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Original Article

Vertical Tailings Approach Utilizing Surface Paste Disposal to Reduce Land Space Waste from Water in Polymetallic Mining in Peru

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Abstract *- Recently, extensive studies on Surface Paste Disposal (SPD) technology have been carried out to address stability issues in mining tailings deposits. However, the problem of space has not been thoroughly examined. This research aims to assess the disposal of polymetallic tailings using the SPD method, optimizing surfaces, and recovering water from mines in central Peru. To accomplish this, a model using SPD will be developed to minimize land space waste in deposits. This approach involves removing water from tailings with 55% solids and then depositing them as a paste with a solids content of 70% to 75%, replicating paste layering in the laboratory. The methodological process took place in a laboratory where three scale models of tailings dams with different configurations were designed, with the optimal arrangement minimizing space use and water consumption. As a result, approximately 20% of the water used in the conventional method was recovered, and about 16% of the space was utilized. This demonstrates that the method effectively addresses the main issue while reducing secondary problems associated with the conventional arrangement.*

Keywords *- Paste tailings, Paste technology, SPD, Tailings deposits, Tailings disposal.*

1. Introduction

The Mining tailings are solid waste from a mine, composed of uneconomical sterile rocks that are obtained from mineral bodies through mining–metallurgical processes of mineral processing plants [1]. Tailings particles are very fine and contain a solid concentration of 20%–45% by weight and are generally discharged as sludge in tailings dams for containment [2]. The enormous number of tailings currently being produced is 5–7 million per year worldwide and as the mining industry grows, the number of tailings does too. Technology development has allowed previously uneconomical low-grade mineral ores to be mined causing an increase in the volumes of tailings. The extraction of mineral resources generates and accumulates a substantial amount of tailings, leading to various issues in mining, environmental, and economic aspects [3]. Typically, tailings are stored in artificial ponds, which are prone to accidental releases and contribute to environmental challenges, posing significant risks to the public and nearby regions [4]. The mining industry often uses the conventional method of tailings' disposal, where it uses a reservoir, cell, or dam to store tailings. This method presents a high percentage of water, which often causes dam failures when they are not well-designed [5].

One of the main problems in mining is ineffective water management, which is the main factor contributing to mine tailings incidents. For this reason, the development of technologies that reduce the water content by increasing the solids' percentage in tailings has been considered to minimize the risk of dike failure and increase the water efficiency levels [5]. New emerging world technologies focusing on tailings management seek to reduce all traces left by the large deposits through conventional disposal, especially aimed at reducing large surface areas and making good use of them. These technologies include the thickening and filtering of tailings, paste filling, the enhancement of existing structures, and subsea disposals [6]. The objective of this research is to conduct a tailings surface method disposal by applying Surface Paste Disposal (SPD) technology to minimize wasted spaces due to the high-water content of polymetallic mining in Peru. The surface paste disposal method can be seen as a viable option for managing mining waste. The technique involves initially removing the upstream water from the tailings through thickening, then depositing the material on the surface as a paste. This method recycles water, reduces the risk of dam failure, and supports the gradual rehabilitation of mine sites [1]. Implementing the SPD system will enable the gradual restoration of the topography, thus reducing the areas of active waste. Upon the closure of a mine for any reason, the tailings storage areas will be rehabilitated. Gradual recovery will ensure a reduction in the coverage area needed for final rehabilitation after abandonment [7].

2. Literature Review

2.1. Vertical or SPD Method in Polymetallic Tailings

Mining companies have used several methods in recent years for disposing of their tailings. The most widely used method involves constructing a dam to contain tailings; however, this approach has frequently resulted in uncontrolled spills, hazardous flow slippages, and the release of toxic chemicals, leading to significant environmental disasters [8, 9]. In addition, depending on the chemical content of the polymetallic tailings, they are continuously oxidized and generate acidic waters that infiltrate the subsoil [1, 2]. Thus, the vertical or SPD method serves as a feasible alternative to surface disposal by reducing certain dangers linked to conventional tailings management and eliminating the need for dams or dikes.

