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Implementation of a deep cone thickener and pumping system to transform an existing conventional tailings dam into paste tailings

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Abstract

This paper presents a successful case study of converting an existing conventional tailings dam with a beach slope of approximately 0.5% into a paste tailings dam with a beach slope of approximately 2%. The disposal of paste tailings began in 2016. The mine is located in the central highlands of Peru at 4,200 m a.s.l. The concentration plant processes 5,430 tpd of polymetallic tailings (lead, silver, and zinc).

Since the mining operation is underground, sand from the tailings is required for mine fill. For this reason, a cyclone system and thickening were implemented prior to discharge to the tailings dam. At times, whole tailings are discharged to thickening, while at other times, fine tailings from the cyclone are discharged to thickening before final discharge to the tailings storage facility.

Finally, to achieve paste tailings, a 19 m diameter and 21 m high deep cone thickener was installed. A piston pump (flow rate of 185 m^3/h at 95 bar) was also installed to propel the paste tailings through a DN200 diameter SCH80 pipeline, 1,350 m long, to the discharge points at the tailings dam. The rheology achieved at the thickener outlet ranged from 80–250 Pa shear stress, corresponding to solids concentration of 60–71% by weight. This rheology achieved an average beach slope greater than 1.5%, thereby increasing the dam's life by approximately 3 years.

Keywords: *paste tailings, beach slope, rheology*

1 Introduction

A mining client located in the central highlands of Peru requested Golder Associates S.A. (now WSP) to provide consulting services to design a new high-density tailings thickening plant, and the associated tailings transport system, in order to discharge tailings onto the existing conventional deposit. This process seeks to achieve a tailings beach slope of approximately 2%, greater than the existing 0.5%. By doing this, the operating life of the existing deposit will be extended by up to 3 years.

The concentration plant outputs 4,523 tpd of whole tailings, with 21%m, into a pump box. From this box, tailings are conveyed through two parallel pipelines to a cycloning station, near the existing tailings deposit, where a pass box receives the tailings. Under normal conditions, the tailings are cycloned, the overflow is thickened in a high-density equipment before being sent to the existing deposit, and the underflow is discharged forming a classified sands pile that feeds the hydraulic paste plant to be discharged to the underground mine. On occasion, the whole tailings are sent to the existing deposit without cycloning but are previously thickened in high-density equipment. The location of the study components can be seen in Figure 1.

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Figure 1 Location overview

2 Data

To guarantee the designs for thickening and transport, thickening and rheology tests were made at a laboratory level. In addition, the process route to follow was verified, keeping in mind the sands production from the tailings for hydraulic filling, as well as the continuous discharge of tailings to the existing deposit, whether whole tailings or only fine tailings from the cyclones.

Initial data for the design of all pumping systems was received from the client. Additional data also came from laboratory tests using tailings samples. The rest of the required information came from previous analysis by the client and thickener data by its supplier.

2.1 Site conditions

Mine elevation, annual precipitation and site temperature are shown in Table 1.

Table 1 Operation parameters, site conditions

Conditions	Value	Unit	Source
Maximum temperature	14.5	°C	Client
Minimum temperature	−5	°C	Client
Average annual precipitation	703.6	mm	Client
Elevation	4,200	m a.s.l.	Client

2.2 Overview of operation parameters of tailings and process route

The process route to follow according to the existing cyclones operation and discharge to the existing deposit is shown in Figure 2.

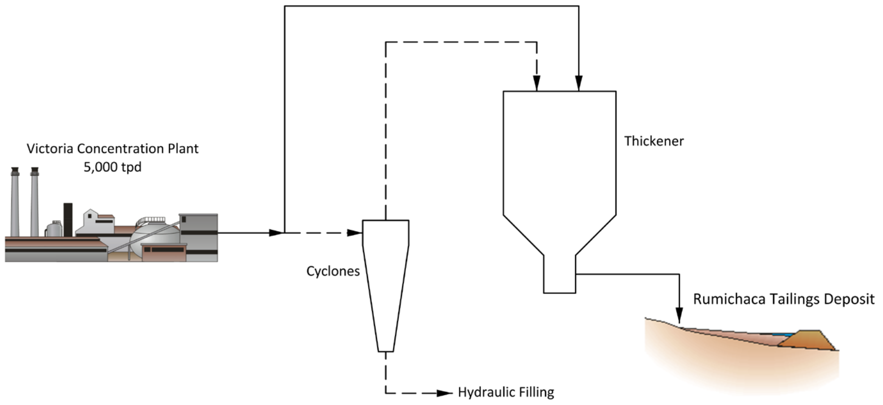

Figure 2 Tailings thickening process flow

The nominal and design tailings tonnage, coming from the concentration plant, as well as the specific gravity and particle size distribution of the slurry, are shown in Tables 2 and 3.

