Flam Valley TMF Pond, 40 Years of Activity and Still Going

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Abstract. Flam Valley is a bauxite residue Tailings Management Facility (TMF) valley pond, operating since 1971, located in Romania, just a few meters away from the Danube Delta protected area. Since then, it has been serving Alum Tulcea alumina producing plant through the different stages of its development. Conceived as a frontal tailings dam, Flam Valley is located in a nonpermanent torrential stream in a very sensitive environmental protected area. Up to 2006 tailings slurry with 15-20% solids were pumped by pipeline in the TMF, in accordance with the old technology. After the EU directives enforcement in 2005 the plant had to stop all activity until the whole process was upgraded, consequently the TMF was upgraded with the structural frontal dam being reinforced, water diversions constructed, some areas of the residual storage area were ecologically restored and the deposition became a dry stacking process by tailing placement, thus transforming it into a new TMF and avoiding the consequences that would have derived from the relocation of the TMF. The presented aspects are aimed at generally portraying the evolution, incidents, the tailing dam behavior and prospects of capacity enlargement for Flam Valley TMF.

1. Introduction

Alum Tulcea was founded in 1971 the first production capacity being put into operation on 31.08.1973. Subsequently, the enterprise developed, so that on 1979 the nominal production capacity was 400,000 t/year of calcined alumina, unattended capacity. At present, works are being carried out to increase production capacity to a value of 600,000 t/year of calcined alumina. The solution of the dam on a valley was adopted through a well-compacted, two-stage waterproof loess-dam. The tailings deposition technology in the Tailing Management Facility (TMF) has undergone changes since commissioning to date. As far as capacity development there is a lot of concern for developing alternative technologies for TMF management thus resulting in more than 100 papers published that reveal emerging alternative technologies for improved tailings management [1].

The main residue resulting from alumina production of ALUM Tulcea plant is the waste [slurry] by the processing of bauxite. It is in the form of a hydro-mass containing ~ 15 - 20% dry matter. The hydro-mass is delivered by a network of piping fixtures. In order to ensure that the plant produces alumina, a TMF for slurry storage was needed. So came the solution of constructing a TMF on Flam Valley (Figure1). It is located in Mineri village, about 3 km away from Tulcea city and from the hydrographic point of view, the TMF site is situated in the tail of Lake Casla belonging to the adjacent terrace of the Danube River.
The "Flam Valley" is a depression of small hills, oriented approximately in the S-N direction, open to the river Cășla from the Danube. Initially, the valley with 5.50 ÷ 6.00 mdM valley would drain to Cășla lake a very low permanent flow, of the order of 1 ÷ 3 l/s. The construction of Flam Valley TMF began in 1974, by building a compact loess dam, reinforced with berms, on the non-permanent stream Flam Valley. In the first stage, the dam crest was at 25 mASL. In the second stage, the dam was extended downwards, strengthened with berms and the height was 35 mASL. Then, in successive stages, the elevation of the dam was accomplished by the construction of rock steps, at 37.00, 39.00 mASL towards the upstream, and 41.00 and 43.00 mASL, in the axle. Considering that this residue results in significant quantities (about 280 m3/h) and is not environmentally hazardous, the initial solution for storage resulted as a decanting pond. This allowed both tailing decanting and clear water recovery for re-use in the alumina plant processes (Figure 2, 3).
2. Analysis of the works

Thus, initially, the tailings were discharged from the tail of the pond (upstream), decanting and clearing the water upstream from the upstream water barrier. The drain water was drained from the lake formed in the area adjacent to the dam (Figure 4). Through the permanent contact of the dam with the clarified water lake, the flow of the exfiltrated water through the dam has increased, as the downstream slope of the dam leads to phenomena of drought and even local collapse. In 1997, a large cavern was found at the level of the second berm with the wetting phenomena of the slope. Probable causes were: the elevated water level in the pond (elevation 36.60 mASL, 1.10 m under the elevation of the core), damage to the old sludge discharge pipe and presence in the damaged area, downstream dam toe, of the emergency water collection basin.
2.1. The behavior of the works in time

With the exception of insignificant seepage and small slope failure of the downstream slope of the main dam of minor importance, which have been rectified, the TMF behaved well, both functionally and environmentally. As a result of a survey in 1997, low safety coefficients were found, namely 1.07 - 1.388 without earthquake and 0.823 - 1.120 with an earthquake. As a result, the downstream toe of the dam was reinforced with a quarry stone prism. For this reason, the solution for depositing the tailings from the dam crest was changed. This led to the heightening of the dam, in the next stages, towards the upstream with also with quarry stone.

In 2002 a new stability study was carried out, which confirmed the results of the previous model and the credibility of the geotechnical parameters.

