

## Clay sedimentation and consolidation behaviour in tailing storage facilities over mine lifetime

S.M. Ehsani<sup>1</sup>, M. Unesi<sup>2\*</sup> and R. Tamartash<sup>3</sup>

1. Gorgan Agriculture and Natural Resource University, Gorgan, Iran

2. Young Researchers and Elites Club, Science and Research Branch, Islamic Azad University, Tehran, Iran

3. Sari Agriculture and Natural Resource University, Sari, Iran

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### Abstract

Changes in the tailing properties (increasing clay mineral content and fine particles) and poor operation of the dewatering systems have negative impacts on the Tailing Storage Facilities (TSF) of the Shahrababak copper complex. The design solid concentration of the thickened tailings is 63 wt.% in the Shahrababak paste plant but it is well below the design value right now (approx. 55 wt.%). The aim of this work is to find the effects of the clay mineral and dewatering operations on the water recovery and tailing dam capacity. The understudied samples were taken from the thickener underflow and prepared at the required solid concentrations (55, 60, 65, and 70 wt.%). The results obtained showed that the initial settled density varied from 1.044 to 1.146 t/m<sup>3</sup> by increasing the solid concentrations from 55 to 63 wt.%. Furthermore, the shrinkage limit density of the two solid concentrations was recorded at 1.52 and 1.62 t/m<sup>3</sup>, and the crack volume was estimated at 6.3% and 7.2% of the final sample volume. Also the sub-aerial tailing beach slope in the upper quarter and the remainder of TSF was too low and exhibited 2.0% and 1.0%, respectively. However, it is far from the design values (3.5%, 2.5%, and 1.7% from head of the beach to the end). Thus it is clear that the clay minerals and fine particles hold more water in their inner network and occupy a more TSF volume. Nevertheless, the beach slope can be increased by improving the thickener performance and removing the leakage and other periodic water, although it seems impractical to achieve the design value due to the changes in the tailing properties.

### 1. Introduction

The increasing demand and ascending price of minerals have led to the extraction of low-grade ores with new technologies, and a much higher volume of tailings has been produced [1, 2]. As the demand for freshwater is expected to exceed supply by as much as 40% by 2030, the expected outcome is the emergence of major local and global water crises [3, 4]. An on-going water risk related to the mining industry is the management of water in the tailing dewatering systems and tailing dams [5, 6]. Almost all mineral processing plants utilize some type of thickener for water recovery from tailings before disposal into the tailings storage facilities (TSF). Thickening

improves the site water management and utilization of the TSF storage and decreases the overall tailing transport costs by reducing the volumetric slurry flow rate. The expected underflow solid concentration is probably one of the most important parameters involved in the thickener design. If this is not achieved during the actual operation of the thickener, it can have a significant adverse impact on the tailing and water management system of the mine [7]. However, as the water reclamation process itself is a secondary stage downstream of the thickener underflow, the efficiency of this process is bounded by the inevitable water retention in the tailings,

✉ Corresponding author: [majid.unesi@gmail.com](mailto:majid.unesi@gmail.com) (M. Unesi).

evaporation rate, and need to operate the pumping equipment on the tailing disposal site [8]. Also TSF is a complex geotechnical engineering structure composed of a viscous and colloid body consisting of fine particles [9]. Two areas of TSF that are directly affected by the thickener performance are the slurry transport system and the tailings beach slope [7].

Fitton et al. [10] have presented a semi-empirical model to predict the tailing beach slope. The model was based upon the non-Newtonian rheology theory combined with some turbulent channel flow equations. It was shown that the solid particles were not deposited from the self-formed channels of the tailings slurry as it flew down the beach and that the slope of the beach was dictated by the channel slope, which was set by the flow and rheological parameters of the slurry [10]. In practice, the beach profiles with some degree of concavity have been commonly encountered [11, 12]. Also Cabrera et al. [13] have used the nuclear magnetic resonance (NMR) technique to analyse the variations in the tailing settling properties in order to estimate the lifetime of a pond and improve the water recovery [13].

Fine solids in mineral tailing slurry require a long settling time, which necessitates the use of large land areas to accommodate mine productivity. This situation is also magnified by the formation of stable particle networks. Such a network structure resists consolidation and traps a significant volume of the water that is not available for recycling. Also certain clay minerals (such as montmorillonite) are able to absorb water into their internal structure, resulting in swelling and an increase in the apparent volume of the discharged material. These phenomena are responsible for a poor water recovery from tailings and directly contribute to increase footprint of the tailing containment structures. A growing number of studies conducted at the mineral tailing containment areas suggest that mobilization of harmful substances by wind, evaporation, and seepage can affect underground water tables [14-17].

The Shahrabak Copper Mine has a design life of 30 years at a concentrator throughput of 4.85 million tons per annum. The growth of copper price has led to a plan to increase the production capacity of the Shahrabak copper complex. Therefore, it seems to be necessary to study the feasibility of increasing the tailing dam capacity. For this purpose, the operational conditions in the current phase were compared with the design phase.

The estimated volume of tailings that is produced over the life of the mine is in the order of 84 Mm<sup>3</sup>. The tailing disposal scheme at the Shahrabak Copper Mine involves thickening tailings to a paste consistency via five paste thickeners and a subsequent down-valley discharge to TSF. The design solid concentration of the thickened tailings was 63 wt.% but it is well below the design value right now. There is a quite low variability in solid concentrations from individual thickeners and even less when the combined output is considered. It is due to the dilution at the downstream of the discharge point, which will be discussed further. However, the solid concentrations are far from the design criteria. The bleed and consolidation water from the tailings are then introduced into a water dam immediately downstream of the tailing dam, either via overflow of the decant overflow system or by controlled seepage through the tailings retaining embankment.

