Production and Environmental Monitoring at PAO Surgutneftegaz

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Abstract. This paper analyzes the performance of systems for removal of sludge from the drilling mud. It shows that the solid-phase particle-size distribution, which depends on the mineral composition and the physico-mechanical properties of rock, the drilling mud process parameters and the type of the rock cutter, as well as the drilling parameters affect the performance of vibrating screens, hydrocyclones, and centrifuges. The paper proposes upgrading the cleaning system by installing a second layer of fine-meshed sieve cassettes where hydrocyclones discharge their output. This improvement reduces the unproductive drilling time.

1. Introduction
Russia’s fuel and energy complex (FEC) currently seeks to implement resource-saving technologies and to be eco-friendly at all times. However, the construction and operation of oil-and-gas production facilities is associated with outstandingly profound and diverse negative environmental impact. This is why continuous production and environmental monitoring is a high priority for PAO Surgutneftegaz.

2. Relevance and Scientific Significance
Using Russia’s current state-of-the-art technology for cleaning drilling muds, 50% to 80% of the extracted rock returns to the bottom [1,2]. Abroad, the maximum sludge content of the drilling mud is 2% to 2.5% [3].

Removing sludge from the drilling mud is extremely important when drilling a well, as excessive solid-phase and sludge concentrations reduce the technical and economic performance (TEP) of drilling. The particle-size distribution of drilling sludge is determined by the type and diameter of the rock cutter, the mechanical properties of rock, the drilling parameters, the properties of the drilling mud, and the efficiency of cleaning it. An inefficient cleaning system will return mud with a high solid-phase concentration, which frequently causes the operating time to be unproductive due to sticking, tensioning the casing and drilling pipes, loss of circulation, sludge jamming and drifting, and extensive wear and tear of the drilling rig [4-10].

The environmental hazard of the drilling mud depends on the heavy metals, petroleum hydrocarbons, and toxic components it contains [11,12]. Therefore, an eco-friendly high-quality drilling process needs an efficient drilling mud cleaning system.
3. Statement of problem
To assess the performance of the drilling mud cleaning system, the research team decided to estimate the solid-phase concentration and particle-size distribution before and after each cleaning stage and to do the same for the solid phase contained in the removed sludge.

4. Theory
Experiments were performed using an NS300 particle-size analyzer, a device capable of automatically reading the particle-size distribution and concentration for all types of solid articles in a range of 0 to 10 to 2,000 µm (the range depends on the analyzer type as well as on the sample properties). 3200/200 EUC (ЭУК) drilling rigs use sieve and hydrocyclone units (SHU), which receive the vibration-screened mud by pumping. Then the bulk of the mud goes through the upper drain to the circulation system (CS), while the pulp and the sludge are diverted to the sand nozzles of hydrocyclones, through which they are fed to an additional fine-meshed vibrating screen. After that, the mud goes to the CS while the coarse-grained sludge is removed. SHUs remove particles sized 250 to 750 µm. The drilling mud cleaning system used by 3200/200 EUC drilling rigs comprises four stages, see Figure 1. The fourth stage comprises centrifuges that can remove fine solid particles sized 1 to 10 µm.

![Figure 1. 3200 EUC drilling rig cleaning system.](image)

The drilled mud carrying the removed rock leaves the well and goes to the first cleaning stage, which uses two vibrating screens (VS1 and VS2), the second one also being a drier. The screens are designed to remove coarse-grained solid phase (usually >100 µm) from the mud. After screening, the mud goes to the CSPC (circulation system for primary cleaning) tank; then it is pumped centrifugally to the hydrocyclones (HC). From there, the mud goes to the receiving tank or, if necessary, to the centrifuge (CF). From the receiving tank, the mud is fed to the drilling pumps (P1, P2), which pump it back to the well.

5. Research findings
To find the particle-size distribution of the solid phase at five drilling ranges as well as how the drilling mud cleaning system equipment (DMCSE) affected it, the research team collected 28 drilling mud samples and 18 drilling sludge samples from the Mamontovskoye Field operated by PAO Surgutneftegaz.

1. In range 0 to 300 m, the wells used a mud of a funnel viscosity > 120 s, 1,250 kg/m³ in density. Drilling was associated with considerable sand recovery.

2. At the well outlet, the solid phase in the drilling mud contained particles sized 10.08 to 48.27 µm, which accounted for 74.5% of its total volume.
3. Before entering the vibrating screen, the drilling mud had a solid-phase concentration of 395.2 kg/m$^3$.

4. Sieve cassettes were selected given 75% coverage of the working surface of vibrating screens; the size was 20 mesh or 841 µm.

