REMEDIATION OF A TAILING POND IN EASTERN SLOVAKIA

Assoc. Prof. Dr. Tomáš Bakalár[1]
Assoc. Prof. Dr. Henrieta Pavolová[2]
Assoc. Prof. Dr. Naďa Sasáková[3]
Dr. Rudolf Hromada[4]
Assoc. Prof. Dr. Ľubica Kozáková[5]
[1, 2, 5] Institute of Earth Resources, Faculty of Mining, Ecology, Process Control and Geotechnologies, Technical University of Košice, Slovakia
[3, 4] Department of Public Veterinary Medicine and Animal Welfare, The University of Veterinary Medicine and Pharmacy, Košice, Slovakia

ABSTRACT

In Eastern Slovakia, due to extensive chemical production in the past, especially production of explosives, and continuing combustion of coal, toxic chemicals, PCBs, fly ash and other substances are stored in a tailing pond. The current state of the tailing pond and the surrounding area, as well as its impact on the environment is analysed. Based on the results of the analysis remediation of the tailing pond is suggested. The closure of the tailing pond, including stabilisation of the pond material and the treatment of the pond surface, is designed. The result of the study proposes two possibilities of the use of pond after remediation – for growing crops as biomass and for building of a recreation and regeneration centre. In both the proposals, their advantages and disadvantages were evaluated. Reclamation will take place through a combination of technical and biotechnical stages. These proposals would be a great plus and benefit not only for the tailing pond but also for the environment and the surroundings of the pond.

Keywords: *tailing pond, toxicity, remediation, biomass, recreation*

INTRODUCTION

Due to adverse effects on the environment, tailing ponds are classified as a very problematic area. It negatively affects all compounds of the environment, including humans, animals, and plants. Tailing ponds mainly affect the bedrock, the quality of air, soil, groundwater, and surface water [1], [2]. People living near a tailing pond are afraid of the sludge as it may pollute the soils and water resources in the surroundings.

Before the sludge pond is closed it is important to decide on the use of the tailing after the remediation. This is mainly for practical reasons, so that we can plan a project for the reclamation of the tailing in the most efficient way. Reclamation should result in the restoration of devastated or contaminated land. The extent, and the requirements for the reclamation of the area depends mainly on the activity it will serve for in the future, which can be, for example, for sports or recreational purposes, for forestry purposes, for agricultural purposes, or for other purposes [1], [3]. The project of the reclamation of a closed tailing pond should be

prepared based on the type and the amount of pollutants, for example heavy metals, in the material of the tailing. The project should identify the stages in which the reclamation will be carried out. When creating a project for sludge reclamation, it is important to follow these measures [1], [3]:

- minimize long-term effects on the environment on and around the tailing pond (including chemical stability),
- guarantee long-term safety, and stability of the pond (including geotechnical stability),
- integrate the tailing pond into the natural environment, e.g. forest (including biological stability).

In addition to the project of reclamation and remediation, the tailing pond must be monitored for a long time so that its safety is not compromised in any way. Monitoring is performed according to the specified schedule [1], [3].

The aim of the study was to propose a suitable method for reclamation of the devastated area, on which there is currently a tailing pond with pollutants and to choose the most suitable method of restoration for the tailing.

STUDY AREA

The tailing pond is located in the eastern part of Slovakia and geologically belongs to the volcanic formations of the Neogene Western Carpathians. Sediments consist mainly of clay, sandstone, gravel, etc. Neogene volcanic rocks are represented by formations with andesites, tuff rocks and rare rhyolites [4]. Next to the tailing is a stream that flows into the Ondava River basin. The source of contamination of these watercourses is the sludge pond. Arsenic contamination in this area has been reported since 1995 and represents one of the most serious environmental risks in Slovakia. The water in the watercourse has a high content of total As in the range from 300 to 11,000 $\mu g.l^{-1}$, as well as a high salinity. The high concentration of As, combined with the high salinity of water, threatens the potential use of water for the surrounding fields, but also for safe irrigation and drinking water [5]. The main consequence of the development of industrial activity is the growing discharge of polluting and toxic substances into water and soil. Heavy metals, which subsequently accumulate in the body, pose a major risk to human and animal health. They bind to the body and cause serious health problems. Some of these metals may not have a high concentration, but they still pose toxically. The most toxic cations include Be^{2+}, As^{3+}, As^{5+}, Cd^{2+}, Cr^{6+}, Hg^{2+}, and Pb^{2+}. It is these heavy metals that come from mining or other industrial activities, cause acidification of the soil and thus increasing problems in agriculture or forestry. Chemical pollution of watercourses is a major threat to aquatic organisms, including fish [6].

