

Chemical Improvements for Cycloned Sand Drainage in Tailings Dams: Comprehensive Assessment and Strategies for Large-Scale Operation

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ABSTRACT

Efficient water recovery and geotechnical stability in tailings dams currently represent two of the main challenges faced by modern mining operations. In operations where cycloned sands contain high proportions of fine particles, particularly lamellar phyllosilicates such as sericite and muscovite, significant drainage limitations arise due to low permeability and high capillary water retention. These conditions directly affect tailings consolidation rates, water recovery efficiency, and the quality of the material used for the walls construction in tailings storage facilities.

This study assess the effect of different chemical reagents on the drainage performance of cycloned sands obtained from an Andean copper porphyry operation through an extensive experimental program comprising approximately 500 drainage tests. Multiple reagent combinations were assessed, including variations in dosage, fines content, temperature, and representative operational conditions.

The results demonstrate that the combined use of Magnafloc and hydrated lime produces a significant improvement in drainage performance compared to the untreated condition. While the baseline sample exhibited drainage times exceeding 7 hours, the best evaluated conditions achieved drainage times in the range of 45–51 minutes using mixtures containing 30 g/t of Magnafloc and hydrated lime dosages between 75 and 250 g/t.

The synergy between chemical coagulation and polymeric flocculation reduces capillary water entrapment, improves the drainage grooves, and enhances gravitational water recovery. The findings indicate that the optimized use of chemical reagents can become an effective operational tool for improving the drainage performance of cycloned sands with high fines content.

These results highlight the importance of developing comprehensive characterization programs, laboratory testing campaigns, and chemical assessments aimed at addressing real operational challenges associated with tailings management, drainage performance, water recovery, and large-scale tailings storage optimization.

INTRODUCTION

Without question, one of the most persistent challenges in the mining industry is achieving maximum water recovery efficiency. Consequently, both the rate of water recovery from tailings storage facilities and the production of sands with adequate quality for walls construction, constitute critical factors for project viability and continuous improvement strategies. These two processes are closely interconnected, as sands suitable for walls construction are commonly associated with high drainage rates, enabling more efficient water recovery, improving the quality of construction materials, and enhancing overall tailings management performance.

Achieving the required sand quality standard strongly depends on an effective classification stage within the cycloning process prior to tailings disposal. This classification step is essential to remove a significant proportion of the fine fraction, since lamellar phyllosilicates tend to concentrate within the finest particles, generating overlapping plate-like structures that drastically reduce drainage capacity. In contrast, the coarser fraction generally presents a higher quartz content with more rounded particle morphology, which promotes improved permeability and drainage behavior.

Operational context

A common issue across several mining operations is the elevated fines content present in the cyclone underflow sands downstream of thickening processes. These fine particles, predominantly composed of lamellar minerals such as sericite and muscovite, negatively affect the permeability of the sands, increasing drainage times, delaying water recovery, and limiting their suitability as construction material for tailings dam walls.

Proposed approach

This challenge can be addressed through two complementary strategies. The first involves optimizing cyclone operational performance to improve particle classification efficiency and achieve better fines separation. The second strategy consists of using chemical reagents to promote agglomeration mechanisms, modify slurry chemistry and pH conditions, and ultimately improve drainage performance.

The present study evaluates the effect of a series of chemical reagents incorporated into cycloned sands containing elevated fines fractions resulting from inefficient cyclone classification. The tested reagents included surface modifiers, rheological modifiers, polysaccharide blends, amine-based compounds, calcium oxide, sodium hydroxide, and multiple flocculants. The objective was to identify the most effective reagent and optimal dosage combination to maximize drainage performance under representative operational conditions.

Process description

The sand production process involves directing thickened tailings from the thickeners to the cyclone classification stage, where the cyclone underflow is used for tailings walls construction, while the finer overflow fraction is discharged into the tailings dam. The process configuration is illustrated in the following figure.

