

# INCIDENTS IN FLOTATION TAILINGS DAMS AND ENDANGERING OF LIVING ENVIRONMENT

**Boris KRSTEV, Blagoj GOLOMEOV, Alexandar KRSTEV**

*Faculty of Mining & Geology-Stip, R. Macedonia,*

*2000 Stip, R. Macedonia*

*blagojg@rgf.ukim.edu.mk, borisk@rgf.ukim.edu.mk*

## **Abstract**

*Dangerous and hazardous flotation tailings dams can be source of endangering of living environment in their normal work and also in case of damages incidents in flotation tailings dams can be caused by natural catastrophes in the area or malfunctions due to unreliable work.*

*Chemical harmful materials which can get to living environment at damages, can cause endangering of ecological factors (soils, water, air) and through them the whole ecosystem of the area.*

*In his paper will be shown the incidents on the tailings dams of the lead-zinc mine Sasa in the Republic of Macedonia.*

**Keywords:** *incidents, tailings dams, environment*

## Introduction

The flotation concentration of mineral raw materials produces large quantities of tailings with significant volumes of water that should be disposed of in appropriate place. The right discharge means better protection of the environment, prevents settling of underflow. It provides certain volumes of water for use in the technological process. The tailing dam that consists of sand dam, settling lake, drainage system and equipment for evacuation of decanted water is an important part of the mine. It must meet the requirements as follows:

- to provide good safety and stability to the dam,
- to have permanent hydraulic input of tailing,
- permanent work of hydrocyclones during separation of sand and overflow,
- to have operational drainage system at any time,
- to provide sufficient time for the physico-chemical processes, or settling of coarse fraction and dissolving of other flotation reagents in order to obtain clear and purified water to be used in the plant or flow into the water courses without contaminating the environment,
- to possess built in collectors to receive and evacuate clear water,
- to have a sand dam with appropriate thickness and porosity to receive and evacuate the clear water,
- to possess sand dam of appropriate thickness and porosity to receive and evacuate clear and percolating water,
- to be economically justifiable in the concentration process.

Over the past years much higher dams (reaching up to 100 meters in height) were constructed. Their economy is seen in the continuation of the lifetime of the drainage system, the collector, the flotation pulp station and the water system between the flotation plant and the tailing pond which are the major costs in construction and maintenance of the tailings dam. Larger dams make possible the housing of flotation waste, to reduce, at the same time; the costs per ton processed ore.

The terrain chosen for the construction of the tailings pond and dam must be examined in order to determine its geological characteristics and rock mechanics.

The construction should be as inexpensive as possible. This requirement leads to the application of the so-called upstream method, since the centreline of the dam extends upstream or downstream. In the application of this method the small starter dam is located at the end of the favourable downstream point, whereas the dam goes upstream. Two major methods are used in dam construction - hydrocycloning and spigoting.

The advantages of the upstream method are its low cost and the time period necessary for the construction during each successive dyke increment.

The disadvantage is that the dam is constructed on earlier deposited unconsolidated slime. The limiting height during the construction of this type of dam (before a failure occurs) led to the less common construction of this type.

The second, so-called downstream method is fairly new system. It has evolved due to the efforts to construct larger and safer tailings dams. Unlike the upstream method, here the centreline increases downstream and the dam is founded on coarse tailings. Most procedures use cycloning or produce sand for the dam construction. The method makes possible the design and construction of the tailings dam with acceptable standards. All tailing dams in seismic areas or almost all-major tailings dams were constructed using the downstream method.

The main disadvantage of the method is the large amount of sand necessary for the construction of the dam. There is also a third method the so-called centre-line method - used in the construction of downstream dams, and the crest remains horizontal as the dam wall is built. The advantages are that it requires smaller volumes of sand-fill for the crest at any given height.

Sand dams differ from dyke dams since they are permanently built during the use of tailings pond by depositing new layers of hydrocyclone sand of lower compactness. The sand comes from the flotation pulp and contains 60 to 75 per cent coarse fractions. The concentration of sulphide minerals in the hydrocyclone sand is higher than in the flotation tailing, particularly higher in the hydrocyclone overflow. With the time, oxidation of sulphide minerals occurs. This changes the

permeability of the sand dams and the angle of internal friction among sand grains, which is also important for the static stability of the dam.

