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New Technologies in Mining Sustainable Production. Tailings Management and Mining Chemicals

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Abstract. Million tonnes of tailings are formed in the world each year due to increasing mining activities along with the increase in need for raw materials. The tailings may cause important environmental problems. Therefore, tailings management is very important issue in mining operations. In recent years, with the developing technology, the new tailing disposal technologies such as paste and using geotextile materials have increased considerably. These methods have many advantages in terms of both environmental and cost reducing. Another important issue in terms of mining is the accidents and occupational health problems in underground coal mines. The problems can be described as spontaneous combustion, roof collapse, gases extraction from coal bed, and etc. These accidents have been significantly reduced with use of mining chemicals in underground mines. In this study, tailing management and mining chemicals which are very important in terms of mining applications are examined.

Keywords: *tailings, mining applications, tailing management, mining chemicals, underground mines*.

1. Introduction

1.1. Tailings Management

A significant number of tailings with a high content of cyanide or sulphur arises from the beneficiation process of metallic mines such as gold, silver, copper, and lead. The influence of these hazardous tailings on the environment may have multiple aspects. The control and configuration of this kind of environmentally dangerous tailings in terms of isolation at disposal site, construction of impermeable layers, transportation from plant, stabilization, safety, their effects on water, and soil quality are the main parameters that could be considered carefully. In this context, tailings management are very important to selection of the optimum disposal method. Also, some parameters such as physical and chemical characterization of tailings, properties of newly formed material (e.g. acid potential, stabilization, cost and applicability of the paste tailings etc.) should be evaluated. Safely disposal of mine tailings under surface conditions is of great importance in the aspect of environment [1].

There are some disposal methods which have been applied in the mining industry for a long time. These methods have some advantages and disadvantages besides environmental considerations. These methods are explained briefly below;

- Tailing dam
- Submarine tailing disposal
- Dry disposal
- Paste technology
- Tailing Disposal Method Using Geotextile Material

1.2.Tailing Dam

Tailing dams are used to store tailings and water together. Tailing slurry is pumped into a dam to allow the sedimentation of solid particles in water. The dam is generally impounded with a dam which is known as tailings dams. In the modern mines, between 40 and 100% of the total tailing's slurries are deposited on the mine-site surface (tailings dam).

Higher volumes of water and tailings (usually 15% solids and 85% water by weight) are sent to tailing dams making it very difficult to control the stability of the dam under conditions such as static and dynamic loads (seismic activities, vibrations caused by blasting, etc.), flooding, and seepage. Meanwhile, 138 mine tailing storage dams have significantly failed so far. Recent examples are given below (Figure 1):

In 1998, the Los Frailes mine tailings dam in Aznalcóllar, Spain, failed releasing five to seven million cubic metres of mine tailings into the Rio Agrio (Figure 1a).

In 2010, releasing of 600–700 thousand cubic metres of red mud and water caused huge devastation in Hungary (Figure 1b).

In 2011, an accident occurred in ETI Silver Company silver production plant in Kutahya, Turkey. A connection walls for four impoundments failed leading to a situation where 25 million cubic metres of water containing cyanide created a great risk to environment (Figure 1c).

In 2019, the Brazilian mining dam which collapsed in January, killing hundreds of people. One hundred and forty-two people died and 194 are still missing after the dam near Brumadinho in Minas Gerais state collapsed on 25 January (Figure 1d).

1.3. Submarine Tailing Disposal

In this method that is also known as submarine tailings disposal (STD) or deep-sea tailings disposal, tailings are discharged by pipelines into the sea marine environment below euphotic zone. This zone is generally considered to be environmentally safe (Figure 2).

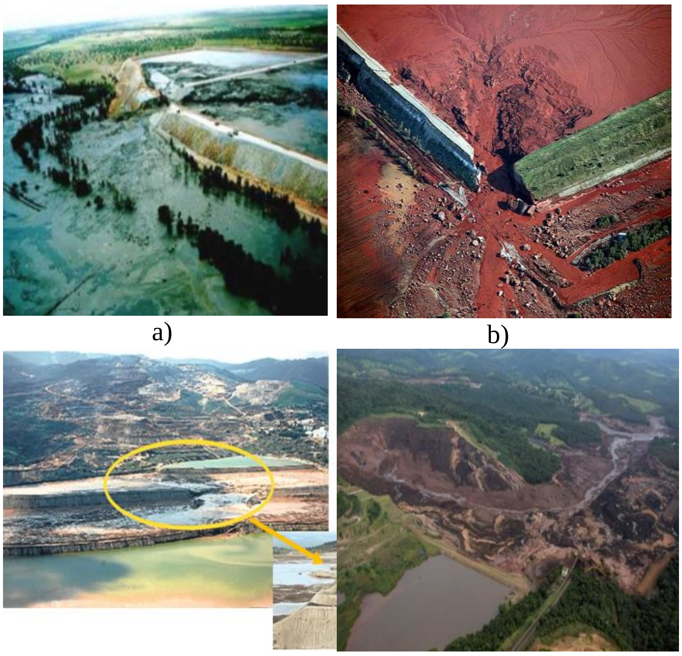

Figure 1. Examples from various tailings dam accidents around the world: a) Los Frailes mine tailings dam in Aznalcóllar, Spain, 1998; b) Kolontar tailings dam failure in Hungary, 2010; c) ETI Silver Company silver production plant in Kutahya, Turkey, 2011; d) The dam was 87 m high, impounding almost 13 million cubic meters of tailings

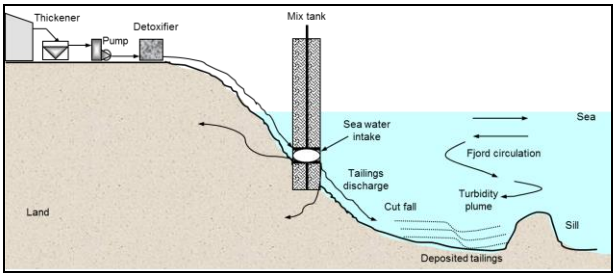

Figure 2. Submarine tailing disposal method

Today's marine disposal discharges are in deep water at final deposition in depths of 30 to 300 m in Norway and over 1000 m in Turkey, Indonesia, and Papua New Guinea. In 2013, submarine tailing disposal was used by 14 mines.

Riverine disposal is a very simple method. Tailings are discharged by pipelines into the river in this method. This technique has been practiced throughout mining history. Economics and technical feasibility factors (e.g. mountainous terrain, earthquake prone, extreme rainfall) are considered when considered this method. In 2013, riverine tailing disposal was used by four mines.

