Numerical study of the cuttings transport by drilling mud in horizontal directional well

V A Zhigarev[1], **A V Minakov**[1,2], **A L Neverov**[1], **M I Pryazhnikov**[1,2]

[1] Siberian Federal University, 79 Svobodny pr., Krasnoyarsk, 660041, Russia
[2] Institute of Thermophysics SB RAS, 1 Acad. Lavrentiev pr., Novosibirsk, 630090, Russia

E-mail: zhigarev.vladimir@yandex.ru

Abstract. The results of numerical simulation of cutting by mud are providing in this article. The influence of flow rate on the values of pressure drop and cutting removal was studied.

1. Introduction

Mud is a complex physical and chemical system with a number of properties characterized by one or more indicators.

For effective performance of the functions in specific geological and technical conditions of wells drilling the mud shall have strictly certain values of indicators of properties or, in other words, to satisfy the regulations on indicators of properties corresponding to these conditions. One of these functions is the effective cutting from the wellbore [1].

The drilled particles forming because of work of a bore bit shall be removed from a well. To do this, the drilling fluid is pumped through the drill string, through the chisel; the drilled rock is captured and carried up through the annular space to the surface. The efficiency of removal of the drilled slurry (cleaning the barrel) depends on the size, shape, and density of solids, penetration rate and rotation of the drill string, as well as the viscosity, density and velocity of the upstream drilling fluid in the annular space.

Analysis of research works and practical experience of the authors shows that polymer solutions meet the requirements of drilling most fully [2]. Such solutions effectively clean the well and cool the drilling tool, reduce hydraulic resistance, do not disperse the rocks.

The most common types of flush water used in drilling are polyacrylamide solutions. When using flocculant polymers, the rheological properties of drilling fluids are of great importance. The removal of cutting depends on these properties. Unsatisfactory rheological properties can lead to such serious complications as the formation of plugs in the wellbore, clogging of the bottom-hole zone with cutting reducing the mechanical speed of drilling, sticking of the drill string, erosion of the walls of the well, absorption of mud [1].

The aim of this work was the calculated study of the transport of particles of drilled rock (cutting) by mud in horizontally directed wells. To achieve this goal, a number of problems were solved, such as numerical simulation of the flow of these solutions in the annular channels based on the geometry of the real well.

2. Mathematical model

For the simulation of the removal of cuttings from the well, we used the approach of granulated medium. The mass conservation equation and the continuity equation preserve the original shape of the Euler description [3-6]. The Eulerian model assumes that the flow consists of solid "s" and liquid "f" phases, which are separate, but they form interpenetrating continuums, so that $\alpha_f + \alpha_s = 1.0$, where α_f and α_s are volume concentrations of the liquid phase and the solid phase, respectively. The basic equations of the Euler model have the following form:

$$\frac{\partial}{\partial t}\left(\alpha_S \rho_S\right) + \nabla\left(\alpha_S \rho_S \vec{v}_S\right) = 0$$

$$\nabla\left(\alpha_S \rho_S \vec{v}_S \vec{v}_S\right) = -\alpha_S \nabla p - p_S + \nabla \overline{\overline{\tau}} s + \alpha_S \rho_S \vec{g} +$$

$$+\sum_{l=1}^{N}\left(K_{ls}\left(\vec{v}_l - \vec{v}_S\right) + m_{ls}\vec{v}_{ls} - m_{sl}\vec{v}_{sl}\right) + \left(\vec{F}_S + \vec{F}_{lift,s} + \vec{F}_{vs,s} + \vec{F}_{td,s}\right)$$

where, ρ_S is phase density *S*, $\vec{g}$ is gravity acceleration, K_{lS} is transfer coefficient of impulse signal between fluid phase *l* and solid phase *S*, $K_{lS}\left(\vec{v}_l - \vec{v}_s\right)$ is interfacial force acting per unit volume, $\vec{F}_S$ is resisting force, $\vec{F}_{lift,S}$ is bearing capacity, $\vec{F}_{vm,S}$ is the force of the added mass, $\vec{F}_{td,S}$ is the force of turbulent dispersion, $\overline{\overline{\tau_S}}$ is tensor of internal shear:

$$\overline{\overline{\tau}}_f = \alpha_f \mu_f \left(\nabla \vec{v}_f + \nabla \vec{v}_f^{\,tr}\right)$$

where μ_s is dynamic viscosity, λ_s is volume viscosity.