The aim of this work was to investigate the capacity of TSF and water recovery by monitoring the beach geometry, changes in the tailing properties, and conditions of the dewatering system operation. This provides an accurate understanding of the tailing sedimentation and the consolidation behaviour in TSF.

## 2. Materials and methods

### 2.1. Tailing characteristics

Particle density of the tailings was measured to be 2.7 t/m<sup>3</sup> using a pycnometer in the Shahrabak laboratory. A Marcy Gauge was calibrated by this density to measure the tailing solid concentrations ( $C_w$ ) in the field. The settled density and solid concentration are defined as:

$$D_s = \frac{w_s}{v_p} \quad (1)$$

$$C_w = \frac{w_s}{w_s + w_w} \times 100 \quad (2)$$

where:

$D_s$  : Settled density,

$C_w$  : Solids concentration,

$w_s$  : Mass of dry solids,

$v_p$  : Occupied volume with slurry or paste in TSF,

$w_w$  : Mass of water.

The particle size distributions for the tailing sample were also determined by lab sieves and cyclosizer. Also the XRD analyses were used to identify the existing minerals in the sample.

## 2.2. Initial settled density and water recovery

These tests were carried out to determine the initial density of the solids as they settled out on the beach of TSF. The values were measured for different solid concentrations in the slurry. The test also permitted the bleed water that would run off as the solids settled out to be calculated.

The initial settled density is an important parameter that represents the starting point for the subsequent consolidation. This occurs as the increasing surcharge pressure squeezes out more water and the tailings build up. In this process, increasing density is a complex interaction among the rising rate of water through sedimentation of tailing and its compressibility and permeability.

The samples were taken from the thickener underflow and prepared at the required solid concentrations. Subsequently, the test was performed by taking a sub-sample and pouring it into a large diameter pan to a target depth. A large diameter pan was used to limit the effect of the friction between the settling sample and the side wall. The tests were carried out at the nominal initial solid contents of 55, 60, 65, and 70 wt.% and at a nominal initial depth of 65 mm. The settlement of the tailing surface was recorded over time until the settlement was judged to be complete. These tests were carried out according to the Australian standards [27].

## 2.3. Shrinkage limit density

Tests were used to determine the maximum dry density that can be achieved by solar dry alone (evaporative drying). Evaporative drying is expected to have a major influence on the tailings, particularly after the first few years of mine life, as the surface area of the deposit increases in view of the climate at Shahrabak. The samples were placed in 300-mm diameter dishes and allowed to settle. When the settlement was complete, the free water was decanted and the samples were then dried out using heat lamps. At regular intervals, the dishes were weighed and the volumes of the samples were calculated from measurements to the tailing surfaces. The volume of the surface cracks was estimated and subtracted from the total volume to give the net volume for calculation. When no further volume changes could be measured while the moisture content continued to decrease, the samples were dried in an oven. The final volume of cracks was measured by sand replacement and the estimated volume was adjusted as required. These tests were also carried out according to the Australian standards [27].

## 3. Results and discussion

### 3.1. Tailings characteristics

The particle size distribution curves for the tailing samples during the design phase and later during the current plant operation are depicted in Figure 1. It can be clearly seen that a particle size less than 75  $\mu\text{m}$  has significantly increased in the tailings during the early plant operation in comparison with the tailings during the design phase. Obviously, the amounts of fine particles (sub 20  $\mu\text{m}$ ) is increased from 30% to 45%, whereas the rate of sedimentation of fine particles is too low and hold part of water into their inner network due to their high specific surface area so they will have negative impacts on the thickener performance and TSF capacity.

The XRD analysis results are presented in Table 1. This is indicative of the fact that the mining operations during the early stage are confined to the ore body with a higher clay content. As it can be seen, the amount of clay mineral (Illite) has significantly increased over years. The Illite found in the sample was about 25.15%, which increased by 7.92% in comparison with the design phase. Clay has a negative impact on the thickener performance, and consequently, the TSF capacity. However, it is apparent that the tailings during the early plant operation are much finer than expected in the long term. The increased clay content and fine particles of these tailings can be expected to have an impact on the thickener performance, rheological properties, and stored density of the tailings.

Clay minerals can be classified into two types based on the degree of swelling in water: high-swelling clays (such as smectite and montmorillonite) and low-swelling clays (such as kaolinite, serpentine, and illite). This behaviour can be attributed to the joint of tetrahedral Si-O and octahedral Al-OH sheets with ratios of 2:1 and 1:1. Thus in the case of 1:1 kaolinite, the tetrahedral and octahedral sheets are linked parallel to each other and cation exchange between the  $\text{Si}^{4+}$  and  $\text{Al}^{3+}$  ions is performed but in the smectite with a 2:1 ratio, the octahedral layer is sandwiched between two tetrahedral sheets [18]. The packing of particles on top of each other during settling influences the rheology and solid concentration of the thickener underflow. The most familiar packing type is referred to as “edge-face”, which is also known as the “house of cards”, “face-face”, and “band structure” packing relationships [19]. As shown in Table 1, the clay mineral of the sample is illite, which is classified as the low-swelling clay. Therefore, the ability to

absorb water in its inner structure is low and the apparent volume and thus the apparent density of clay particles do not change significantly in water. It should be considered that the small dimensions and the surface-to-volume ratio of clay particles lead to the formation of nano-scale voids in the clay structure that can hold water [20]. Consequently, the presence of clay minerals will inevitably reduce the water recovery in the thickeners and subsequently the TSF capacity but

this reduction in non-swelling clays is less than swelling clays. In other words, clays and fine particles typically stack into a honeycomb structure and absorb large amounts of water in their voids. Hence, a highly effective dewatering system is required to remove this interstitial water. Regarding the low permeability of clay minerals, the thickener performance and TSF water recovery were expected to decrease with increase in the clay content in the ore [21].

