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Tailings Disposal Options Study for Sangan Iron Mine Project, Iran

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Abstract

This paper is an overview of the tailings disposal options study for Sangan Iron Mine Project situated in north-eastern Iran. The first development phase of the project consists of two oerbodies, a primary crusher, crushed ore handling, stacking and a 2.6 mtpa concentrator plant. The total tailings of this phase is estimated to be 45 Mm^3 and in accordance whit the original design, the tailings produced will be stored in three adjacent cells that will be located approximately 3 km southeast of the concentrator plant. The three cells will all roughly be the same size; each cell will store approximately 15 Mm^3 of tailings. Each cell is constructed with a rock fill downstream retaining embankment in three stages. Based on this design, no water will be recovered from the tailings storage facility and this is a considerable shortcoming, because the mine site is situated in an arid climate and the only available source for raw water supply is Sangan plain aquifer that for long term is not reliable. This study shows that by applying the paste thickening technology, 0.87 Mm^3 per annum of water can be recovered.

Introduction

Two great revolutions in mining occurred during the 20th century. The first took place more than 100 years ago (1903-1905) with Daniel Jackling's experiment in the economies of scale for large scale mining at Bingham Canyon. Jackling's ideas changed the focus of base metal exploration toward lower grade, high tonnage deposits. The second revolution was the impact of environmental and social concerns on mining. It started near the end of the 20th century and is still under way (Hitzman, 2009). One of the major challenges in current and future open-pit mining is tailings disposal. Tailings and mine wastes have the potential to leave environmental, social and economic legacies for thousands of years. Tailings deposition as well as site preparation and tailings containment are design decisions that will determine the site impacts identified under the broad terms of economics, environmental, social and governance (van Zyl, 2009). Environmental issues are one the main pillars of the sustainable development and there is no room for doubt that environmental issues of a mining project cannot be ignored in the third millennium. The International Council on Mining and Metals (ICMM) definition of sustainable development for the mining and metals sector means that investments should be: technically appropriate, environmentally sound, financially profitable, and socially responsible (Commonwealth Government, 2007).

Sangan Iron Mine Project (SIMP) is one of the Iran's major iron ore resources. In this paper the original design of tailings disposal system as well as all feasible options for the project is reviewed. As the major objective of this study is achieving the maximum water recovery, the paste thickening technology and surface stacking which is the most efficient system for reclaiming the process water is examined.

Planning and implementation phases of SIMP

The pre-feasibility study of the SIMP has been carried out by a joint venture (JV) formed by BHP Engineering from Australia and Know-How Corporation from Iran (BHP/KH JV) in 1992. Feasibility study of project has been done by another JV formed by Simons, Bateman and Iritec (SBI JV) in 1998. In 2001 the design of the plant was to produce 1.3 mtpa of oxide pellet. In 2004 the capacity of the plant has been increased and therefore the current design is for 2.6 mtpa of iron ore concentrate. The engineering for a 2.4 mtpa expanded concentrator plant and a 5 mtpa pelletizing plant is underway. The feasibility study for the tailings disposal plan for the project has been done by Klohn Crippen Consultants Ltd. of Canada in 1998. The basic engineering of the tailings dam has been done by AMEC Americas Ltd. in 2007.

Project location

The Sangan iron ore deposits form part of the east-west trending Kuh-e-Taleb mountain range, and in the Khorasan-Razavi Province in north-eastern Iran (Figure 1). The deposits lie approximately 300 km south of the city of Mashhad, 30 km west of the Afghanistan border and some 18 km north-east of the Sangan town. The deposits can be accessed from Mashhad via two separate ways, one via Torbat Heydariyeh and the other via Torbat Jam.