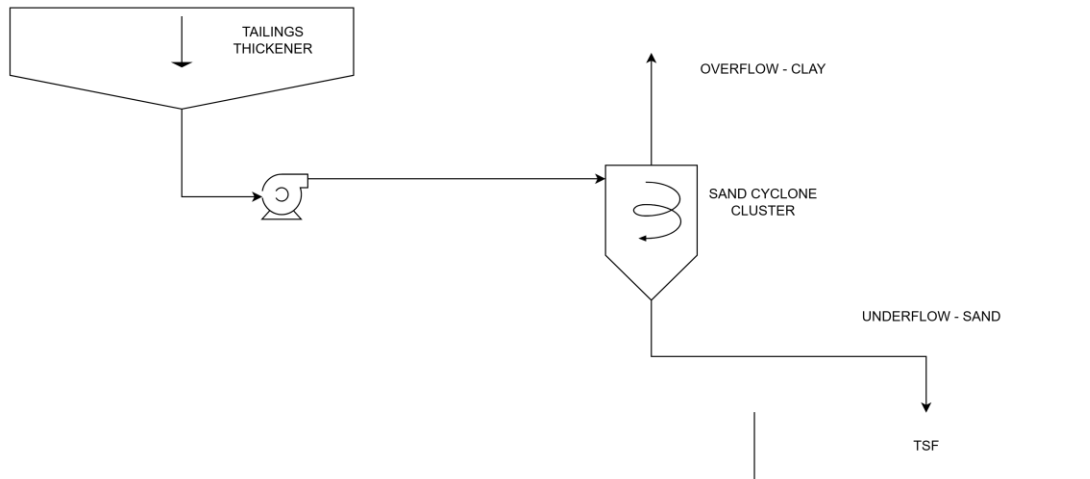


Figure 1 Process description

METHODOLOGY

To assess the effectiveness of different chemical agents on the drainage rate of cycloned sands *containing* fine particles, an experimental system is used that will allow comparison of the effectiveness of the different reagents according to their drainage rate. The experimental setup consisted of a PVC cylinder, a support mesh, filter paper, a collection tray, and a graduated cylinder containing process water. The experimental arrangement is illustrated in the following figure.



Figure 2 Experimental system for assessing sand drainage velocity

The test procedure consisted of measuring the elapsed time at different stages of the cylinder drainage process, defined as follows:

- T0 Time corresponding to the initial filling of the cylinder
- T1 Time at which the first drainage is detected
- T2 Time corresponding to complete discharge into the graduated cylinder
- T3 Time at which the water level reaches the top surface of the sample
- T4 End time of the test

A total of 12 chemical reagents were evaluated during the testing program, including two surface modifiers (PEG-400 and PEG-3350), three rheological modifiers, one polysaccharide-based reagent, one amine-functional polymer, sodium hydroxide, calcium oxide, calcium hydroxide, Magnafloc 1011, and Rheomax 1050.

The testing methodology and study workflow comprised the stages presented in the following figure.

