Selection of the drilling fluid density as specified with the expected deformation of the cross-section of the well

L Z Zainagalina¹ and F Z Bulyukova²

¹ Ufa State Petroleum Technological University, Branch of the University in the City of Oktyabrsky, 54a, Devonskaya St., Oktyabrsky, Republic of Bashkortostan, 452607, Russian Federation
² Ufa State Petroleum Technological University, 1, Kosmonavtov St., Ufa, Republic of Bashkortostan, 450062, Russian Federation

E-mail: flura2003@mail.ru, info@of.ugntu.ru

Abstract. During inclined and horizontal drilling, the cross-section of the well is deformed in the form of uneven displacement of its walls, which is one of the reasons for tightening and tool sticking. To limit the displacement of the walls, it is proposed to adjust the density of the drilling fluid taking into account the elastic properties of the rock and the angle of curvature of the well.

1. Introduction

Nowadays, the choice of drilling fluid density is carried out under the conditions for preventing three types of complications: the inflow of reservoir fluids; the opening of the absorption of drilling fluid and the instability of the well walls [1, 5, 6]. The condition for stability of the well walls is based on strength calculations of rocks.

In [2] it is shown that ensuring the stability of the well walls is a necessary condition for preventing complications caused by deformation and destruction of the well walls, but it is not sufficient. When drilling, the bit forms a round borehole with a radius \( R_b \approx R_0 \) (\( R_0 \) - the radius of the bit), but as the bit moves away from the fixed cross-section of the wellbore, its deformation occurs, changing not only the size but also the shape of the section, as shown in figure 1.

At the same time, the more the angle \( \alpha \) of curvature of the well, the more the shape of the section changes (in figure 1, section A-A), becoming more elliptical. This statement is confirmed by viewing the cavernograms of inclined wells recorded by the cavernometer in two mutually perpendicular directions. Examples of such recording in wells in Western Siberia are shown in figure 2. The interval is composed mainly of heavy clays, for which the Poisson’s ratio \( \mu \) is assumed to be 0.35 [3].

Figure 2 shows that the dimensions of the well in two mutually perpendicular directions differ significantly. In this case, the radius of the well can be either more or less than the nominal one.
**Figure 1.** The bottom-hole part of an inclined well

**Figure 2.** The cavernograms of inclined wells recorded by a cavernometer in two mutually perpendicular directions: row 1 – nominal radius; rows 2 and 3 – measured radii of the well
As the angle of curvature increases, the displacement of the lateral wall $\Delta R_b$ of the well decreases and changes sign (rows 2), and the displacement $\Delta R_v$ of the upper wall monotonously increases, reducing the size of the well (rows 3). This displacement of the walls above the bit can cause tightening and even jamming of the bit when lifting from the well. Therefore, the measures should be taken to prevent this phenomenon.

2. Materials and methods

The solution of the problems was performed analytically with the formulation and conduct of special experiments and the involvement of published results of testing of rocks on well models, as well as the results of cavernometry of inclined wells in Western Siberia.

3. Results and Discussion

The main means of controlling the stress-strain state of the rock composing the well wall is the selection of the required density $\rho_{d.f.}$ of the drilling fluid. In vertical wells, there was almost no need to take into account the displacement of the well walls. But as the angle of curvature increases and, especially in cases of the horizontal borehole, neglect of this phenomenon can lead to serious complications. In [4], a program for calculating the displacement of the walls of an inclined well is presented. Using this program, the values of the actual lateral expansion coefficient ($\lambda = 0.69$) and the modulus of deformation ($C = 1,870$ MPa) for the range of 3,140-3,160 m (see figure 2) were estimated using the cavernogram as one of the dangerous ones from bit jamming.

The obtained rock characteristics were used to calculate the dependence of the displacement $\Delta R$ of the well wall on the ratio $r_s/r_g$ ($r_s$—static pressure of the drilling fluid in the well; $r_g$—geostatic pressure) at different curvature angles of the well and to assess the influence of the well curvature angle and geostatic pressure on the choice of the drilling fluid density. The calculations were performed at three levels of geostatic pressure: 57; 70 and 100 MPa. The $r_g$ value = 57 MPa corresponded to an interval of 3,140-3,160 m (see figure 2), as well as at three levels of well curvature: 0 (vertical well); 45 (inclined well) and 90 degrees (horizontal well).

Figure 3 shows the obtained dependencies of $\Delta R$ on $r_s/r_g$.

Figure 3 shows that when $r_s/r_g = 0$, the displacement is negative and the largest in absolute value. As the $r_s/r_g$ ratio increases, the displacement changes linearly, reaches zero and then becomes positive. As the angle of curvature increases, the difference between the upper and lateral wall displacements increases.

From complications, the main role is played by the displacement of the upper wall. Ideally, the displacement of the upper wall should be zero, and the displacement of the lateral wall should be positive [7, 8]. The second condition can be assumed to be equal to the module of displacements of the upper and lateral walls. Finally, the third condition is to accept the maximum allowable amount of displacement of the upper wall of the well. For roller-cone bits, the value of the roller plugs can be taken as an acceptable value [9-12]. For example, for bits with a diameter of 215.9 mm, this value is 2.5 mm.

The equations in figure 3, describing the dependence of $\Delta R$ on $r_s/r_g$, allow calculating the values of $r_s/r_g$ and the corresponding density $\rho_{d.f.}$ of drilling fluid for the accepted conditions at a known average density $\rho$ of the overlying rocks, which was about 2.4.