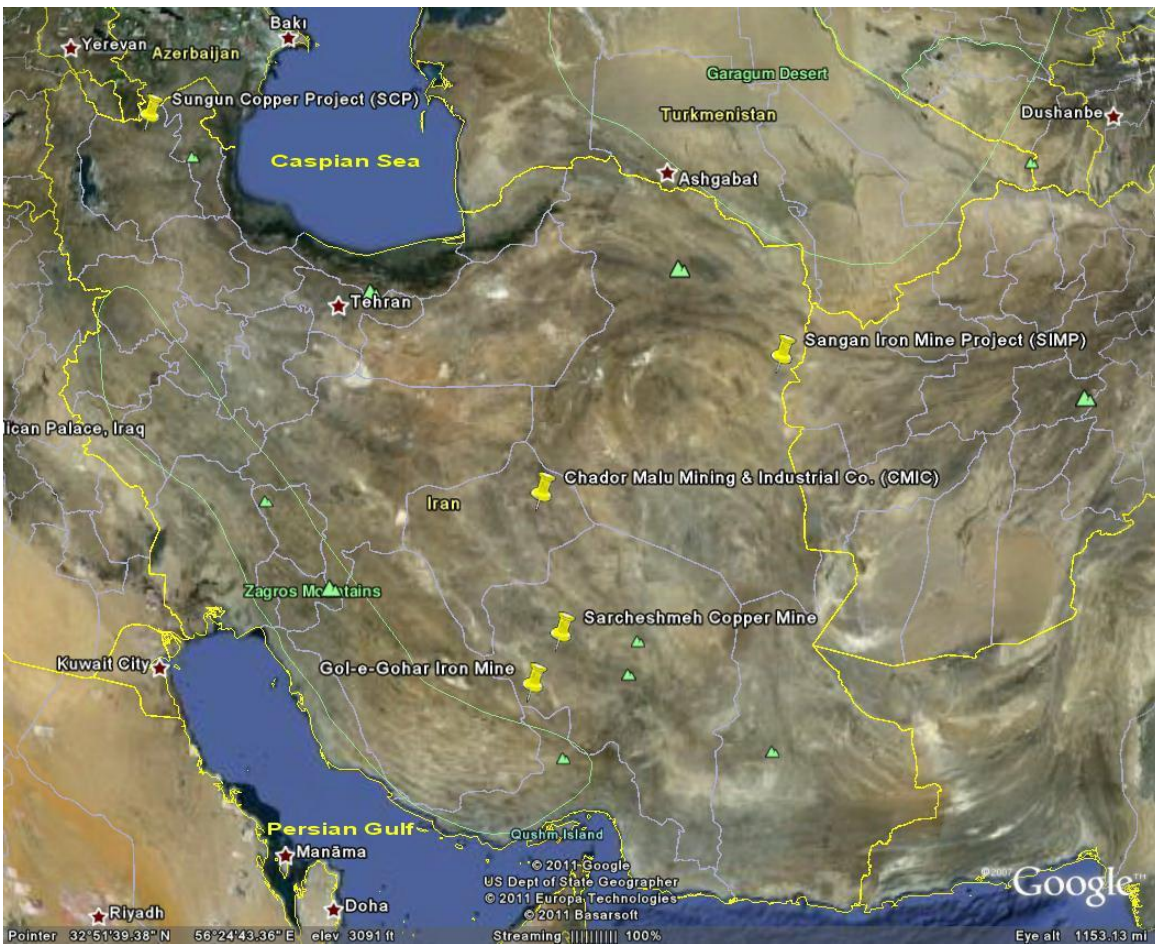


Figure 1: Geographical location of the SIMP and some other world class Iranian mines

The project is being developed by the National Iranian Steel Company (NISCO) which is a subsidiary of the Iranian Mines and Mining Industries Development & Renovation Organization (IMIDRO) that has been established 2001. The project is being developed to increase the national supply of iron ore for the Iranian steel industry as the first priority and for export as the second priority.

Site description

Climate

Climatic data has been recorded at the mine site since 1987. The area is semitropical/arid and semi-alpine with high relief (1700 m altitude in the mineralised areas). Maximum temperatures of 35 to 40°C are experienced in July/August while minimum temperatures of -5 to -15°C occur in January/February. The highest peak, Nole e Khorus, at Sangan falls in orebody A at about 263,900 E, 3,818,520 N and is at 1719.30 m. Less than 150 mm/y of rain is experienced, with rainfall often occurring as torrential showers in April and May. Drainage is generally to the south-west into the alluvial flats of the Khaf basin. Evaporation exceeds rainfall throughout the year and the experiences the Herat high constant winds of 30 to 120 km/h in the summer. Table 1 summarises the climatologic data of Sangan site. Dusty conditions are present. Surface soils are generally of poor quality with gravel predominating. Agriculture is generally limited to irrigated areas. The limited water supply severely restricts vegetation and wildlife.

Table 1: Climate of Sangan

Parameters	Amount	Unit
Average Altitude	1240	m ASL
Latitude (Orebody B)	34°28'N	
Longitude (Orebody B)	60°26'E	
Mean Rainfall	145	mm
Maximum Daily Rainfall	20	mm
Mean Freezing Days	7	days
Maximum Annual Evaporation	3900	mm
Maximum Recorded Daily Snowfall	15	mm
Height of Primary Crusher Area	1440	m ASL
Height of Complex Buildings Area at Plant Site	1150	m ASL
Maximum Temperature at Plant Site (about)	35	°C
Maximum Temperature at Mine Site (about)	32	°C
Minimum Temperature at Plant Site (about)	-2	°C
Minimum Temperature at Mine Site (about)	-5	°C