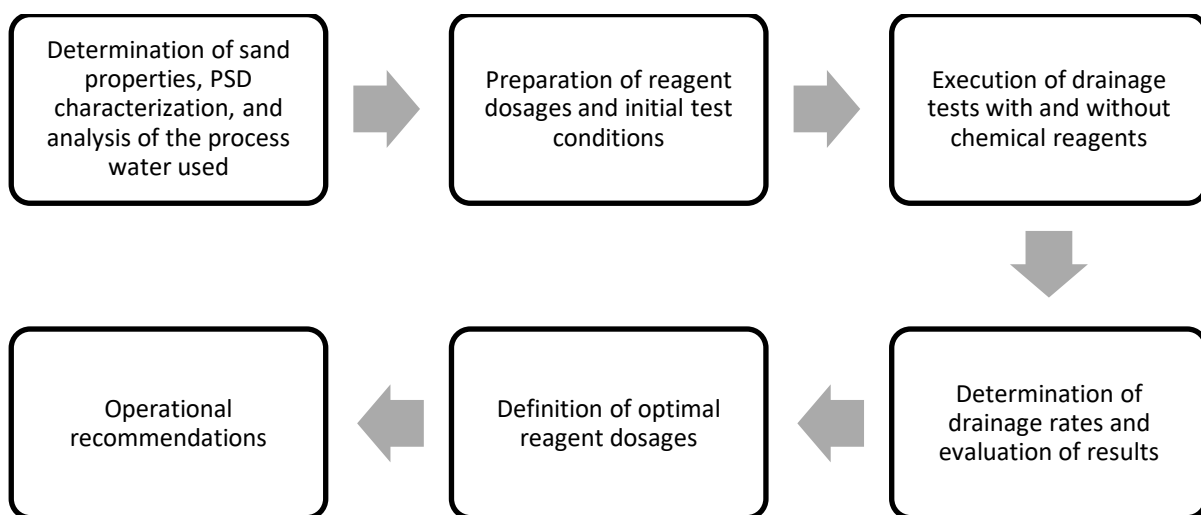


Figure 3 Experimental methodology

Characterization of sand samples and process water used

The samples received correspond to the final tailings of a typical Andean copper porphyry deposit located in northern Chile, which is deposited in the tailings dam following conventional processing of copper sulfide ores. Their mineralogical composition is presented in the following table.

Table 1 Mineralogical characterization of tailings samples

Mineral / Component	Estimated proportion in total tailings	Predominant size fraction
Sericite / Moscovite	~25.9% (weighted average)	< 20 µm (fines)
Biotite	~5%	Similar distribution to sericite

Mineral / Component	Estimated proportion in total tailings	Predominant size fraction
Chlorite	< 5% (estimated ~2-4%)	Mainly fine fraction
Kaolinite	< 5% (estimated ~1-2%)	Mainly fine fraction
Montmorillonite	< 5% (estimated ~1-2%)	Mainly fine fraction
Quartz	40-55%	> 20 µm (coarse fractions)
Plagioclase	Not quantified (present in gangue)	Not spicified
Other trace minerals	Remaining fraction (< 3%)	Variable

The study was conducted based on a total of 54 cycloned sand samples received. The coarser-fraction samples were subsequently combined and composited into a single representative bulk sample. The particle size distribution of both samples is presented in the following figures.

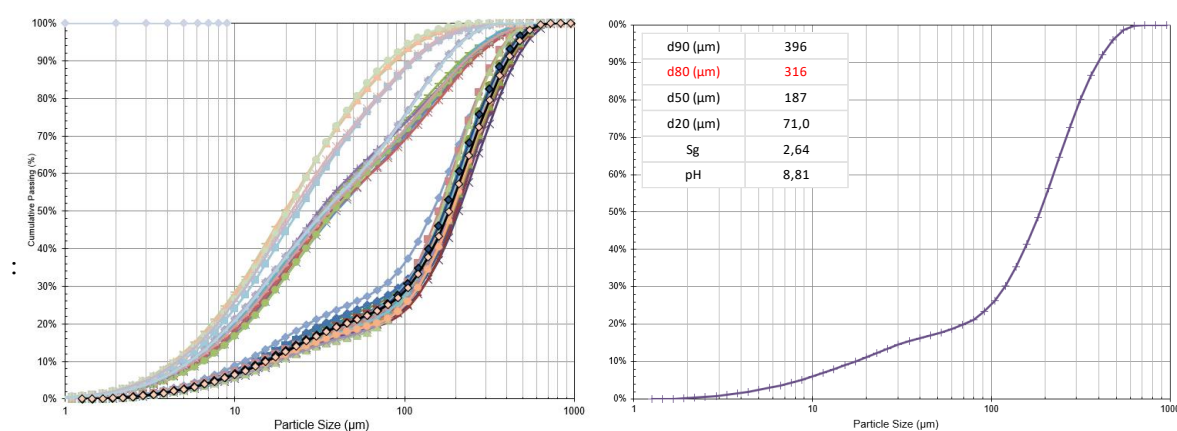


Figure 4 Particle size distribution: Left: PSD of the 54 received samples – Right: PSD of the composite sample

All tests in this study were conducted using the composite sample. The characteristics of the process water used for drainage are summarized in the following table.