1.4. Dry Disposal

In this method, the dewatering of tailings is done using vacuums and high-pressure filters which save the water and reduce the impact on the environment. Tailings are filtered to a percent solid greater than about 85%, and transferred using conveyor and truck (Figure 3).

1.5. Paste Technology

Paste technology is a good alternative for waste management systems because it has many benefits in the aspects of environment, cost, and safety.

Figure 3. Dry Disposal

In particular, the tailings which include harmful chemical ingredients can be disposed without causing any environmental damage in this method. Paste backfill is a pumpable, flowable, and non-Newtonian fluid consisting generally of mine tailings and cement. The process tailings are usually used as paste backfill material in some underground minings (Figure 4), but it is not possible to apply this method in open-pit mining. For this reason, tailings can be stored above ground in the open-pit mining as surface paste disposal. Therefore, the behaviour of the paste material is different from the other applications.

Figure 4. Underground (left) and surface (right) application of the paste technology

Paste is defined as a thickened material formed by mixing dewatered fine tailings with water and preferably binder (cement). Addition of cement into paste changes both the chemical and physical characteristics and buffers acid-producing oxidation reactions, resulting in less mobilization of metals. In order to form a flowable paste, it is required to have particles at least 15% of solid ratio and finer than 20 μm.

1.6. Tailing Disposal Method Using Geotextile Material

Geotextile material was first used in the field of dehydration in the 1970s, and then in mining in the 1980s. The tailing disposal method using geotextile material is based on the principle of pumping, dehydrating, and disposing of the tailing of the facility in a material called geotextile tube. Geotextile tubes are produced with high strength, braided or not braided, and in required dimensions. The biggest advantage of this method is not toneed forany disposal area. The application of the tailing disposal using the geotextile material is shown in figure 5.

Figure 5. Geotube technology

As it is seen in figure 3, the material is pumped into geotextile tubes with the help of pumps, and the water that flows through the pores of the tube is fed once again into the facility. The disposal design with geotextile material first starts with determining which type of geotextile tube will be used. Here, the pore opening and strength of the geotextile tube are the parameters to take into consideration. Then, the type and amount of the flocculant that prevents the flocculating and getting of very fine materials off the pores of geotextile tubes should be determined. The total cost increases in case of the excess use of the flocculant material, while the fine material does not flocculate when it is used sparsely. The pump and transmission line should be designed after the selection of the flocculants and geotextile tubes.

2. Mining Chemicals

Since ~20 years, mining chemicals are used successfully in the coal mining industry for stabilizing coal and strata, preventing roof falls and spalling, coal spontaneous combustion prevention, and for sealing. Fast curing resins were tested in the coal mining industry. In the first attempt, epoxy resins were used. Soon they were outperformed by polyurethane foam resins, characterised by much shorter setting times. In recent years, Mining chemicals have been established as a very effective means for stabilising coal and strata in hard coal mining industry. Their main advantages are their simple application, fast action and ability to stabilise rock formations under high stress and movement. Mining sector demands more lightweight, cheaper and more efficient materials, especially in underground coal mines. Polymer based foams are remarkable with their properties such as high toughness, high impact resistance, higher thermal stability, lower electrical conductivity and thermal insulation. Because of these advantages the usage of mining cehmicals such as polyethylene, poly-urethane, polyvinilclorur, polypropylene has been increased for mining sector. Resin and foams are the most important chemicals for use in underground mining (Figure 6) [2,3,4].

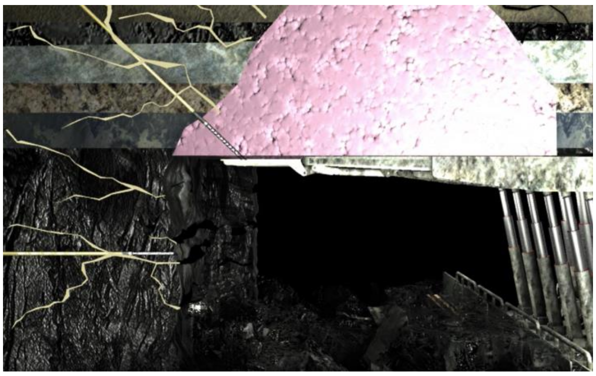

Figure 6. The use of Resin and Foams in underground mining

By employing a suitable chemical blend, the performance of the resin can be adjusted to the engineers' needs in respect of mechanical strength, setting time and other characteristics. Table 1 shows the technical properties of phenolic resins in mining chemicals and in table 2, phenolic foams.

Table 1. Technical specification of phenolic resin

Technical Specification	Values
Compressive Strenght (MPa)	~30
Bond Strenght (MPa)	3.5 -7.5 (24h, broken surfaces)
Flexural Bond Strenght (MPa)	3.5
Bending Tensile Strenght (MPa)	~7 (24 h)
Viscosity Mpa*S (A Comp./B Comp.)	250-425/150-180
Foam Expansion Factor	1
Flash Point	>200 (comp. B)
Elasticity Modulus (MPa)	250
Final Strenght Time	15 min
Flow Time (25 C^o)	1’ 20’’ - 2 ‘30’’
Setting Time (25 C^o)	2’ 35’’ - 3’ 45’’
Border Time (Min 1MPa Flexural Bond Strenght)	<5 min

Table 2. Technical specification of phenolic foams

Technical Specification	Values
Compressive Strenght (KPa) (%10 Deformation)	~60
Foam Expansion Factor	25
Start of Foaming	Immediately
End of Foaming	30 S
Temperature of Reaction	90 C^o
Viscosity 25 C^o Mpa*S (A Comp./B Comp.)	200-900/<100

3. Case Studies

3.1. The effects of cement on some physical and chemical behavior for surfacepaste disposal method [5]

Environmental impacts resulting from conventional tailings disposal such as tailings dam accidents are a common problem for base metal mines around the world. In this context, laboratory-scale researches have been carried out on the Surface Paste Disposal (SPD) method, which is one of the alternative surface storage methods. In this study, three different designs were attempted for surface paste disposal and volumetric water content, oxygen consumption and matric suction sensors in 1st, 5th and 10th paste layers and pH-electric conductivity (EC) values were measured.

Especially, it has been determined that the amount of oxygen in the environment required for the oxidation of sulfur minerals is reduced in cemented layers of Design 3. In addition, the cement additive keeps the pH values (over 7) of the seepage in an alkaline environment so that it minimizes the risks of Acid Mine Drainage (AMD) and heavy metal mobilization at low pH values. Also, EC values started a downward trend and ion dissolution decreased in cemented layers with designs. As a result, it is understood that the cemented layers act like a barrier according to the sensor measurements (Figure 7 and 8).