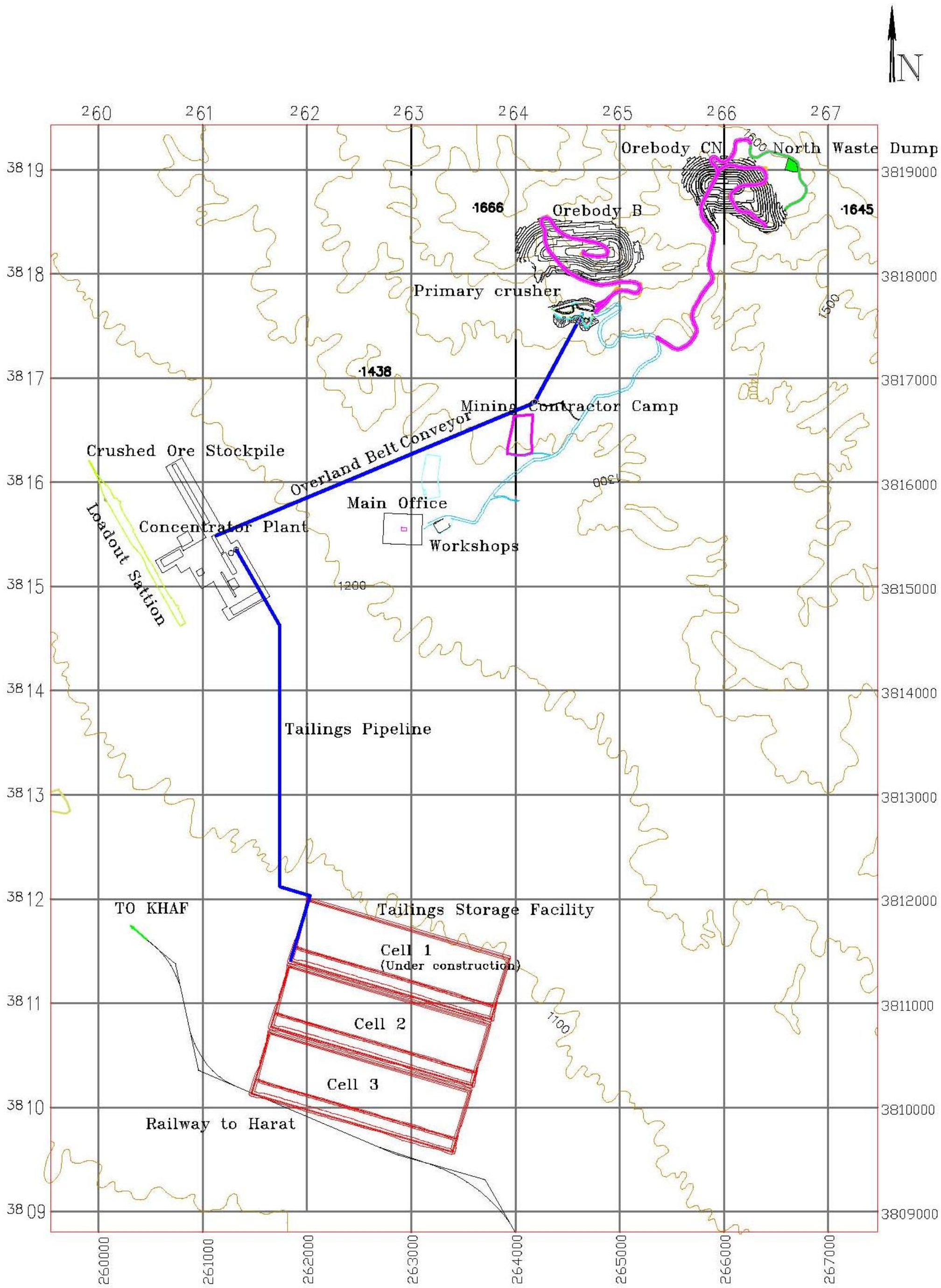


Figure 2: **General layout**

Site setting and topography

The concentrator plant located about 5 km south-east of the deposits. The tailings storage facility (TSF) is located to the south-southeast of all the other mine facilities on a broad alluvial plain. The plain is gently graded at approximately 2-5 percent towards the south-southwest and exhibits signs of channelling from water erosion. In the immediate vicinity of the TSF, the elevations range from approximately 1010 m at the southern most extent to approximately 1120 m at the northern most extent.

Geology

The Sangan Project is located in a region of the Iranian Plateau that exhibits diverse geological formations and seismicity. The orebodies are located in the sequence of sedimentary rocks with Tertiary igneous intrusions located in the Sangan Heights forming the northern border of the project site. The project site is located on a vast alluvial plain located south of the Sangan Heights. Apart from the mountains forming the northern border of the site, the plains exhibit a gently rolling topography. Within the limits of the project site the water table generally occurs at depths in excess of 25 metres below ground surface and appears to remain at these depths year round.

The iron mineralization is identified as being to the class of deposits known as Iron Skarn. A number of anomalies (orebodies), referred to Orebody A, Orebody B and Orebody CN, have been identified by the exploration program, which consist of drilling trenching and tunnelling to collect assay and geological data.

There are many alluvial placer iron ore deposits in the Sangan plain as well as in the TSF and some private companies are working on extraction and magnetic separation of iron ore. Almost all of processed iron ore with different grades and particle size distributions (PSD) are trucked to Bandar Abbas to be exported to China.

Three small crushing and separation facilities belong to IMIDRO with total capacity of 1.5 mtpa are working with run-of-mine ore extracted from some of the Sangan orebodies.

Hydrology

At site, water typically drains to the southwest from the hills to the gently sloping terrain. Natural drainages at site are ephemeral and typically do not have well defined bed and banks. Regional flow data was not available for design purposes; therefore, the design precipitation event combined with watershed information was used to calculate the design flood.

A runoff coefficient of 0.5 representing average runoff conditions was for the water balance. For the calculation of design floods a slightly higher runoff coefficient of 0.6 was used which accounts for more overland flow. These are conservatively high but are considered reasonable estimates of runoff for this area based on the soil conditions and precipitation events. Based on potential ranges in the runoff coefficient, precipitation event and changes in the watershed area caused by avulsions, the 100-year peak flow was estimated to range from 10 m^3/s to 26 m^3/s.