Also, the eventual catastrophic failures that are associated with traditional reservoirs are reduced [1, 2, 9, 10]. Storing SPD tailings has proved that unused water can be reduced, which is one of the major issues with standard tailings dikes [1, 8, 9]. In this method, wetting and drying cycles are performed. This involves stages where the paste is deposited, moistened, and dried. Samples are then extracted and examined following the wetting cycle, and the SPD vertical model is monitored over the long term. The last layer is deposited with Portland cement, and the model is dismantled for subsequent layer characterization [1, 9]. Furthermore, it is evident that the essential studies required to obtain the necessary information from the Vertical or SPD method involve measuring volumetric water content, oxygen consumption, and the presence of cracks or fractures [1, 2, 9]. The vertical method has been implemented with various modifications, particularly by incorporating cement as an additive in the mixture. Adding a proportion to both the bottom and top layers, ensures that the stored materials are more reliable regarding their physical and chemical characteristics. Moreover, this ensures the material remains stable within a specific range of water content under its own weight [2, 9]. The top cemented layer is essential for protecting the underlying layers from evaporation. Once in place, the tailings pile experienced a slower rate of desaturation compared to previous cycles [2]. However, it is vital to factor in the weather, as it causes changes in the mix's physical traits, its quality, and its uses, depending on shifts in temperature and humidity conditions [1, 2].

2.2. Vertical or SPD Method Applying the Disposition of Polymetallic Tailings

Emerging tailings disposal technologies aim to minimize the environmental footprint of deposits. Among these, thickening, paste, and filtering technologies stand out. These have arisen because tailings dams statistically have a higher likelihood of dam failure, flaws in the applied tailings disposal method, and poor water management [6, 7]. On the other hand, the location where these tailings are to be disposed of is a determining factor. A well-chosen or advantageous disposal site aids in preventing the seepage of dissolved waste materials into groundwater and can be customized to suit the type of tailings, such as those with high density [11, 12]. This factor is evident in such conventional high-density tailings that are disposed of upstream. If not dried, they become susceptible to softening due to groundwater content, which could, at the least, lead to their shearing [12]. Among the general types of tailings disposal, there is direct tailings disposal, which discharges into rivers, lakes, and oceans, and indirect tailings disposal, where they are placed in a dam or deposit. These can be divided based on thickening technology, such as conventional tailings disposal, thickened tailings, paste disposal, and filtered tailings [5, 13].

That said, tailings disposal is a process that, depending on the type chosen for each operation, will show its drawbacks. This is the case with conventional disposals, such as low water recovery, poor tailings stabilization and security, high occupancy, and low reconstruction potential. Likewise, there are advantages, as seen in paste and filtered tailings disposal. These emerging tailings management technologies aim to minimize the footprint left by conventional disposal structures, especially by reducing surface area. They showcase high water recovery rates, improved environmental conditions at the storage site, less groundwater contamination due to the absence of water with tailings, lesser infiltration, and also faster vegetation stability post-reconstruction [6, 13].

2.3. Vertical Method or SPD Applying Surface Paste Technology

Among the various types of arrangements, paste arrangement technology can be identified as significant. The primary factors influencing the fluidity of paste materials include the type and proportion of binder, mineral and chemical additives; surface and particle properties; as well as their physical, chemical, and geochemical characteristics [6, 14, 7]. Recently, paste technology has gained prominence in this field and is increasingly being utilized for the disposal of tailings from both surface and underground mining due to economic and environmental considerations. Specifically, the SPD technique stores large quantities of ground tailings in surface openings, thereby minimizing environmental and engineering problems compared to conventional methods. A major advantage of SPD is the elimination of the need for large dams to store tailings [14, 7]. Additionally, the Cemented Paste Tailings (CPT) method involves a pumpable, non-Newtonian fluid that generally contains mine tailings, water, and ordinary Portland cement. It is typically prepared from diluted cement waste by dewatering through conventional thickening or filtering, which is used for the integrated disposal of surface sinking wells and surface solid waste through backfilling [15, 16].

Paste technology offers numerous advantages for tailings management systems, both environmentally and economically. For mining companies employing paste technology, pumping costs are adversely affected by changes in the particle size distribution of process tailings. Thus, the particle size distribution of the tailings should be regularly monitored [14, 7]. In summary, paste disposal reduces environmental impact by providing significant disposal advantages, such as requiring a smaller storage area, offering greater stability, producing minimal alkaline wastewater, and reducing the risk of soil or groundwater contamination [17, 7].

2.4. Vertical Method or SPD Applying Paste Polymetallic for the Disposal of Tailings

Different SPD studies at the laboratory have applied a polymetallic Pb–Zn tailing paste technology model. They analyzed in detail the surface grits of the paste in the layers and the importance of cement as a binder. As a result, the number of fine cracks in the first layer is especially higher than in the other layers. This resulted in water draining through the microcracks, causing a slight sinking in the upper layers. Consequently, it is believed that incorporating cement as a binder will enhance the stability of the paste system layers [1, 10]. However, the variation in water volumetric content across the different layers can be attributed to the slow water filtration to the middle and lower parts of the model due to the compaction of cracks, cement dissolution, and crack formation in the underlying layer [1, 2].The vertical method of disposing of polymetallic tailings in paste will allow for the progressive recovery of part of the topography and water. This provides an active area with less waste, and its rehabilitation will be achieved, ensuring a reduction in the amount of cover required for final closure. Additionally, the risk of deposit collapse due to infiltrations is reduced because of the lower water content used, which enhances its stability [3, 7].