The total area of the tailing pond is approximately 0.38 km^2. The dam is 16 m high and the storage area is 0.328 km^2. The tailing pond was created for the storage of mostly waste in liquid form from industrial activities [7]. Ash generated as waste in the production of explosives and waste from coal combustion were also deposited at the tailing pond. Waste from the production of benzene chemistry, cyclohexanol,

industrial fertilizers, nitrogen, ammonia, concentrated acids and others were mostly present in the sludge [8].

RESULTS AND DISCUSSION

Insufficient slope stability might be a problem. The degree of stability of the slope of the pond can be calculated or graphically represented based on the analysis of samples taken during the operation of the tailings pond. First, an expert opinion on the stability of the slopes is necessary. The most basic methods for solving slope stability are balance or deformation. If the bodies are unstable for a long time, landslides may occur. The degree of the stability factor of the slopes after the closure of the tailing pond should be at least 1.3, while, if there was a larger water cover on the tailing pond, this factor can also be 1.5. The higher this safety factor the better we can reduce the cost of long-term monitoring after the closure of the tailing pond [9].

The surface treatment of a tailing can be divided into two most basic stages: technical and biotechnical stage. For preventing unfavourable processes in the tailing, it must be insulated, drained from surface and rainwater, but also biological reclamation must be done, for example: soil movement, storage, spreading, etc. To prevent the formation of acids and bases, the sludge must be sealed and insulated properly [3].

It is important to develop selective disposal, so hazardous waste must be deposited in the lowest layer as far as possible. As a result, hazardous waste will not come into contact with fertile soil and will therefore not have any negative effects on plants or even animals. Waste that is not inert must not come into contact with groundwater or seepage liquids. The toxic material must be covered with a neutral material, or if necessary, the storage with toxic material can be covered with waterproof material for safety. In the final step of the reclamation of the sludge, the material, that is applied to the top layer, works for a long time, which means that it can be compressed or otherwise deformed. The sealing system must sufficiently work against certain water leaks, such as surface water or leak liquids. It is important that this system is resistant to physical and chemical influences at anytime. This sealing layer still needs to be enriched with other technological layers, e.g. drainage, separating, protective or reinforcing [3].

After closing and sealing the tailing, last stage, biotechnical, starts. The task of this stage is to stabilize and revitalize the reclaimed area with greenery. The most important thing is to cover it with fertile soil. As there is a shortage of fertile soils, more complex solutions, such as modifying the chemical, physical properties of soils (e.g. acidity or structural change) or supplying nutrients to the soil (such as fertilization) can be applied. If the soil has a low pH, less than 4.5, the pH must be increased to at least 6.0. The slopes of the tailing must be protected from erosion. This biotechnical stage depends mainly on the mineralogical composition of the pond. Low dumps are most suitable for agricultural crops, but medium-high dumps with acidic soils tend to be immediately afforested [3].

The merit of reclamation is to create a new surface, so it is an advantage to know from the beginning what the area will be used for. The following four steps must be followed when recultivating the tailing pond [1], [10].

- Geotechnical stability. It is necessary to secure and strengthen the dam of the tailing pond and at the same time stabilize the subsoil. It is also necessary to ensure the stability of the slope of the tailing pond, but mainly to ensure the entire sludge pond against further weathering and thus possible further pollution of the surroundings. A regime for groundwater and sand water, monitoring of their level and flow rate, must be introduced.
- Chemical and filtration stability. It is important to ensure the chemical stability of the materials, i.e. the construction of the dam on the tailing pond, to prevent further aggressive effects of deposited material, etc. The tailing must be secured against burning, penetration of pollutants, prevention of further degradation and the release of solid, liquid, but also gaseous emissions into the environment.
- Biological stability. From the point of view of biological stability, it is essential to ensure the restoration of the ecosystem.
- Ecological stability. Complementary step to minimize any further pollution in the area that could enter the air and spread the pollution.