Mining and milling

The total mineral resources of the area (Sangan iron ore deposits), which has been divided into three regions (western, central and eastern) are estimated to be 1200 Mt. The western region consists of five orebodies (A, A', B, CN and CS) with 700 Mt mineral resources of which the orebodies B and CN with total minable reserves of 160 Mt, consisting of 109 Mt for ore type B and 51 Mt for ore type CN have been considered for the first phase of the project.

Mining is by shovel and truck, open pit method. Once the ultimate pits and phases were designed production was scheduled to produce 2.6 mtpa of concentrate. The concentrate is composed of an equal blend of ore type B and ore type CN material until Year 27 when the Orebody CN pit is mined out. Mining continues from Orebody B until Year 34. After Year 31 the weight recovery of Orebody B is too low to meet the target of 2.6 Mt of concentrate a year (AMEC Americas Ltd., 2008).

Ore is hauled to a gyratory crusher located near the mine with the crushed ore delivered from the crusher to the mill via 5 km of overland steel cord belt conveyors. Mine waste dumps are created around the periphery of each pit by end-dumping from haul trucks. A total of 193 Mt of waste rock will be generated during the 34 year project life. A geochemical assessment of the waste rock has indicated that waste rock disposal does not represent any significant concern with respect to acid generation or environmental impact. The two different ore types will be processed utilizing a single process plant on a batch campaign basis. The weight recovery of ore type B and ore type CN are 45.5 percent and 67.1 percent respectively. Total tailings production over the life of the project will be 73 Mt or approximately 45 Mm^3 (based on an assumed tailings dry density of 1.6 t/m^3), with 77 percent originating from Orebody B and 23 percent from Orebody CN (AMEC Americas Ltd., 2007). Ore type CN, which contains high sulphur values, will require a flotation step to remove pyrite from the concentrate prior to final magnetic separation and filtration while B ore type will bypass the flotation circuit. The concentration process includes several stages of grinding (AG mill, ball mill and tower mill), with magnetite separation occurring after each grinding stage. Tailings will be produced at each stage, in different proportions depending on the grade and the ore type being processed.

After coming into operation the future 2.4 mtpa concentrator plant the existing plant and the new one will be allocated for ore type CN and ore type B respectively.

Tailings disposal options study

A siting study aims to identify and evaluate locations and disposal methods for the safe and cost-effective storage of tailings. The study should consider a broad range of options. The objective of the tailings disposal options study is finding the best location for TFS from technical, environmental and economical standpoints (Rashidinejad & Raouf Sheibani, 2004). The main criteria for the tailings disposal options study is the need to provide enough capacity to contain the tailings produced over the 34 years mine life. Some other considerations included:

- Operational parameters
- Site setting: climate, mine site layout, topography, potential for orebody sterilisation, storage volume requirements, public health and safety risks, and potential social and environmental impacts
- Hydrology, hydrogeology, water balance and water management
- Proximity and elevation of the proposed site in relation to the processing plant, affecting the tailings delivery method
- Type of tailings: PSD, rheology and potential to contaminate
- Production capacity
- Tailings transportation, distribution and water reclaim
- Dam construction method (if applicable)
- Availability of borrow material for the dam construction (if applicable)
- Geotechnical analysis
- Seismicity of the site
- Operational management
- Closure options
- Financial analysis
- Expandability

As with all tailings disposal methods and tailings dam designs, the designer must balance the cost and risk of different tailings disposal technologies to select the best available technology. The options study of Sangan has been summarised in Table 2.

Table 2: Possible TSF for SIMP

	Disposal method	Possibility of utilization in Sangan
1	Slurry disposal to a valley storage, TSF with containment wall (retaining embankment), i.e. downstream, upstream & centreline dams	There are several TSF with containment wall for iron and base metal mines in the country. On the other hand the site has an arid climate and the precipitation is extremely less than evaporation that causes this category to be technically feasible for Sangan site. But due to lack of topographic depression and an efficient site, an entirely engineered retaining embankment is needed.
2	Slurry disposal to a ring containment wall on relatively flat ground, usually with a centrally-located decant facility	The estimated volume of total tailings is too high for this type of TSF. Likewise, the expandability of this type is limited. So, this method of tailings disposal is not recommended for Sangan site.
3	Slurry disposal to a series of cells with tailings deposition cycled between the cells to facilitate consolidation and desiccation	This type has been recommended by well-known companies for the Sangan site.
4	Central Thickened Discharge (CTD) on relatively flat ground, with supernatant water collected behind a water-retaining perimeter containment wall or in a water-tight perimeter channel	The topography of the site and surrounding areas is such that there are suitable flat sites to allow the formation of a CTD style tailings stack.
5	Down valley discharge (DVD) of thickened tailings towards a containment wall, located at the head of a catchment	Only one candidate site in a valley south of the primary crusher site could be found in the surrounding areas. This alternative was deemed inappropriate during feasibility engineering due to storage capacity limitations and estimated costs associated with pumping thickened tailings to an elevation which was approximately 200 metres higher than the plant site.
6	Disposal of thickened tailings to cells, possibly in combination with mechanically enhanced evaporative drying, as used for red muds in the alumina industry	This is not a suitable method for iron ore tailings disposal.
7	In-pit placement of tailings as a slurry, as thickened tailings or combined with waste rock (co-disposal)	There is no open pit available for the storage of tailings at start-up, nor will there be at any time during mining operations, so the in-pit disposal option is not an option in this case. Likewise, the elevations of the waste dumps are very higher than the elevation of tailing thickener(s), so the co-disposal option is not an option as well.
8	Underground backfill of mined-out stopes, in the form of hydraulic fill, rock-fill or cemented paste tailings backfill.	This option is not applicable for the Sangan site.
9	Direct disposal – underwater (submarine) tailings disposal	As there is no river, lake, deep sea or ocean in the surrounding areas, so this option is not an option in this case.

