Numerical study of cuttings transport by drilling polymer solutions

A Zhigarev¹, A V Minakov¹,², D V Guzei¹,³, A L Neverov¹, Z I Nabizhanov¹, and A V Matveev¹

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. This paper presents the results of laboratory tests and numerical simulation of polymer drilling fluids. The influence of the rotation speed on the values of the pressure ratio and cutting transport is studied. The influence of rheological parameters on the efficiency of cuttings transport is investigated.

1. Introduction

In recent years, more and more works are concerned with development and improvement of drilling mud. Drilling mud circulation in wellbore aimed at drilling tool cooling-off and cutting transport is one of the main processes which occurs during borehole drilling. Ineffective cutting transport can cause emergencies, such as sticking and jamming of drilling tools [1].

Any solid particles that are too large to pass through borehole annulus can jam between drill stem and wellbore wall, so that can cause pipe sticking. However, small particles can cause pipe sticking against stabilizers of major diameters and other parts of “downhole drill stem assembly”. A roller cone that drops down in a borehole from the wellbore walls can be attributed to such particles that can cause pipe sticking. When small amount of roller cones fall simultaneously in a borehole, we can avoid pipe sticking by skillful manipulation with drilling tools. By cautious pulling out, rotation and pulling down of drill stem, and also by starting and stopping of circulating pump we can urge roller cones to fall down to the bottom-hole, where it can be ruined by drilling bit. Therefore, the urgent task is the development of muds that will have high transport ability for cutting transport during the building of boreholes.

The aim of this work was the calculated study of the transport of particles of drilled rock (cuttings) by different composition 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

Computational fluid dynamics method was used to compute drilling mud motion [2-4]. The Power Law Model is of use as rheologic flaw law in borehole described in works [5]. The granulated medium approach was used to simulate cutting transport from borehole. Mass conservation equation and continuity equation save the initial form of Eulerian representation [6-12]. The Gidaspow model was
used to describe inter-phase resistance force for Eulerian approach with granulated medium. In general, vortex flow of drilling mud was considered. The two-parameter k-w SST model was used for turbulence simulating.

Average parameters of drilling and well geometry were selected to compute cuttings transport in a borehole during drilling mud pumping. The diameter of the inner tube is $D_1 = 0.127$ m, the diameter of the outer tube is $D_2 = 0.220$ m. The rotary speed of a drill pipe is 0-60 rpm, drilling mud circulation rate is 40 kg s$^{-1}$. Drilling mud density was equal to 1030 kg m$^{-3}$. Spherical particles with the size of 0.003 m and density of 2719 kg m$^{-3}$ were considered as mud particles. The cuttings concentration at the channel inlet was set to 5% by volume. The computational grid, described in the [5], was used for numerical simulation. The properties of the drilling muds used for computing are presented in table 1.

### Table 1. The compositions and rheological properties of model solutions.

| No. | Gammaksan | PAC-LV | Thrutrol | NaCl | liquid glass, ml | n | K, mPa·s$^{n}$ | $r^2$ (PowerLaw) | Gel1 | Gel2 |
|-----|------------|--------|----------|------|-----------------|---|----------------|------------------|------|------|
| 1   | 0.5        | 0.5    | 2.0      | -    | -               | 0.43 | 0.89 | 0.996           | 2    | 3    |
| 2   | 0.2        | 0.5    | 2.0      | -    | 50              | 0.33 | 2.68 | 0.998           | 4    | 5    |
| 3   | 0.5        | 0.5    | -        | 2    | -               | 0.43 | 1.39 | 0.998           | 4    | 6    |
| 4   | 0.5        | 0.5    | -        | 5    | -               | 0.42 | 1.76 | 0.998           | 5    | 8    |
| 5   | 0.5        | 0.5    | -        | -    | 100             | 0.42 | 1.42 | 0.998           | 5    | 7    |

As the result we obtained the pressure ratio values and particle velocity profile for different drilling mud compositions in a horizontal borehole, also the efficiency of drilling mud transport ability was shown. Cutting transport efficiency was estimated by the value equal to average by volume of slip velocity of mud particle (velocity difference of drilling mud and bit cuttings) ASV. High ASV means low transport of sludge.

![Figure 1. Volume concentration of mud particles at the outlet of the borehole at different speeds of rotation of the inner tube. a) 0 rpm, b) 20 rpm, c) 40 rpm, d) 60 rpm.](image-url)
3. Results and discussion

Figures 1-5 present the results of numerical simulation of drilling mud flow in a horizontal borehole.

![Figure 2](image)

**Figure 2.** The volume concentration of mud particles on the walls of the borehole at different speeds of rotation of the inner tube 0-60 rpm. The tube length scale is reduced by 5 times.

In the figure 1 you can see the following: the ground mass of drilling cuttings shift on a wellbore wall during inner tube rotation; drilling cuttings are at the wellbore center during zero speed. Figure 2 shows the distribution of the volume concentration of drilling cuttings on the walls depending on the rotation of the inner tube.

It is seen that the process of particle accumulation has the dune-like formation. After reaching the critical concentration of bit cuttings, a certain proportion of particles are disrupted and then the following dunes are formed along the channel.

![Figure 3](image)

**Figure 3.** The profile of mud particles velocity at the rate of 40 kg s\(^{-1}\), and the rotation speed of 60 rpm for different solutions (left) and velocity profile of particles for drilling mud No. 2 at the rate of 40 kg s\(^{-1}\), depending on the speed of rotation (right).

Figure 3 shows the motion profiles of the bit cuttings for different drilling muds. As you can see the highest speed of the bit cuttings has a drilling mud with the order number 2. Further we studied the influence of inner tube rotation velocity on particle velocity. As you can see the particle velocity decreases when the rotation velocity increases.
4. Conclusion
We made this research to study sludge flow during horizontal borehole washing. We obtained an experimental value of the pressure ratio depending on rheologic properties of drilling mud during borehole washing.

Profiles of sludge particle velocity in the borehole were constructed depending on drilling mud rheology. As it can be seen from figure 5, drilling mud number 2 has the most effective cutting transport ability; drilling mud number 1 has the lowest efficiency of cutting transport ability. It is because drilling mud number 1 has the lowest consistency index and stability index.
The efficiency of cutting transport ability was shown. We found out that the most effective one is the drilling mud with a high consistency index.

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