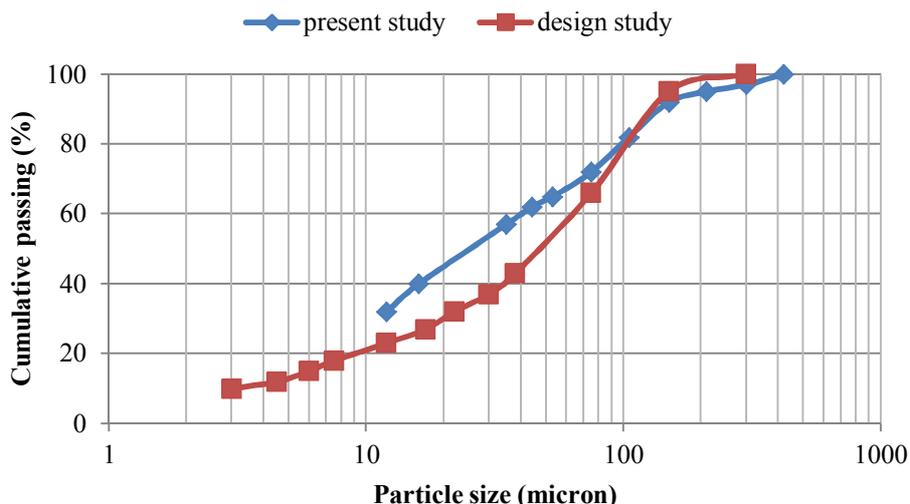


Figure 1. Particle size distributions of tailings during early plant operation and design phase.

Table 1. XRD analysis of samples.

Minerals	Present study	Design study
Quartz (%)	28.96	43.28
Illite (%)	25.15	17.23
Pyrite (%)	7.24	10.1
Albite (%)	12.64	13.46
Muscovite (%)	24.63	14.2
Other minerals (%)	1.38	1.73

### 3.2. Existing thickeners performance

The aim of tailing thickening in the Shahrabak copper complex is to recover processed water and produce a paste with sufficient consistency to enable the tailing beach slope to be maximized. Currently, neither of these aims is being achieved to any significant degree of efficiency. To investigate the performance of the existing paste thickeners, the underflow solid concentrations of each thickener were measured individually for six months and the data obtained was shown in Figure 2.

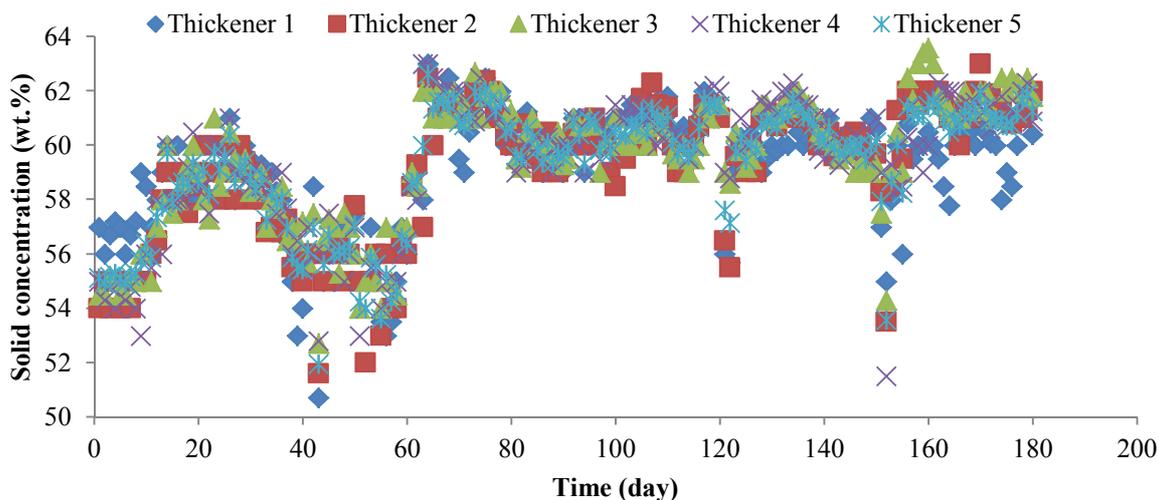
On average, a thickened tailings solid concentration of 59.2 wt.% (compared with a design target of 63%) was achieved by the thickeners. Prior to this, the average solid concentration was 54.3 wt.%. The reasons for this

poor performance are as follow:

- Poor operator training,
- Inadequate flocculent mixing plant, which was poorly maintained and poorly controlled,
- Uneven feed to each thickener,
- Failure of the underflow density and flow instrumentation,
- High clay content in the ore.

Accordingly, some modifications were required for the paste plant. If the current operational trends continue, there will be two significant outcomes:

- The potential for increased loss of processed water to evaporation,
- The requirement to construct the higher tailing retaining embankment than would otherwise be required.



**Figure 2. Underflow solid concentration of each thickener for six months.**

As shown in Figure 2, the thickener modification had a significant effect on the final solid concentrations so that the average solid concentration increased from 54.3 wt.% to 59.2 wt.%. Besides, the solid concentrations were reduced between the 40<sup>th</sup> and 60<sup>th</sup> days. This reduction is due to some modifications mentioned above. After that, the proper solid concentrations were achieved by an appropriate process control.

