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MINING AND ENVIRONMENTAL PROTECTION

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MINING AND ENVIRONMENTAL PROTECTION

PROCEEDINGS

Editor
Prof. dr Ivica Ristović

Sokobanja

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FOREWORD

After the consultations with business entities in the field of mining and environmental protection, faculties and scientific institutes, an initiative for organizing a scientific meeting on mining and environmental protection was taken in 1996. The Faculty of Mining and Geology in Belgrade, CENTER FOR ENVIRONMENTAL ENGINEERING, have organized the First Yugoslav Conference with International participants held from 25 to 27 April 1996. in Belgrade, Serbia. The second International Symposium was held in Belgrade from 25 to 27 May 1998. The third Symposium was held in Vrdnik from 21 to 23 May 2001. The fourth International Symposium was held in Vrdnik from 23 to 25 June 2003. Due to the large number of subjective and objective reasons organization of the symposium was discontinued in 2003. Fifth International Symposium was held in Vrdnik from 10 to 13 June 2015. The sixth International Symposium was held in Vrdnik from 21 to 24 June 2017. The seventh International Symposium was held in Vrdnik from 25 to 28 September 2019. and the eighth International Conference was held in Soko Banja from 22 to 25 September 2021.

On the basis of the conclusions made at the 8th Conference MEP 2021 and great interest of domestic and foreign scientific and professional public, the Faculty of Mining and Geology in Belgrade, in cooperation with co-organizers (Berg Faculty TU Košice, Slovakia, University of Ljubljana, Faculty of Natural Sciences and Engineering, Slovenia, Goce Delčev University in Štip, N. Macedonia, Geological Survey of Slovenia, Ljubljana, Slovenia, University in Banja Luka, Faculty of Mining, Prijedor, Republic of Srpska, Bosnia & Herzegovina and Association of Mining and Geology Engineers), shall organize the 9th International Conference Mining and Environmental Protection – MEP 2023.

The previous Symposium, were very successful and scientist and companies from many countries gathered to exchange information and research results. The objective of this Conference is to bring together engineers, scientists and managers working in mining industry, research organizations and government organizations, on development and application of best practice in mining industry in the respect of environment protection.

At the Book of Proceedings of 9th International Conference on Mining and Environmental Protection are 56 Papers. Almost half is from abroad, or their authors is from different countries. At least 166 authors and co-authors took part in the preparation of these papers. The papers were reviewed by Reviewers. Only high-quality papers were selected, from two side, one from the scientific basis and the second from point of view of applicability in resolving problems at the development of mining.

We are very grateful to the authors of the papers, who contributed to a great extent to the success of this meeting by having sent enough number of high-quality papers, and thereby made the work of the reviewers a pleasant one in respect of selecting the best quality papers. Also, we would like to thank all of the participants in the Conference, as well as the sponsors who helped and enabled us to hold such a great meeting.

Editor

PROCEEDINGS

9th International Conference **MINING AND ENVIRONMENTAL PROTECTION**

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TAILINGS IN-PIT DISPOSAL AND COVERING TECHNIQUES - CASE STUDY

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Abstract: *The application of environmental standards and the circular economy are already realities in the mining industry. Respecting this operating strategy necessitates the use of ecologically safety disposal methods for mining waste. Generally, tailings are often disposed in old open pits, but making this decision depends on a number of factors. After the disposal process is completed, it is necessary to apply appropriate covering techniques. These tailings management processes along with influencing factors as well as a case study of a mine in North Macedonia are presented in this paper.*

Keywords: *underwater disposal, pit backfilling, environmental impact, waste*

1. INTRODUCTION

The disposal of mining waste is becoming an increasingly scrutinized issue in terms of environmental impact. The practice of inappropriate disposal of this type of waste in the past is a constant reminder of the serious negative mining environmental impacts. Some of the key public and environmental issues relate to: long term stability of impoundment sites; long term leaching; and erosion of surface disposal sites. One method of mining waste disposal which often mitigates these concerns is the disposal of mining wastes in mined-out pits [1].

Tailings in-pits disposal is already a practice in some countries. Historically, industrial, municipal and mining waste was disposed of in old and already closed quarries and open pits. Although the specific use of open pits for the disposal of mining waste is common, however, the reason for using open pits was more for convenience than a conscious decision to environmental protection [1,2].

The practice of tailings disposal in open pits is well accepted in more countries. More recently, mine operators have even proposed that open pits can be used for the sole purpose of removing mining waste [3].

However, disposal of mining waste in open pits cannot be presented as a universally good waste management strategy. It is necessary to investigate certain specific factors for the mine location, which will show that this strategy is appropriate. Some of the key factors to consider when assessing the applicability of a mining waste disposal methodology includes: hydrogeology of the location, geochemistry of the waste, and morphology of the open pit [4].

