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Improved Tailings Consolidation Using Dewatering Agents: A Step towards Safer and Sustainable Mining Waste Management

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Abstract: Tailings consolidation is a critical step in mining waste management. Tailings are a byproduct of mining and mineral processing operations, and they are typically composed of finely ground rock particles, water, and reagents used in the mineral processing. The tailings disposal is a significant environmental and safety concern, as unconsolidated or unstable tailings can result in catastrophic failures and environmental damage. Therefore, it is crucial to use reagents for tailings consolidation to ensure the stability and safety of tailings storage facilities (TSFs). That is the reason to decide to test different dewatering aids to determine which one gives the best results in tailings dewatering. Many experiments were carried out using the reagents Aerodri 104, Aerodri 105, PEG – 400, and polyvinylpyrrolidone K30 and K90. Factors such as water release, consolidation speed, and consolidation time were considered and monitored. The best results are obtained with the Aerodri 104 using 300 g/t and 500 g/t reagents.

Keywords: Consolidation, Dewatering, Flocculants, Tailings disposal

Introduction

Efficient and safe disposal of the waste generated in the mining activity is one of the most important things in the mining industry. Plenty of authors (Tayebi-Khorami at al., 2019; Yankova, 2020; Yankova, 2021), emphasize the critical problems with mining and processing waste along with tailings storage, mining waste amount reduction, and safe storage. Effective waste management is the basis of sustainable development. The tailings from ore and coal processing are composed of fine material, water, and reagents from the process. The traditional tailings disposal in conventional tailings storage facilities (TSF) with high water content and unconsolidated tailings can lead to dam failure and high ecological casualties.

According to Grigorova & Koprev (2020), using an integrated mine waste facility (IMWF) minimizes the overall project footprint and avoids needing a conventional tailings dam because the facility can be progressively rehabilitated while the project is operational. During operations, the external faces of the completed portions of the IMWF can be covered with topsoil and vegetated. This means that the majority of the IMWF can be rehabilitated prior to the end of the mining operations. For this purpose, to ensure better consolidation and water drainage in the facility, reagents can be used. Wide use have the surfactants for dewatering sulfide, non-sulfide flotation concentrates, iron and coal concentrates, tailings and aluminum trihydrate etc. (Besra et al., 1998; Yan et al., 2003; Pears, 2003; Burat et al., 2015; Patra et al., 2016, Rezaei et al., 2020 etc.). The selection of an appropriate reagent depends on many factors, such as water content, particle size distribution (PSD), mineral and chemical composition, and pH of the material and used reagents for the beneficiation process. In the current research, many experiments are conducted so that the suitable reagent is found for dewatering and enhanced consolidation of the tailings. The laboratory tests were conducted using the reagents Aerodri 104, Aerodri 105, PEG 400, and the flocculants PVP K30 and PVP K90. The reagents

consumption was 150, 300, and 500 g/t. They were added as 1 % water-reagent solution. First, the particle size distribution, mineral and chemical composition, pH, water content, suspension density, and dry material density were determined.

Methodology

A thickened tailings sample was collected for the research. The PSD, water content, pH, and chemical and mineral composition were determined. The particle size distribution is determined by wet sieving with sieve openings +75 μm, +45 μm, and +32 μm. The chemical analysis was conducted using the ICP OES analysis, and the mineral composition was studied using X-ray diffraction analysis. In the current experiment, to decrease the water content and enhance faster consolidation are used anionic surfactants from the series Aerodri 104 and 105, manufactured by Cytec, nonionic surfactant PEG-400, delivered by Parchem and the nonionic polymers PVP K30 and PVP K90 made by Roth, Germany. Indicators such as speed and time of consolidation and the volume of water released from the tailings were monitored. The material monitored was with different consumption for each reagent. The consumption was 150, 300, and 500 g/t. All the reagents used are water-soluble and biodegradable, with low toxicity and minimal negative impact on nature.