Characteristics of the original design

The tailings with consistency of fine, silty sand will be thickened to 60 percent solids by weight prior to being pumped to a TSF consisting of three large cells, each providing 11 to 12 years of tailings storage. Sizing Cell 1 of the TSF has assumed that the deposited tailings will develop beaches sloped at an overall angle of 1% from the embankment to the upstream end of the facility. The 1% slope has been considered during crest planning and will accommodate the development of a water pond at the north end of the impoundment during the wet season. Impoundments in arid areas are designed to conserve and recycle water for mining processes during the mine's active life, but no seepage collection or return facilities have been designed for Cell 1 of the TSF. Based on seepage modelling, the estimated total quantity of seepage from Cell 1 could be in the order of 100 m^3/d to 750 m^3/d.

To reduce capital costs, it is envisioned that each cell will be constructed in stages. The first cell to be constructed is the northern most Cell 1 (Figure 2), which will be constructed in three separate stages to optimize storage and construction considerations. Stage 1 for Cell 1 will accommodate the first two years of tailings production plus freeboard. For the designated two year Stage 1 period of the project, it is expected that a total of approximately 3.12 Mm^3 of tailings will be produced. All tailings produced will be pumped to and deposited in the TSF by spigotting (Figure 3).

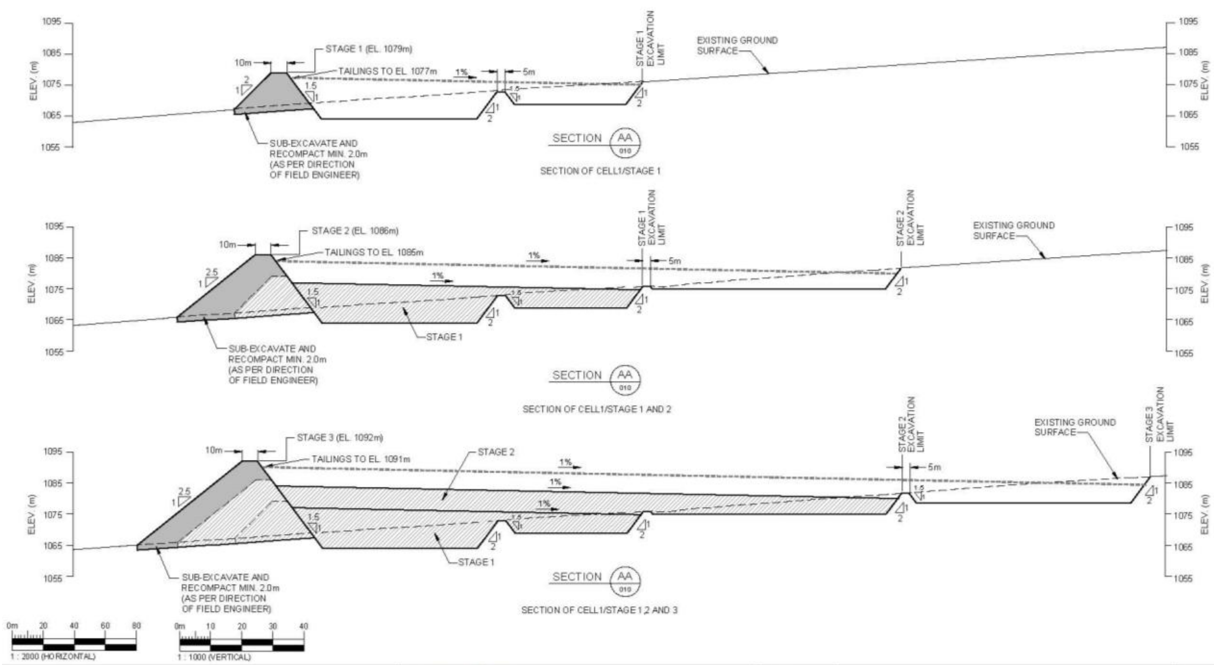


Figure 3: Cell 1 of the TSF - Downstream retaining embankment

The Sangan tailings are expected to generally consist of fine sandy silt to silty sand. Various grinding stages will produce subsequently finer tailings and therefore the gradation of the final tailings will vary with the proportion of tailings produced at each stage. The final tailings for both orebodies B and CN are expected to consist of fine sandy silt with gradations similar to those shown in Figure 4. Orebody CN is expected to produce slightly finer tailings than Orebody B with nearly 70 percent by weight passing 74 µm (the number 200 sieve). The Ore B tailings are expected to have approximately 60 percent passing 74 µm. Maximum particle sizes are expected to be less than 1 mm, but there is no estimation for particle sizes less than 37 µm.