In this paper, several disposal techniques, as well as covering techniques of disposed tailings in mined-out open pits have been presented. A case study of the application of some of these techniques in a mine in North Macedonia have been also presented.

2. IMPORTANT DECIDING VARIABLES FOR TAILINGS IN-PIT DISPOSAL

The decision of tailings disposal in a certain mined-out open pit and disposal method depends on:

- the tailings characteristics and
- the pit wall characteristics

Characterization of the tailings is extremely important for defining appropriate methods for in-pit disposal placement. Key factors requiring characterization are given in Table 1.

Table 1. Key factors for tailings characterization [5]

Factor	Description
Acid generation potential	Acid mine drainage is the result of the combined chemical and biological oxidation of sulphide minerals and release of associated metals, such as iron, aluminum, manganese, uranium and other toxic heavy metals, depending of mineral composition of the tailings.
Leachate quality, leachable mass and future geochemistry of pore water, pit water and groundwater	The quality of pore water within the in-pit disposal tailings is a key factor in determining the engineered controls necessary for a suitable in-pit disposal strategy. If leachate quality is only marginally contaminated, predictive modelling of contaminant releases may well demonstrate that the potential environmental impacts are insignificant, but it may also show that engineered controls such as "pervious surrounds", diffusion barriers, engineered covers etc. are required to develop a satisfactory in-pit disposal option.
Grain size	Grain size is an extremely important parameter as it affects several important processes: rate of acid production (surface area), reactivity of buffering minerals, permeability/porosity, moisture content and mechanisms of contaminant transport (diffusive versus convective) [8,9].
Permeability	Permeability is important to permit an assessment of the hydraulic transport of infiltrating water or groundwater through the waste. Usually, the tailings have very low permeability in comparison with the fractured rock around the pit. Under these conditions, minimal infiltration may occur and groundwater will tend to pass around the pit through fractured zones rather than through the tailings disposed in the pit, that result with slower release of metals and contaminants from the wastes [8,9].
Consolidation characteristics	The consolidation effects will vary depending from the deep of the pit.

The characteristics of the rock material of the pit wall are extremely important in deciding whether it is suitable as a space for the tailings disposal. These characteristics are given in Table 2.

Table 2. The pit wall characteristics

Characteristic	Description
Volume	The volume of the open pit is very important factor and should be large enough to accommodate the expected tailings amount.
Sterility of the pit wall	The ore reserves, which at some future time will be exploited, under and around the open pit is also very important.
Occurrence of springs and inflow of groundwater in the open pit	In this case, the examination of the water pH is necessary and if it is an acid water, it must be pumped out. The appearance of a spring with acid water would mean that this location is unsuitable for tailings disposal.
Structural characteristics of the surrounding rock material – degree of cracking	If thickened tailings are disposed, the greater degree of cracking would allow free circulation of groundwater around the disposed tailings.

3. ENVIRONMENTALLY ACCEPTABLE TAILINGS DISPOSAL AND COVERING TECHNIQUES

In practice, there are three techniques for the tailings disposal in pits, which refer to the disposal of reactive tailings, but the same can be used for the disposal of non-reactive tailings [1,2]:

- Underwater Disposal;
- Pit backfilling;
- Dry Disposal;

The underwater disposal in open pits can be considered on four options, such as: simple underwater disposal, underwater disposal with a surface barrier, underwater disposal with groundwater barriers and underwater disposal with surface and groundwater barriers. At the simple underwater disposal, tailing is disposed at the bottom of the pit and inundated. In an ideal pit, convective groundwater transport would be minimal and the prime mechanism for release would be through mass transfer (diffusion) from the surface of the tailing into the pit water. For the option underwater disposal with a surface barrier, a barrier is placed over the surface of the submerged reactive tailings to reduce upward contaminant transport into the water. The most commonly used barrier would be a clean soil (sand, till, clay, etc.). If there is a significant convective flow of groundwater through the tailings, then is used the option underwater disposal with groundwater barriers.

At the pit backfilling technique, the pit would be backfilled to near the original ground surface. The primary concept is to control oxidation by raising the water level above the reactive tailing into a layer of clean fill/tailing. The follows options of this technique are knowns: saturated reactive waste, saturated reactive waste with surface barrier, saturated reactive waste with bottom barrier, saturated reactive waste with surface and bottom barriers and elevated water table within reactive wastes using a bottom liner.

In the case that it is not possible to create a pond or an elevated water table, four dry disposal options are possible: engineered cap/cover, acid buffering barriers, alkali blending and engineered cover with water table drawdown. Dry covers can act as: barrier to water, barrier to oxygen, and barrier to both water and oxygen.

