Modeling of the egress of a drilling liquid from the nozzle of a drill bit with Ansys Fluent

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Abstract. A 3D model was built for the cylindrical outer nozzle of a drill bit which was in an immersed space at the distance of four diameters from the formation. A tetrahedral lattice was applied to the space filled with liquid, and a hexahedral lattice was applied to a section of the 3D model which imitated the rock (formation). A boundary layer was built near the walls. As a result of the calculations, the impact of the jet on the rock has been demonstrated, and it is similar to the impact of a drilling liquid jet on the bottom of a well during drilling. Distribution of the pressures, as well as the vector of velocities, the change in the volume ratio of a rock and the depth of penetration of the jet have been understood.

1. Introduction
Modern methods of designing rock destruction tools are quite advanced, however, in order to achieve the maximum performance of a drill bit when drilling oil and gas wells, one should account for a number of factors [1]. One of the factors is hydrodynamic parameters of a drilling liquid during the drilling process. Since it is rather difficult to perform the analysis of processes during well drilling due to extensive depths, by solving this problem, it would be possible to model the physical processes of drilling using the finite elements method. Currently, engineers worldwide utilize a great many tools for CFD computations, however, many years of international experience in running the software of this type point to the advantage of the ANSYS Fluent software package for a particular problem. An important factor for this study is that the ANSYS Fluent software package has the functionality to model two-phase and multicomponent operating environment including discrete granulated particles which are formed as a result of rock destruction. In order to perform calculations of this type, one requires significant computational capabilities, however, the use of average parameters of the operating environment enables us to determine the optimal ratio between the accuracy of results achieved and the time invested in the calculation, as well as to develop the methodology of calculation of the structure of drill bits at the stage of designing the relevant rock destruction tools, as well as the system of washing of drill bits, which enables a significant improvement of drilling KPIs, such as a drilling rate and a sinking advance per drill bit.
2. Setting of the problem

In this problem, we modeled the egress of a drilling liquid from the nozzle of a drill bit into the bottom of a well with an ablation effect. We used the parameters of water as a drilling liquid at the start of our study. The problem’s solution is based on the numerical solution of Navier-Stokes equation which was implemented in ANSYS Fluent [2], while the moment of transfer from laminar conditions to turbulent conditions is determined by Reynolds criterion [3] which determines the ratio of viscous and inertia forces in a flow.

\[ R_e = \frac{\rho \vartheta D_e}{\eta}, \]  

where \( \rho \) – the density of the operating environment, \( D_e \) – the hydraulic diameter, \( \vartheta \) - the velocity of the liquid flow, \( \eta \) – the dynamic viscosity of the operating environment.

In order to model the flow hydrodynamics, we used a two-phase model, where one phase is discrete granulated particles of the mine rock, and another phase is a drilling liquid. In order to describe changes in properties of the rock, we used empirical data from our works [5-8].

The change in viscosity of the granulated particles is described by Gidaspow equation [6]:

\[ \mu_{i,\text{kin}} = \frac{10 \rho_d d_s^{\frac{1}{4}} \Theta \sqrt{\pi}}{96 \alpha_s (1 + e_{ss}) g_{0,ss}} \left[ 1 + \frac{4}{5} g_{0,ss} \alpha_s (1 + e_{ss}) \right]^2 \alpha_s. \]  

The volume viscosity of the granulate material determines resistance in case of expansion and compression. It can be demonstrated by the following ratio [7]:

\[ \lambda_s = \frac{4}{3} \alpha_s \rho_d d_s g_{0,ss} (1 + e_{ss}) \left( \frac{\Theta_s}{\pi} \right)^{\frac{1}{2}}. \]  

In the dense flows and at low shift velocity with a high level of concentration of solid particles, the stress is mostly formed due to friction between the particles. The viscosity of solid particles cannot be calculated by default; therefore the following equation is used to determine the viscous friction [8]:

\[ \mu_{s,f,r} = \frac{\rho_s \sin \varphi}{2 \sqrt{I_{2D}}}, \]  

where \( \rho_s \) – the pressure of solid particles, \( \varphi \) – the internal friction angle, while \( I_{2D} \) – the second invariant of the deviator of a stress tensor.