Excess processed water accumulating at the decant pond did not result in any significant loss because the beach area was quite small and the potential for evaporation was relatively low. Thus the processed water was allowed to transfer to the water dam via groundwater and embankment seepage. However, if the beach area increased, the evaporative potential of the system would be increased and it would be anticipated that a significant quantity of the excess processed water was lost due to evaporation prior to having the opportunity to be introduced as groundwater seepage.

Based on these findings, it is clear that the operational efficiency of the thickeners must be improved to prevent the loss of processed water and minimize the number of earthworks required for the future raising of the tailings retaining embankment to the final crest height. The following actions are recommended:

- Discontinue the dilution of the thickened tailing stream by processed water as a matter of urgency.
- Take the necessary steps to improve the thickener performance including the recommended modifications to the tailings thickening circuit.

The underflow from each one of the five thickeners combines into a single stream and thence flows down a natural stream channel into TSF. Immediately after discharge from the thickeners, the thickened tailings stream was diluted by leakage from the return water tanks, which received the paste thickener overflow and by other periodic discharge. This was carried out to increase the flow-ability of the paste, which is an incorrect operation because the viscosity or flow-ability of the paste could be decreased by the recirculation pumps located in the thickener underflow. Further dilution also occurs from small streams and/or groundwater seepage joining the thickener underflow as it flows down the valley to TSF. Dilution from this latter source is relatively small and is seasonal in nature.

These factors complicate the issue of recording thickener underflow solid concentrations. In addition to measuring the underflow solid concentrations of the thickeners, the density of the combined underflow after dilution from the tank leakage and plant discharge was measured. These values are also plotted in Figure 3. The average solid concentrations after-dilution were 55.1 wt.% and 51.8% prior to the thickener modification.

The main consequences of the lower tailing solid concentrations entering the impoundment are flatter beach slopes, lower overall in-situ density, increase pumping costs for return water, increase evaporation from the decant pond, and reduce potential for drying and strength gain of the tailings beach.

By comparing Figures 2 and 3, it can be seen that water removal from leakage and other periodic discharge water along with the thickener modification can increase the final solid

concentration from 55.1 wt.% to 59.2 wt.% (approx. 4.1 wt.%). Also if the thickener modification was not made and only the leakage and other periodic discharge water were removed, the final solid concentration would increase from 51.8 wt.% to 55.1 wt.% (approx. 3.3 wt.%). This means that continuous monitoring of the dewatering and water supply systems can greatly help to increase the dewatering system efficiency

and save fresh water consumption. Furthermore, a higher solid concentration can increase beach slope in TSF and the maximum dam capacity can be reached. Besides, the solid concentration was below 50 wt.% in some days (Figure 3). This indicates that the paste thickeners did not work properly on these days. Therefore, the comprehensive and integrated management was required for the dewatering system.

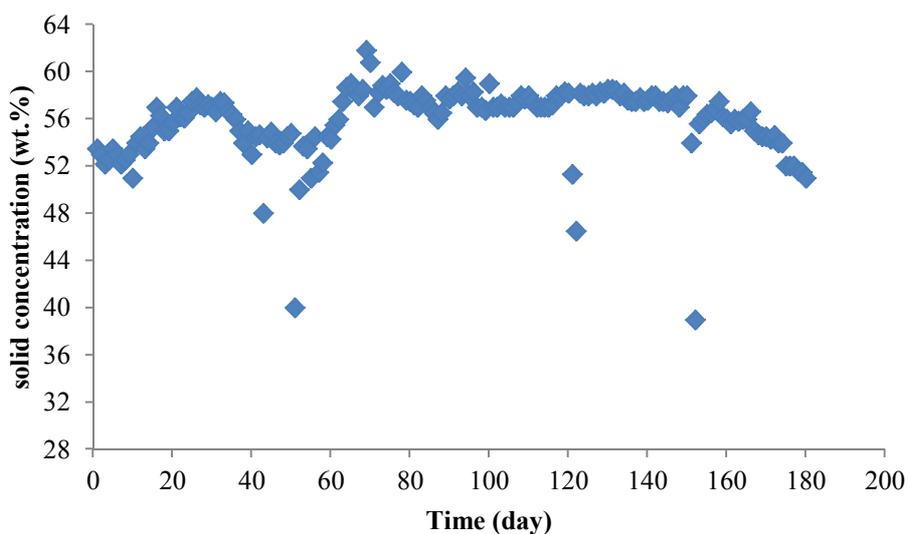


Figure 3. The solid concentrations of combined underflow after dilution for six months.

### 3.3. Existing tailings beach slope

The beach slopes in non-segregating TSF typically vary between 0 and 5% [22]. In cases where the tailings are thickened to the point that they can be categorized as a 'paste', the slope of the deposit formed will usually be significantly steeper than that of less concentrated tailing slurry [23]. However, in most cases of tailing disposals, the concentration of the slurry is so low that segregation of particles occurs on the beach (such that the larger particles settle sooner than the fines) and the end result is that the beach slope is typically less than 1% [24]. In most cases, beaches are formed by the sub-aerial discharge of mineral slurry form a concaved cross-sectional profile [25]. The reasons for this concavity have been widely discussed but the most commonly presented one is based upon the theory that segregation of the particles in the slurry occurs as the slurry runs down the beach, with the larger particles depositing a short distance from the spigot and the smaller ones going further down the beach. The larger particles are thought to form steeper beach slopes than the smaller ones [25]. The discharged paste typically flows down with a confined slope to reach TSF and then spreads out

and deposits on that area and forms the overall slope or beach slope [26].