Covering techniques for in-pit tailings facilities depends primarily from tailings classification whether they are inert or tailings with acid potential. In Table 3 have been shown the covering techniques that are most frequently used.

Table 3. Covering techniques for in-pit tailings facilities

Covering technique	Description
Covering with a water layer	This technique can be used regardless of tailings categorization, but it is still required to constantly monitoring and control of the water height to keep it at a desirable level.
Covering with a natural or artificial waterproof layer, over which a layer of fertile soil is placed and revegetation is carried out	This technique is applied for tailings with the acid potential. Compacted clay is used as a natural sealing covering material, and a combination of geoclay, geomembrane and other artificial materials is used as an artificial material.
Covering with a layer of fertile soil, after which revegetation is carried out	This technique is applied for inert tailings.

4. CASE STUDY

The open pit of metallic mineral resources in North Macedonia was have been taken taken as a case study. From the several mined-out open pits, three possible locations were considered for depositing of 17

000 000 m^3 tailings. Based on the data in Table 4, such as, volume, the presence of water and natural springs and their pH, among the three locations, location no. 3 is chosen.

Table 4. Required data from possible locations

Data	Unit	Location 1	Location 2	Location 3
Volume of the open pit	m^3	62 000 000	50 000 000	21 000 000
Water on the bottom in the open pit	m^3	2 500 000	2 000 000	Small amount
SO_4^{-2} in the water	mg/L	4 421.16	N/A*	1 233.88
Water pH value		2.75	N/A*	8.21

* no possibility of sampling due to unsafe access

The use of shallow water covers to flood reactive mining tailings is one of the most effective and common methods of managing sulfide-rich reactive tailings in temperate climates. This area is characterized by a cold and wet winter, characteristic of the continental climate, and a dry and hot summer, which corresponds to the Mediterranean climate. The minimum temperature for this year was measured in February (-14°C), while the maximum temperature was measured in August (41°C). The average maximum annual temperature in the area is 20°C, and the average minimum annual temperature in the area is 8°C. During the year, the average monthly wind speed ranges is 3.3 - 7.7 m/s, while the average annual amount of precipitation is 47.2 mm.

According to Mustafa and Ernest (2005) [6] a maximum water cover depth of 2.5 m is necessary to eliminate tailings resuspension, a maximum depth of 1.5 m could still be used, as the resulting concentration of suspended tailings remains within the regulatory limit. Due to these facts, the method of simple underwater disposal was chosen (Figure 1) [7], the tailing is placed at the bottom of the pit and covered with water. Having in mind the wind speed data, the recommendation is that the water height should be between 2 and 2.5 m. While based on the average temperatures and precipitation data, the recommendation is continuous monitoring of the water layer height and, if necessary, bringing or pumping a certain amount of water, in order to maintain the recommended height during the tailings life cycle.

