Drilling mud upward velocity modelling in Ansys CFX software

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Abstract. Drilling mud has various functions, one of which is to carry cuttings to the surface. All other things being equal, the removal of cuttings is characterized by the upward velocity. This paper simulates the rheology of polymer-glycolic non-dispersing mud (in particular viscosity) to achieve the required upward velocity in the «Ansys CFX» software. The viscosity of the mud varies from 6 to 12 mPa·s, on production casing drilling in Arctic conditions. The results of the study showed that for such conditions, the viscosity should be in the range from 6 to 8 mPa·s.

1. Introduction
To successfully conduct the drilling process, an important task is to select the optimal parameters of the drilling mud in order to ensure effective cooling of the bit, to create pressure on the bottomhole to prevent oil gas water shows, cuttings removal to the surface, and also for many other functions.

Carrying cuttings through the annulus to the surface is one of the most key functions of the drilling mud. Predicting the behavior of mud and its ability to transport cuttings is a difficult task due to the many different parameters that must be taken into account.

For the correct selection of the optimal rheological parameters of the drilling mud, it is necessary to simulate the fluid flow using software. In this paper, the study will be carried out using the «Ansys CFX» software.

The purpose of this scientific work is to simulate upward velocity of drilling mud in the software «Ansys CFX» and to select necessary rheological parameters, in particular viscosity, for the successful removal of cuttings on the example of the Arctic fields.

Research objectives:
1) Drilling mud classification review in Arctic conditions.
2) Well model creation in «Ansys CFX» software.
3) Modeling the upward velocity of the drilling mud in «Ansys CFX».

2. Drilling mud classification review in Arctic conditions
In conditions of Arctic, water-based fluids are used due to minimal environmental pollution, safety, as well as for a number of other reasons [5].

In case of drilling in the Arctic fields, non-dispersing mud (NDM) is recommended for use. This type of drilling mud contains an inhibitor - a substance that prevents the flow of a chemical process, therefore, does not allow clay to swell, and also slows down hydration.

Table 1 shows drilling muds that are used in the Arctic, taking into account their advantages, disadvantages and field of application [4].
Table 1. Drilling mud classification.

| Drilling mud                                      | Advantages                                                                 | Disadvantages                              | Application area                      |
|---------------------------------------------------|-----------------------------------------------------------------------------|--------------------------------------------|---------------------------------------|
| Non-dispersing potassium chloride mud on sea water | - Stability of parameters for a long time and easy adaptability to changing conditions, -high resistance to polymineral aggression, -low toxicity (IV class of hazard), -low material consumption | The complexity of well logging conduct     | Unstable shales, granular reservoirs   |
| Potassium-gypsum drilling mud                      | The advantage of gypsum potassium drilling muds over potassium chloride is in a higher inhibiting effect | Difficulties in interpreting well logging results | Weakly stable highly colloidal clays and clayey rocks, predominantly of the sodium type; completion of clay-covered productive formations |
| Non-dispersing lime mud                            | Mud keep stability, while accumulates solid phase, cuttings, weighting agent, drilled out cement. Mud is less sensitive to formation waters containing electrolytes. | Thickening at temperatures above 120 °C, which can lead to their hardening | Drilling of highly colloidal clayey rocks |
| Polymer-glycol non-dispersing drilling mud (PG-NDM) | - High inhibiting properties - eliminates the problems associated with swelling, hydration of soft clayey rocks; -stabilizes unstable dispersing and crumbling mudstones; -reduces the dispersion of drilled cuttings; | High cost                                 | Unstable clays, deviated / horizontal wells |

As part of the study, the behavior of a polymer-glycol non-dispersing drilling mud will be modeled. At a slightly higher cost and complexity of the solution compared to standard clay solutions, PG-NDM provides a number of significant advantages.

3. Well model creation in «Ansys CFX» software

In order to simulate the rheological parameters of the solution and predict its behavior in the well, it is necessary to use software. In this work «Ansys CFX» software is using, which has proven itself well in many industries, including oil and gas.

Software package CFX - a high-performance program for simulating fluid dynamics tasks.

To start working in this program, you need to set the geometry of the well (figure 1A).

Based on the constructed geometry, a structural mesh is built (figure 1B), within which the necessary parameters will be calculated.

Further, the initial and boundary conditions are set, i.e. the direction of the entry of the drilling mud into the drill string and its exit through the annular space, the flow rate of the drilling mud is set, the parameters of the mud - viscosity, density, type of mud, rheological model etc [1].
Figure 1. Well geometry (A), meshing (B), initial and boundary conditions (C).

The well model consists of a drill collar, through which the solution is delivered to the bottom hole and well itself.

