Influence of spent drilling mud on sedimentation time of activated sludge flocs

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Abstract. Co-treatment of drilling muds with municipal wastewater in the reactors operating on the activated sludge principle constitutes a potentially safe method of their disposal. The method is based on the process of biological degradation of pollutants by assemblages of activated sludge organisms (prokaryotic and eukaryotic), which include different species described as functional and trophic groups. When the ecosystem in the bioreactor is in equilibrium, high wastewater treatment efficiency and process stability can be achieved. Analysis of qualitative and quantitative changes occurring in assemblages of activated sludge organisms may facilitate understanding the causes and mechanisms involved in the observed processes. In such a context, using a model of an SBR wastewater treatment plant, a study was performed to assess the feasibility of co-treating spent drilling mud with municipal wastewater using the activated sludge method. The floc constitutes the basic structural and physiological unit forming activated sludge. In this study, the sedimentation velocity of activated sludge flocs was analysed, and the obtained results were subjected to statistical analysis.

1. Introduction
The ways of managing drilling wastes that result from hydrocarbon exploration and prospecting depend on their physical and chemical properties, environmental, legal (legally permitted methods), technical (available recovery or disposal facilities) and logistical (cost-effective transportation of wastes to these facilities) considerations [1].

The available and permitted methods for recovery or disposal of drilling wastes mainly include physicochemical methods, recycling, incineration and thermal waste conversion bioremediation, as well as disposal in underground landfills [2,3].

The above-mentioned methods of drilling mud disposal allow its management in an efficient way. However, the literature also presents the studies involving co-treatment of drilling muds with municipal wastewater using the activated sludge method. This seems to be a particularly attractive solution, as it enables to almost completely eliminate the added drilling mud [4-7].

Floc constitutes the basic structural and physiological unit forming activated sludge [8]. It consists of: living microorganisms: true bacteria, filamentous organisms (bacteria, archaeobacteria, fungi, actinomycetes), protozoa (e.g., periwinkles, amoebae, flagellates, etc.), multicellular organisms (e.g., rotifers, nematodes, non-sporidia, gastropods, etc.), dead cells of the afore-mentioned organisms, undecomposed large organic particles together with spare substances in the form of extracellular polymers, and mineral parts, e.g. sand (10% to 50% of the total mass of flocs) [9].
Flocs are formed as a result of numerous factors, based on the chemical bonding reactions of multivalent metal cations together with the reactions of hydrophobic compounds, which form bridges [10,11].

The study of flocs focuses on the following issues:
- morphology – size and shape,
- composition or internal structure,
- identification of microbial species,
- spatial distribution of microorganisms.

The morphology of a floc is important to the wastewater treatment process itself and largely influences its efficiency. It is characterized by: shape, structure, persistence and size. Rounded and irregularly shaped flocs can be distinguished. The more filamentous bacteria in the system or the higher the sludge load, the more irregular the floc structure may be [12,13,14].

The structure determines the sedimentation properties of the floc. Three types of structure can be distinguished: compact (the model and most suitable structure – the formation of dense flocs with good sedimentation properties provides good treatment conditions), loose (when perforations between floc components are abundant) and with agglomerates [15,16,17].

Floc stability is related to the level of wastewater pollutant load. Low or highly loaded activated sludge is characterized by weak flocs with unstable structure, which disintegrate under the influence of physical factors. In contrast, stable (strong) flocs are formed at medium sludge loading; they are characterized by a clear boundary line and high durability [18].

Floc size also depends on many factors, which include:
- sludge age,
- pollutant load,
- retention time of wastewater in the nitrification chamber,
- amount of nitrogen compounds,
- type and rate of mixing,
- quantity and quality of predatory organisms (bacteria feeding) [12,19].

The flocs with diameters in the range of 150-300 μm are the most common. The flocs with diameter lower than 150 μm may occur in new WWTPs, where activated sludge is being adapted or if there is a sludge disturbance and larger flocs are disintegrating. In contrast, the flocs with diameters much larger than 300 μm may occur in the treatment plants where there is an excess of filamentous bacteria in the activated sludge. Both situations – involving either too small or too large flocs – negatively affect the sedimentation capacity of activated sludge and hence deteriorate the quality of treated wastewater [20,21].