The first experiment was conducted without adding additional reagents. The test was carried out in a glass cylinder, and the sedimentation rate was monitored every 24 h. The volume of the cylinder was 3930 ml, and the mass of the solid was 3836 g (3.386 kg). Experiments with different reagent consumption were conducted after determining the sample consolidation rate without reagent. The impact of the different consumption on the consolidation rate was determined. The tailings used for the different experiments had the same characteristics. The solid content was 61%, tailings density 1.60 g/cm^3, and dry solid density 2.60 g/cm^3. All the experiments were conducted in cylinders with 4 l volume. The measurements were taken from the initial start to the top of the consolidated layer of solids. The consolidation rate is determined by calculating the sedimentation rate.

Results and Discussion

The particle size distribution is determined by wet sieve analysis with sieves sizes +75 μm, +45 μm, +32 μm. The results show that the tailings are composed mostly of (75.36 %) particles - 32 μm (Table 1). The results from the conducted ICP OES analyses (table 2) show that the main components in the tailings sample are mainly SiO_2 and less Al_2O_3, Fe_2O_3, and K_2O. Minor amounts (< 1%) of other oxides and sulfur are present.

Table 1. Particle size distribution

Size sieve	Yield		Oversize	Undersize
μm	g	%	%	%
75	3.57	3.44	3.44	96.56
45	6.89	6.7	10.14	89.86
32	17.9	14.49	24.63	75.36
-32+0	77.47	75.36	99.99	0
Total	102.8	99.99	-	-

Table 2. Chemical composition of the tailings

Components	Content (wt %)
SiO_2	70.69
Al_2O_3	9.07
Fe_2O_3	4.69
TiO_2	0.51
CaO	0.64
MgO	0.40
MnO	0.13
Na_2O	0.16
K_2O	3.75
P_2O_5	0.07
SO_3	0.50
Loss on ignition	4.97
Moisture	0.45
S	< 0.05

The data from the X-ray diffraction (XRD) study show that the tailings are composed chiefly of quartz (66%), feldspars – potassium feldspar, and plagioclase (3%). In small percent, there are also clay minerals – kaolinite (6%) and muscovite or hydromica–illite (6%). Also, carbonates - calcite (2%) and dolomite (2%) are present in the waste. The presence of sulfides is not found. The ore minerals are composed of minimal quantities of iron oxides - ilmenite or titanomagnetite (1%) and hematite (< 0.05%).

Tailings Consolidation Experiments

Sedimentation Rate Determination of the Solids in the Tailings, without Additional Reagents

A well-homogenized 3930 ml tailings sample was poured into a 4-liter cylinder. The consolidation process was monitored by measuring the height of the newly formed clear water volume and the height of the consolidated solids every 24 hours till the end of the consolidation process. The 24 h readings continued for eight days from the experiment's start till the consolidation process's end. The consolidation ended when the solids layer will not change its height. In this experiment, the height of the volume of water reached 10 cm. Both the volume of the solids and the sedimentation rate were calculated. The obtained results are given in Table 3 and Figure 1. The data shows that without any additional reagents, the consolidation of the tailings is slow, and it takes seven days till complete consolidation.

Table 3. Sedimentation rate of the sampled tailings

Consolidation time, h	24	48	72	96	120	144	168
Height of the volume of water, cm	3.2	5.3	7.3	8.8	9.5	9.7	10
Height of the solids layer, cm	39.8	37.7	35.7	34.2	33.5	33.3	33
The volume of the solids layer, ml	3577.0	3388.3	3208.5	3073.7	3010.8	2992.8	2965.9
Sedimentation rate, mm/min	0.0222	0.0184	0.0169	0.0153	0.0132	0.0112	0.0099