5. After vibration screening, the mud had a solid-phase concentration of 377.8 kg/m$^3$.

6. Thus, the vibrating screen performance was $\frac{14.4}{395.2} \times 100 = 4.4\%$.

High funnel viscosity and density of the mud resulted in clogging the vibrating screens with clay and fine-grained sand.

Recycled drilling mud could not pass through the 20 mesh sieves timely across two vibrating screens; it would overflow onto the auger, which resulted in losing a considerable portion of the drilling mud. This necessitated opening the valve so that some of the mud would bypass the screens; however, such action is highly undesirable, as it compromises the performance of VS (and of the cleaning system generally).

7. After vibration screening, the mud had a 6.3% higher concentration of particles sized 35.56 µm and a 20.7% higher concentration of particles sized 76.32 µm, which was due to the dispersion of larger particles in sieves.

8. The desander hydrocyclone did not perform well, as it failed to change the concentration of the solid phase in the mud. According to specifications, it should be able to remove particles sized 70 to 80 µm; vibration screening left particles sized 88.91 to 850 µm (15.3%). Desanding actually increased the proportion of such particles to 25.2% indicating additional dispersion caused by centrifugal and gravitational forces.

Replenishing the mud and subjecting it to chemicals reduced the funnel viscosity to 40 s and the density to 1,150 kg/m$^3$.

Then the team sampled the mud at 300 to 730 m:

1. In the drilling mud exiting the well, the solid phase contained particles sized > 10 µm (45%), 10.48 to 222.8 µm (55%).

2. Before entering the vibrating screen, the drilling mud had a solid-phase concentration of 484.0 kg/m$^3$.

3. After vibration screening, the mud had a solid-phase concentration of 282.4 kg/m$^3$; screening removed 201.6 kg of solid phase from each cubic meter of the drilling mud.

4. Thus, the vibrating screen performance was $\frac{201.6}{484} \times 100 = 41.7\%$.

Reducing the drilling mud funnel viscosity to 40 s and the density to 1,150 kg/m$^3$ at 300 to 730 m resulted in a 9.5x vibrating screen performance. The desander failed, as it only removed 2.4 kg of solid-phase content per cubic meter, a performance of 0.8%. Particles sized 88.91 to 850 µm were found in the mud before (8.9%) and after desanding (10.4%), meaning that the desander dispersed the particles sized >70–80 µm.

Particle-size distribution in samples taken at 730 to 1,218 m:

1. In the drilling mud exiting the well, the solid phase contained particles sized 0 to 103.58 µm (89.9%), 120.67 to 222.28 µm (10.1%).

2. Before entering the vibrating screen, the drilling mud had a solid-phase concentration of 391.5 kg/m$^3$.

3. After vibration screening, the mud had a solid-phase concentration of 143.0 kg/m$^3$.

4. Thus, the vibrating screen performance was $\frac{248.5}{391.5} \times 100 = 63.5\%$.

5. Hydrocyclones removed 15.0 kg of solid-phase content from each cubic meter of the drilling mud; they thus had a performance of 10.5% (15.0/143.0·100 = 10.5%).

6. The centrifuge was able to remove 58.5 kg of solid-phase content from each cubic meter of the drilling mud it processed. Therefore, its performance was $\frac{58.5}{128} \times 100 = 45.7\%$.

Particle-size distribution in samples taken at 1,218 to 1,754 m:

1. In the drilling mud exiting the well, the solid phase contained particles sized 0 to 10 to 103.58 µm (89.9%), 120.67 to 222.28 µm (10.1%).
2. Before entering the vibrating screen, the drilling mud had a solid-phase concentration of 438.6 kg/m³.
3. After vibration screening, the mud had a solid-phase concentration of 179.2 kg/m³.
4. Thus, the vibrating screen performance was 259.4/438.6·100=59.1%.
5. Testing the hydrocyclone cleaning performance showed that particles sized 222.28 to 140.58 µm were not removed; more than that, there appeared more of them, as centrifugal and gravitational forces had a crushing effect, which resulted in a zero performance of the hydrocyclone in this range (179.2-179.2)/179.2·100=0%.
6. The centrifuge removed 109 kg of solid-phase content from each cubic meter of the drilling mud, which meant it had a performance of (109/179.2)=60.8%.