The volumetric water content for layer 1 and the correspondingly calculated values in the solid content by weight (SC = Solid Content/ Total Mass of Pulp) value are given in figure 9 for design 1 and design 3 respectively.

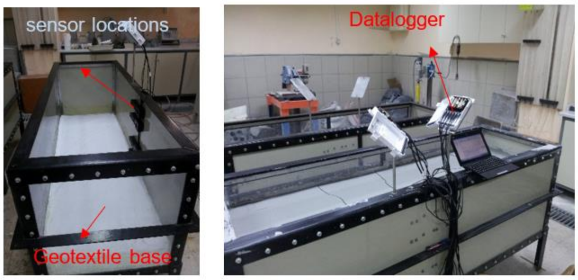

Figure 7. General view of test cabins

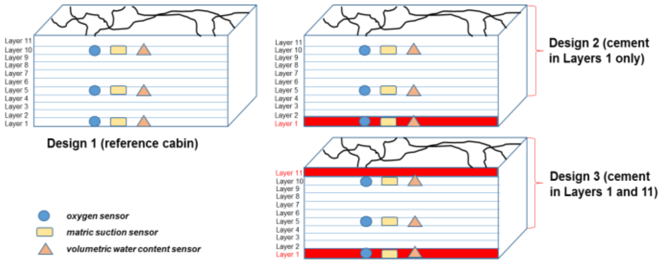

Figure 8. Test cabin designs with different configurations

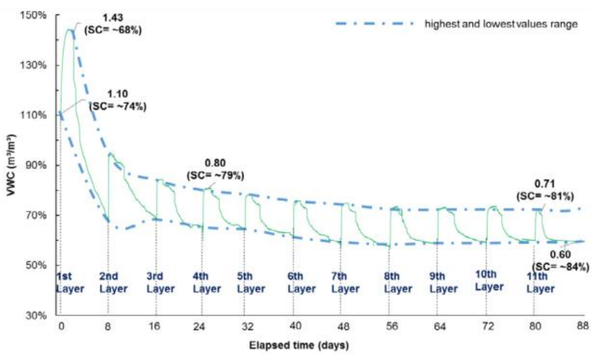

Figure 9. VWC and SC values of Layer 1 in Design 3 (cement in Layers 1 and 11)

As seen in figure 9, after the first layer is stored, an increase in volumetric water content of ~35% is observed. It was determined that design 3 remained stable between at 81%–84% of SC after the storing of the fifth layers. These results can be expressed as the paste material being consolidated with the loads upon it and reaching hydrostatic balance after a certain period of time. The pH and EC values of seepage water collected after the depositing of each layer were measured. The pH changes are shown in Fig. 10. The EC values are also given in figure 11.

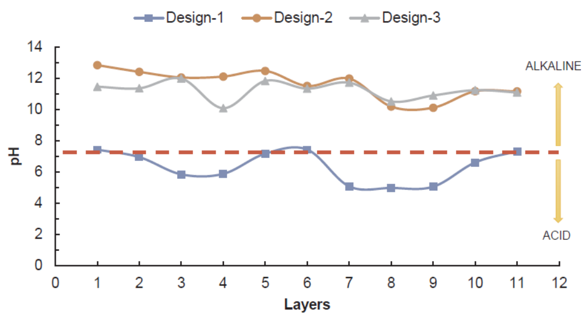

Figure 10. pH of seepage in three different designs

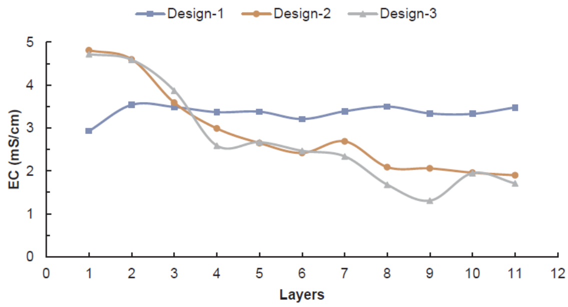

Figure 11. EC values of seepage in three different design

As seen in figure 10, the pH values in design 1 are often lower than 7. On the other hand, it is understood that the cemented layers in designs 2 and 3 do not allow the pH values to fall below 10 because they generate alkaline silica reactions in these layers after solving the alkali minerals that act as a barrier. The sulfide oxidation on seepage quality was reduced through the presence of minerals and cement that buffered pH. In figure 11, it can be seen that the EC values of design 1 are greater than 3 after the deposition of first layer, and this state continues in each subsequent deposition of other layers. In designs 2 and 3, it was determined that the EC values started a downward trend and that ion dissolution decreased according to design 1 after deposition of the first layer. As a result, the cement additive keeps the pH values of the seepage in an alkaline environment so that it minimizes the risks of AMD and heavy metals mobilization at low pH values. Furthermore, it can be said that this theory supports the decrease in the number of dissolved ions in designs with cemented layers.

3.2. Application of Pb-Zn tailings for surface paste disposal: geotechnical and geochemical observations [6]

Surface paste disposal (SPD) technology has been investigated recently to solve the geotechnical (tailings dam failure) and geochemical (acid mine drainage formation) problems relating to tailings disposal. The tailings dam accidents occurred in the last few years have expedited the researches to search for safer tailings disposal methods in mining industry. The aim of this study is to investigate which parameters affect the geotechnical and geochemical stability of sulphidic paste tailings as SPD. The pH, EC and crack intensity of paste tailings placed in layers were measured to observe how the parameters affect their stability. In this study, it can be seen that solid concentration of the paste material increases above ~80 wt.%, and its shear strength is above 20 kPa. In addition, the pH values reduced from 7.4 to 6.6 and the EC values increased from 2.9 to 3.3 mS/cm in seepage water of the paste layers. According to these values, it can be said that there is a very low environmental risk using the SPD. Results showed the applicability of the SPD method by obtaining geochemical and geotechnical stability.

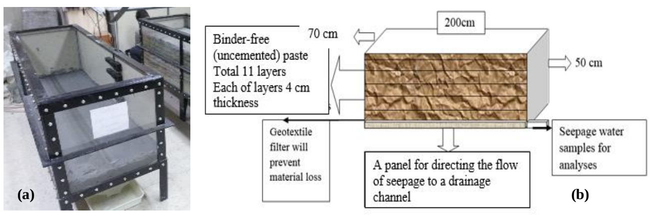

Figure 12. Test cabin design

The VWC of paste mixtures in the storage process was measured by the sensors placed in 1st, 5th and 10th layers, and the changes of the solid concentration calculated accordingly are given in figure 13.