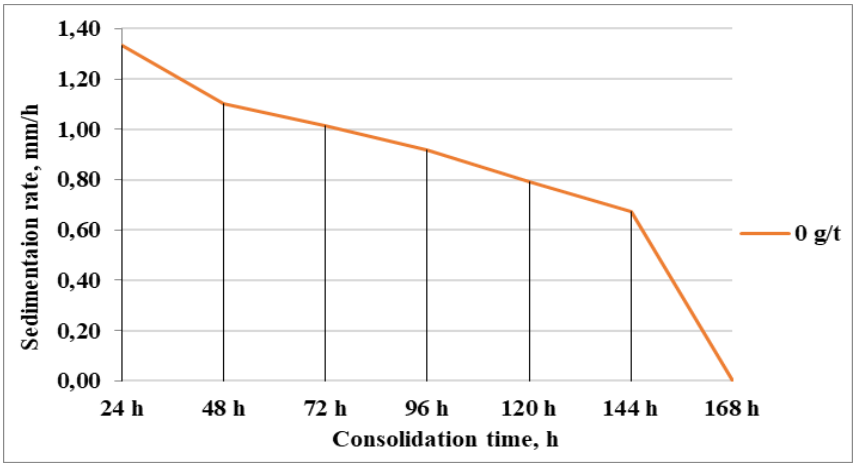

Figure 1. Sedimentation rate as a function of consolidation time

Consolidation Rate Determination of the Tailings Solids, with Added Additional Reagents

The impact of the Aerodri 104, Aerodri 105, PEG-400, PVP K30 and PVP K90 was studied with a series of laboratory experiments. The reagents were added as a 1% solution into the 3930 ml tailings, with a 1.6 g/cm3 density and solid content of 3836 g (3.386 kg). The laboratory tests were conducted in four separate tests for each one of the reagents. The tailings were placed in 4-liter cylinders and the reagent was added as 0, 150, 300 and 500 g/t for each cylinder. The height of the volume of water and the volume of solids was monitored every 24 hours and the sedimentation rate was calculated.

Determining the Impact of the Aerodri 104 over the Consolidation of the Tailings

The results show that the Aerodri 104 gives the best outcome with reagent consumption of 300 and 500 g/t, with which the consolidation time is shortened for two days compared to the results without adding additional reagents (Figure 2). With the 500 g/t reagent consumption the sedimentation rate is at its highest.

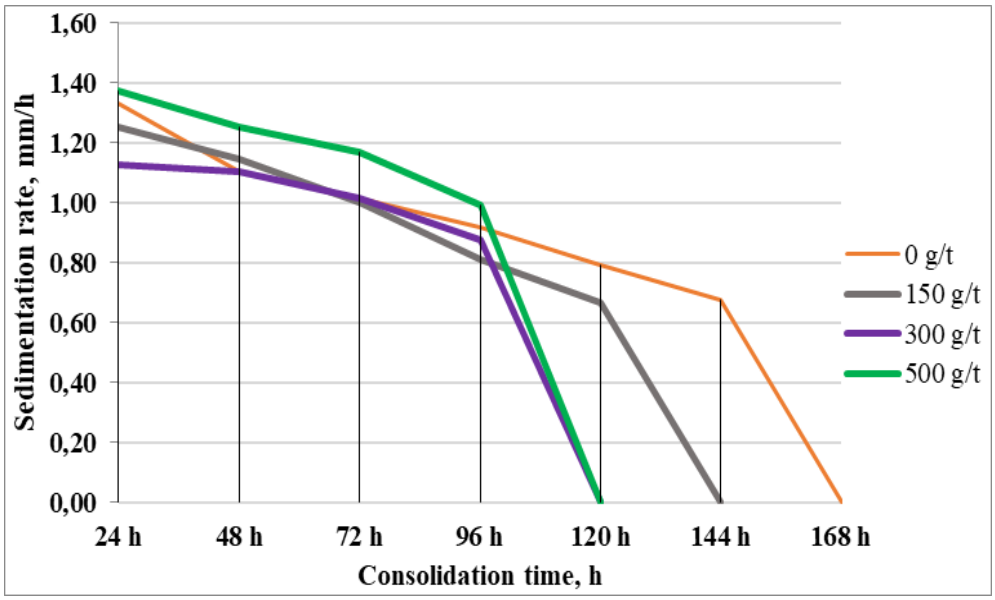

Figure 2. Sedimentation rate as a function of different Aerodri 104 dosage

Determining the Impact of the Reagent Aerodri 105 over the Consolidation Rate of the Tailings

The results from the experiments with adding Aerodri 105 with a consumption of 300 and 500 g/t show that the consolidation time reduces by one day compared to the sample without additionally added reagents (Figure 3). The dewatering surfactants from the series Aerodri 104 and 105 show different results, and it might be because of the difference in viscosity, which is higher in Aerodri 105.