In general, the turbulent flow of the drilling mud was considered. Two-parameter *k-ω* SST model was used for turbulence modeling. The inhibited low-clay solution was considered as the test drilling fluid.

This solution is non-Newtonian. Its rheology was well described using a power-law model.

Depending on the drilling fluid rheology, the effective viscosity is: $\mu(\dot{\gamma}) = K$, for Newtonian medium (*K* is the molecular viscosity of the fluid), $\mu(\dot{\gamma}) = K\dot{\gamma}^{n-1}$ for a power-law model, where *n* and *K* are the coefficients of the rheological models.

Testing of mathematical model is given in [7-10]. It has been shown that mathematical model correctly describes the velocity profiles and pressure drop for non-Newtonian flows in annular channels.

To calculate the flows in the well during pumping of drilling fluid, typical process parameters of drilling directional wells were selected. The diameter of the inner pipe was $D_1 = 0.127$ m, the diameter of the outer pipe was $D_2 = 0.220$ m. The rotation speed of the drill pipe was 60 rpm, the flow rate of the drilling fluid varied from 10 to 40 kgs^{-1}. The density of the drilling fluid was equal to 1050 kgm^{-3}. The rheology of drilling fluids was determined from the experimental data obtained earlier. The rheological Power-law model was used for modeling. The computational grid consisting of 40×140×120 (40 nodes in radius and 140 nodes in circumference and 120 nodes in channel length) computational nodes was used for numerical simulation. Spherical particles with the size of 0.003 m and density of 2719 kgm^{-3} were considered as cutting particles. The cutting concentration at the channel inlet was set to 5% by volume. The angle of inclination of the well to the horizon was 90°, which corresponded to the horizontal well. The length of the calculated area of the annular channel was set to 10 m. This length was sufficient to establish the flow and concentration of sludge along the length of the channel. The concentration profile of the slurry at the entrance to the well was set to be uniform. The speed of the particles of the cutting and the speed of the mud at the entrance to the well were equal.

Figures 1-4 show the results of modeling the flow of mud with sludge in a horizontal well. The mud flow rate varied from 10 to 40 kgs^{-1}. Figure 1 shows the distribution of cutting particles in the cross section depending on the mud flow rate.