For the Shahrabak TSF, the map of the tailings beach has been estimated from the survey of the beach perimeter provided by the Shahrabak surveying group. The inferred beach map is illustrated in Figure 4. The exposed tailings beach exhibits an average slope of approximately 2.0% in the upper quarter at the head of the beach, while the remainder of the beach has an average slope of approximately 1.0%. These beach slopes are considerably flatter than the predicted design beach slope of 3.5%. There are several contributing factors that may account for this, which will be discussed further.

### 3.4. Tailings initial settled density

The initial settled density of the tailings is an important parameter for estimation of bleed water and consolidation seepage. Bleed water is the water in tailings that tends to rise to the surface of the placed material during the sedimentation process in TSF, and it continues until the paste has compacted sufficiently. Whilst this figure cannot be directly measured on the tailings beach, a number of laboratory tests were undertaken on the

pre-production samples to estimate the initial settled density as a function of tailings solid concentrations. Tailing initial settled density varies as a function of the tailing solid concentrations and ore type. The results of the laboratory tests are shown graphically in Figure 5. It shows that the quantity of bleed water varies with the initial settled density. Thus the initial settled density varies from 1.044 t/m<sup>3</sup> at the underflow solid concentrations of 55 wt.% to 1.146 t/m<sup>3</sup> at the design underflow solid concentration of 63 wt.%. Furthermore, when the slurry solid concentration was increased from 55 wt. % to 63 wt. %, the bleed water rate

significantly decreased from 27.62% to 14%. In other words, by increasing the solid concentration, the large amount of water will not be exposed by evaporation and infiltration in TSF and also a higher solid concentration leads to an increase in the capacity of the tailings dam significantly. The amount of bleed water can be seen to be small at the solid concentration of 63 wt.% (only about 14%). This is to be expected for heavily thickened tailings. However, evaporative losses as the water flows down the beach and ultimately transfers to the water collection pond will further reduce these amounts.

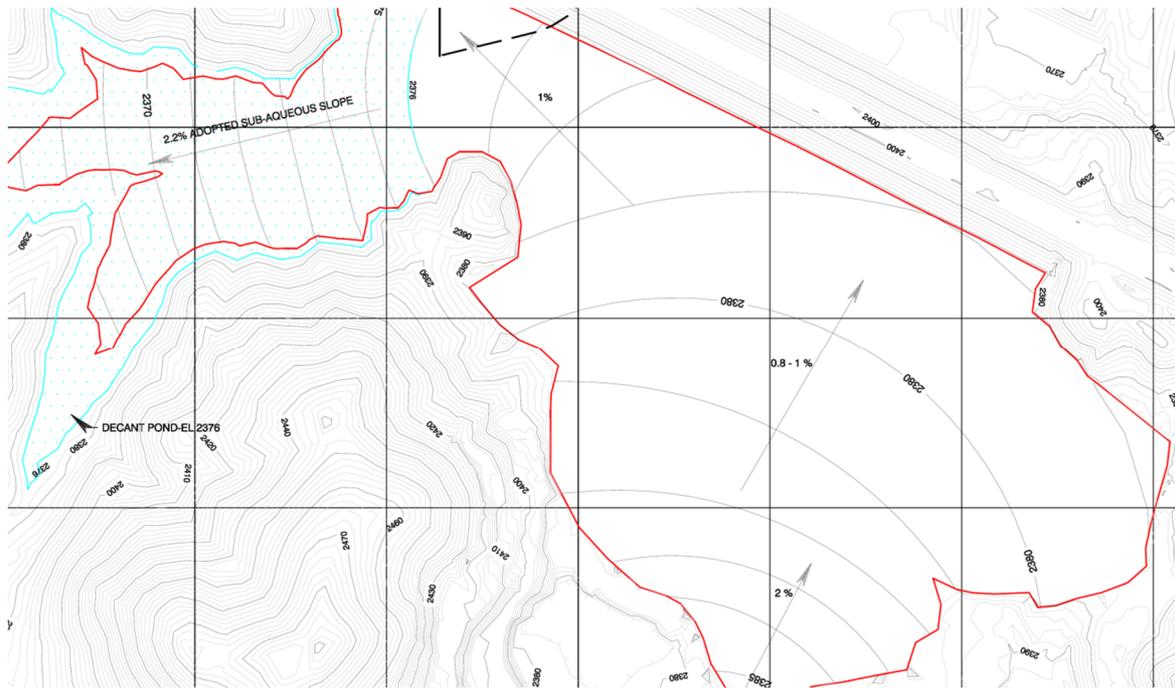


Figure 4. Tailings beach map [29].

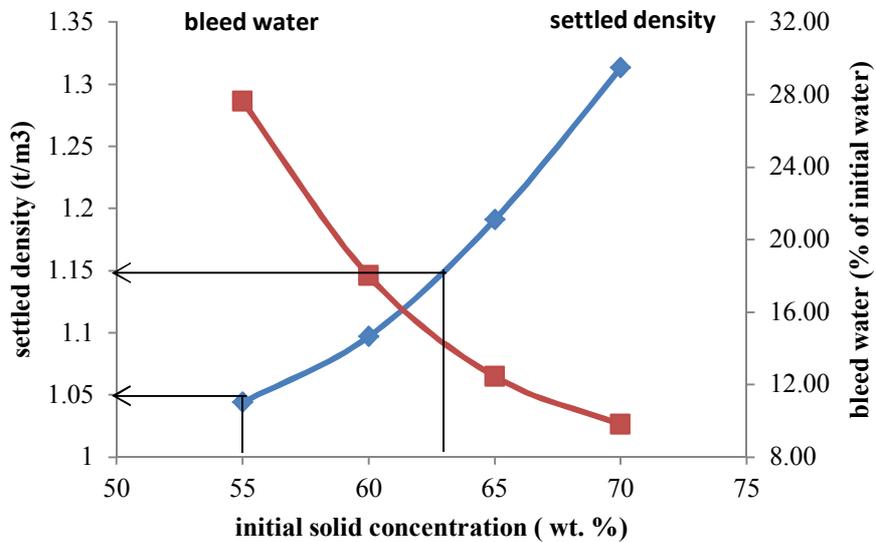


Figure 5. Initial settled density and bleed water rate at different initial solid concentrations.