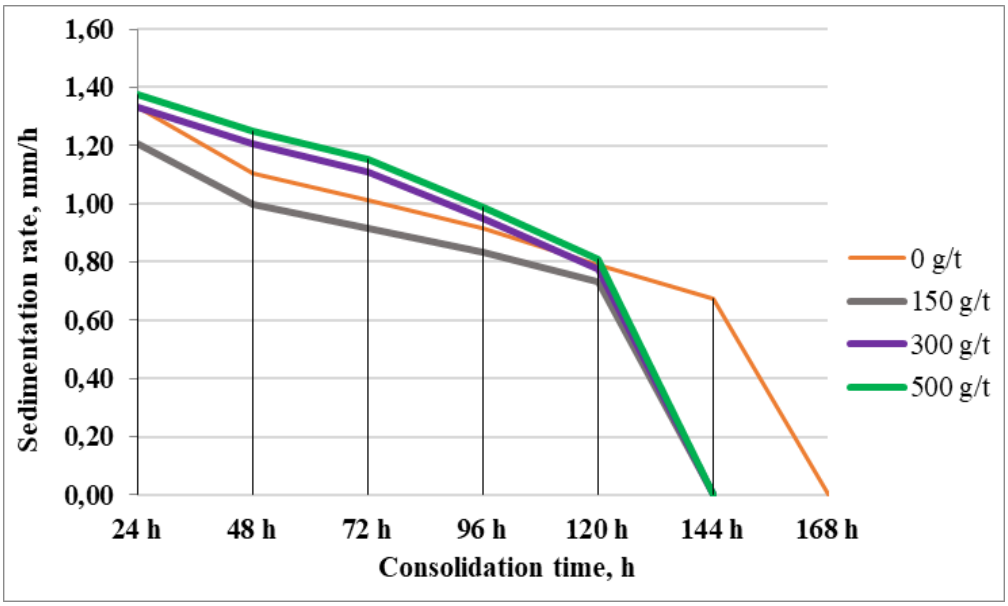

Figure 3. Sedimentation rate as a function of different Aerodri 105 dosage

Determining the Impact of the PEG-400 over the Consolidation Rate of the Tailings

The reagent PEG 400 is a low molecular weight polyethylene glycol (average about 400), biodegradable and low toxicity. Therefore, it has a variety of applications, including in the pharmaceutical industry. According to some authors, PEG-400 is an effective surfactant that can be used for dewatering different mineral raw materials, coal, tailings, etc. PEG-400 increases the hydrophobicity of solid mineral particles (Burat et al., 2015).