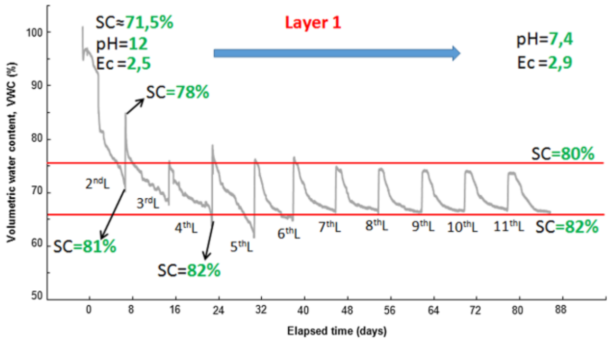

Figure 13. The volumetric water content and solid concentration of layer 1

The solid concentration of the layer 1 at the time of being casted is seen in figure 4 as 71.5% for 1st layer. Because of the effective stresses formed by the next 3 layers, layer 1 was consolidated and quickly lost its water, and 82% of solid concentration was reached at a time period of 24 days. The loss of total water consists of seepage (17 wt.%) and evaporation (83 wt.%). In the next layer casting process, it was determined that layer 1 was not affected by the effective stresses created by the cumulative 7 layers which were stored successively. After layer 4 and by seepages, and it remained constant for the next 64 days in 82% solid concentration. Therefore, it was determined that the water content value of the layer 1 with the highest risk of liquefaction is due to excessively added paste layer. According to seepage analyses performed, the seepage of layer 1 was determined to be in the value of 7.4 and 2.9 mS/cm bearing no risk in terms of pH and EC values. The crack intensity generally remained below the average up to layer 11 when going ahead to upper layers along with layer 5 (Figure 14).

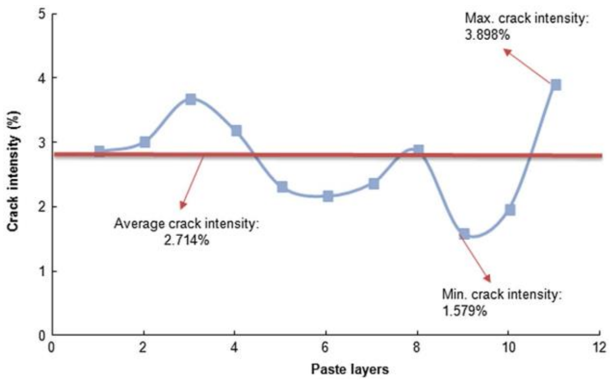

Figure 14. Crack intensity values of paste layers

These changes in the crack intensity of layers can be said to be dependent on many parameters such as evaporation-drying, precipitation and disposal conditions, fast-draining consolidation and matric suction on the formation of cracks. After the storage process was completed, samples were taken from the different cabin heights, and the paste's shear strength was determined by direct shear box test. Accordingly, cohesion and internal friction angle determined by different heights (0–15 cm, 15–30 cm, 30–44 cm) are given in figure 15. In this context, the layers 1, 2 and 3 remained within the area of 30–44 cm, the layers 4, 5, 6 and 7 remained within the area of 15–30 cm and the layers of 8, 9, 10 and 11 remained within the area of 0–15 cm.

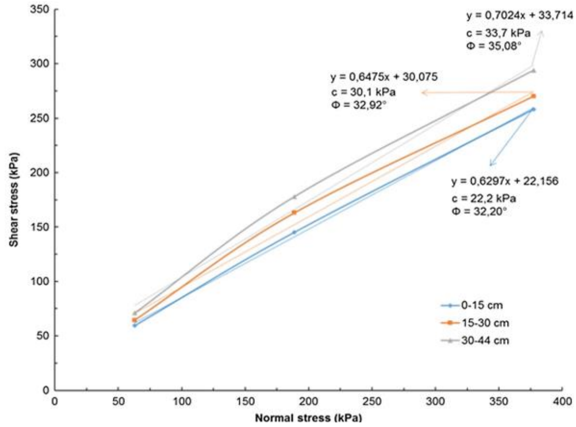

Figure 15. Graphic of normal stress-shear stress of the areas determined by different heights

As can be seen from figure 15, the gradual decrease in the spaces between the particles of the bottom layers which are consolidated of their own weight ensured a more stable structure formation. Accordingly, it was observed that the average cohesion value of first 3 layers was ~34 kPa and the angle of internal friction was 35.08°; the average cohesion of layers 4, 5, 6 and 7 was ~30 kPa and the angle of internal friction was 32.92°; the average cohesion of the top 4 layers was ~22 kPa and the angle of internal friction was 32.20°. Thus, the land stresses formed in the bottom layers more than the upper layers during the storage of the material in the field would be met with the strength of the material increasing to the bottom layers, and the paste will maintain its stability.

3.3. An investigation of crack formation in surface paste disposalmethod for pyritic Pb–Zn tailings [7]

Surface paste disposal method can be used to minimize environmental risks during storage of mine process tailings. There are some researches and industrial applications which prove success of the method. The surface paste disposal of mineral process tailings obtained from a Pb–Zn underground mine was simulated considering mine site conditions at laboratory scale in the study. The paste material was stored in the cabin/container layer by layer, and then, the cracks occurred after the paste formation of each layer were analyzed by image process. Meanwhile, leachate water collected from the bottom of the cabin was subjected to electrical conductivity (EC) analysis. Furthermore, the wetting–drying process was conducted to simulate the climatic conditions of the region. Additionally, some physical and geochemical parameters such as matric suction, volumetric water content, and oxygen consumption of the paste material were obtained using sensors displaced into different layers. The results of the crack analysis for each layer showed that the cracks intensity increased at lower layers (Figure 16). Moreover, the crack intensity and EC values of each layer showed a similar trend, and the crack intensity increased almost five times during the wetting–drying tests. The measured values of the parameters obtained from the tests indicated that the deposited paste material can be stabile during the deposition over the years under the climatic conditions of the region.