A numerical example is presented here using the industrial data of the Shahrabak copper complex for a rough evaluation of water losses in tailing dam. This copper concentrator plant working with the throughput of 900 ton of dry solids per hour uses five paste thickeners. The tailing stream with 28% solid concentration by weight containing 2314 m<sup>3</sup>/h of water is introduced to the paste thickeners. The solid concentration of thickener discharge is about 55 wt.% containing 736 m<sup>3</sup>/h of water. In other words, 68% of the thickener feed water content is recycled in the dewatering plant and 32% is lost in the thickener discharge and introduced to TSF. According to Figure 6, 533 m<sup>3</sup>/h of this water is lost and 203 m<sup>3</sup>/h is recycled in TSF. In this case, the total water recovery in the dewatering plant and TSF is 76.97%. Suppose that the thickener performance is improved by applying some modification as discussed above and the thickener discharge solid concentration is increased to 63 wt.% containing 528 m<sup>3</sup>/h of water. Hence, 77% of the thickener feed water content is recycled in the dewatering plant and 23% is lost in the thickener discharge and introduced to TSF. It could be predicted from Figure 6 that 454 m<sup>3</sup>/h of this amount of water is lost and 74 m<sup>3</sup>/h is recycled in TSF. In this case, the total water recovery in the dewatering plant and TSF will increase to 80.38%. Consequently, the total water recovery could increase approximately 3.41% by improving the paste thickener performance.

Although the poor operation of the thickeners has led to reduce their performance, the main problem is the presence of clay mineral and fine particles in tailings. As noted, the inappropriate performance of the thickeners cannot be

compensated in TSF. Despite the fact that the residence time will increase in the tailing dam, the solid-liquid separation will occur slightly. Thus the clay mineral has negative impacts on both the thickener and TSF performance.

As shown in Figure 7, a decrease in the solid concentrations leads to an increase in the settling rate of particles or the rate of solid-liquid separation. It does not mean that the final solid concentrations will necessarily increase but it will also show that as the materials become pulp-to-paste, the particle segregation and the settling rate are reduced. It should be noted that a proper paste plant is the system where the main sedimentation operation takes place within the thickeners, not in TSF.

### 3.5. Tailing shrinkage limit density

The shrinkage limit tests are carried out to determine the maximum dry density that could result from the evaporative drying of the tailings on a beach. The results of these tests are plotted in Figure 8. It can clearly be seen that the shrinkage limit density of the tailings tested during early plant operation has significantly decreased in comparison with the design phase. A shrinkage limit density of 1.52 t/m<sup>3</sup> was recorded for the flocculated tailing sample in the present study, while it was measured to be 1.62 t/m<sup>3</sup> during the design phase. Also the crack volume was estimated at 6.3% and 7.2% of the final sample volume in the current and design study, respectively. It also showed that the clay minerals could hold more water in their inner network and occupy more volume. Thus the volume of TSF will be decreased by increasing the clay mineral and fine particles in tailings.

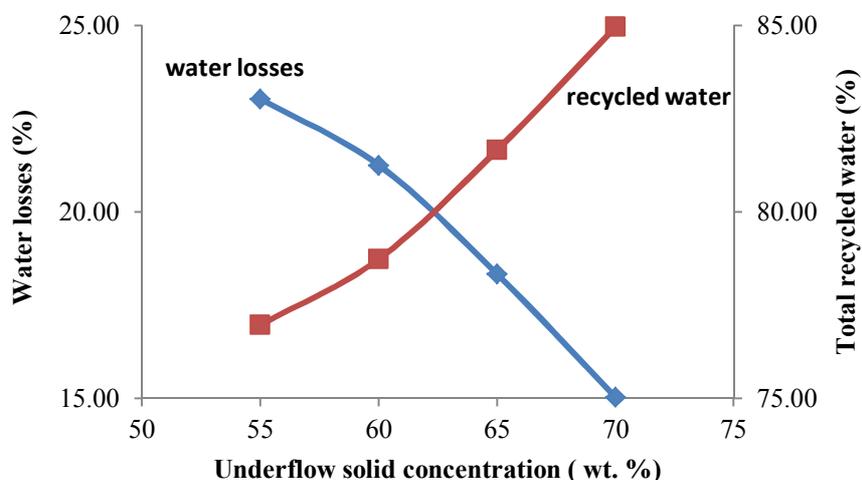


Figure 6. Total recycled water from dewatering area and water losses in tailing dam at different underflow solid concentrations.