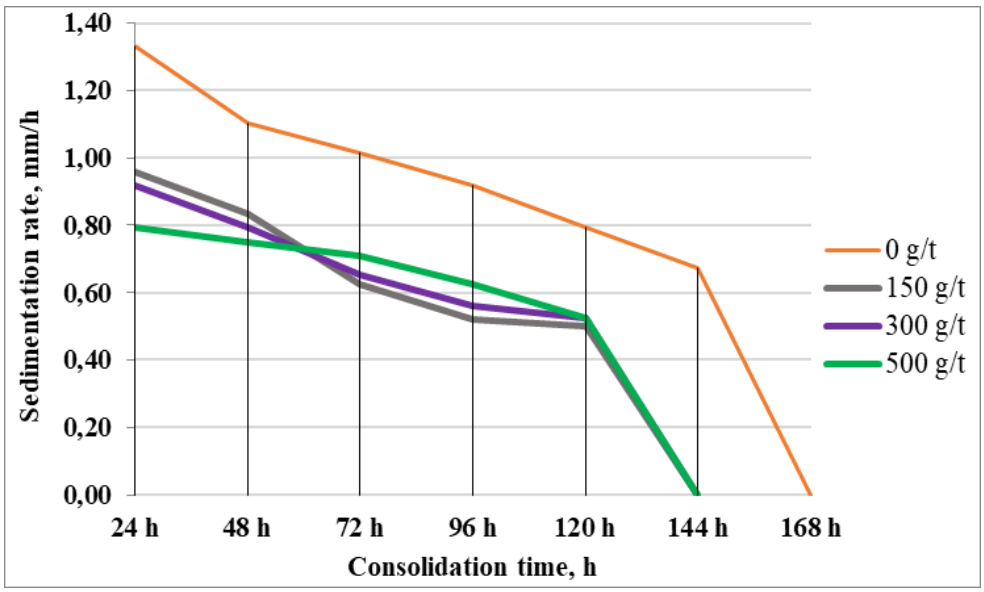

Figure 4. Sedimentation rate as a function of different PEG 400 dosage

The data from the laboratory experiments show that the different reagent dosage does not significantly affect tailings dewatering (Figure 4). At all different reagent dosages (150, 300, and 500 g/t), the sedimentation rate remained almost the same and lower than that without added reagents (Figure 4). It should be noted that the consolidation time decreases by one day, but the water content in the volume of the solid phase substance does not decrease significantly. It was found that this reagent was unsuitable for the tailings consolidation.

Determining the Impact of the Reagent PVP K30 over the Consolidation of Tailings

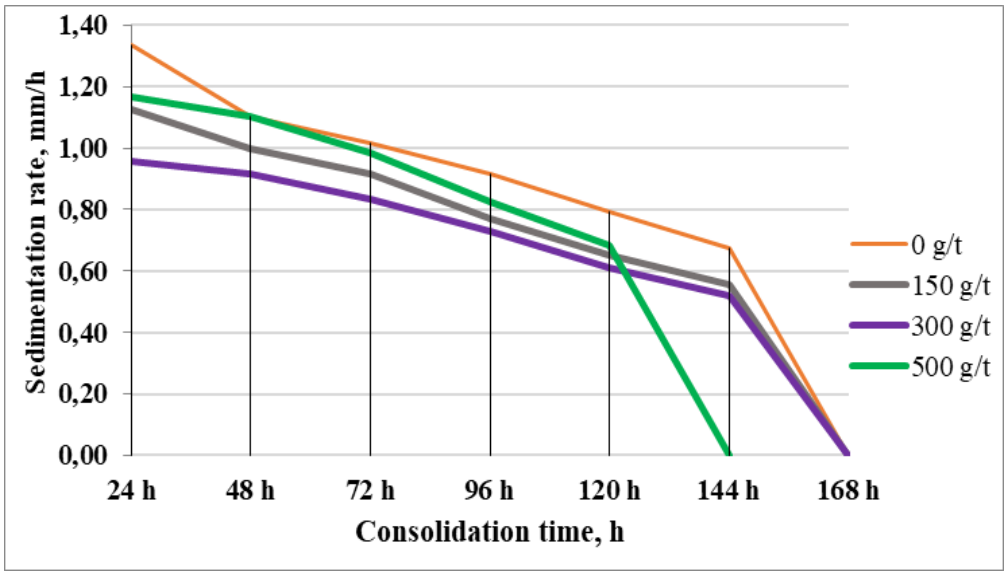

Figure 5. Sedimentation rate as a function of different PVP K30 dosage

The reagents from the series PVP (K25, K30, K60, K90 etc.) are flocculants and nonionic biopolymers. The value of K is related to the molecular weight of the polymer and characterizes its viscosity in a water solution. At larger coefficient K values, the polymer's viscosity in water solution is greater, and the adhesion properties are much stronger. According to Wang et al. (2021) polyvinylpyrrolidone (PVP) is a polymeric flocculant that adsorbs on the surface of quartz and kaolinite particles at low doses and eases their aggregation. The same authors consider that polyvinylpyrrolidone (PVP) can be successfully applied for the removal of quartz and clay impurities in coal flotation. Due to the high content of quartz (66%) and the presence of kaolinite in the flotation tailings, experiments were carried out to enhance the consolidation with the application of PVP K30 and PVP

K90. The data from the four laboratory tests showed that with the use of PVP K30, at a consumption of 500 g/t, the settling time of the solid phase is accelerated and compared to gravity settling and is shortened by one day (Figure 5).