The water from the accumulation area penetrates sand dams causing physical, chemical, hydrogeological and consolidation processes to take place during and after the construction of the dam.

Oxidation of sulphide minerals in tailings depends on the time necessary for the reaction of their surfaces with the oxygen in the air. The speed of the oxidation process is related to the quantity of air, temperature, the degree of moisture and the specific surface of oxidising minerals. Of all sulphide minerals - pyrite, which is most common in flotation tailings, is most prone to fast oxidation in a sand dam due to its crystallo-chemical properties and easy comminution. Products of pyrite oxidation are: ferrous hydroxide -  $Fe(OH)_2$ , ferric hydroxide  $(Fe(OH)_3)$ , ferrous sulphate  $FeSO_4$  and sulphur hydrogen  $H_2S$ .

Seeping waters in the tailings pond often contain heavy metals such as iron, zinc, copper, nickel, and manganese. Lead is known to be of limited solubility. Larger presence of individual elements is harmful for the environment. In that regard we must prevent outflow of water with heavy metals in order to keep water safe. Understanding the chemical reactions that take place in the flotation tailings helps to prevent the aggressive action of water of concrete reservoirs whose disasters may cause undesired consequences.

The most serious issue regarding the protection of the environment related to the disposal of flotation tailings in the ponds is the discharge of contaminated waters in surface and underground courses. It must be said that it is more complex in surface courses.

#### Sasa mine tailings dam

The water from the tailings pond is released into the closest water course - the River Sasa. Most of the waters are released through the overflow collector, and a small part (filtration and percolating waters) is released as drainage waters. Part of the drainage water is filtered in the underground courses. It is assumed, however, that underground courses are less polluted. In spite of all measures for the control and improvement of quality of water that is released (decanting of several days), in some seasons it is contaminated. The lack of dissolved oxygen in water also has a negative impact since it is essential to all species living in waters.

Long-term disposal of contaminated waters in the River Sasa results in the disappearance of a large number of animals and plant species and only the most robust ones survive. The harmful components cause significant physiological and biological changes in animal and plant species creating at the same time harmful materials. The materials, through the global food chain, reach other animal species and eventually human beings.

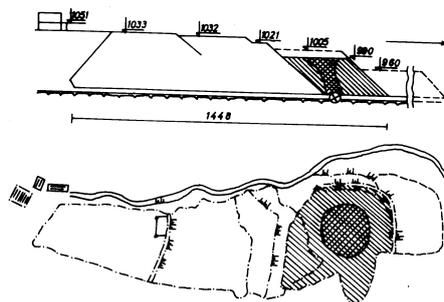


Fig. 4 Cross sections of the Sasa tailing pond.

The long-term release of contaminated waters results in settling of harmful materials in rivers and surrounding land. The most dangerous situations become when flotation tailings directly enter the water-course.

The water flow from the collector is within the limits and ranges on average from 5 to 8 l/s. Drainage waters are also within the limits allowed ranging from 0.25 to 0.50 l/s. In cases when the water is turbid, the overflow collector is sealed until the water is decanted. Protection watershed collectors are built for the intake of surrounding atmospheric waters.

The quality of overflow and draining waters are subject to measurements that include measurement of their physical-mechanical cleanness (solids residue), chemical toxic elements and pH. Measurements are carried out every month and the average maximum results are shown in tables.

The values allowed refer to the legal norms for maximum allowed concentrations (MKD) for the waters of the Sasa River (III category waters). They amount to dry residue from filter 1 500 mg/l; pH value 6.0 - 8.5; Pb = 0.1 mg/l; Zn = 1/0 mg/l; Cu = 0.1 mg/l; Cd = 0.01 mg/l. The previous results (Table 1.) and results obtained from the measurements carried out on waters discharged into the New tailing pond - I phase of the Sasa Mine (Table 2.) indicate that the waters of the River Sasa satisfy the norms required for MKD categorisation.