Table 2 lists all parameters of the well.

| Parameter                  | Value | Unit of measurement |
|---------------------------|-------|---------------------|
| Bit diameter              | 212.7 | mm                  |
| Outer drill collar diameter| 159   | mm                  |
| Inner drill collar diameter| 57    | mm                  |
| Drilling mud flow rate    | 32    | l/s                 |
| Well length in the model  | 1000  | mm                  |

Thus, the well model is being built in «Ansys». After constructing the geometry, meshing and specifying the initial and boundary conditions, the model is launched for calculation.

4. Modeling the upward velocity of the drilling mud in «Ansys CFX»

4.1. Rheological model

The Ostwald-de Waale model is used as the rheological model. This model does not give an absolutely accurate characteristics of the drilling mud, in comparison, for example, with the Bingham-Shvedov model, but its use is preferable if the drilling mud is polymer-based or completely clay-free polymer [2].

If the fluid flow obeys a power-law model, then the curves of yield and viscosity in logarithmic coordinates will be straight lines. In this model, the drilling mud is a pseudoplastic fluid with no yield point. Thus, the liquid begins to flow immediately after the application of a shear stress to it [3].

This power law looks like this:

\[ \tau = K \left( \frac{\partial u}{\partial y} \right)^n \]  

(1)
Where $K$ – flow consistency index, Pa · s; $\frac{\partial u}{\partial y}$ - shear rate or the velocity gradient perpendicular to the plane of shear, $s^{-1}$; $n$ – flow behaviour index (dimensionless).

4.2. Determination of the required drilling mud viscosity

Based on the data from the Arctic field, the following parameters of the PG-NDM are required (Table 3).

| Mud type | Density, kg/m³ | Funnel viscosity, s | Filtration, sm³/30 min | SSS, dPa after 1min | DSS, dPa after 10min | Mud cake, mm | Dynamic viscosity, mPa·s |
|----------|----------------|---------------------|------------------------|------------------|---------------------|-------------|------------------------|
| PG-NDM   | 1170           | 25-35               | 3-4                    | 5-15             | 15-40               | <1          | 6-12                   | 30-60         |

Based on Table 3, it can be seen that the dynamic viscosity varies in the range from 6 to 12 mPa·s, respectively, it is necessary to choose such viscosity values (in this range) that will support transportation of cuttings on the surface and correspond to the supplied functions of the PG-NDM.

After analyzing PG-NDM with different viscosity values – 6, 8, 10 and 12 mPa · s, the optimal viscosity for the given field will be selected, since increasing or decreasing viscosity will affect the upward velocity in the annulus.

The upward velocity, specifically in this Arctic field, should not be less than 1.75 m / s, otherwise, the removal of cuttings will be extremely difficult, which will affect the efficiency of process (figure 2-3).

![Figure 2. Velocity contours (A – 12 mPa·s, B – 10 mPa·s, C – 8 mPa·s, D – 6 mPa·s).](image)
Thus, PG-NDM with a viscosity of 6-8 mPa·s is the most optimal for this field, as for solutions with a viscosity of 10-12 mPa·s, the simulation results showed, that upward velocity is less, than minimum necessary value.

5. Conclusion
The main function of drilling mud is to carry cuttings to the surface, which depends on many parameters, including the upward velocity.

The simulations were carried out in «Ansys CFX» software, which has been used by engineers for 20 years to calculate problems with the flow of liquids and gases.

In this work, were studied the PG -NDM with different viscosities. Viscosity affects the rate of upward velocity in the annulus. The smaller it is, the worse is the removal of sludge.

The study showed that mud with the lowest viscosity of 6 and 8 mPa·s showed better results in comparison with solutions with a viscosity of 10-12 mPa·s.

According to the results of the study, in this particular well of the Arctic field, the range of viscosity change should not exceed 6-8 mPa·s.

References
[1] Al-Yasiri M, Al-Gailani A, Wen D. Numerical study of cuttings transport of nanoparticle-based drilling fluid. Engineering Reports. 2020:2:e12154.
[2] Tianle Liu, Leushova E. L., Morenov V. A., Lixia Li, Guosheng Jiang, Changliang Fang, Ling Zhang, Shaojun Zheng and Yinfei Yu. Influence of polymer reagents in the drilling fluids on the efficiency of deviated and horizontal wells drilling. Energies. 2020:13:e04704.
[3] Rafał Wiśniowski, Krzysztof Skrzypaszek and Tomasz Małachowski. Selection of a Suitable
Rheological Model for Drilling Fluid Using Applied Numerical Methods. *Energies*. 2020:13:e03192.

[4] Gubanov V.N., Lopatin D.V., Sychev V.S., Tolstoukhov A.A. Mortar Engineer's Book. Library of the Siberian service company. 2006.

[5] Kletter V.U. Improvement of drilling fluids for well construction in the Arctic shelf. 2010.