Determining the Impact of the Reagent PVP K30 over the Consolidation of Tailings

Adding 300 and 500 g/t PVP K90 the highest sedimentation rate is reached. The consolidation stops on the second day after adding the PVP K90, but there is not enough dewatering as with the rest of the reagents. When 150 g/t is added, the sedimentation rate is even less than the sample without any additional reagents. The results show that the PVP K90 does not give a satisfactory result as it does not release enough volume of water (Figure 6).

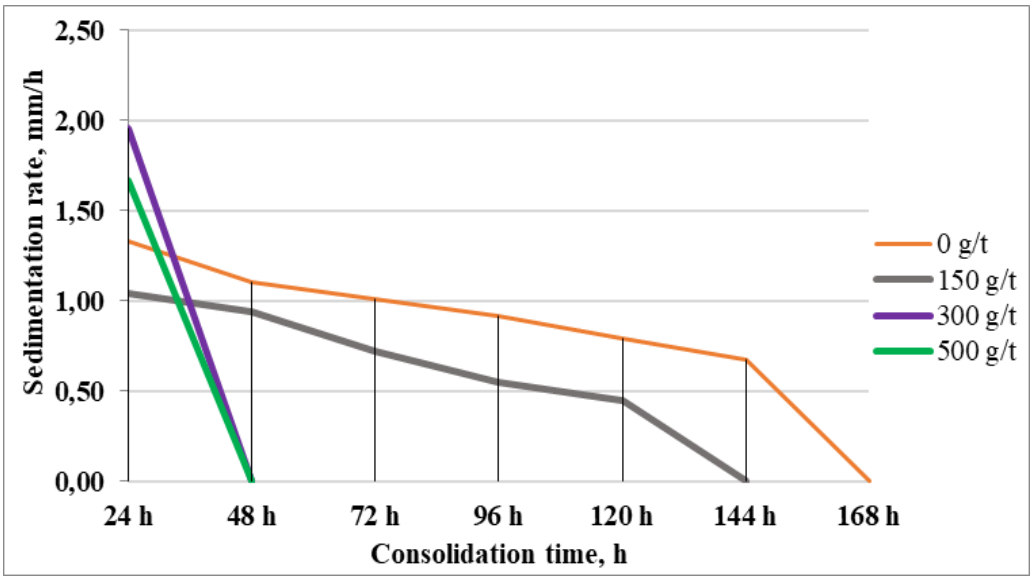

Figure 6. Sedimentation rate as a function of different PVP K90 dosage

The data from the experiments show that when the reagent consumption is lower, the settling rate is also low, and the settling rate increases with increasing reagent consumption. When PVP K90 is added, the tailings turn from slurry to paste in seconds, making mixing even more difficult. The best results are given by Aerodri 104, with the shortest consolidation time and high settling speed.

Conclusion

The results of the series of laboratory experiments for the determination of a suitable reagent to shorten the time of tailings consolidation showed that the most appropriate reagent is the surfactant Aerodri 104. With a consumption of 500 g/t Aerodri 104, the consolidation time shortens for two days compared to the sample without additional reagents. A shorter consolidation time will enhance the operational sequence and improve water drainage. That means that, the construction of the next bench can begin earlier hence a new cell will be available sooner than without additional reagent. Also, the water will be released faster and can be reused in the process. When adding the surfactant, the consolidated tailings do not have a lower moisture content than the one without additional reagent. The high content of fine mineral particles (75.36%) has an adverse effect. Some authors (Patra et al., 2016) note that the fine particles adsorb much moisture due to their extensive surface area, and that leads to higher water content hence it is difficult to significantly lower the moisture content in flotation tailings and concentrates.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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