In the flows with a high volume share of solid substances, an instantaneous collision is less important. The application of kinetic theory is not necessary for such flows, as the particles are in contact, and, therefore, the resulting friction must be taken into account.

In this section, the study began with computation of soft rock, 1-2 as per the IADC code which corresponds to a very soft and soft formation with the angle of internal friction of 14°-23°.

3. Results and Discussion

In order to perform CFD computation, we built a grid-scale model (Figure 1, a) which is composed of tetrahedral and hexahedral grids on two domains connected with a penetrable interface. The grid dimensions were 7.5 million elements with the maximum tapering of 0.84. We also built a prismatic borderline layer with a 1-mm thickness (Figure 1, b) [9-10].
The problem was solved in an unconventional setting, using turbulence model k-ε. It was determined that in case of consumption of 1 kg/s of the drilling liquid via a submerged cylindrical nozzle with a 20 mm diameter, the flow reaches the established mode in 1 second (Figure 2).

As a result, we have the patterns of distribution of the parameters by the model cross sections, which enables us to receive the data necessary for the relevant verification (Figures 3-4). Figures 3 a, b, c, d show the change of the volume ratio of the rock over time.
a) Computation time — 0.005 s                                  b) Computation time — 0.26 s.

c) Computation time — 0.613 s                                 d) Computation time — 0.943 s.

Figure 3. Distribution of the volume ratio of a hard rock formation during different time intervals.

Figure 4. Vectors of velocities of the egress of a drilling liquid.

4. Conclusion

Based on the results of the calculations, it is demonstrated that in this problem setting for soft and very soft rock formation, the depth of penetration of the drilling liquid in the rock was around four diameters of the nozzle hole. This indicates the degree of approximation of this numerical simulation to the reality [1]. However, in order to continue the studies, it is necessary to verify the model and the calculation for other types of formation. Also, it is required to account for the stressed-deformed state of the well bottom and unevenness of properties of the formation due to this. This methodology of calculation also enables us to evaluate the cutting transport which is formed as a result
of the impact of the drilling liquid jet on the well’s bottom, and its quantity and areas of maximum concentration in the annular space which may indirectly point to packing formation.

Acknowledgements
This work was supported by the Ministry of Education and Science of the Russian Federation in the framework of the implementation of the Program ‘Research and development of priority directions of the scientific-technological complex of Russia for 2014–2020’

References
[1] Shatsov N I 1961 Drilling of oil and gas wells (Moscow: State Scientific and Technical Publishers of Oil and Mining and Fuel Literature)
[2] Baturin O V, Popov G M, Goryachkin E S and Novikova Y D 2015 Proc. 5th Inter. Conf. on Simulation and Modeling Methodologies, Technologies and Applications (Vienna) vol 1 (Vienna: Institute of Electrical and Electronics Engineers) p 227-232
[3] Kramchenko V V and Savichev O G 2009 Hydraulics Part 2 (Tomsk: Tomsk Polytechnic University Publishers)
[4] Armsfield S and Street R 1999 J. of Computational Physics 153 660-665
[5] Ding and Gidaspow D 1990 AIChE J. 36(4) 523-538
[6] Gidaspow D and Huilin L 2003 Chemical Engin. Sci. 58(16) 3777-3792
[7] Lun C K, Savage S B, Jeffrey D J and Chepurniy N 1984 J. Fluid Mech. 140 223-256
[8] Schaeffer D G 1987 J. Diff. Eq. 66 19-50
[9] Biryuk V V, Tsapkova A B and Shimanov A A 2016 Key Eng. Mat. 685 153-157
[10] Saigakov E A, Gorshkalev A A, Kayukov S S and Blagin E V 2014 Res. J. of Appl. Sci. 9(10) 669-673