It is known that

$$p_s = \rho_{d.f.}gh_d = \rho_{d.f.} \frac{g h_d}{\rho},$$

(1)

$$\rho_{d.f.} = \frac{p_s}{p_g} \rho.$$  

(2)
Figure 3 shows that the first condition for this example can only be implemented for a vertical well \((r_s/r_g = 0.69; \rho_d.f. = 1.66)\). With increasing \(\alpha\), these values grow rapidly.

Figure 3. The dependencies of \(\Delta R\) on \(r_s/r_g\) and their corresponding equations

Table 1 shows the results of calculating the density of drilling fluid for two other conditions.
Table 1. The recommendations for the density of the drilling fluid

| α, ° | \( \Delta R_{uw} = -2.5 \text{ mm} \) | \( \Delta R_{lw} = -2.5 \text{ mm} \) | \( \Delta R_{uw} = -2.5 \text{ mm} \) | \( \Delta R_{lw} = -2.5 \text{ mm} \) |
|------|-----------------|-----------------|-----------------|-----------------|
| 0    | 0.48            | -               | 0.70            | -               |
| 45   | 0.96            | 1.85            | 1.18            | 1.85            |
| 90   | 1.42            | 2.04            | 1.66            | 2.04            |

4. Conclusion
The table and figure 3 demonstrate that the lower limit of the drilling fluid density for all three conditions depends significantly on the angle of curvature of the well. The drilling fluid densities for the first and second conditions do not depend on the geostatic pressure value, while for the third condition the drilling fluid density depends on all the factors considered. The third condition gives the smallest restrictions on the density of the drilling fluid.

Consider the provision of the third condition depending on the angle of curvature of the well. These data of this table allow compiling the dependency \( \rho_{df} \) on \( \alpha \). This dependence is linear and for \( R_g = 57 \text{ MPa} \) has the form

\[
\rho_{df} = 0.0104\alpha + 0.483, \quad (3)
\]

where \( \alpha \) is the angle of curvature in degrees. For example, for the drilling interval 3,140-3,160 m considered in the example (see figure 2), the value of the drilling fluid density from the third condition is

\[
\rho_{df} = 0.0104 \cdot 70 + 0.483 > 1.21.
\]

This interval was drilled with a fluid density of 1.14. At the same time, the displacement of the upper wall of the well was about 3 mm. The well report shows the tool tightening in this drilling interval.

References
[1] Khisamov R S, Abdrakhmanov G S, Kadyrov R R and Mukhametshin V V 2017 New Technology of Bottom Water Shut-off Oil Industry 11 126–128. DOI: 10.24887/0028-2448-2017-11-126-128
[2] Malyarenko A M, Bogdan V A, Kotenev Yu A, Mukhametshin V Sh and Umetbaev V G 2019 Wettability and Formation Conditions of Reservoirs IOP Conf. Ser.: Earth Env. 378(1) 012040. DOI: 10.1088/1755-1315/378/1/012040
[3] Suleimanov R I, Zainagalina L Z, Khabibullin M Ya, Zaripova L M and Kovalev N O 2018 Studying Heat-Affected Zone Deformations of Electric Arc Welding IOP Conf. Ser. Mater. Sci. Eng. 327(3) 032053. DOI: 10.1088/1757-899X/327/3/032053.
[4] Petrova L V and Yarullin D R 2019 Evaluation of the Effect of Asphalt Resin Paraffin Deposits on Oil Well Performance IOP Conf. Ser.: Mater. Sci. Eng. 560(1) 012084. DOI: 10.1088/1757-899X/560/1/012084.
[5] Polyakov V N, Chizhov A P, Kotenev Yu A and Mukhametshin V Sh 2019 Results of System Drilling Techniques and Completion of Oil and Gas Wells IOP Conf. Ser.: Earth Env. 378(1) 012119. DOI: 10.1088/1755-1315/378/1/012119
[6] Zainagalina L Z, Petrova L V and Petrov V A 2019 Analysis of the Efficiency of Telemetric Systems for Drilling Wells IOP Conf. Ser.: Mater. Sci. Eng. 560(1) 012096. DOI: 10.1088/1757-899X/560/1/012096.
[7] Nie Z, Liu Z and Sun X A 2018 Multirelay Cooperation Method for Wireless Transmission of MWD and LWD Signals IEEE Transactions on Geoscience and Remote Sensing 56(3) 1229-1237
[8] Säikia K 2018 A proposed methodology of 3D geomodeling-while-geosteering for optimum
horizontal well placement and enhanced geological risk management *Indian J. of Geo-Marine Sciences* 47(4) 826-830

[9] Gillen M E, Moody B and Dymmock S 2018 New LWD technology provides high-resolution images in oil- and water-based muds for improved decision making in real-time *Proc. of the Annual Offshore Technology Conf.* 4 2617-2626

[10] Liu Z, Nie Z, Sun X, Wen D and Tan J 2017 A low-frequency forward-looking antenna array for LWD and MWD *Progress in Electromagnetics Research Symp.* pp 151-154

[11] Rogachev M K and Mukhametshin V V 2018 Control and Regulation of the Hydrochloric Acid Treatment of the Bottom-Hole Zone Based on Field-Geological Data *J. of Mining Institute* 231 275-280. DOI: 10.25515/PMI.2018.3.275.

[12] Kuleshova L S, Kadyrov R R, Mukhametshin V V and Akhmetov R T 2019 Auxiliary Equipment for Downhole Fittings of Injection Wells and Water Supply Lines Used to Improve Their Performance in Winter *IOP Conf. Ser.: Mater. Sci. Eng.* 560(1) 012071. DOI: 10.1088/1757-899X/560/1/012071