3. Contribution

3.1. Basis

The proposed method is based on paste technology. Unlike traditional paste arrangements, it involves dehydration through waste thickening or filtering prior to deposition, resulting in a self-sufficient and homogeneous tailings pile. Given that filtration costs are a primary challenge with this technique, recent studies have predominantly focused on addressing this issue. The SPD method allows large quantities of mill tailings to be stored in surface openings, and there is no need for large dams to store tailings [7]. This method involves layering fresh paste, as coating each waste layer with new material before oxidation prevents the formation of acidic waters. Likewise, research studies have been conducted applying additives to obtain better results from the method. Cement is mainly added to obtain lower infiltration of acidic waters and greater physical stability of the paste tailings [9]. Therefore, the quality of the paste matrix is a direct function of the precipitated hydrates that generate acidic waters and of the three main components, which are the same tailings, cementitious additives, and water, since the increase in resistance will depend on their quality [6].

3.2. General Contribution

Innovation in the vertical or SPD method, adding cement as an additive to the bottom and top layers of the physical model, favors the recycling of wasted water and the control of free water during deposition (see Figure 1). In addition, it reduces the need for costly retention of dikes and facilitates the rehabilitation of the site. In this manner, the SPD method implementation with additives, i.e., cement, will allow for a progressive recovery of the topographic area through the disposal of paste tailings, which will reduce active waste area with greater physical stability and less water infiltration.

When the mine is abandoned for various reasons, the rehabilitation of waste storage areas will be accomplished. Progressive recovery will reduce the amount of coverage needed to ensure final rehabilitation after the mine's decommissioning and abandonment.

The advantages of adding cement to the method include more economical and environmentally friendly disposal of tailings from both surface and underground mining, enhanced water recycling and free water control during deposition, reduced need for costly dikes, and facilitated site rehabilitation. Additionally, it provides environmental benefits due to the physical characteristics of the paste and the operational benefits associated with its placement.

Furthermore, the relatively low permeability of poorly classified plant tailings limits infiltration or thickening of the paste, resulting in a lower volume of infiltration present in the deposited paste [7].

4. Indicators

Wasted space is the main problem with the conventional arrangement of polymetallic tailings; therefore, the motivation is to minimize the amount of space by applying the surface paste arrangement. To achieve this, 3 indicators have been considered, as shown in Figure 2. These indicators allow us to analyze and compare how much space will be recovered between the 3 proposed designs, subtracting the conventional design with the uncemented paste and the cemented one since they occupy the same volume but at different percentage of water. Therefore, by reducing water, this space is used vertically for stacking more tailings layers. The difference between designs 1 and 2, and 1 and 3, will give us the exact percentages.