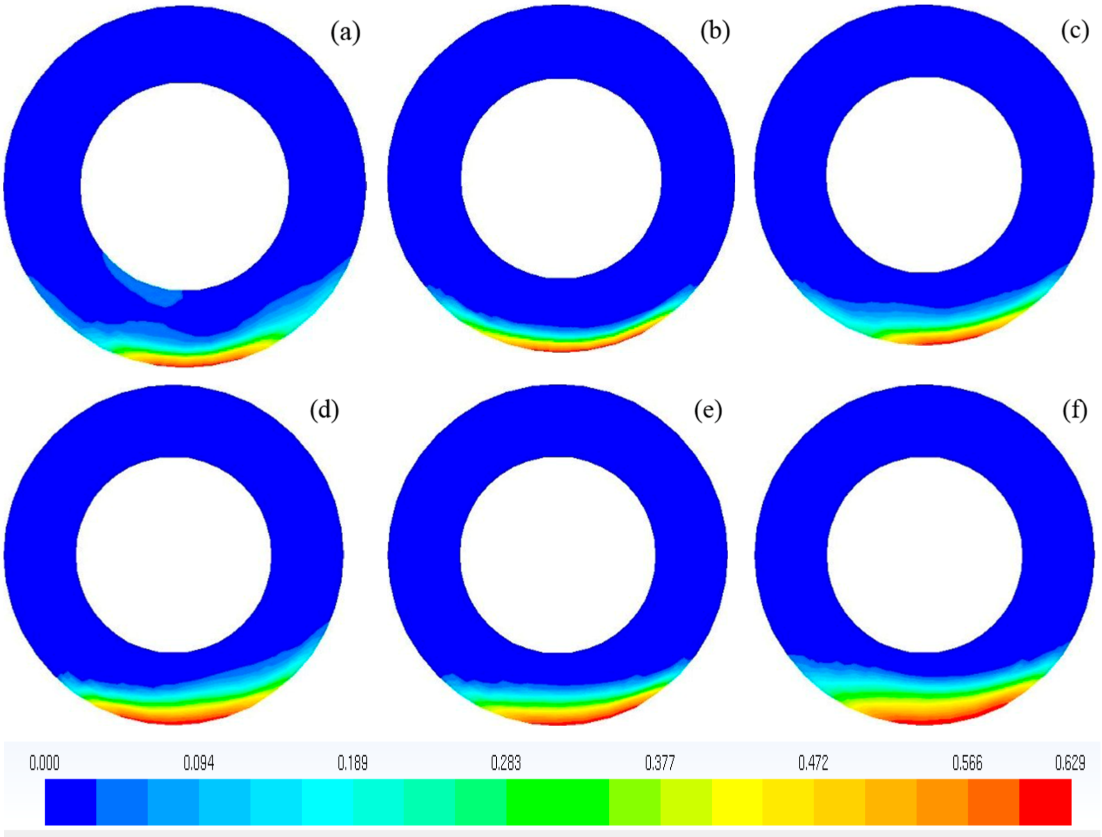
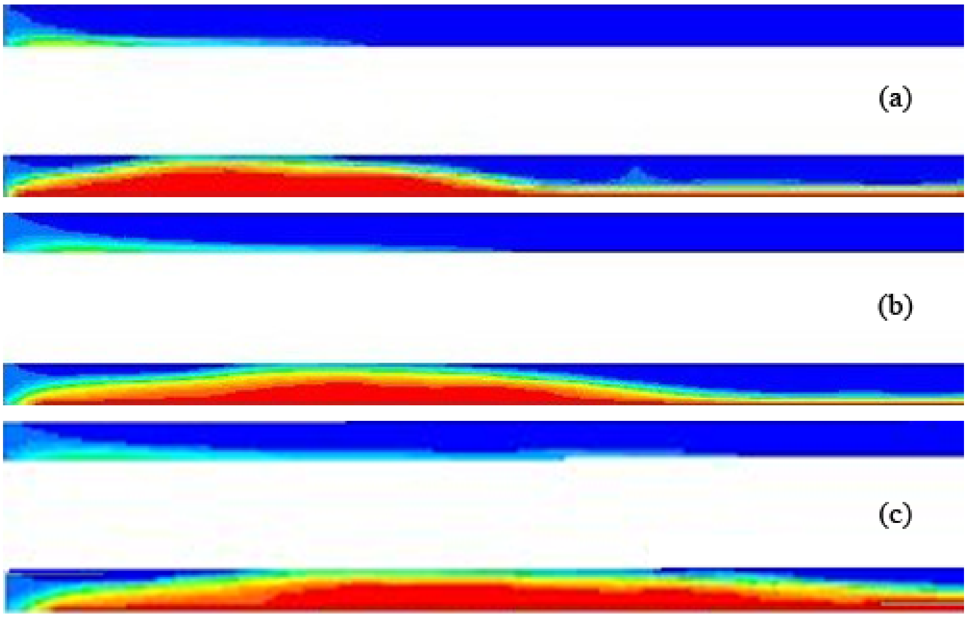


Figure 1. Distribution of cutting particles in the cross section of the borehole for a various ratio of drilling mud rate a) G = 10 kgs^{-1}, b) G = 15 kgs^{-1}, c) G = 20 kgs^{-1}, d) G = 25 kgs^{-1}, e) G = 30 kgs^{-1}, f) G = 40 kgs^{-1}