In order to close a tailing pond with mostly acidic seepage liquids, the physical and chemical properties of the deposited material must be considered. Most reclamation and remediation methods are aimed at reducing the rate of sulphide oxidation, thus reducing the subsequent mobilization of weathering products to limit or even prevent further transport of oxygen to the sulphides, by using a barrier of either dry or wet cover. Other methods can also be used – removal of sulfidic minerals, addition of minerals with buffering ability, reduction of the surface of grains which weather etc. As a diffusion barrier against the transfer of oxygen from the atmosphere to the pond, the level of free water must be used. Thus, the oxygen diffusion coefficient for water must be less than the diffusion coefficient for air, and that is why the subsequent oxidation of sulphides is removed by the water layer. This method is conditioned by a relatively positive water balance, it also has a long-term physically stable dam, which is provided with sufficient drainage capacity to prevent the formation of further suspension due to waves that are on the surface. The water that is on the tailing pond is removed. The surface of the sludge is then allowed to dry, but the material in the body of the tailing is still in the form of saturated water (fine-grained particles are soaked in water, so the material is soft). The surface of the entire tailing pond is covered with layers of material, which must have the ability to bind water well and have low permeability. When covered with dry material, a separating and drainage layer can also be considered. This dry coating reduces the reaction rate by limiting the diffusion of oxygen present on the surface of the tailings and venting it to the intergranular spaces. This also reduces the formation of acidic seepage liquids, infiltration of surface water and consequently the transfer of reactive products is limited. This cover is composed of several layers, which are formed by different soils. The total thickness of the coating is in the range from 0.3 to 30 m and the permeability of the (sealing) layer is from

1.10^{-7} to 1.10^{-9} $m.s^{-1}$. The tailing pond must be sufficiently drained before coverage [9], [10].

Precautions must sometimes be taken against dust emissions before coverage. In order to avoid further collection of rainwater as well as water from surface runoff, the slope of the sludge pond must be adjusted to 0.5 to 1° towards the collecting ditches, which are intended for drainage. The layer, which is located completely on top, must serve to protect the cover, especially from drying out and erosion. The top part is in most cases green with grass [9].

First, the tailing must be covered with a cohesive layer of soil. This is one of the simplest cases. In particular, this soil must have the lowest permeability. If this is not the case, a reduction in permeability for some soils can be achieved by spreading the soil over a thin layer or by compacting the soil at a suitable moisture content. The most effective way is to cover the compacted clay layer, which, however, must have a low permeability. The thickness of the clay layer depends on climatic conditions, such as potential evaporation, but mainly depends on precipitation. The local fauna and flora also have an impact on it. The third type is the reduction of infiltration, which can be achieved by building a drainage layer, which will be placed above the surface layer. This reduces infiltration, but there may also be some tendency to increase oxygen diffusion in the water-saturated zone, resulting in inappropriate use of the infiltration reduction method. The last fourth method is a coarse-grained layer, which will be located between the sealing layer and the tailings. The sealing layer can also act as a capillary barrier, which prevents drainage and diffusion transfer of dissolved components [9], [10].

Geotextiles are used for dry cover reclamation. Their durability can be quite problematic in the long-term perspective. When it is teared up, the layers can be mixed, and thus the drainage effects of the drainage layer are either reduced or eliminated. When afforesting the uppermost part, the roots must not negatively affect the permeable layer in any way. Thus, the thickness of this layer must be sufficient to prevent such disturbance. The effects that can be caused by frost when melting snow and ice must also be considered. This could cause an increase in permeability. To prevent erosion, it is also advisable to sow the area with grass [11].

Crops for biomass

During last years, before closing, wet ash and slug was stored in the tailing. After closing, the pond must be isolated from the surrounding environment to stabilize the impact. The top surface of the tailing is covered in stabilizer and soil to prevent the leakage of rainwater into the lower layers of solid pollution and thus also prevent the subsequent run-off of the accumulated liquid waste. If run-off occurred, the perimeter of the dam could be weakened by hydrostatic pressure and subsequently cause the dam to rupture. Growing some crops on a closed and remediated tailing pond would be very beneficial not only for the area of the tailing but also for the surrounding landscape. As this design has not yet been carried out experimentally, we cannot determine with certainty what thick layer of covering material we should use for the sludge pond [12].