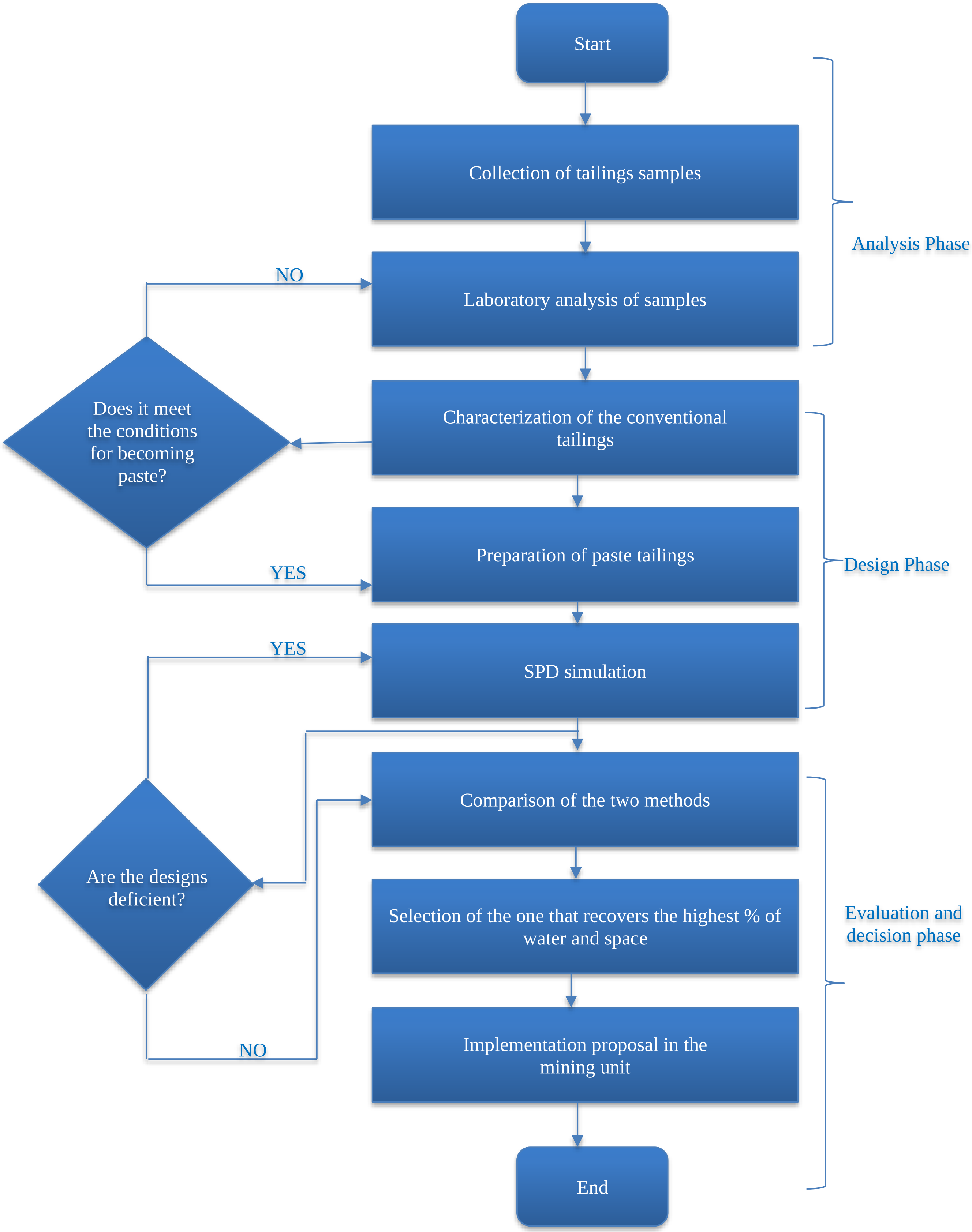

Fig. 1 Classification method

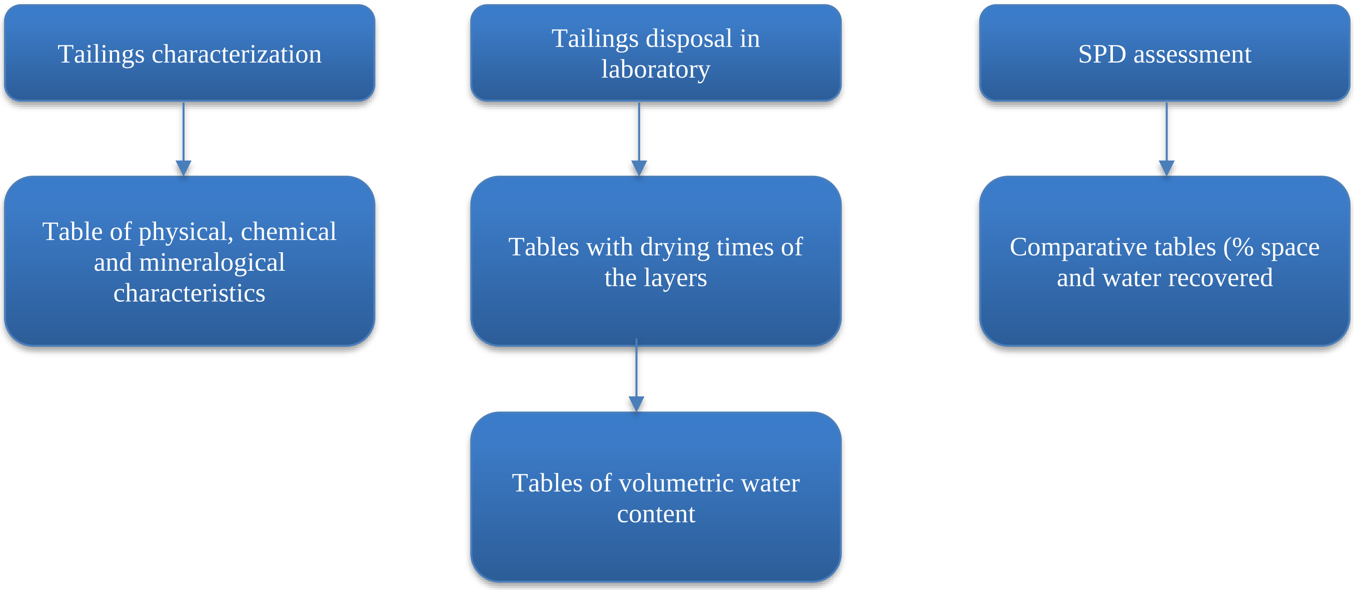

Fig. 2 Objectives achievement indicators

Degree of Saturation:

$$Gw\ (\%) = \frac{\text{Vw}}{\text{Vv}} \times 100 \qquad (1)$$

Where:

Gw: Degree of saturation
Vw: Water volume
Vv: Voids volume

Percentage of used space:

$$Ea\ (\%) = \frac{V.occupied\ by\ layers}{\text{V. space occupied by conventional tailings}} \times 100 \qquad (2)$$

Where:

V: Volume
Ea: Used space

If more than 30% of space and water can be recovered, then the objectives of this research study will be achieved. If the SPD fails to reduce more than 5% and only recovers 10% of the spaces, changing the disposal method would not be profitable, and other alternatives would have to be evaluated.

5. Validation

5.1. Validation Scenario

To conduct the SPD method, in the first place, 3 laboratory-scale tanks were designed, which will contain the tailings under study, but in 3 different types of disposals; Design 1 uses the conventional tailings, Design 2 uses the surface paste tailings without additives, and Design 3 is the SPD that adds 2% of cement to layers 1 and 5 of the design. These designs will be observed for 48 hours, before taking weight measurements. Then, through analysis and using the formulas for the degree of saturation, volumetric water content, and comparative analytical relationship from the conventional design, data will be obtained for designs 2 and 3 and used to find the percentage of space used by each design.

5.2. Previous Studies

The present study used as a base and point of comparison the study [2]. This study consists of the application of the SPD method to polymetallic tailings through a tailing deposit model design at the laboratory. This method consisted of the model being deposited in paste by layers with a lower geotextile mesh without the use of any additive [14]. In contrast, the current study consists of 3 laboratory models, wherein the first model places tailings using the conventional method, the second model uses the vertical or SPD method, and the third laboratory model uses paste tailings applying the SPD method using cement as an additive both in the lower and the upper layers of the model. The results obtained from the study are observed in the following tables, which show the physical characteristics of both the cementless and CPT. According to the data obtained, it is evident that the uncemented tailings will occupy more space than the cemented one, as well as the results obtained by [5]. However, CPT denotes high water content in the upper layer. In addition, some water content can be observed in the lower layer, which indicates that this layer initially did not retain a lot of water. Still, as the upper layer did retain a larger volume, a good fluid retention rate is observed, which means that water infiltration has been reduced.

5.3. Validation Design

This study developed 3 tailings deposit designs at the laboratory level; physical characterization of each one was conducted, and the layers of designs 2 and 3 were evaluated every 12 hours. The cement addition in the upper and lower layers of design 3 will allow conducting an adequate analysis of the volumetric water content, porosity, degree of saturation and the space of the recovered tank that each design has in order to obtain the behavior of the cement in the first and last layers of design 3 and determine whether this optimizes the use of the tank spaces that have been wasted due to the existing water content. The laboratory used for the experimentation contributed variables that must be considered in the research process, such as the ambient temperature and humidity, since they affect the percentages of water in each layer in the simulation stage of designs 2 and 3.

The equipment, instruments, and supplies used in this research were an industrial balance for measuring the weights of each design, a laboratory kiln for drying samples, as well as pipettes and beakers for carrying out tests and calculations for physical characterization. In a matter of inputs, cement, polymetallic tailings, and sand were used as additives to perform an efficient simulation. Regarding the statistical and percentage analysis, the Microsoft Excel 2018 software was used to obtain the data shown in Tables 1 and 2.

Table 1. Summary of the layers drying sequence in Design 2

Summary of the deposition sequence of the layers of design 2		
Layer No.	**Cement %**	**Drying time**
5	0	t (0) + 240 hours
4	0	t (0) + 192 hours
3	0	t (0) + 144 hours
2	0	t (0) + 96 hours
1	0	t (0) + 48 hours

Table 2. Summary of the drying sequence of the layers design 3.

Summary of the drying sequence of the layers of design 3		
Layer No.	**Cement %**	**Drying time**
5(up)	2%	t (0) + 240 hours
4	0	t (0) + 192 hours
3	0	t (0) + 144 hours
2	0	t (0) + 96 hours
1(bottom)	2%	t (0) + 48 hours

Fig. 3 Conventional tailings design in the laboratory - Design 1

Fig. 4 Surface paste tailings disposal - Design 2

Figure 3 shows the conventional design that was carried out in the laboratory, which served as a guide to determine how much space and water could be recovered by changing the disposal method, and Figure 4 shows the Surface Paste tailings Disposal (SPD) of Design 2.