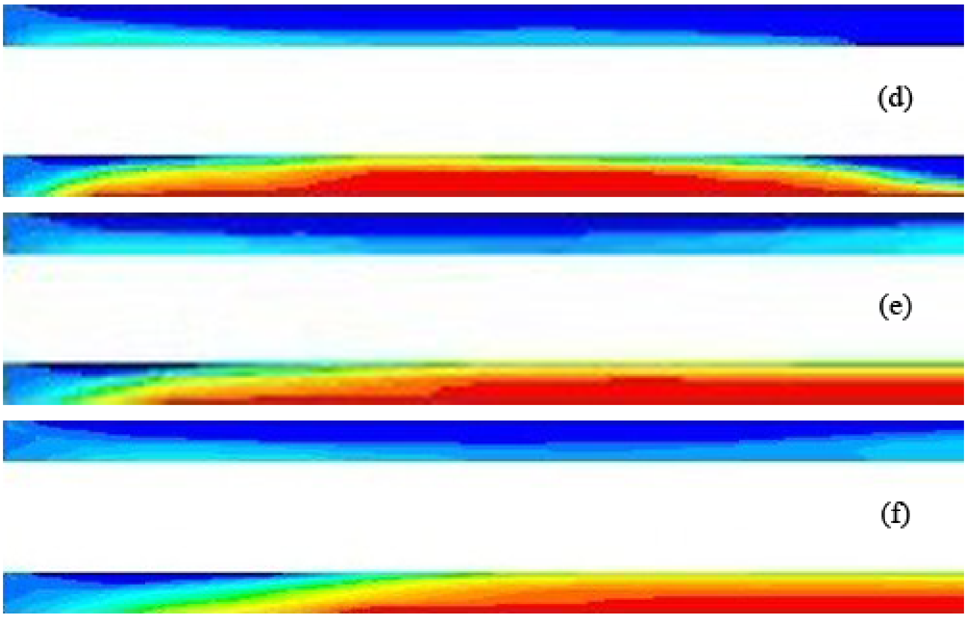


Figure 2. Distribution of cutting particles in the lengthwise section of the borehole for a various ratio of drilling mud rate a) G=10 kgs^{-1}, b) G=15 kgs^{-1}, c) G=20 kgs^{-1}, d) G=25 kgs^{-1}, e) G=30 kgs^{-1}, f) G=40 kgs^{-1}

As it can be seen in figures 1-2, the distribution of the cutting in the cross section is highly dependent on the flow rate of the mud.

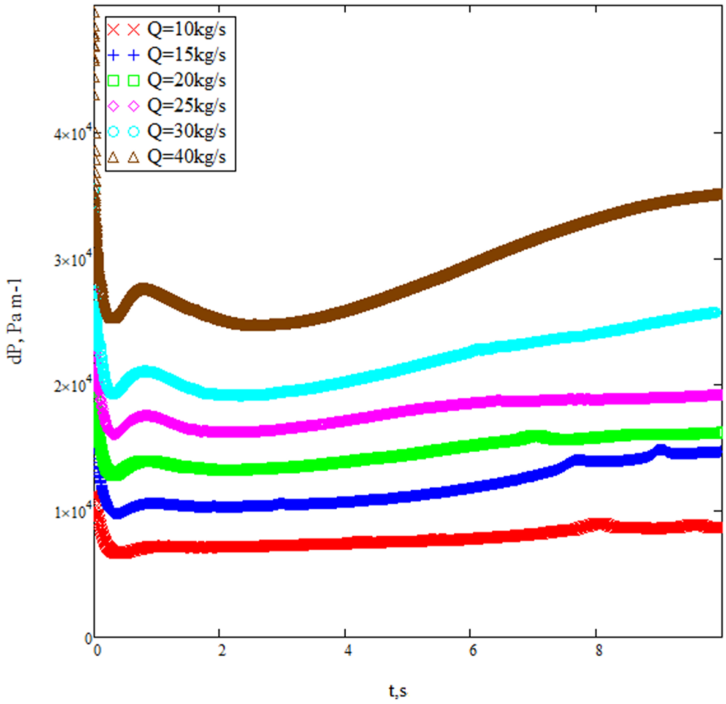


Figure 3. The pressure drop in the annular channel for the ratio drilling mud rate depending on the pumping time

Figure 3 shows the time dependence of the differential pressure for different flow rates. It is seen that the pressure drop increases over time because there is accumulation of cutting particles in the cross section of the channel. In horizontal wells, the cuttings are removed in separate portions. There is a so-called dune formation. Sludge particles accumulate gradually in the well, the thickness of the sediment layer grows, then there is a rapid failure of the formed layer, and the process is repeated again.