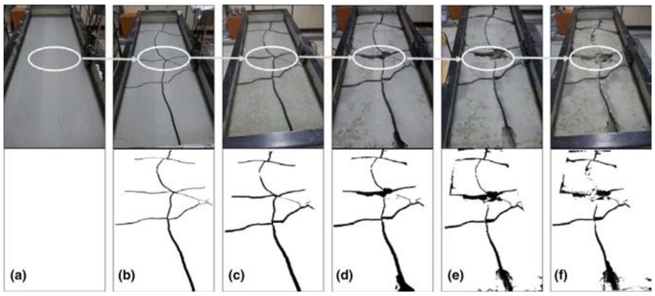

Figure 16. The results of the crack analysis for each layer

Based on the crack analysis from figure 16, the CIF values for each layer were determined along with EC values, and the results are seen in figure 17.

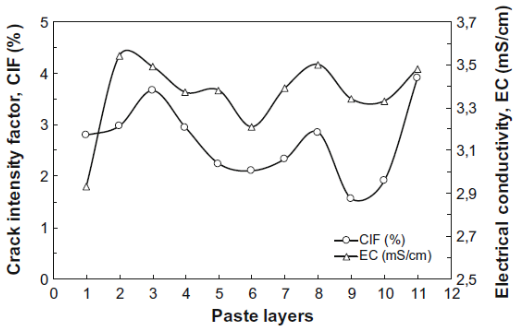

Figure 17. CIF and EC values of the each paste layer

Figure 17 shows that the crack intensity increased from the 1st layer to the 3rd layer, and the similar tendencies were observed between the 6th and 8th and 9th and 11th layers. However, particularly the crack densities of the 3rd and 11th layers are much more than those of the other layers. As seen in figure 17, while the maximum and minimum crack intensity of the layers was obtained as 3.898 and 1.579%, respectively, the average intensity was calculated as 2.714%. Figure 17 shows that the electric conductivity (EC) value also changed along with the changes in the crack densities. While the average EC value of the process or mixing water for the paste material was 1.66 mS/cm, the average EC value of the paste layer seepage water was measured as 3.36 mS/cm. An approximately double increase was observed in the EC value after the layers were poured. Besides, it was seen that the ions in the paste material dissolved at values below pH 7, and the EC value increased according to the relationship between the pH and EC values of the seepage waters of the layers. Figure 18 shows the crack intensity of 11th layer increased during thewetting–drying process.

As seen in figure 18, the crack intensity of the layer on the 8th day was obtained as 3.89%, and this value increased to 6.54% during 117 days of the drying process. Then, the layer was wetted for 1 day using 180 L of water. After the wetting process, the crack intensity of the layer increased to 9.21%. Then, the layer was kept drying for 27 days, and this process increased the crack intensity to 11.20%. Finally, the layer was wetted and dried periodically for 32 days (wetting 35 L for 1 day and drying for 7 days for four cycles).

After the drying cycle, the crack intensity of the layer reached 15.49% as seen in figure 5. These results clearly showed that the amount of water significantly affected the crack intensity occurred on the layer surface.

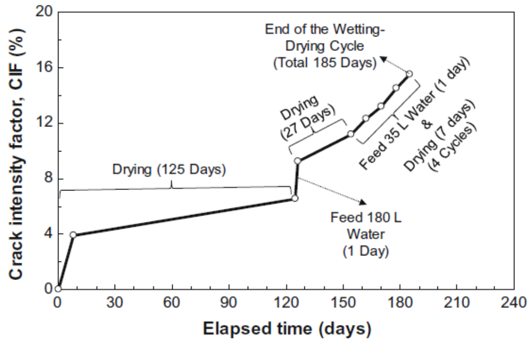

Figure 18. CIF values of 11th paste layer during wetting–drying cycles

3.4. New Technologies on Mine Process Tailing Disposal (Comparasion of the new methods based on Cost) [8]

Tailings are formed as a result of mine processing. When these tailings are left in an environment in an inappropriate manner, they create a danger against the environment and human health. Therefore, the safe disposal of mine tailings above the ground is environmentally quite important. Today, tailing dams are generally used in the disposal of these mine tailings. However, this method has many environmental disadvantages such as acid mine drainage (AMD), heavy metal mobilization etc. For this reason, the use of alternative methods such as surface paste tailing disposal or geotextile methods are gradually increasing in the world. In this study, the advantages and disadvantages of the surface paste tailing disposal method and tailing disposal method using geotextile material compared to the traditional tailing dam method were evaluated in detail, and, the costs of these three methods for a typical Pb-Zn mine establishment were compared. The cost items for each of these tailing disposal methods are presented in table 3. The operation and capital costs of 3 methods are shown in figure 19.

Table 3. Cost items of the tailing disposal methods

Cost		Surface paste disposal	Tailing dam	Tailing disposal using geotextile material
Capital cost	Dam construction	X	X	-
	Pump	X	X	X
	Pipe	X	X	X
	Thickener	X	-	-
	Silo	X	-	-
	Mixture tank	X	-	-
	Land tax	X	X	X
Operational cost	Energy consumption	X	X	X
	Labour	X	X	X
	Maintenance	X	X	X
	Cement	X	-	-
	Flocculant	X	-	X
	Geotextile tube	-	-	X
	Land cost	X	X	X

As also seen in figure 19, total costs of the tailing dam and the surface paste disposal methods were calculated as ~14,000,000$.

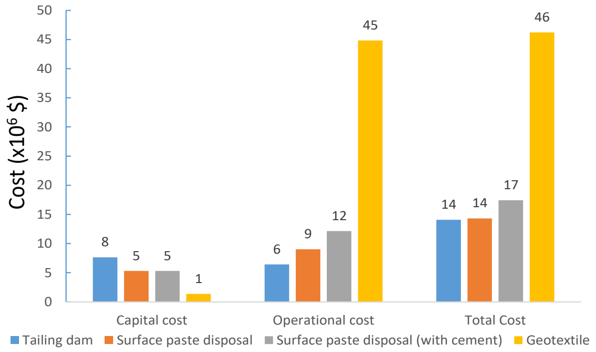

Figure 19. Operation and capital costs for the 3 methods

In the case of cement, it is used for the surface paste disposal method, the operation cost rises from ~9,000,000$ to ~12,000,000$, and this makes the calculated total cost of ~17,000,000$ to be higher than the total cost of the tailing dam method. As more tailing disposal areas are needed for the tailing dam method, a higher capital cost is in question when compared to other methods. However, the operation cost is lower than in other methods. While the capital costs for the tailing disposal using the geotextile material method is lower than that of the other methods with ~1,000,000$, the operation, and thus the total cost of this method is quite high with ~46,000,000$ because of the high cost of the geotextile tubes.