Figures 5 and 6 show the disposition of paste tailings with cement in the first and last layers. Design 3 does not present cracks on the surface, and as the hours pass, it loses weight due to the evaporation of the supernatant water.

Figure 7 is the result of the pH measurement in the different layers of designs 2 and 3; the design that contains cement in layers 1 and 5 is more basic, maintaining its values between 12 and 11.

Fig. 5 Disposal of paste tailings with cement in the first layer - Design 3

Fig. 6 Disposal of paste tailings with cement in the last layer - Design 3

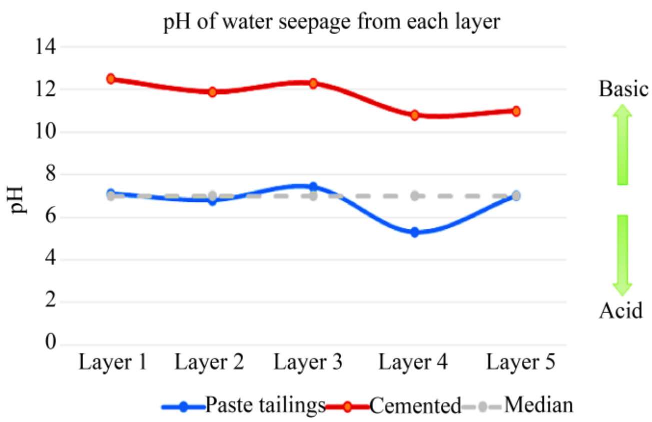

Fig. 7 pHs of the filtrations of each layer

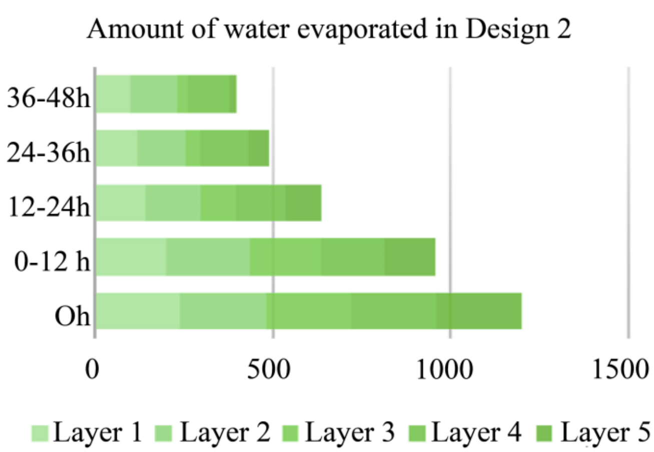

Fig. 8 Evaporation of water every 12 hours in the uncemented layers

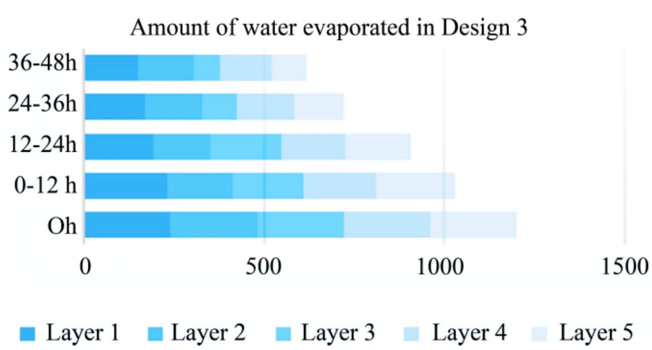

Fig. 9 Evaporation of water every 12 hours in the cemented layers

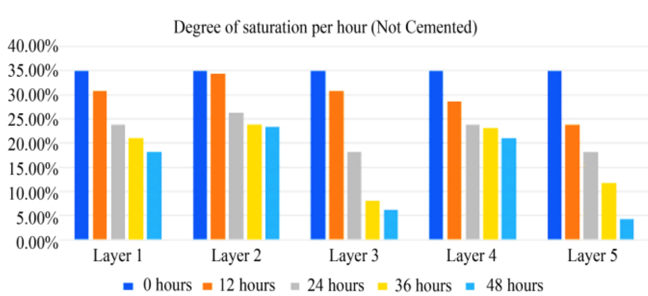

Fig. 10 Comparative graph of the degree of saturation of design 2

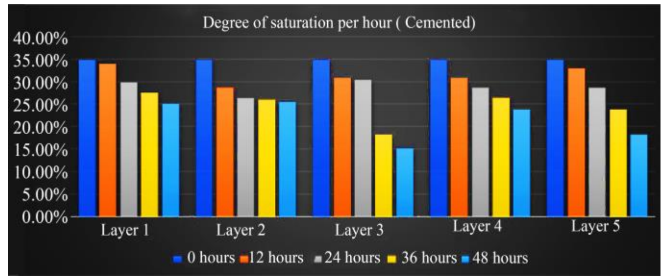

Fig. 11 Comparative graph of the degree of saturation of design 3

As shown in Figures 8 and 9, the amount of evaporated water decreases steadily in all layers. This leads to a reduction in the space occupied in the tailings deposit, thus allowing the accommodation of a greater amount of it. Figure 9 shows that the water evaporated in the cemented layers is less than in the layers of Design 2. This is due to the cement slowing down the rate of water evaporation due to its water retention property. In relation to the degree of saturation, Figures 10 and 11 show a notable difference in the degrees of saturation between layers 1 and 5 of the cemented design and the design without additives. This variation is due to the presence of 2% cement in these layers, which allows a greater amount of water to be retained, resulting in a higher degree of saturation compared to the disposition without additives. In addition, the climatic factor also influences the degree of saturation since it affects the amount of water per layer, especially when observations are made every 12 hours, as reflected in both figures. As a result, the percentage of water that was recovered from the simulated paste tailings for both designs, the percentage of solids used, and the percentage of spaces used were obtained. As evidenced in Tables 3 and 4, in the design without additives, a percentage of 16.52% was obtained, and the cemented design obtained a space used of 12.02%; in terms of percentage solids, both designs used 36% solids in the deposit. As analyzed, the uncemented tailings take advantage of a higher percentage of spaces than the cemented tailings. However, as seen in the previous results, the application of cement offers improvements in various difficulties, such as water infiltration and evaporation, due to its characteristics.

6. Discussion

6.1. New Scenarios vs Results

