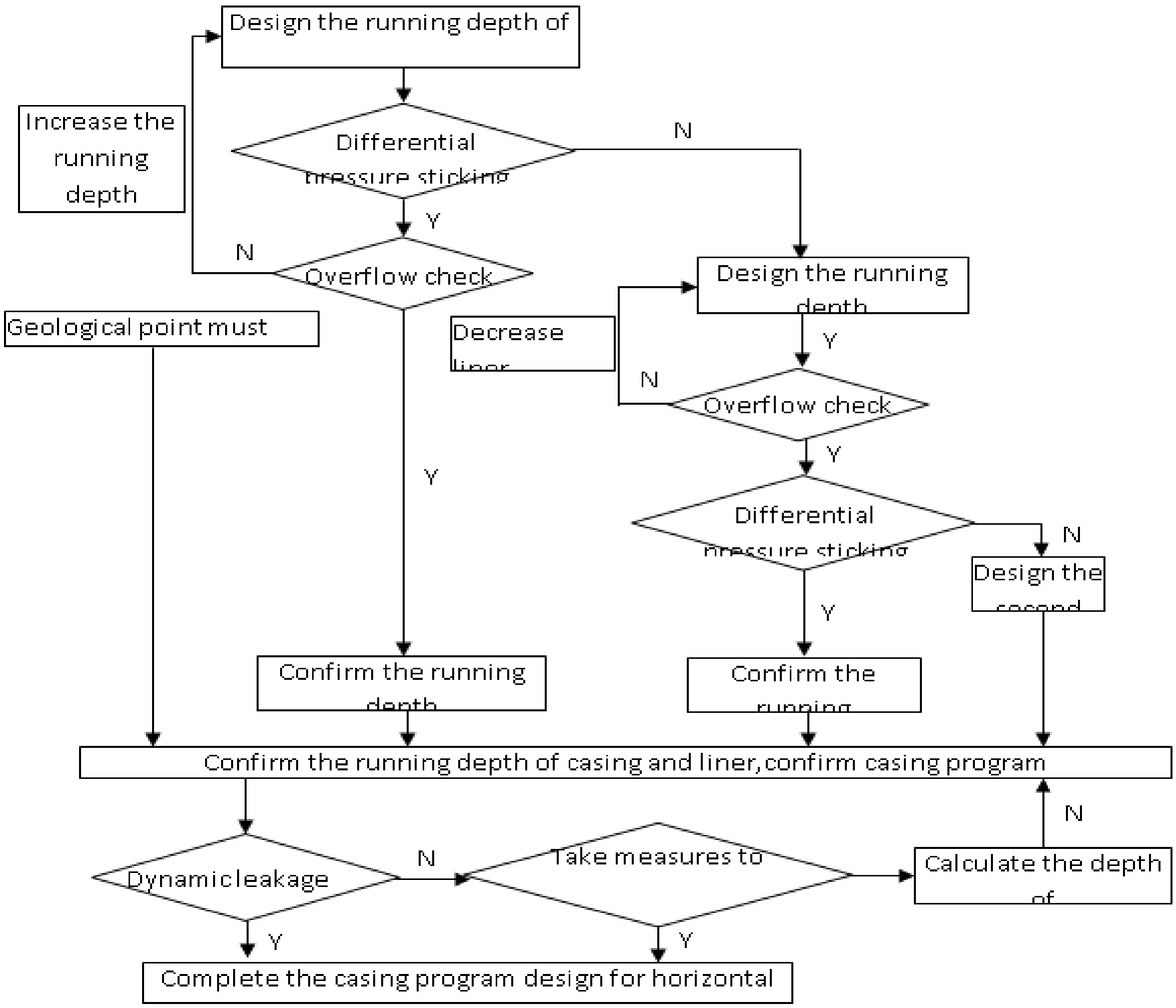

Fig. 1 *Design flow chart of casing program for horizontal wells*

Formation leakage pressure in Guang2 block is lower generally. Because of this, well leakage occurred frequently in the drilling process of horizontal wells, especially for horizontal section, which was proved by drilling data of adjacent wells. It led to waste of large amounts of mud, lowered drilling efficiency and more formation damage. The fundamental reason of well leakage is high bottom hole pressure caused by gradually increased annulus circulating pressure drop along with the extension of the horizontal section. Therefore, it is very important to design the casing program for horizontal wells scientifically.

Based on the Formation pressure data and drilling construction experience of Guang2 block, the casing program was designed by this software, the design results are as follows.

Table1: *The design results*

Spud number	Drilling depth (m)	Casing running depth (m)	Mud density(g/cm^3)
First spud	54.3	53.0	1.05
second spud	943.1	942.0	1.12
third spud	3598.4	3596.2	1.12 (943.1-1885m) 1.31(1885-3092.2m) 1.24(3092.2-3598.4m)

Due to the lower formation pressure in Guang2 block, the fresh water drilling fluid system was used in the first, second and third spud(943.1-1885m); Due to the large section of salt layer, saturated salt water drilling fluid system was used in the section of 1885-3092.2m, for drilling in, design using 1.31 g/cm^3.

According to calculation, the depth of 3092.2m is Leakage critical point, if drilling fluid density is 1.31g/cm^3 from the beginning to the end when drilling, well leakage occurs in the later stage of horizontal section drilling process. Under this condition, decreasing drilling fluid density is an applicable solution, in order to balance formation pore pressure and plastic rock stratum pressure, the mud density can decrease to 1.24g/cm^3 at most, and the plastic viscosity and dynamic shear of mud were adjusted. Well leakage will not occur in down hole when the drilling fluid density is1.24g/cm^3, which is carried out by the casing program designing software for horizontal wells. Therefore, it is helpful to avoid the additional casing, guarantee the drilling construction safety, and save the drilling cost through adjusting the mud density and performance.

The drilling facts showed that well leakage phenomenon didn't happen in this well, compared with the other adjacent Wells of this block; the obvious comprehensive economic benefits were obtained. Therefore, the analysis results by the leakage check method is accurate; it was in good agreement with the real drilling situation. the method is applicable to highly deviated directional wells, horizontal wells and extended reach wells, especially narrow motion range of density formation. Horizontal section leakage could be reduced greatly by applying this method, which could optimize casing program, improve drilling efficiency, and reduce drilling cost. The proposed leakage check method is not mentioned in all references of this paper.

4. Conclusions

(1) The rationality of casing program design heavily depends on the awareness for drilling geological conditions. Thus, to achieve a better casing program design, we should be fully aware of horizontal wells conditions by various methods, especially about its formation pore pressure and rock distribution.

(2) A new design method of casing program for horizontal wells has developed with consideration of dynamic leakage on the horizontal section. This method can optimize casing program, improve drilling efficiency, and reduce drilling cost, which can make up for the deficiencies of conventional methods.

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