The analysis indicated that the unit costs of the tailing dam, the surface disposal method, and the geotextile method were calculated as 2.25 $/ton, 2.29 $/ton, and 7.39 $/ton, respectively (Figure 20). However, the unit price of surface paste disposal method become 2.79 $/ton when cement was used. The higher cost of the unit price of the tailing disposal method using geotextile method was attributed to the high cost of geotextile material.

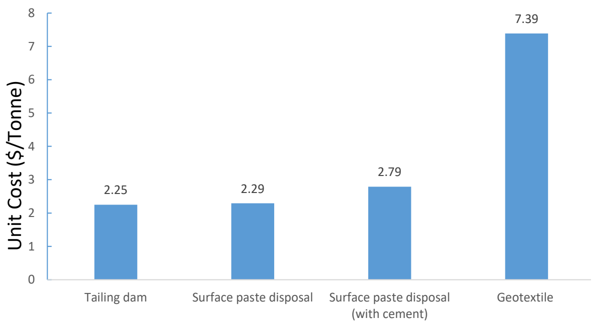

Figure 20. The results of the cost analysis

3.5. Field Properties and Performance of Surface Paste Disposal [1]

Recently, the detailed study about utilization of flotation tailings for the application of SPD has been carried out at Mining Engineering Department, Istanbul University, Turkey. In this study, firstly, in order to simulate the field disposal conditions and testing of the layer configurations, a unique laboratory-scale test cabin seen in figure 21 was used for the experiments. The length, width, and height of the test cabin are 200 cm, 70 cm, and 50 cm, respectively. The sides of the cabin are made of a transparent material of plexiglas to provide sufficient visibility. The bottom of the test cabin was covered with a geotextile filter to prevent material loss and to allow seepage for the sampling.

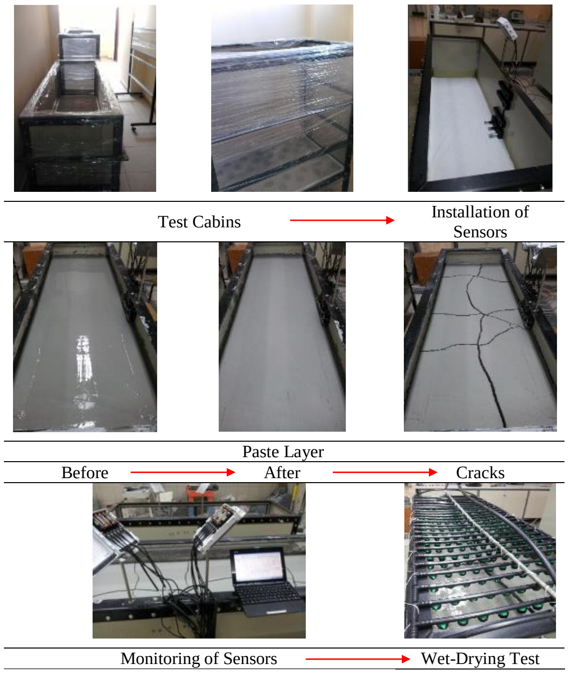

Figure 21. laboratory-scale test cabin

It was planned to apply different set-ups in the test cabins to determine the optimum design layout by testing several SPD configurations in terms of the important parameters which affect surface paste disposal method.

Set-up 1 was the test cabin consisting of completely uncemented paste tailings which poured layer by layer. This set-up was used to compare other test cabins where different configurations were tried. Set-up 2 was the test cabin where first layer consisted of cement by the weight of 2% of the amount of solid, and remaining layers consisted of the paste tailings with uncemented. The solid-water ratio of the sample for each set-up was adjusted as the slump value of 10″ (250 mm). With this test configuration, it was planned to make the alkaline level of the first layer increase, and hence to prevent the mobilization of heavy metals into groundwater. Also, the cement used as a binder in this set-up increased stability of the paste materials while strengthening the bonds between the particles. The cement as a binder is one of the important parameters increasing the cost of this process. Meanwhile, how reducing the cement ratio in the binder affects the process will also be investigated. Each set-up has 11 layers with 4 cm in height of each layer. During the setting up of the layers, next layer is cast on the previous layer after the completion of the drying period of that layer. Depending on the temperature and humidity conditions in the laboratory, drying period was chosen as approximately 7 or 8 days. Also, all of the layers must have an equal drying period. Oxygen, matric suction, volumetric water content, and temperature sensors were placed on the first, fifth, and tenth layers. The sensors and their ancillary equipment are seen in figure 22.

Figure 22. Sensors and data logger (a) Decagon 5TM moisture and temperature sensor (b) Decagon MPS-1 dielectric water potential (suction) sensor (c) Apogee SO-100 & 200 Series oxygen sensor (d) Decagon Em50 Datalogger Decagon DataTrac3 Software

3.6. Determination of The Optimum Design Parameters of Pb-Zn Mine Tailing Dam Using 2D Modelling [9]

The most common tailing disposal methods are tailing dams. The physical stability of tailings stored in tailing dams is very important. The accidents in tailing dams are an important part of environmental events that have taken place in mining operations. It has also a cost in the mining activities of tailing dams. It is very important to plan the tailing dams economically and safely (Figure 23). In this study, appropriate numerical modeling for different scenarios for the tailing dam was carried out considering the capacity, geographical conditions, geomechanical properties and geometry of the present state of a Pb-Zn tailing dam. In the created models, the areas of the overhead sections are considered as the unit cost of the dams and evaluated together with the safety coefficients. It was observed that limit slope angle is 40 degrees for the downstream tailings dam, and it is about 38-39 degrees for the upstream tailings dam. It was seen that the volume of downstream tailing dam is ~3.5 times higher than the cross-section area of upstream tailing dam for the same safety factor Figure 24).