Through the review of various studies on the disposal of surface paste tailings, it was evidenced that comparisons are made in question to the physical and chemical characteristics of physical models of surface paste tailings disposal on a laboratory scale. Said comparison has been made by [9] between superficial paste tailings without additives, paste tailings where cement is applied to the first layer and models where it is applied only in the last layer to deposit the paste. In comparison to the study carried out, a comparison has been made between conventional tailings with a 55% solids content, a paste tailing arranged in layers without added additives, and a paste arrangement where 2% cement was added as an additive. In the first layer and the last layer of the laboratory model, identify the physical characteristics of each one and make a comparison in terms of infiltrations, percentage of space used and percentage of recovered water. Regarding the tailing's disposal method used, the studies of [9] used the addition of cement to analyze its behavior in relation to water infiltration and its resistance and physical stability. For this reason, in the study carried out, characteristics such as porosity and void ratio were identified, which, through a statistical analysis of correlations carried out, it was identified that these are positively correlated, acting positively on water retention and decreasing the infiltration of these, since the values of porosity and void ratio in the cemented model were lower than in the uncemented model. Likewise, it was demonstrated through the water contents obtained in the cemented and uncemented tailings that the upper cemented layer prevents the evaporation of water since it was obtained that this layer maintained a greater weight than the upper layer of the uncemented model [1]. On the other hand, in relation to the simulation and observations made of it, the results obtained by [18] were verified since, in the study, it was observed that once the layers were placed and after 36 hours had passed, a sample was extracted of the model, in which it was identified that the layers were internally unified, however, in comparison with the studies carried out by said researchers, who identified a degree of saturation of 40% in the uncemented layers and 46% in cemented layers. Thus, in the elaborated study, results were obtained within those obtained by the researchers, which would be a few degrees of saturation between 40% and 60%, both in cemented and non-cemented layers. This shows us that the tailings used in the investigation have a higher percentage of water than the one used by [18].

On the other hand, in relation to the environmental conditions, the study was simulated in an environment with moderate temperature and without climatic conditions that affect it; however, it was compared with an investigation carried out in rainy tropical climates and clayey tailings [8]. Unlike the study carried out, the clayey composition of the tailings, in comparison, has greater water retention than the polymetallic tailings under study since it is a finer and softer rock than a polymetallic tailing. In addition, it was evidenced that, for both studies, the paste tailings applying the vertical or SPD method show greater physical stability than conventional tailings; however, the clayey tailings have lower permeability than the polymetallic tailings since in the experimentation at comparison was verified through simulations of tropical rainy climate at laboratory scale [8].

6.2. Analysis of Results

A percentage of water of 20% was obtained, being within the range of the various scenarios analyzed. Regarding the percentage of space recovered, a higher percentage of space recovery was obtained, of 60%, this being the highest value among the various scenarios studied.