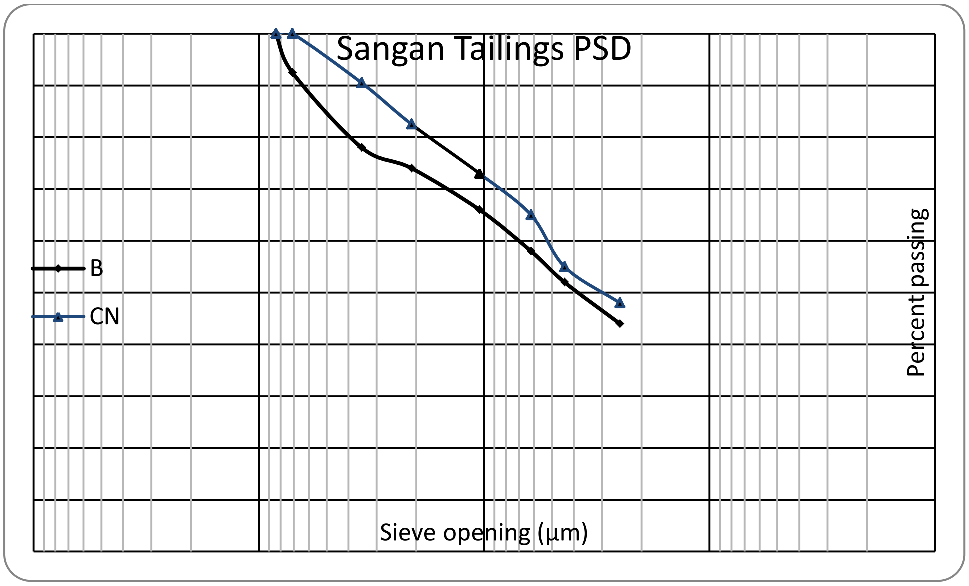


Figure 4: Sangan tailings PSD

Because of their sulphide content, the tailings produced from the processing of ore type CN will be potentially acid generating and are classified as theoretically acid-generating, while tailings from Orebody B is non-acid generating. Overall, however, the tailings will consist of a natural, non-toxic waste. Preliminary leach tests carried out by AMEC Americas Ltd. (AMEC, formerly H.A. Simons Ltd.) on simulated tailings samples have indicated that the tailings do not contain leachable metals and therefore should have no negative impact on local aquifers. Lining of the tailings facility is therefore not considered warranted. Progressive reclamation of each tailings area with coarser material and the construction of wind breaks may be required to prevent excessive formation of dust.

Tailings dewatering

Dorr patented the first commercial thickener in 1907, which utilized revolving rakes. It was a sedimentary machine that worked on the basis of settling particles using gravity. In the mineral industry, sedimentation equipment is ubiquitous. Thickeners are used the most commonly used equipment for solid-liquid separation. There are four general types of thickener rake drive mechanism: bridge mounted, centre column mounted, traction drives, and cable torque.

Conventional thickener design uses centre underflow outlets with the floor sloped at 1:12 – 2:12 towards the centre (Schoenbrunn and Laros, 2002). Slurry enters through a feed-well to the thickener tanks. The purpose of using a feed-well is to dampen the turbulence of the incoming feed in order to produce a laminar flow and reduce interference with solids that are already inside the tank. In order to improve thickening efficiencies, flocculent may be added in the process. The purpose of flocculent is to aid agglomeration of the solids and speed settling. Conventional tailings typically range 30–50 percent solids, thickened tailings 55–75 percent and paste over 75 percent (solid concentrations vary with particle size and shape, clay content, mineralogy, electrostatic forces and flocculant dosing).

The term "High-Rate" is used for the thickeners that the throughput rates for the flocculated feed slurries are considerably higher than for unflocculated slurries. Most high rate thickeners use feed dilution systems.

Tailings from the concentrator plant will be fed to two 55 m conventional thickeners. Underflow, with a density of 60 percent of solids will be fed to the tailings transport slurry pump feed box.

Paste thickening technology

Paste thickening technology is rapidly emerging as an effective method for handling tailings for water recovery and an alternative to conventional dams and ponds. The solids concentration of paste thickener underflow and non-settling character has a rheology that allows the tailings to be deposited on a surface with a slope and without the need for expensive dams. Paste deposited in existing tailings impoundments will extend the life of pond by reducing the number or height of the dam lifts. The use of paste and thickened tailings has become an established alternative conventional disposal the world-wide minerals industry. This technology also has a great potential in arid climates, where the reduction of the makeup water supply produces an important net saving in the operation.