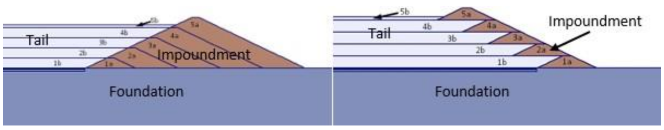

Figure 23. The design, construction steps and materials of the downstream (left) and upstream (right) dam

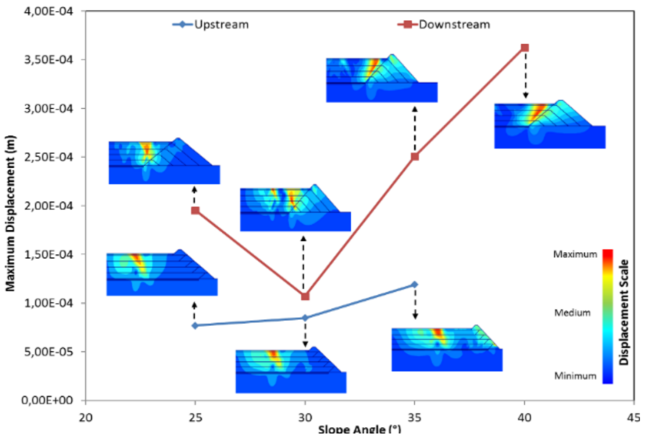

Figure 24. The relationship between slope angle and maximum displacement

3.7. Determination of Optimum Mixture Ratios of Paste Backfill Materials for Disposal of Mineral Processing Tailings [10]

In recent years, use of mineral processing tailings as a paste backfill has been significantly increased due to the environmental problems occurred during the disposal of the tailings in mine area. The paste material used to fill the stopes excavated is generally consisted of tailings (solid ratio: 70–85%) and cement (3-7%w/w). Meanwhile, the strength of the paste material is completely related to ratios of these materials. Cemented Paste Backfill (CPB) system is used as support depending on the roof pressure and also as an underground disposal method. Therefore, temporary strength value of the paste material gains a great importance. For example, the paste backfill material must compensate the minimum 4 MPa strength value in order to procure the permanent fortification, and the mixture cost must be minimal as well. For this reason, in this study, the Pb-Zn tailings were used to prepare for the paste backfill material using cement in order to perform the uniaxial compressive strength (UCS) tests. Additionally, a statistical experimental design and linear programming techniques was used to find the optimum mixture in terms of strength and cost. The pulp solid ratios (PSR) of the tailings and cement (by the solid) were varied as 75-85% and 3-8%, respectively. The results of this study; the optimum mixture is ~79.5%PSR and 6.8% cement ratio (by the solid) for 4 MPa UCS (28 day) and 16-17 cm slump value determined by this method with statistically reviewed experimental data. In this study, uniaxial compressive strength and slump tests were performed on paste materials prepared in different mixing ratios. These test results are given in table 4.

Table 4. Uniaxial compressive strength and the slump test results of the mixtures

Mix No	UCS (7th Days) MPa	UCS (28th Days) MPa	Slump
1	1.16	1.71	3
2	1.08	1.6	3
3	0.56	0.92	17
4	1.13	2.07	15
5	0.5	0.82	23
6	0.72	2.28	22.5
7	0.82	1.51	1
8	0.93	1.76	1
9	1.09	1.96	1
10	0.66	1.78	28.5
11	1.2	3.2	28
12	1.67	4.1	1
13	1.39	2.89	1
14	1.45	3.85	16
15	0.4	0.72	28.5
16	1.21	2.72	3

As can be seen from table 4, changes of the compressive strength and slump results of the paste material is prepared in different ratios are quite compatible. The mixture numbered 12 gave the maximum value in terms of compressive strength. As a result of the statistical analyses performed as part of this study, the effect of different mixing ratios on the compressive strength and slump properties of the paste material were determined, and empirical formulas were developed to be used in estimating these properties.

3.8. Use Of Geotextile Filtration System (Geotube® Technology) For Dewatering And Disposal Of Mineral Processing Plant Tailings [11]

The aim of this study was to investigate the use of Geotube® technology of TenCate in dewatering and disposal of mineral processing tailings obtained from the Pb-Zn flotation plant in Turkey. In this purpose, the dewatering process was performed using Geotube® Cone Test set-up. The flocculation experiments were carried out using four commercial flocculants (Drewfloc270, Amerfloc487, Praestol1857BC, and Perform Pk2325). The experiments were carried out at 20% solid ratio in pulp. The results showed that 99% of the particles were trapped in the Geotube® system, and the turbidity value of the discharged water was very low. Additionally, after the process, the solid contents of the samples were about 65%. The results also indicated that the optimum flocculant type and dosage was found to be as Drewfloc 270 and 200 g/t, respectively. Based on the results obtained from this study, it can be concluded that the Geotube® technology can successfully be used for dewatering and disposal of mineral processing tailings.

The study was firstly performed using Geotube® Cone Test set-up (GCT) (Figure 25).

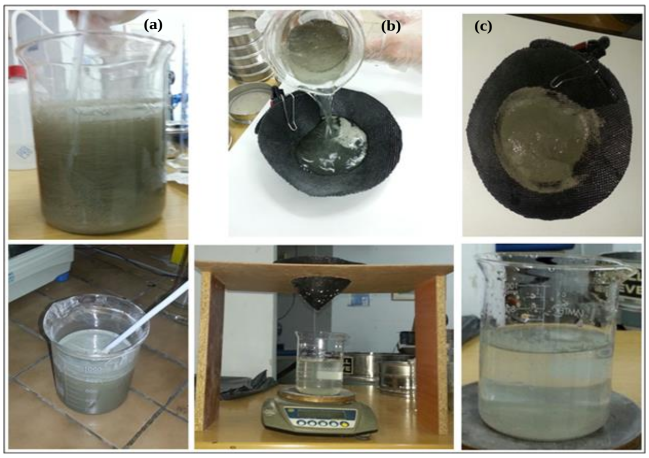

Figure 25. Geotube® Cone Test steps (a) conditioning (b) filtration (c) cake formation

The tests continued to investigate the effect of the flocculant dosage on the filtration process using the Geotube®. In this purpose, Drewfloc 270 which is the best flocculant so far was chosen for these studies. The flocculant dosages were varied between 25 g/t and 200 g/t. Table 5 shows the results of these tests. As seen from table 5, the amount of solid passed through the Geotube® filter decreased with the increase of the flocculant dosage. Figure 26 clearly shows this trend which the filtration process affected particularly at 50 g/t of the flocculant dosage.