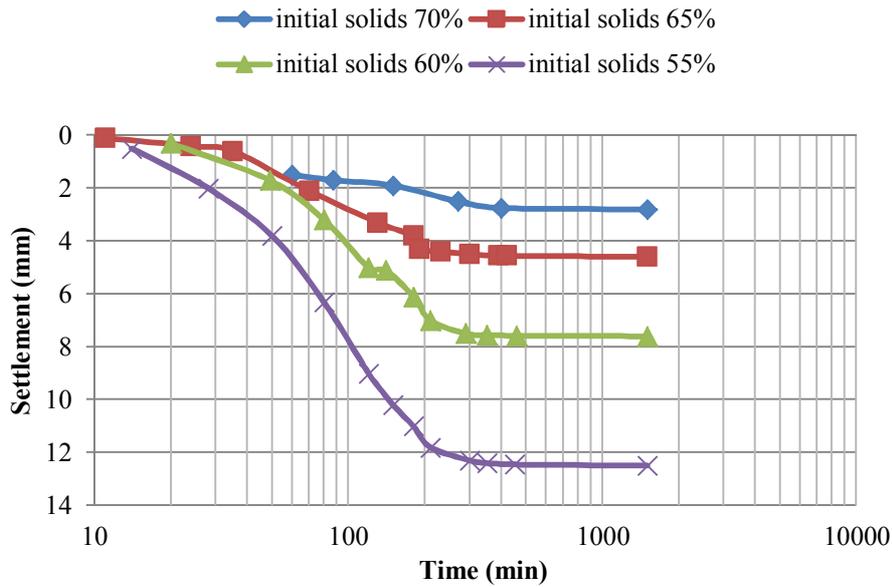


Figure 7. Final settlement of tailings at different initial solid concentrations.

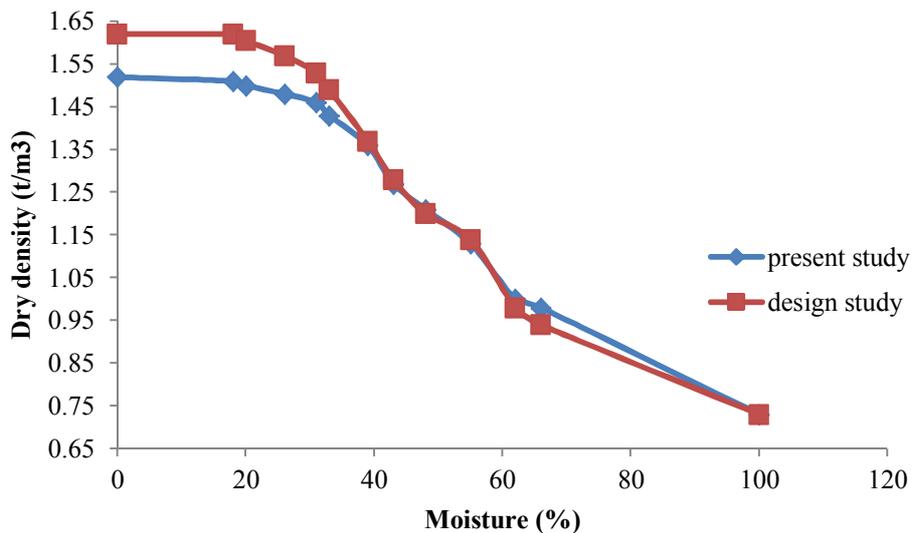


Figure 8. Tailing shrinkage limit density during early plant operation and design phase.

### 3.6. Estimation of tailing beach slope

The primary aim of tailing thickening to a paste consistency is to enable steeper beach slopes to be achieved that would be possible. The achievable tailing beach slope is dependent on the solid concentrations, the rheological properties of the thickened tailings, and also the rate of thickener discharge. The actual beach geometry achieved is a function of the consistency of plant operational parameters, drainage conditions, environmental factors, and properties of the thickened tailings [28]. In order to form a planar beach slope, the plant operational parameters, ore properties, and tailing properties must not be varied.

The original design of TSF adopted a planar beach slope of 3.5% at a solid concentration of 63 wt.%. The tailing beach slope can in part be related to the rate of tailing discharge inversely. The beach slope increases with decrease in the rate of discharge. As mentioned above, the underflow from five thickeners combines immediately after discharge. The maximum sub-aerial tailing beach slope exhibited to date is 2.0%. This occurs in the upper quarter of the beach. The remainder of the exposed tailing beach has an average slope of 1.0%. This is believed to be a result of the poor thickener performance and the high clay content of the early mine life tailings, resulting in less

than optimal thickened tailing solid concentrations.

The beach geometry regimes listed in Table 2 were adopted for assessment of the future tailing storage requirements. The beach slope for solid concentration of 60 wt.% is estimated by the average of the two other cases. In fact, it is not an accurate estimation but it can provide an overview to assess the tailing storage requirements. It is

believed that Case 2 can be achieved simply by intercepting the dilution water from the return water tanks and by making some small improvements in the thickener operation. It should also be admitted that achieving the beach slope of 3.5% with an increase in clay mineral and fine particles in the tailings is very difficult and may be impractical. However, it can be close to the design value by the thickener improvement.

**Table 2. Beach slope under different operating conditions.**

Case	Thickener underflow solid concentration (wt.%)	Upper 1/3	Middle 1/3	Lower 1/3
Continuation of existing practices	55	2.0%	1.0%	1.0%
Small improvement on existing thickeners	60	2.75% (estimated)	1.75% (estimated)	1.35% (estimated)
Design case	63	3.5%	2.5%	1.7%

Fresh tailing particle weather in TSF and secondary oxidized minerals form when exposed to oxide conditions. Depending on the interaction between source mineralogy and local conditions such as pH, climate, and redox potential, particular secondary minerals may form. The secondary mineral assemblage often hosts the major contaminant metals and metalloids by both the structural incorporation and surface sorption [8]. In order to prevent the release of environmental pollutants from various elements in TSF, it is recommended to use plant species. The primary factors considered for plant type selection could be the climate and nature of the soil. Shahrabak has cold winters and hot summers; it is a desert region with a dry climate and an average rainfall of approx. 100 mm. Thus the desired plants should be compatible with this climate.