Increasingly, paste and thickened tailings techniques are being used more widely, due to a larger range of thickener technologies, reduced costs, increased familiarity and access to expert knowledge, and increased water scarcity at some localities. Paste and thickened tailings can require additional capital expenditure but, over the long-term, thickening techniques may result in decreased management, lower dam construction and rehabilitation costs and significantly lower water use (Franks et al., 2011).

Definition of paste

Paste can be defined through different approaches. Within the context of rheology, paste is a non-Newtonian fluid material. It is a saturated and homogenous mixture that may show time-independent (base metals) or time-dependent behaviour (Saebi-moghaddam, 2005). Paste is typically described as a non-segregating, pumpable mineral suspension, which can be divided into three groups: inert material (solid-water), binding agents and chemical additives. The inert materials commonly used are total tailings or alluvial sand and silt with a relatively solid content between 70-75 percent and 85 percent. These concentrations mean additional water recovery compared to conventionally thickened (non-segregating) tailings using high rate slurry underflow thickeners producing lower concentrations in the settling solids range. If the paste thickener is operated to produce a material that can be easily pumped to but it segregated upon discharge, forming a beach and a pond that shortens the life of the tailings dam and disposal site (Slottee et al., 2011).

Paste characteristics

Paste is generally characterized by a yield stress, which is measured in units of pressure and is related to the force required to make a paste flow. Some of the solid-liquid mixtures such as paste behave as viscoplastic fluids. By applying shear stress, these fluids begin deforming plastically like solids. When the applied shear stress is more than a certain critical stress, these fluids flow as viscous material with finite viscosity. This critical stress, which depends on the characterization of the mixture, is called yield stress, typically in the range of 50 Pa. Identifying the yield stress curve is important for the design and operation of a paste thickener, downstream pumps and deposition. Under gravity a tailings paste will flow to a point dictated by the yield stress and stop.

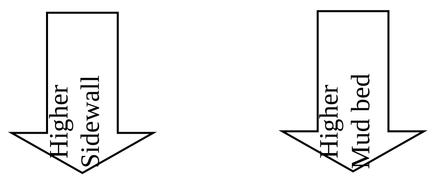
The density of paste depends on water content, particle shape and surface chemistry, supernatant pH and chemistry. A wide range of size distributions has been employed to produce paste. However, paste should have a minimum weight of 15 percent of the partic1es that are smaller than 20 μm. The role of fine particles (20 µm) is to preserve the water to obtain a non-segregated mixture even if paste is not in motion. Also, the surface area of aggregate partic1es affects paste properties. The finer the PSD, the more water exists surrounding the partic1e surface area. This is due to an increase in aggregate partic1e surface area. The density of paste decreases with an increase in fines of the PSD. Paste tailings has low slump tailings which will release little or no water.

Paste thickeners

Paste thickeners have been used in the alumina industry for several decades to improve chemical recovery and allow stacking of the red mud for disposal (Boger& Nguyen, 1998). The paste thickener is characterized by a height to diameter ratio typically greater than one to one (Figure 5). This aspect ratio, combined with a floor slope of 30 degrees allows high yield stress (and therefore high solids concentration) paste to be discharged. The high density style paste thickener has an aspect ratio less than one but with sidewall and mud bed heights significantly higher than conventional thickeners (Table 3).

Table 3: Thickener types

	Type	Aspect ratio
1	Conventional	<1
2	High-Rate	<1
3	Paste	>1



Unit areas (m^2/tph) for paste thickeners are smaller than for conventional and high-rate thickeners.

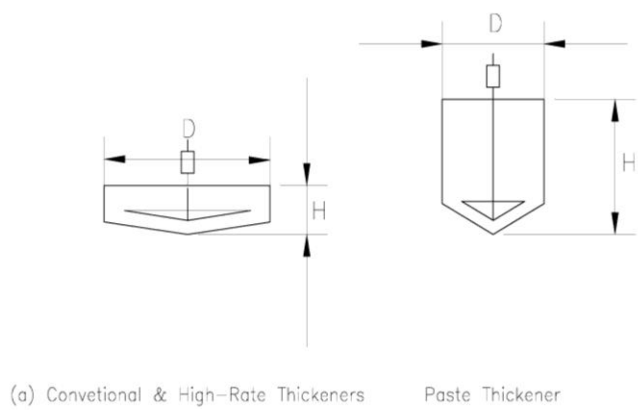


Figure 5: Typical thickeners

Surface stacking

The traditional method of disposing of the waste is to use a settling pond and a dam (i.e., a tailings pond). Since the dam retains loose unconsolidated tailings and considerable process liquid, failure of a TSF may result in an uncontrolled spill, a dangerous flow-slide and/or the release of poisonous chemicals, leading to a major environmental disaster. A new disposal system, involving the deposition of dewatered tailings on the ground surface (no dam), is of interest. Dewatering changes the tailings' state from a low viscosity fluid to a paste, thereby increasing the stability of the deposited stack (Kweak et al, 2005).

Surface stacking refers to the disposal of tailings on the surface, as a paste. Stacking as a method of tailings disposal, offers significant advantages over ponding. There is less water in the pond and a lower risk of containment breach, less groundwater contamination and easier final reclamation of the site.