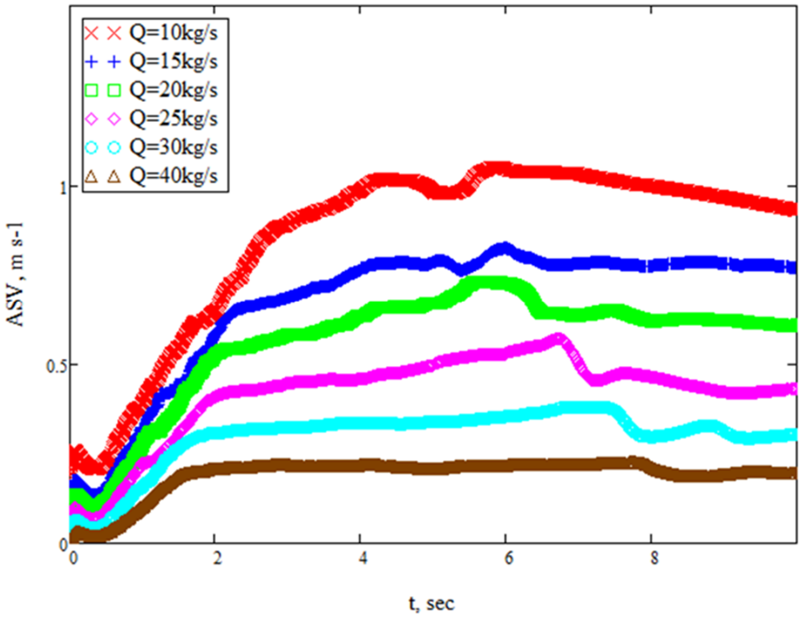


Figure 4. The value of the slip rate from time to time for different mud flow rates.

To assess the effectiveness of carrying out cutting was used the average volume value of the slip speed of cutting particle (ASV). In other words, ASV means the difference of speed of the drilling fluid and the speed of sludge. A high ASV value means that the sludge is not carried well. As it can be seen in figure 4, the efficiency of cutting removal increases with increasing mud flow rate. In horizontal sections of wells, the process of particle accumulation can take place, so the dynamics of the behavior of the average volume fraction of particles in the volume of the well was also analyzed in the calculation process.

3. Conclusion

A numerical simulation of cutting transport in a horizontally directed well is carried out. The dependence of the sludge removal on the drilling mud flow rate is studied. It is shown that the drilling mud flow has a strong influence on the distribution of cutting along the length of the channel. In the future, it is planned to conduct a study to assess the effect of cutting removal efficiency depending on the rotation speed of the drill pipe and the rheological parameters of the brown solution. These results will serve for the selection of an effective balance of rate and speed of rotation of the drill pipe with the aim of improving the quality of cleaning the well.

Acknowledgments

The reported study was funded by the Russian Foundation for Basic Research, Government of Krasnoyarsk Territory, Krasnoyarsk Regional Fund of Science, the research project: «18-41-240001 Numerical-experimental study of the cutting transport in the annular channels».

References

[1] Gray J R and Darley G S G 1985 *The composition and properties of drilling agents (drilling fluids)* (Moscow: Nedra)

[2] Afanasyev I S, Blinov G A, Bukharev N N, Egorov N G, Egorov E K, Ivanov O V, Kukes A I, Morozov Yu T, Osetsky A I and Ponomarev P P 2000 *Reference book of geological profecting well* (Saint Petersburg: Nedra)

[3] Lun C K K , Savage S B, Jeffrey D J and Chepurniy N 1984 *J. Fluid Mech.* **140** 223–256

[4] Ogawa S, Umemura A, and Oshima N 1980 *J. Appl. Math. Phys.* **31** 483-493

[5] Ding J and Gidaspow D A 1990 *J. AIChE.* **36**(4) 523–538

[6] Gidaspow D., Bezburuah R., and Ding J. 1992.Proc. 7th Eng. Found. Conf. on Fluid. 75–82

[7] Zhigarev V A, Neverov A L, Guzei D V and Pryazhnikov M I 2017 *IOP Conf. Series: J. Phys.: Conf. Series* **899** (092016) 1-6

[8] Zhigarev V A, Minakov A V, Guzei D V and Mikhienkova E I 2018 *IOP Conf. Series: J. Phys.: Conf. Series* **1105**(0120771) 1-6

[9] Zhigarev V A, Minakov A V and Mikhienkova E I 2019 *IOP Conf. Series: Earth. Env. Sci.* **272**(022217) 1-6

[10] Minakov A V, Zhigarev V A, Mikhienkova E I, Neverov A L, Buryukin F A and Guzei D V 2018 *J. Petroleum Sci. Eng.* **171** 1149-1158