Particle-size distribution at 1,754 to 2,354 m:
1. In the drilling mud exiting the well, the solid phase contained particles sized > 0-10 to 103.58 µm (95.3%), 120.8 to 222.28 µm (4.7%).
2. After vibration screening, the mud had a solid-phase concentration of 232.3 kg/m³; screening removed 280.2 kg of solid phase from each cubic meter of the drilling mud, resulting in a 54.7% performance.
3. Desanding performance was close to zero, as particles sized 140.58 to 258.95 were not removed from the mud; on the contrary, there were more of them after desanding, as centrifugal and gravitational forces had a crushing effect on larger particles. Desanding was thus inefficient. Besides, it did not remove particles sized 10.48 to 22.49 µm, as such particles were to be removed by the desilter.
4. Adding a desilter to the DMCSE removed an additional 10.3 kg of solid-phase content from each cubic meter of the drilling mud. Thus, the desilter performance was merely (236.0-225.7)/236.0·100=4.4%.
5. The CF received 225.7 kg and removed 110.1 kg of solid-phase content per cubic meter. Thus, the CF performance was 48.8%.

Particle-size distribution in samples taken at 2,354 to 3,714 m:
1. Rock the drilling mud carried from the well at this range was fine-grained at 0-10 to 103.58 µm (96%). This was due to using scraping and cutting drag bits and solid-phase dispersion in the drilling mud; another reason was the altered geological and mechanical properties of drilled rock.
2. Vibrating screen performance depended on the sampling depth and and drilling mud pre-processing. At the onset of drilling for installing a production casing, 730 to 1,218 m, the vibrating screens had a performance of 63.5%. At 3,174 m (bottom), the performance dropped to 46%, reducing the solid-phase content from 626.3 kg to 338.3 kg per cubic meter. This was due to a different mineralogy at greater depths; beside composition, rock there differed in strength and in the manner of destruction, all of which affected the particle-size distribution in the sludge. Finer particles were able to pass freely through the vibrating screen, making it less efficient. However, the screen was (and is) the most efficient unit for preliminary cleaning.
3. Adding a desander proved inefficient, as it only reduced the concentration of particles sized 190.8, 163.77, 140.58, 120.67, 103.58, 88.91, and 76.32 µm. The desander was unable to remove particles of any other size. Besides, drilled rock was found to be crushed after desanding, resulting in a <1% performance.
4. The desilter was also inefficient at 4%, as it only removed 13.4 kg of the received 336.2 kg of solid-phase content per cubic meter of the drilling mud.
5. Although the centrifuge was able to remove up to 148.2 kg per cubic meter, its performance greatly depended on that of the cavity pump, which was about 2 l/s, apparently insufficient for efficient mud cleaning.
6. The desander, the desilter, and the centrifuge were also found to be crushing the solid phase.
6. Experimental results
Efficient removal of the solid phase by means of hydrocyclones (desanders and desilters) requires installing sieve cassettes (min. 200 mesh) to remove particles sized <74 µm, which is not an option when drilling for placing a conductor, and is difficult when drilling the upper range for placing a production casing; it will inevitably result in losing the mud or force bypassing the vibrating screens. The reason is that the mineralogy and mechanical strength of rock within such ranges result in such particle-size distribution in the sludge that matches that of coarse-grained sand (> 841 µm) and 2 to 10 mm gravel (2,000 to 10,000 µm). Hydrocyclones will definitely not be able to remove such particles, as shown by the experiments described herein. Since the 3200 EUC drilling rig has a very small surface for vibrating screens, replacing the SV1L screens with complete SHUs or screens of a greater filtering area that could accommodate 200 to 320 mesh sieve cassettes is not an option.

7. Results and proposals
Analysis of the above led to a proposal to install a second layer of finer-meshed sieve cassettes right under where hydrocyclones discharge their output. Upgrading the cleaning system in such way improved the desanding and desilting performance, with the solid-phase removal rate raising from 0 to 45–80 kg per cubic meter in the desander, to 39.8 kg in the desilter.

8. Conclusions
1. Researchers have found out that the drilled rock at the Mamontovskoye Field has particles sized 10 to 300 µm on average.
2. Vibrating screens are the most efficient cleaning tool with an average performance of 60%, effectively reducing the solid-phase content of the drilling mud from 550 to 330 kg/m³.
3. Use of standard drying vibrating screens with the 3200 EUC drilling rig in combination with 20 mesh cassettes does not enable hydrocyclones to run reliably.
4. Upgrading the DMCSE by installing a second layer of >200 mesh sieves under the hydrocyclones improved the desanding performance from 0–1% to 37.2% and the desilting performance from 10.5% to 24.7%.
5. This reduced the unproductive cleaning time from 45 to 32 hours per well.
6. After 4-stage cleaning, the drilling mud was classified as Class IV mud in terms of hazard. Drilling sludge can be used in embankment or site constructions.

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