2. Materials and methods
The laboratory setup used during the experiments consisted of 6 SBRs. The laboratory model consists of reactor chamber; mixing system; aeration system and temperature control system.

Using the model of the SBR wastewater treatment plant, tests were performed to evaluate the possibility of co-purification of spent drilling mud with municipal wastewater. The experiments were carried out in six chambers (cylinders) in parallel, maintaining the same work regime in each chamber. The reactors were operated on a 12-hour cycle (2 cycles per day) in accordance to the schedule shown in Figure 1.

The drilling mud addition during the experiments was scheduled as follows:
Chamber 1 – control, reference samples to chambers 2-6; 0.0% drilling mud addition
Chamber 2 – 0.25% drilling mud addition (v/v)
Chamber 3 – 0.5% (v/v),
Chamber 4 – 1% (v/v),
Chamber 5 – 2% (v/v),
Chamber 6 – 4% (v/v),
2.1 Activated sludge flocs
The floc sedimentation analyses were conducted after the aeration phase. Sedimentation studies were conducted during the sedimentation phase, following aeration. The study lasted 30 minutes, the level of flocs undergoing sedimentation was read after 1, 2, 3, 4 and 5 minutes, as well as 10, 15, 20, 25 and 30 minutes. The sedimentation velocity tests were calculated using equation:

\[ V = \frac{\Delta S}{\Delta t} \text{ (cm/min)} \]  

Where:
\( V \) – sedimentation velocity,
\( \Delta S \) – path change,
\( \Delta t \) – time change.

3. Results
Averaged results for the values pooled from all experiments were presented and analyzed. The boxplot shows the floc sedimentation velocity values at different drilling mud doses over time (1 - 30 minutes), along with the median, Q3, Q1, and range of outlier observations (Figure 2). Friedman tests were performed to determine if the time factor affects the sedimentation velocity.

Figure 2. Distributions of floc sedimentation velocities for different flush rates relative to measurements over time, along with median, Q3, Q1 and range of outlier observations.
The results show that the first 5 minutes are important in the analysis of sedimentation velocity, since there are statistically significant differences between the averages, manifesting themselves in the form of distinct homogeneous groups. Subsequent measurements after 10-30 minutes are classified as homogeneous groups, showing no statistically significant differences. Thus, sedimentation velocity studies under laboratory conditions of small SBRs should be conducted for the first 5 minutes.

An errorplot was prepared for the mean velocity values (Figure 3), which shows the data averaged over all experiments for different mud doses along with the 95% confidence interval.

![Figure 3](image)

**Figure 3.** Mean values of sedimentation velocity, averaged over all experiments for different drilling mud doses together with 95% confidence intervals, letter designations – homogeneous groups.

The graph shows the influence of the amount of the added drilling mud on the sedimentation velocity of activated sludge flocs. It is especially visible at the drilling mud doses of 0.5% - 4.0%. The analysis of significant differences showed that the samples with drilling mud added are statistically significantly different from the control.

4. **Conclusions**

On the basis of the biological and physicochemical results obtained and their analysis, the following conclusions were drawn:

1. The use of a laboratory SBR enabled to reproduce the conditions occurring in the bioreactors treating municipal wastewater by means of the activated sludge method. It also allowed co-treatment of potassium-polymer drilling muds in the system.

2. Analyses of activated sludge sedimentation velocity indicated a statistically significant influence of drilling mud addition size on floc sedimentation velocity. The models describing sedimentation velocity in relation to the considered measures characterizing the properties of activated sludge flocs exhibited high values of coefficient of determination.

To conclude the conducted investigations, it can be stated that all the drilling mud doses, including the lowest one, caused an increase in the sedimentation velocity which suggests that their addition can be used as a factor supporting the sedimentation process.
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