The acidity of soil and bleed water is too high due to the presence of pyrite in tailings (Table 1). Therefore, the other elements found in this soil could be dissolved in water and lead to environmental contamination. Regarding the mentioned properties of the tailings, species should be proposed as to consistency and viability against the acidic condition and compatible with the region conditions mentioned above. The native species that may be suitable for this condition are *Amygdalus scoparia*, *Pistachio*, *Tamarix*, *Ephedra*, *Astragalus*, and *Salsola*. A series of tests including characterization of soil and water and the growth ability of native species in this area will be carried out in future research works.

#### 4. Conclusions

The tailing disposal scheme at the Shahrabak Copper Mine includes the thickened tailings via five paste thickeners and the subsequent down-valley discharge to TSF. The design solid concentration of the thickened tailings was 63 wt.% but it is well below the design value right now (approx. 55 wt. %). The experimental results show that the initial settled density varies from 1.044 to 1.146 t/m<sup>3</sup> by increasing the solid concentrations from 55 to 63 wt.%. Furthermore, the bleed water rate significantly decreases from 27.62% to 14% at these two solid concentrations, respectively. The low solid concentration of tailings was due to the changes in the tailing properties and poor operation of the dewatering systems. A shrinkage limit density of 1.52 t/m<sup>3</sup> was recorded for the flocculated tailing sample in the present study, while it was measured to be 1.62 t/m<sup>3</sup> during the design phase. Also the crack volume was estimated at 6.3% and 7.2% of the final sample volume in the present and design study, respectively. It can be deduced that the clay mineral can hold more water in its inner network and occupy more volume. Thus the volume of TSF will be decreased by increasing the clay mineral in tailings. Furthermore, the sub-aerial tailing beach slope in the upper quarter exhibited to date is 2.0% in TSF and the remainder beach has an average slope of 1.0%, which is far from the design values. This is believed to be a result of the poor thickener performance and high clay content of the early mine life. It should also be admitted that achieving the beach slope of 3.5% with an increase in clay mineral in the tailings is very difficult and may be impractical. However, it can be close to the design value by increasing the

thickener performance and removing the leakage and other periodic water at the discharge point.

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## رفتار تهنشینی و سفت‌شدگی رس در انباشتگاه باطله در طول عمر معدن

سیده محدثه احسانی<sup>۱</sup>، مجید یونسی<sup>۲\*</sup> و رضا تمر تاش<sup>۳</sup>

۱- دانشکده مرتع و آبخیزداری، دانشگاه علوم کشاورزی و منابع طبیعی گرگان، ایران

۲- دانشگاه آزاد اسلامی، واحد علوم و تحقیقات، باشگاه پژوهشگران جوان و نخبگان تهران، ایران

۳- دانشکده منابع طبیعی، گروه مرتع و آبخیزداری، دانشگاه علوم کشاورزی و منابع طبیعی ساری، ایران

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\* نویسنده مسئول مکاتبات: majid.unesi@gmail.com

### چکیده:

تغییرات در ویژگی‌های باطله (افزایش مقدار کانی‌های رسی و ذرات ریز) و عملکرد ضعیف سیستم‌های آبیگری اثرات منفی در انباشتگاه باطله در مجتمع مس شهر بابک داشته است. مقدار درصد جامد طراحی برای باطله آبیگری شده در واحد تیکنرهای خمیری شهر بابک ۶۳ درصد وزنی بوده است ولی در حال حاضر این مقدار کمتر از مقدار طراحی است (حدود ۵۵ درصد وزنی). هدف اصلی این پژوهش، یافتن اثر کانی‌های رسی و عملیات آبیگری در بازیابی آب و ظرفیت سدهای باطله است. نمونه‌های مورد مطالعه از تهریز تیکنر تهیه شده و در درصد جامدهای مورد نیاز آماده‌سازی شدند (۵۵، ۶۰، ۶۵ و ۷۰ درصد وزنی). نتایج نشان داد که دانسیته تهنشینی اولیه با افزایش درصد جامد از ۵۵ تا ۶۳ درصد به ترتیب از ۱/۰۴۴ تا ۱/۱۴۶ تن بر مترمکعب تغییر خواهد کرد. علاوه بر این، دانسیته محدوده ترک این دو درصد جامد به ترتیب ۱/۵۲ و ۱/۶۲ تن بر مترمکعب بوده و حجم ترک ۶/۳ و ۷/۲ درصد از حجم کلی نمونه تخمین زده شده است. همچنین شیب نشست باطله در یک سوم بالایی و الباقی انباشتگاه باطله پایین بوده و به ترتیب ۲ و ۱ درصد است. با این حال، از مقادیر طراحی بسیار فاصله دارد (۳/۵، ۲/۵ و ۱/۷ درصد از بالای انباشتگاه تا انتهای آن). در نتیجه می‌توان دریافت که کانی‌های رسی و ذرات ریز می‌توانند آب بیشتری را در شبکه داخلی خود نگه دارند و حجم بیشتری از انباشتگاه باطله را اشغال می‌کنند. با این حال، شیب نشست می‌تواند با بهبود عملکرد تیکنر و حذف نشتی‌های آب افزایش یابد. البته دستیابی به مقادیر طراحی به دلیل تغییر ویژگی‌های ماده معدنی غیرعملی به نظر می‌رسد.

**کلمات کلیدی:** کانی‌های رسی، انباشتگاه باطله، دانسیته تهنشینی اولیه، دانسیته محدوده ترک، شیب نشست.