The subsoil intended for sowing crops shall be prepared based on the needs of the plants. Plants that are planted on the remediated tailing not only stabilize it, but, with root system, also capture a large amount of rainwater, and thus serve to drain the sludge. For a successful and useful plant growing, a suitable subsoil for growing selected crops must be selected. To prevent water leakage, hydrolysing foils, and stabilizers, with a thickness of about 30-60cm (Table 1), are recommended. A 3mm thick hydrolysing foil is placed on the tailing pond and four large-scale plots are prepared in the required subsoil structures [12] as follows:

- stabilizer with a thickness of 30cm, 60cm and without stabilizer,
- subsoil, from 30 to 55cm thick, reflecting the subsoil profile of the reclaimed area,
- topsoil, from 15 to 30cm thick, reflecting the soil profile of the reclaimed area.

Table 1. *The structure of experimental seeding variants and the number of rooted individuals in the sludge pond [12].*

Plot	Stabilizer (cm)	Subsoil (cm)	Topsoil (cm)	Sum (cm)	Proportion of rooted plants (%)
1	30	55	20	105	87
2	60	50	30	140	91
3	-	45	20	65	92
4	-	50	15	65	95,5

A grass mixture, composed in a way suitable for the conditions of tailing, is used as the cover layer. The sowing must be in the given term, according to the climatic and agroecological conditions of the area. The composition of the suitable grass mixture is, therefore, as follows [12]:

- grass mixture composed of perennial mint – Barrage 35% and Bartwingo 20%, red fescue – Barustic 30%, and meadow grass – Brooklawn 15%,
- grass mixture composed of perennial mint – Barrage 25% and Bargreen 25%, meadow fescue – Baron 20%, and crawling clover – Barbian 10%.

The acceptance of these plants is individual, and it depends mainly on climate change or on consumption by animals in large quantities. However, we hope that such biomass cultivation as sludge reclamation will be beneficial for the area. The tailing pond will be monitored after planting these plants and prepare it for planting trees.

Building of a recreation and regeneration centre

Since there are mostly heavy metals, arsenic, PCBs substances and others, in the sludge pond, a compacted barrier formed of clay (bentonite) must be created. Bentonite is mainly used because it has a low permeability, lower than the permeability of waste in the pond [13]. One of the measures in reclamation is to

prevent further disposal of waste to the tailing and subsequently its long-term monitoring. The entire surface of the tailing pond must be secured against flood, seepage, or disturbances, etc. All these, but also other measures are used to ensure the safety of the tailing pond [14].

After closing the tailing, these steps follow [3]:

- identify the possible environmental risks posed by tailing,
- identify a procedure to stabilize heavy metals, arsenic, PCBs, and other in the sludge,
- design and develop a specific reclamation plan for a recreation centre,
- verify the suitability of the reclaimed tailing pond for selected purpose and subsequent long-term monitoring of the centre.

After the application of bentonite to the surface layer of the tailing, another layer of soil of a specific pH is applied onto this layer to grow trees and plants. First, a grassy area and later also trees and plants (e.g. meadow flowers) are planted. Between these plants and trees, a multifunctional playground, where not only children but also adults can play, is build. Near the playground, a freshwater lake with fish, which will then be used for fishing is built. There are several benches around the lake.

Near the reclaimed tailing pond, a feeder for forest animals is placed. A few meters from the lake and the playground, a lookout tower, which will serve tourists and locals, is build, to enjoy the view of the whole area of dense forest and the village. If this project is implemented, a panel road will be built to this recreational and leisure zone, so that people do not have to wade through muddy and dirty fields. Unfortunately, cars at this resort will not be able to park. However, a parking lot will be in the nearby village. People will enjoy less cars and more relax in this resort and recharge their batteries.

CONCLUSION

Nowadays, the issue of tailing ponds is very topical. In Slovakia, there are several tailing ponds that pose not only a great environmental burden but also risk for people's lives. One of them is in the east of Slovakia. There were released polluting (toxic) substances such as PCBs, fly ash and other hazardous substances, which are still deposited in the tailing pond. If it is not closed, the sludge pond will have negative effects not only on the soil, groundwater and surface water around the pond, but also on the surrounding plants and animals living there. Therefore, it is proposed that the tailing pond be closed as soon as possible, secured against further leakage of pollutants and subsequently recultivated (reclaimed). When proposing the reclamation of the given site, it was found that two ways would be the best for the area, and they are: cultivation of biomass and building of a recreation and regeneration centre. At this resort there would be a playground, a small lake, but also a lookout tower. In both the proposals, their advantages and disadvantages were evaluated. Reclamation will take place through a combination of technical and biotechnical stages. These proposals would be a great plus and benefit not only for

the tailing pond but also for the environment and the surroundings of the pond, as high concentrations of heavy metals were also found in the Ondava River.

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