Table 1.

sampling site	rN	dry residue (mg/l)			elements (mg/l)			
					Pb	Zn	Cu	Cd
over. col	8,0	700	400	300	0,05	0,14	0,13	0,01
drainage	7,5	1500	1000	500	0,07	0,15	0,03	0,01
tunnel	-	700	400	300	0,01	0,35	0,04	0,02
average	7,5	800	600	200	0,06	0,30	0,03	0,01

sampling site		overflow water, mg/l	tunnel water, mg/l	common, mg/l	allowed concentration. mg/l
Dry Residue	non- filtered	414	1020	1763	-
	filtered	355	380	409	1500
	suspension	69	640	1354	60
pH		8.0	7.5	7.5	6.0-8.5
Ca		102.559	96.144	104.198	-
Mg		1.86692	1.83244	2.1793	-
Na		4.85165	5.49556	5.67332	-
K		6.83857	4.52829	5.05803	-
Al		0.77348	0.25788	0.40304	-
Fe		0.00757	0.01098	0.01245	1.0
Mn		1.84884	1.85961	2.16111	-
P		0.0128	0.0276	0.0166	-
Ti		0.01023	0.0126	0.01257	-
Sr		0.3575	0.43265	0.43037	-
Ba		0.04502	0.04446	0.04554	-
Zn		0.05441	0.4213	0.45764	1.0
Pb		<0.001	<0.001	0.0039	0.1
Ni		0.00133	0.00897	0.0056	0.1
Co		0.00632	0.00573	0.00783	2.0
As		0.00798	0.05048	0.05536	0.05
Cr		<0.001	<0.001	<0.001	0.6
Cu		<0.001	<0.001	<0.001	0.1
Cd		<0.0001	0.00061	<0.0001	0.01
Ag		<0.0001	0.00282	<0.0001	0.02
Tl		<0.01	<0.01	<0.01	-
Bi		<0.01	<0.01	<0.01	-
Ga		<0.001	<0.001	<0.001	-
In		<0.01	<0.01	<0.01	-
B		<0.001	<0.001	<0.001	-
Li		<0.001	<0.001	<0.001	-

Table 2.

Elements mgL <sup>-1</sup>	Sample					
	1	2	4	5	6	7
Ca	65.97	59.94	35.86	92.43	43.68	38.17
Mg	14.71	11.26	7.47	18.95	12.38	10.63
Na	5.29	5.29	4.44	6.64	9.32	8.95
K	2.01	2.22	1.42	8.34	3.25	2.96
Al	<0.001	<0.001	<0.001	1.859	0.076	0.194
Fe	0.0106	0.0208	0.0296	2.126	0.162	0.1806
Mn	0.0025	0.0027	0.0059	2.207	0.402	0.415
Sr	0.239	0.229	0.152	0.481	0.220	0.174
Ba	0.048	0.057	0.032	0.106	0.051	0.048
P	0.024	0.005	0.026	0.039	0.016	0.081
Zn	0.014	0.046	0.013	0.297	0.216	0.036
Pb	0.0083	0.0005	0.0063	0.354	0.035	0.0004
Ag	0.0167	0.0227	0.0043	0.0442	0.0086	0.0049
Cu	<0.001	<0.001	<0.001	0.018	0.102	<0.001
Cd	<0.0001	<0.0001	0.00042	0.0051	0.0036	0.0015
As	0.024	<0.005	<0.005	<0.005	<0.005	<0.005
Cr	<0.001	<0.001	0.0020	0.0037	<0.001	<0.001
Co	0.0005	0.0070	0.0016	0.0065	0.0040	0.0026
Ni	<0.001	<0.001	<0.001	0.004259	0.0042	0.0093
pH	6.52	6.41	6.56	6.93	7.43	7.46
Total dry residue, mgL <sup>-1</sup>	530	539	550	21408	489	447
Dry residue after filt., mgL <sup>-1</sup>	274	336	150	493	206	160
Susp. particles mgL <sup>-1</sup>	256	203	400	20915	283	287

Based on the results obtained it is obvious that water quality is within the limits prescribed with some exceptions. These are mainly the tunnel and joint water which possess enormous quantities of suspended materials. This is due to the exploitation of mineral raw materials since tunnel water comes mainly from caves. The issue should be paid greater attention since the waters from the River Sasa are used for irrigation of crops. It should be mentioned that the tailings pond discharges purified waters and their impact on the environment is insignificant. This indicates that the tailing pond carries out its obligation and purifies the water.