Application of paste thickening technology in SIMP

Ore type B will be treated for 60 percent of the operating time (7296 h/y). Tailings from LIMS concentration steps will be fed to two 55 m conventional thickeners. Underflow, with a density of 60 percent of solids will be fed to the tailings transport slurry pump feed box. Also into this box will be slurry of around 50 percent solid which represents the underflow from the de-girt cyclone of the cobber tailings system. Ore type B tailings slurry thus contains approximately 55 percent. The hourly and annual conditions are summarised in the Table 4.

Table 4: Tailings of ore type B

Orebody B (60%)									
Nomination	Solid		Slurry		Water	Concentration		S.G. Solids	Slurry Density
	t/h	m^3/h	t/h	m^3/h	m^3/h	wt %	vol. %	g/cm^3	kg/l
Thickener feed	244.00	61.93	4,277.90	4,095.95	4,034.02	5.70	1.51	3.94	1.04
Thickener OF	-	-	3,872.70	3,872.70	3,872.70	-	-	-	-
Thickener UF	244.00	61.93	407.50	225.36	163.50	59.90	27.48	3.94	1.81
Gland & Seal Water	-	-	8.00	8.00	8.00	-	0	-	-
Cobber Tailings Cyclone UF	124.40	32.74	207.40	115.71	82.97	60.00	28.29	3.80	1.79
Total Tailings	368.40	94.67	614.90	341.07	246.40	59.93	27.76	3.89	1.80

Ore type CN will be treated for 40 percent of the operating time. Tailings from LIMS concentration steps will be fed to two 55 m conventional thickeners. Underflow, with a density of 60 percent of solids will be fed to the tailings transport slurry pump feed box. Also into this box will be slurry of around 50 percent solid which represents the underflow from the de-girt cyclone of the cobber tailings system as well as tailings from the flotation process. Ore type CN tailings slurry will thus contains approximately 55 percent. The hourly and annual conditions are summarised in the Table 5.

Table 5: Tailings of ore type CN

Orebody CN (40%)									
Nomination	Solid		Slurry		Water	Concentration		S.G. Solids	Slurry Density
	t/h	m^3/h	t/h	m^3/h	m^3/h	wt %	vol. %	g/cm^3	kg/l
Thickener feed	105.50	32.97	6,618.30	6,545.50	6,512.53	1.60	0.50	3.20	1.01
Thickener OF	-	-	6,443.10	6,443.10	6,443.10	-	-	-	-
Thickener UF	105.50	32.97	176.70	104.18	71.21	59.70	31.65	3.20	1.70
Gland & Seal Water	-	-	8.00	8.00	8.00	-	0.00	-	-
Cobber Tailings Cyclone UF	86.10	27.77	143.50	85.17	57.40	60.00	32.61	3.10	1.68
Flotation Tailings	20.50	4.46	78.40	62.32	57.87	26.20	7.15	4.60	1.26
Total Tailings	212.10	65.20	398.60	251.67	186.48	53.22	25.91	3.25	1.58

In an underflow of 75 percent can be achieved in practice and the recovered water is returned to the process, the following benefits in water conservation can be expected (Table 6).

Table 6: Paste Tailings

Nomination	Solid		Slurry		Water	Concentration		S.G. Solids	Slurry Density
	t/h	m^3/h	t/h	m^3/h	m^3/h	wt %	vol. %	g/cm^3	kg/l
Paste of ore type B	368.40	94.67	483.40	214.01	119.35	75.00	44.23	3.89	2.26
Paste of ore type CN	212.10	65.20	298.10	143.25	78.05	75.00	45.51	3.25	2.08

In total, tailings down the pipeline to impoundment amounts to that shown in Table 7:

Table 7: Total Annual Tailings in Pipeline

Nomination	Solid		Slurry		Water
	t	m^3	t	m^3	m^3
Tailings of ore type B	1,612,707.84	414,408.90	2,691,786.24	1,493,056.12	1,078,647.22
Tailings of ore type CN	618,992.64	190.278.12	1,163,274.24	734,486.80	544,208.68
Annual Tailings	2,231,700.48	604,687.02	3,855,060.67	2,227,542.92	1,622,855.90
Annual Thickened Tailings B	1,612,707.84	414,408.90	2,116,113.84	936,861.26	522,452.36
Annual Thickened Tailings CN	618,992.64	190,278.12	869,975.04	418,066.28	227,788.16
Annual Thickened Tailings (Paste)	2,231,700.48	604,687.02	2,986,106.88	1,354,927.54	750,240.52
Potential water recovery					872,615.38

One can see that potentially more than 0.87 Mm^3 of process water from the concentrator plant can be recovered if paste thickening system is to be used in the Sangan Mine.

Conclusions

The thickened tailings (generally referred to as "paste") method presents a new paradigm in tailings disposal. The most important advantage of this method is higher water recovery. The concentrator plant of Sangan will produce 2.23 mtpa of tailings (dry basis) which will be sent to a TSF as slurry. The original TSF has a negative water balance in which no water is recovered to the process. It is estimated that when a paste of 75 percent solids produced, approximately 0.87 Mm^3 of water can be recovered from the tailings system and reuse in the process. More water can be reclaimed from the decants of the TSF, but it needs more studies.

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