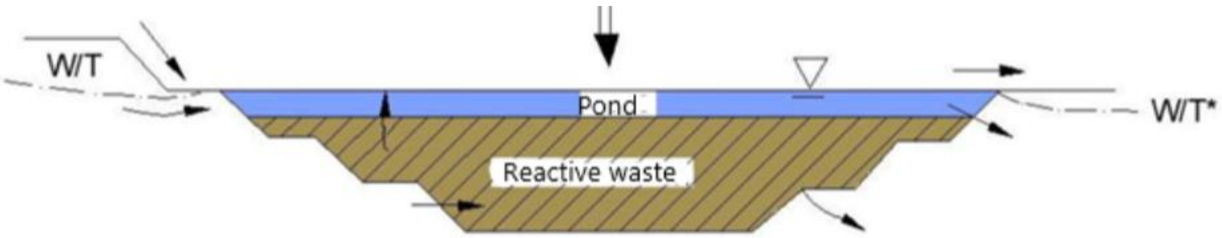


Figure 1. Underwater tailings disposal

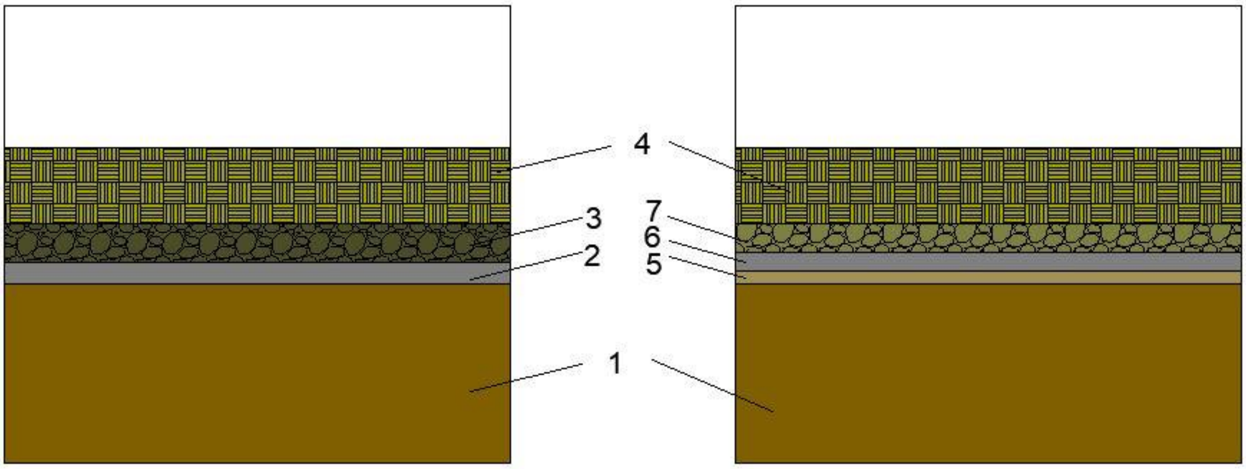
Gravity transport of the tailings (in a system of open channels) from the flotation plant to the disposal site (empty excavated area in location 3). Then follows a cyclonication process, after which the liquid phase would go to a precipitator, and the resulting solid phase (with about 70-80% solid) to the empty space of location 3. The water from the sedimentation tank is pumped through a pipeline to the flotation plant as e technical water.

The obtained results for acid-neutralization potential of the examined samples from tailings in this mine show very variable values. Two of the four samples examined revealed relatively high acid potential, while the other two samples do not have such potential. Therefore, it is necessary to increase the number of samples and the time period of sampling. If the results of the tests on a larger number of samples, to determine the acid-neutralization potential, show that the tailings have a high potential for generating acid mine drainage, then it is necessary to add a certain amount of lime or limestone to the deposited material. Otherwise, the disposal would be carried out without the addition of alkaline materials.

The values of the water permeability coefficient in old tailings facilities in sulfide ore mines is in the range 10^{-6} - 10^{-7} m/s, which indicates that the terrain is characterized by low water permeability. This leads to the conclusion that during the deposition phase the terrain would be characterized by medium water permeability (k is between 10^{-5} and 10^{-6} m/s). This implies that the topography would have medium water permeability throughout the disposal phase (k is between 10^{-5} and 10^{-6} m/s). In order to make more accurate assessments, it is necessary to perform an examination of the water permeability of the existing tailing facilities. If the results show water permeability values $<10^{-7}$ m/s, then the tailings would be deposited without the cement addition.

Taking into account the tailings composition and characteristics, which is characterized as hazardous waste, the possible covering method of in- pit tailings, after completion of disposal, would consist of the following steps:

- pumping out all the water created in the disposal phase;
- placement a layer that will allow reduction of oxidation (straw, wood shavings, etc.);
- covering with a waterproof layer ($k \leq 2$ x10^{-7}m/s) of natural (Figure 2a) or artificial materials (Figure 2b);
- placement a layer of fertile soil with a thickness of 0,3 m;
- the last step is revegetation.



a) ***b)***

Figure 2. Covering the installation, a) with natural waterproof materials and b) with artificial waterproof materials

1- tailings, 2 – compacted layer of clay (10 – 15 cm), 3 – drainage layer of bulk rock mass or other inert material (20 - 30 cm) to water permeability coefficient k = 2x10⁻⁴ m/s, 4 – 30 cm layer of fertile soil, 5 – geomembrane, with layer thickness ≥ 1 mm, 6 – artificial clay, with layer thickness ≥ 6 mm and 7 – artificial drainage layer, with layer thickness ≥ 10 mm

5. CONCLUSION

The choice of an appropriate tailings disposal technique is one of the most significant issues in terms of environmental impact. The practice of inappropriate disposal of this type of mining waste in the past, constantly reminds of the serious negative environmental impacts of mining. One of the tailings disposal technique that contributes to reducing the environmental impact of mining waste is in-pit disposal of this type of mining waste.

Theoretically, oxidation is prevented when mining waste is in-pit disposed and covered with water. Additionally, this method of in-pit waste disposal, which involves covering it with water, can significantly reduce the release of pollutants, either through diffusion as a management control mechanism or by almost completely eliminating the hydraulic gradient through the pit, which in turn reduces convective outflow. In both cases, the control of the oxidation process greatly reduces the potential of pollutants, that indicates the conclusion that the tailings in-pit disposal covering technique, are imposed as one of the most environmentally acceptable techniques for tailings disposal.

The covering technique with a natural or artificial waterproof layer, over which a layer of fertile soil is placed and revegetation is carried out, is another environmentally responsible method and at the same time it allows a more sustainable monitoring manner of the closed waste installation compared to the underwater tailings disposal technique, considering it necessitates of continuous monitoring and maintenance of the water height above the waste installation.

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