The tailings pond has an impact on air pollution. The wind transports the dry particles from the tailings into the air and the surrounding areas. This action is not dependent on the technology applied or the type of tailings pond. Still, it depends on the weather. This means that air pollution is more intense in summer. Air pollution is easily seen so that the population living close to the pond often complains. Air pollution has a very negative impact on the plant and animal life, first of all on people causing various diseases the main being those of respiratory organs. This is greater when the dust contains heavy metals, silicium or similar metals. The impact of old tailing dams is reduced to the minimum because they have been recultivated. Currently, greatest air pollution comes from the actual tailings pond New pond - phase I where the major polluters are the crest, the slopes and dry beaches of the reservoir.

The climate in the area is entirely mountainous and is characterised by long and snowy winters and short, but fresh summers. The tailings pond is surrounded by high hills in the east and the

west. The air currents create large clouds of dust coming from the open areas, slopes and the crest. Depending on the intensity of the wind sometimes the air currents are quite wide, particularly in summer when the top of the pond is dry. Then, south air currents destroy the dam crest. The damage may amount up to one meter in size during the summer period.

Tailings dust is aggressive due to its specific mineralogical composition. It has negative impact on the health of the people. Wind takes the dust and transports particles on the surrounding area and contaminates the land. The effects of the tailings pond on land can be:

- direct, by taking the land away from the place on which the pond is built,
- indirect, pollution of surrounding land, waters and dispersion of tailings dust by air currents.

The selection of the site is an important issue involving a number of conditions (technical, geotechnical, economic, environments and urban planning). The greatest risks come from tailings ponds built in plane areas occupying fertile land.

The tailings pond of the Sasa Mine is situated in the riverbed and the valley of the River Saska. The waste dump extends some 1 450 meters along the river where about 11 500 000 tons of tailings, 3 180 000 tons of sand and 8.320 000 tons of silt have been discharged.

The earlier tailings ponds have been covered by new soil brought from the surrounding places and planted with grass and locust trees. Forestation has not succeeded, but planting of grass is partially successful.

Recultivation of the pond envisages new and more efficient methods. The land used to be a good valley, but today it is a plane area of greyish colour and a pond with no animal or plant life. Changes of the relief result in changes of the climate that have an enormous impact on the biota. It should be mentioned that the planned dislocation of the road Sasa - Makedonska Kamenica would include part of the good land and reduce the area for construction of the new tailings dam.

The high concentrations of heavy metals in the soil have an impact on its quality and prevent the formation of humus material. They break the bonds between the humus material and the mineral part of the soil that leads to the destruction of the soil and loss of humus and reducing the anti erosive capacity. Heavy metals enter the plants and crops causing a number of biological distortions. Many plants are resistant to saturation of heavy metals and survive. However, saturation of heavy metals in vegetables that are consumed by humans may result in serious health problems. Possible disaster of the dam would result in serious disturbance of the environment and casualties, including great material damage. The issue should be given greater attention.

Experience has shown that disasters are caused due to various factors such as instability of slopes, earthquakes, floods, large quantities of drainage waters, poorly constructed foundations, erosion etc.

In dam construction it is of importance to use all project parameters. Exceeding the dam means disposal of new layers of waste so that the body of the dam increases and the fine particles in the substrate make the large mass unstable.

Retention area should have optimum sides because in case of clogging the overflow collector and reduction of retention area increase the possibility of incidents in the dam. Shortcoming in hydroisolation layer may result in the increase of drainage waters which will have a negative impact on the dam stability. Stability analysis consists of determination of coefficient of safety which is a nondimensional number and expresses the relationship between shear strength of material and mobilised shear strength so that the coefficient of safety for tailings ponds for downstream slope amounts to 1.50.

The environment is a complex system consisting of mutually connected factors. The changes in one factor may cause changes in the other. So, the issue of the protection of the environment from contamination can be solved through integrated and systematic approach. Any partial solutions are not permanent solutions and mean improvisation that take us away from the real solution of the problems. The measures to be taken in protection call for good understanding of the negative effects in mining operation and their elimination. The measures include protection of waters, air, and soil. In environment protection it is important to pay attention to the reduction of pollution of water courses in which waste waters from the tailings pond are discharged. Today, large volumes of contaminated water are recycled and fresh water input does not exceed 5%. As mines use their own wells for the supply of fresh water, the use of the water from the tailings pond would be noneconomical.