6.3. Future Work

Regarding work to be carried out in the future, to achieve a better result in the percentage of space used and water recovered, it will be carrying out more experiments with other types of additives that optimize the vertical method or SPD and generate benefits for the mining industry, either in polymetallic tailings or others to study. This research is proposed to be developed by a mining unit in central Peru, taking into account the procedure on an industrial scale but using a greater amount of cement in the first and last layer of the paste tailings disposal.

Table 3. Results from compared studies – Not cemented

Results of comparative studies						
Not cemented	**Layer 1**	**Layer 2**	**Layer 3**	**Layer 4**	**Layer 5**	**Total**
Container volume (cm3)	960	960	960	960	960	4800
Accumulated volume	960	1920	2880	3840	4800	4800
Dry sample weight 48 hours (g)	720	720	720	720	720	3600
Water volume (cm3)	100	137	30	120	20	407
Total	820	857	750	840	740	4007
Cumulative total	820	1677	2427	3267	4007	4007
Weight percentage conventional comparison	17.08%	17.85%	15.63%	17.50%	15.42%	83.48%
Accumulated percentage	17.08%	34.94%	50.56%	68.06%	83.48%	83.48%
Solid percentage compared to conventional	27%	27%	27%	27%	27%	136%
Accumulated solid percentage compared to conventional	27%	55%	82%	109%	136%	136%
Water percentage compared to conventional	4.63%	6.34%	1.39%	5.56%	0.93%	18.84%
Accumulated water percentage compared to conventional	4.63%	10.97%	12.36%	17.92%	18.84%	18.84%
Percentage of water recovered						81%
Percentage of solids used						36%
Percentage of spaces used						16.52%

Table 4. Results from compared studies – Cemented

Results of comparative studies						
Cemented	**Layer 1**	**Layer 2**	**Layer 3**	**Layer 4**	**Layer 5**	**Total**
Container volume (cm3)	960	960	960	960	960	4800
Accumulated volume	960	1920	2880	3840	4800	4800
Dry sample weight 48 hours (g)	720	720	720	720	720	3600
Water volume (cm3)	150	153	80	140	100	623
Total	870	873	800	860	820	4223
Cumulative total	870	1743	2543	3403	4223	4223
Weight percentage conventional comparison	18.13%	18.19%	16.67%	17.92%	17.08%	87.98%
Accumulated percentage	18.13%	36.31%	52.98%	70.90%	87.98%	87.98%
Solid percentage compared to conventional	27%	27%	27%	27%	27%	136%
Accumulated solid percentage compared to conventional	27%	55%	82%	109%	136%	136%
Water percentage compared to conventional	6.94%	7.08%	3.70%	6.48%	4.63%	28.84%
Accumulated water percentage compared to conventional	6.94%	14.03%	17.73%	24.21%	28.84%	28.84%
Percentage of water recovered						71%
Percentage of solids used						136%
Percentage of spaces used						12.02%

7. Conclusion

According to what has been studied, it can be concluded that through the application of the vertical method or SPD with the addition of cement, the wasted space due to the water content in conventional polymetallic tailings can be used through this technique, placing it in layers with a higher percentage of solids, generating that the deposit can be used to its full capacity. This generated better benefits in terms of the physical stability of the deposit, percentage of water recovery and reduction of water infiltration than other methods of tailing disposal. Unlike past studies, when comparing conventional tailings, uncemented paste tailings, and cemented paste tailings, it was directly identified that water recovery for both the cemented and uncemented methods avoids waste of space of the tailings dam since it is evident that a greater volume of paste tailings was deposited, managing to optimize this space.

The application of cement must be considered in the method since it generates a greater resistance to fracturing of the paste tailings. However, the addition of this must be monitored in the process since depending on the type of rock in the deposit, this will affect its physical stability. In addition, it was evidenced that said application, both in the lower layer and in the upper layer of the tailings, offers the use of space in the same way as the uncemented paste tailings; however, in this, a lower degree of saturation is seen than in the uncemented method, generating less infiltration and reducing the possibility of liquefying the tailings due to its high plasticity. The pH of the three disposal methods should be considered as a variable to be analyzed since it will indicate the alkalinity of the water that contains the cemented paste. In this case, the result was that the pH of the cemented layers rose to pH 12, being a basic state instead of an acid state, in which the water was found when the conventional arrangement was analyzed.

For the application of the vertical method or SPD, the environmental conditions of temperature and humidity must be considered since they will affect the drying process within 48 hours per layer, since as observed in the amounts of water evaporated during the 48 hours, this varies constantly taking outliers, due to these climatic variations that affect laboratory models. Thus, these variables must be considered when carrying out the analysis of percentages of both water and recovered space, which are correlated.

Data Availability Statement

All data, models, and code generated or used during the study appear in the submitted article.

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