In accordance with new Romanian norms, based on a European directive, ALUM Tulcea had to stop the storage of liquid waste by 31.12.2010. As a result, following the solution, expertise, consultancy, environmental impact assessment, land survey, etc., the following package of solutions was adopted:

- as the Flam Valley topography allows, it would be still be used for sterile storage (no other site is justified)
- partial closing of the TMF surface, through the construction in the upstream of a subdivision dike. As the downstream dam can no longer be safely heightened, the solution also solves the problem of increasing storage capacity by raising the subdivision dike and the left bank dike (up to 45 mASL)
- installing a sludge thickening plant to increase the concentration of solid content from 15 to 20% to 55-65%
- construction a system of diverting channels to collect the waters upstream of the TMF and direct them to downstream. The water would not pass through the TMF and consequently it would not be polluted by the contact with the tailings
- safety and hydrological calculation revealed the need of an upstream non-permanent polder to protect the TMF and diversion system.
On the 13th of September 2013 (Figure 5), an extraordinary rainfall occurred in the area of the heap, which resulted in a flood with a maximum flow of 48 m³/s, well above the design flow rate of 34 m³/s (1%) [2]. On this occasion, the diversion channel system and the polder worked well, with only some damage, especially in the rapid channel area due to the high velocity and debris flow. In order to solve the outcome, a plan of works was established, which also improved the stability and resistance in the affected areas. In the lower section of the channel where the channel flow section decreases, the existence of an access bridge is preventing good flow. Downstream of the bridge, the flow section is reduced only to the concrete lining, which obviously could not ensure that the maximum flow rate would be exceeded. As a result, the area around the canal was flooded. During the flood of 13.09.2013 on the lower section of the canal there was a massive outflow from the left bank of the canal, which seems to have been in the core of the stationary rain cloud that date. With the exception of this inferior sector, affected by the presence of the bridge, the rapid channel was safe, allowing the evacuation of the collected flows from the Flam Valley basin without affecting the TMF integrity.

![Figure 5. Diversion channel damage due to the 13.09.2013 events](image)

2.2. Deviation works
The major risk of TMF's that are situated in the stream or river valleys is the fact that they close off the natural valley and thus prevent large water transit (Figure 6). In the case of the Flam Valley, this problem was not properly addressed in the initial design. In October 2010, the stream diversion solution was adopted through a channel on the left bank. The Flam Valley has a basin of 4.6 km² and the diversion collects via two access channels the two main tributaries in the upstream of the TMF. In order to lower the capacity of the main diversion a lateral non-permanent storage was designed with a volume of about 65,000 m³. This serves to route the flood, as the main restraint is a culvert located in the downstream...
that crosses the national road DN 22 having a 14 m³/s capacity. The difference of the peak flow, 18.6 m³/s, must be provisionally stored in the polders capacity [3].

![Figure 6. Water-diversion-work-salon-side the TMF](image)

3. Results and discussions

The frontal subdivision dike defines the landfill in the downstream, on the TMF, that will be ecologically closed (total area that was permanently closed is of 28,800 m²). The surface of the TMF was in the first phase covered with a support layer made of sand or ballast over which the geomembrane composite waterproofing layer was applied. Over the geocomposite a layer of the fertile soil of approx. 15 cm which was immediately greened. Stability calculations allowed the subdivision dike to be located as close to the main dam as possible thus loosing as little as possible TMF storage (Figure 7). The average height of the subdivision dike is about 5 m, corresponding to an average rate of current sludge deposition of 45.00 mASL. The dike stability is provided by the foundation being laid on the slurry over a rock-filled geocell mattress that increases slurry load capacity [3].

Together with the non-permanent storage, the division area ensures both ecological responsibility and function by ensuring flood routing and wetland areas on the surface of the former TMF.

In order to provide storage capacity for the future, the only alternative is to raise the TMF outline. The contour has four distinct areas: the division dike, the left bank, the right bank and the upstream dike. Moreover, through erosion, the natural contour has advanced to the vicinity lands. As a result, the development of the TMF can only be done on the TMF, with the foundation of the dikes on the consolidated slurry, inwards. For a reasonable 10-year perspective, the landfill will provide another 5.5 million cubic meters. Taking into account the slope geometry and the 54.8 hectare average area of the TMF in the current configuration, there is a 10 m elevation contour calculation (a storage volume of about 550,000 cubic meters for each meter of its contour).
Furthermore, in order to optimize the storage capacity, the dike bodies will incorporate the geocontainers filled with slurry that will allow for an additional cca 400,000 m³ of storage and also save up construction costs.

4. Conclusions

Given the production prospects and technical capacities but also the inherent fluctuations of production due to the market developments, it is reasonable that the expansion of the TMF capacity is phased in. Therefore, a rational solution is to divide the dike height contour works into two stages, both of which have a height of about 5 m. Given the fairly large costs of the works, the beneficiary will execute each of the stages one at a time when the deposited sludge will reach about 1 m below the existing dikes. This will also make possible savings by placing elevations on the TMF at the next step, with higher elevation. Red slurry deposits, in the initial pond-type management facility, were stopped in 2006, and in order to ensure the storage for the slurry resulting from the bauxite treatment, a solution was adopted to modify the old pond in a dense TMF, partially closing the old facility-pond with a compartment dike.

Taking into account the production capacities of the preparation plant, for a reasonable 10-year perspective, the capacity requirement is about 5.5 million m³. Considering the slope and geometry of the average 54.8 hectares for the TMF in the current configuration, it is necessary to raise the contour by 10 m. The capacity build-up, in this particular case, is done with an innovating technique by using the volume of the embankment for the enclosure dikes as a storage capacity, by means of geotextile use, thus granting an approximate of 10-12% in the capacity savings for the slurry deposition, using the slurry as a raw material for the dikes and relieving pressure on the environment by using less earth-fill and rock (from the adjacent quarries), less transport for the materials and less labor.

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