Table 2 Characterization of the water used

Characterization of the water used	
Water type	Process water
pH	7,30
Conductivity [µS]	2,89
Eh [mV]	330
TDS [mg/L]	3.400
Sulfates [mg/L]	1.300
Chlorides [mg/L]	3,26
Calcium [mg/L]	1.550
Carbonates [mg/L]	64,0

Characterization of the water used	
Bicarbonates [mg/L]	37,0
P-Alkalinity "[mg/L] de CaCO ₃	64,0
M-Alkalinity [mg/L] CaCO ₃	101
Total Hardness [mg/L] CaCO ₃	101
Dissolved Inorganic Carbon [mg/L] CO ₂	44,0
Dissolved Organic Carbon [mg/L] CO ₂	626

Both the sand samples and the process water used in this study are representative of actual plant conditions, with drainage times without reagents in the laboratory adjusted to match those observed in the tailings storage facility.

Test matrix

Approximately 500 tests were conducted under different conditions, including variations in reagent type, dosage, reagent combinations, temperature, and fines content in the sand samples. A summarized matrix of the experimental program is presented in the following figure.

Table 3 Summary of test matrix, reagents used, and drainage times

Test un	Reagent	Reagent dosage g/ton	Cp Initial %	Cp Final %	pH Initial	pH Final	T1 s	T2 h	T3 h
1	None	None	73,4%	90,9%	8,16	7,42	4	5h 07min	7h 16min
2	None (2)	None	73,4%	81,0%	8,16	7,42	7	5h 14min	7h 34min
3	Magnafloc	15	73,4%	84,4%	8,16	7,63	3	1h 39min	3h 02min
4	Magnafloc (2)	15	73,4%	84,1%	8,16	7,62	2	1h 18min	3h 05min
5	Magnafloc	30	73,4%	84,0%	8,16	7,62	2	0h 53min	1h 40min
6	Magnafloc (2)	30	73,4%	83,8%	8,16	7,68	4	0h 56min	1h 42min
7	Ca(OH) ₂	360	73,4%	86,0%	12,16	7,64	12	1h 08min	2h 21min
8	Ca(OH) ₂ (2)	360	73,4%	86,1%	12,31	7,61	9	1h 11min	2h 26min
9	MF + Ca(OH) ₂	15 + 360	73,4%	84,2%	11,29	7,77	2	1h 13min	2h 09min
10	MF + Ca(OH) ₂ (2)	15 + 360	73,4%	84,2%	11,78	7,79	6	1h 05min	2h 01min
11	MF + Ca(OH) ₂	30 + 360	73,4%	83,4%	11,73	7,76	5	0h 33min	1h 04min
12	MF + Ca(OH) ₂ (2)	30 + 360	73,4%	83,3%	12,02	7,75	4	0h 39min	1h 08min

RESULTS AND DISCUSSION

The experimental results show a clear improvement in water drainage performance in cycloned sands when using a combination of Magnafloc (MF) and slaking lime (SL). Complete dewatering at

stage T3 was achieved in 51 minutes using a reagent combination of 30 g/t MF and 75 g/t SL. In contrast, the same untreated material exhibited drainage times exceeding 7 hours.

The observed behavior can be explained by the interaction between fine tailings particles, the surface chemistry of the constituent minerals, and the mechanisms of action of the applied reagents. A fine-grained tailings material presents a high specific surface area, negatively charged particle surfaces, the formation of stable electrical double layers, and strong capillary water retention. These conditions significantly hinder natural drainage, as particles remain dispersed and tend to form compact structures with low permeability [4][6]. The untreated condition confirms this behavior, showing the longest drainage times recorded.

Slaking lime increases the system pH and provides Ca^{2+} and OH^- ions. Calcium ions promote compression of the electrical double layer around fine particles, reducing electrostatic repulsion and enhancing particle coagulation. This mechanism effectively decreases the zeta potential, promotes charge neutralization, and facilitates interparticle contact and aggregation [7]. However, coagulation alone typically produces relatively small and dense aggregates, which still retain a significant amount of interstitial water, resulting in slow drainage. This explains why lime-only conditions improve performance relative to the baseline case but do not achieve optimal drainage rates.