Water protection includes certain measures. The most common are those that in the flotation process the toxic reagents are replaced by non toxic or less toxic, settling of water in the pond in order to assist decomposition of residual flotation reagents, clogging of overflow collector when the water is not sufficiently clean, temporal extension of overflow collector and drainage pipe etc. Extension of overflow collector calls for urgent measures since during the dam construction, the flotation waste has not passed the part where the overflow collector ends. The drainage system is functioning well as seen from the measurements carried out by piezometers. However, for better monitoring of filtration and rising waters it is necessary to clean the broken piezometers or replace them with new ones. The impact on ground waters is small. Each raise of the dam results in overflow and run off part of the water into the ground. The problem could be solved through controlled hydroisolation. Contamination of earlier tailings ponds has been reduced to a minimum. They have also been recultivated and do not pose any danger to the air.

The new tailings pond is a potential danger to the air. The major sources of pollution are the dam crest, slopes and the dry parts of the beach. As for the dry beaches the most economical solution is control of the water in the accumulation.

For the crest and the slopes several solutions are possible one being water spraying with nozzles under high and low pressure.

The low-pressure nozzles work under pressure of 4 bar and have a small range amounting from 15 to 30 meters and economical use of water. This does not require installation of expensive high-pressure pumps.

One of the advantages also is that the low pressure of the jet does not damage the dam. Their disadvantage is that a number of pipes have to be fixed and requires higher investment. Low-pressure nozzles are most common in dam spraying. Combined spraying is when one part (the crest) is sprayed with low-pressure nozzles, whereas the downstream slope is sprayed with high-pressure nozzles - water guns.

Possible solution is spraying with certain suppressants that form crusts husks that connect fine fractions and prevent the formation of large volumes of dust.

Lands formed from discharged flotation waste are called floatisalts. Because of the harmful component parts and the manner of discharge they pose multiple danger to the environment. They have no biological importance and the chances for their revitalisation are very slim.

Part of the flotation tailings of the Sasa mine is used for filling of underground stopes. The advantages of this method are that the tailings pond would occupy smaller area. Unfortunately, only 10 per cent of the tailings are used to fill the underground stopes although it is planned to amount to 30 per cent. Although production costs using the cut and fill method are higher than those in other methods are it should be used more often. The advantages of the method are: it reduces the possibility of lowering the terrain over the underground stopping facilities, it reduces the area necessary for the construction of the tailings pond, and reduces the risk of contamination of the environment.

### **Conclusions**

The possible disaster of the dam may cause great material and ecological damages or losses in human lives. The issue should be paid great attention. Statistics says that collapse of dams occur due to several factors (according to data from USCOLD 1994, US Conference of Large Dams). The most common causes are unsuitability of slopes (amounting to 22%), earthquakes (17%), floods (16%), poorly constructed fundaments, excessive quantities of drainage waters (9%), erosion etc.

Three dam disasters have taken place in the Republic of Macedonia over the past years. They all caused significant damages to the waters, air, and land in particular. Such were the disasters in Zletovo lead and zinc mine in Probiship, the Buchim copper mine and the latest in the Sasa lead and zinc Mine ( the last one in September 2003).

The collapse in the Sasa flotation dam formed a crater of 120 - 160 m at a depth of 30 to 40 m. After the disaster over 1.000.000 tons of waste with heavy metals entered the River Kamenica, further on Lake Kalimanci, the River Bragalnica and the surrounding land.

### **References**

1. Wills, B.A. (1989). Mineral Processing Technology, Pergamon Press. pp 686-698;

2. Klohn, E.J. (1981). Current Tailings dam design and construction methods *Min Eng.* 33, pp 798
3. Krstev B. (2000). Using Administrative Controls to Reduce Tailing Dams Risk on the Active Tailing Dams in Macedonia; /International Conference "NEW TRENDS IN MINERAL PROCESSING IV" Ostrava, Czech Republic, 26-28.6.2000/
4. Krstev B. (2000). Tailings Dams in the Republic of Macedonia; /International Conference "NEW TRENDS IN MINERAL PROCESSING V" Ostrava, Czech Republic, 28-30.6.2001/
5. Krstev B. (2001). Dust Control Technologies for Mineral Processing Plants; /IX Balkan Mineral Processing Congress, Istanbul, TURKEY 11 - 13.09.2001/