Table 5. Results for GCT as a function of Drewfloc 270

Dosage (g/t)	Moisture (%)	Amount of solid passed through Geotube® (g)	Water Recovery (%)
No floculant	23.20	64.7	94.1
25	32.09	17.8	88.1
50	34.46	2.6	84.1
100	35.59	0.5	84.2
200	33.28	0.1	84.6

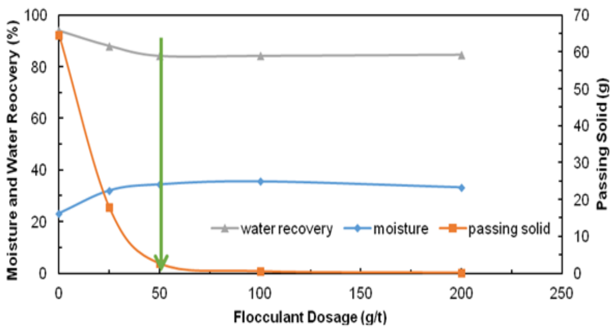

Figure 26. Results for GCT as a function of Drewfloc 270

For example, the number of solids decreased drastically after this dosage, and reached a plato which indicates that the optimum dosage must be higher than 50 g/t. Therefore, the optimum dosage was chosen as 200 g/t due to the minimum number of solids, and the size of the flocs.

References

[1] Başçetin, A., Tüylü, S., Adigüzel, D. & Özdemir, O. (2017). Field Properties and Performance of Surface Paste Disposal. *Springer, (6), 145-176.* https://doi.org/10.1007/978-3-319-39682-8_6

[2] Cornely, W. (2001). Elastifield silicate resins and polyurethane foam resins for the stabilization of strata – a comparison. Proceedings of the 6th International Seminary Reinforcement and sealing of rock and construction at the beginning of 21 st century. *Ostrava*

[3] Yetgin, H., Ünal, H. (2008). Polymer Based Foam Materials. *D.P.U. Institute of Science Studies*

[4] Kocaer, I. (2000). Two Component Resin Grouting Applications in German Hardcoal Mining. *CarboTech Berg- und Tunnelbausysteme GmbH*

[5] Tuylu, S., Bascetin, A. & Adiguzel, D. (2019). The effects of cement on some physical and chemical behavior for surfacepaste disposal method. *Journal of Environmental Management, (231), 33-40.* https://doi.org/10.1016/j.jenvman.2018.10.007

[6] Bascetin, A., Tuylu, S. (2018). Application of Pb-Zn tailings for surface paste disposal: geotechnical and geochemical observations. *International Journal of Mining Reclamation and Environment, (32), 312-326.* https://doi.org/10.1080/17480930.2017.1282411

[7] Bascetin, A., Tuylu, S., Ozdemir, O., Adiguzel, D. & Benzaazoua, M. (2018). An investigation of crack formation in surface paste disposal method for pyritic Pb–Zn tailings. *International Journal of Environmental Science And Technology, (15), 281-288*

[8] Bascetin, A., Tuylu, S., Adiguzel, D., Ozdemir, O. (2016). New Technologies on Mine Process Tailing Disposal. *Journal of Geological Resource and Engineering, 4(2), 63-72.* https://doi.org/10.17265/2328-2193/2016.02.002

[9] Başçetin, A., Adigüzel, D., Odabaş, E., Tüylü, S. & Eker, H. (2017). Determination of The Optimum Design Parameters of Pb-Zn Mine Tailing Dam Using 2D Modelling. *26th International Symposium on Mine Planning and Equipment Selection (MPES 2017), Lulea, Sweden*

[10] Bascetin, A., Tuylu, S., Adiguzel, D., Ozdemir, O. & Cinar U. (2016). Determination of Optimum Mixture Ratios of Paste Backfill Materials for Disposal of Mineral Processing Tailings. *SME Annual Meeting & Exhibit, Phoenix, Arizona/USA*

[11] Bascetin, A., Ozdemir, O., Adiguzel, D., Tuylu, S., Baktarhan, Y. & Harmsel, M.T. (2015). Use of Geotextile Filtration System (Geotube® Technology) for Dewatering and Disposal of Mineral Processing Plant Tailings. *XVI Balkan Mineral Processing Congress, Belgrad, Serbia*

Тау-кен өндірісіндегі тұрақты өндірістің жаңа технологиялары. Қалдықтарды басқару және тау-кен химиясы

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Аңдатпа. Шикізатқа деген қажеттіліктің артуы мен тау-кен өндірісінің ұлғаюына байланысты әлемде жыл сайын миллиондаған тонна қалдықтар түзіледі. Қалдықтар маңызды экологиялық проблемаларды тудыруы мүмкін. Сондықтан қалдықтарды басқару тау-кен өндірісінде өте маңызды мәселе болып табылады. Соңғы жылдары технологияның дамуымен паста және геотекстильді материалдарды пайдалану сияқты қалдықтарды жоюдың жаңа технологиялары айтарлықтай өсті. Бұл әдістер экологиялық жағынан да, шығындарды азайту жағынан да көптеген артықшылықтарға ие. Тау-кен өнеркәсібіндегі тағы бір маңызды мәселе – жерасты көмір шахталарындағы апаттар мен кәсіби денсаулық проблемалары. Мәселелерді өздігінен жану, шатырдың құлауы, көмір қабатынан газ алу және т.б. деп сипаттауға болады. Бұл апаттар жерасты шахталарында тау-кен химикаттарын қолдану арқылы айтарлықтай төмендеді. Бұл зерттеуде тау-кен өндірісі тұрғысынан өте маңызды болып табылатын қалдық қоймасы және тау-кен химикаттары қарастырылады.

Негізгі сөздер: *қалдық қоймалары, тау-кен өндірісі, қалдық қоймасы, тау-кен химикаттары, жерасты кеңіштері.*

Новые технологии устойчивого производства в горнодобывающей промышленности. Управление хвостохранилищами и горнодобывающие химикаты

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Аннотация. Ежегодно в мире образуются миллионы тонн хвостов в связи с увеличением добычи полезных ископаемых наряду с увеличением потребности в сырье. Хвосты могут вызвать серьезные экологические проблемы. Таким образом, управление хвостохранилищами является очень важным вопросом при добыче полезных ископаемых. В последние годы, с развитием технологий, значительно расширились новые технологии удаления хвостов, такие как паста и использование геотекстильных материалов. Эти методы имеют много преимуществ с точки зрения как защиты окружающей среды, так и снижения затрат. Другой важной проблемой горнодобывающей промышленности являются несчастные случаи и проблемы со здоровьем на производстве в подземных угольных шахтах. Проблемы можно охарактеризовать как самовозгорание, обрушение кровли, выделение газов из угольного пласта и т.д. Эти аварии значительно сократились благодаря использованию горных химикатов в подземных шахтах. В этом исследовании рассматриваются управление хвостохранилищем и химические вещества для добычи полезных ископаемых, которые очень важны с точки зрения применения в горнодобывающей промышленности.

Ключевые слова: *хвостохранилища, применение в горных работах, управление хвостохранилищами, горнохимические продукты, подземные рудники.*