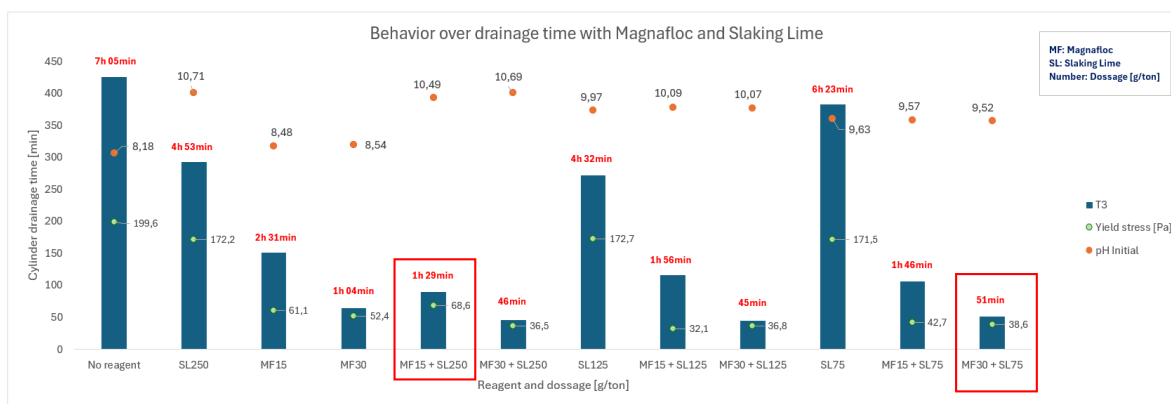


Figure 5 Results for the best reagent combination and dosage

On the other hand, it is observed that excessively high lime dosages do not necessarily optimize drainage performance. An excess of Ca^{2+} may lead to surface site saturation, the formation of fine precipitates, increased local viscosity, and adverse effects on flocculant adsorption. Consequently, lime dosages of 75 and 250 g/t do not exhibit a simple linear relationship with drainage improvement.

Magnafloc acts as a high-molecular-weight polymeric flocculant. Its primary mechanism involves adsorption onto particle surfaces, polymer bridging, and the formation of large, open-structured flocs. These flocs enhance sedimentation, exhibit higher internal permeability, and therefore release interstitial water more efficiently [8].

An increase in Magnafloc dosage from 15 g/t to 30 g/t results in a significant improvement in drainage performance, due to enhanced surface coverage, stronger interparticle bonding, and improved floc stability. This improvement is reflected in a reduction in drainage time from approximately 2.5 hours to 1 hour.

The synergy between Magnafloc and lime combines their respective chemical effects, where Magnafloc aggregates partially coagulated particles into highly permeable flocs, while lime reduces electrostatic repulsion and promotes particle interaction.

In summary, the combined application of Magnafloc and lime at optimized dosages produces larger floc structures, reduces capillary water entrapment, improves drainage channel formation, and consequently enhances gravitational water release and overall drainage efficiency.

CONCLUSIONS

From an operational perspective, the results suggest that:

- The flocculant has a stronger influence than lime on drainage rates.
- Lime primarily acts as a chemical conditioning agent for the system.
- There exists an optimal dosage range where the combined use of reagents enhances floc structure without leading to overdosing effects.

The combined application of Magnafloc and lime provides a better balance between:

- Drainage time.
- Yield stress.
- Chemical conditioning of the tailings system.

On an industrial scale, these improvements could translate into:

- Increased water recovery efficiency.
- Reduced consolidation times.
- Improved geotechnical stability.
- Reduced area requirements for tailings disposal.
- Optimization of reagent addition points within the process.

This study highlights the importance of implementing integrated programs of material characterization, laboratory testing, chemical evaluation, and specialized engineering analysis aimed at addressing real operational challenges, particularly in sand drainage systems.

It is also essential to prioritize operational practicality in reagent selection, initially focusing on chemicals already used in plant operations. This approach helps maintain operational familiarity with known reagents while improving cost predictability associated with tailings treatment for dewatering purposes. Additionally, the test program should be designed to capture different cyclone operating configurations, to reduce fines content in sands, control reagent demand, and ultimately maximize dewatering efficiency.

NOMENCLATURE

PCSA	Paterson and Cooke South America (Santiago Office)
T0	Time corresponding to the initial filling of the cylinder
T1	Time at which the first drainage is detected
T2	Time corresponding to complete discharge into the graduated cylinder
T3	Time at which the water level reaches the top surface of the sample
T4	End time of the test
MF	Magnafloc 1011
SL	Slaking Lime

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