Table 2 General operation parameters, tailings production

Parameter	Value	Unit	Source
Plant availability	95	%	Client
Design factor	1.2	–	WSP
Whole tailings (WT) nominal tonnage	4,523	tpd	Client
WT design tonnage	5,427	tpd	Client
Cyclone overflow (O/F) nominal tonnage	2,488	tpd	Client
O/F design tonnage	2,985	tpd	Client

Table 3 General operation parameters, tailings slurry characteristics

Parameter	Value	Unit	Source
#60 sieve (250 µm) cumulative passing	91	%	Laboratory
#100 sieve (149 µm) cumulative passing	82	%	Laboratory
#150 sieve (105 µm) cumulative passing	73	%	Laboratory
#200 sieve (74 µm) cumulative passing	65	%	Laboratory
39 µm cumulative passing	45	%	Laboratory
20 µm cumulative passing	36	%	Laboratory
Whole tailings solids specific gravity (SG)	3.14	–	Laboratory
Cyclone overflow solids SG	3.03	–	Client

2.2 Tailings feed pipeline from the concentration plant to the thickening plant

The existing tailings pipeline design will be revised for the new process flow. Calculations for this transport were made using the theories presented by Colebrook (1939), Hallbom (2008), Wasp et al. (1978) and Wilson et al. (2006). Solids concentration and slurry density for both whole tailings (WT) and cyclone overflow (O/F), data required for pipeline calculations, are shown on Table 4.

Table 4 Operation parameters, non-thickened tailings slurry characteristics

Parameter	Value	Unit	Source
Whole tailings (WT) solids concentration by weight	21	%m	Client
Cyclone overflow (O/F) solids concentration by weight	13	%m	Client
WT slurry density	1.16	t/m^3	Golder
O/F slurry density	1.09	t/m^3	Golder

2.3 Thickening plant and high-density thickened tailings pipeline

The deep cone thickener will be dimensioned based on the thickening tests, as well as the appropriate flocculant, in order to design the flocculant plant. The high-density tailings pumping pipeline from the deep cone thickener to the tailings deposit will be designed considering a single spigot discharge, following a discharge sequence according to the tailings deposition plan studied. Data evaluated for the thickener underflow, for both WT and O/F, is shown on Table 5.

Table 5 Operation parameters, thickened tailings slurry characteristics

Parameter	Value	Unit	Source
Whole tailings (WT) solids concentration range by weight	66.5–70	%m	Laboratory
Cyclone overflow (O/F) solids concentration range by weight	60.8–66	%m	Golder
WT thickened slurry density	1.83–1.96	t/m^3	Golder
O/F thickened slurry density	1.69–1.80	t/m^3	Golder
WT sheared yield stress	80–250	Pa	Laboratory
O/F sheared yield stress	80–207	Pa	Laboratory
Viscosity	0.071–0.023	Pa·s	Laboratory

Testing the thickening process for both WT and O/F allowed the identification of the adequate flocculant to be used in the process. Flocculant dosage data is included in Table 6.

Table 6 Operation parameters, flocculant dosage

Parameter	Value	Source
Flocculant name	Floerger PHP 60 Plus	Laboratory
Flocculant type	Anionic	Supplier
Dosage for whole tailings, g/t	40	Laboratory
Dosage for cyclone overflow, g/t	50	Golder
Flocculant density, t/m^3	0.8	Supplier
Concentration for preparation	0.1%	Client
Concentration for dosage	0.02%	Golder

3 Results

With this data, hydraulic evaluations and calculations were separated by system. The pumping system from the concentration plant to the thickening plant, as well as the deposition system from this plant to the tailings deposit, were calculated and designed. The thickening plant was also evaluated and an appropriate thickener – given the required parameters – was selected.

3.1 Tailings transport from the concentration plant to the thickening plant

The system designed to pump tailings to the thickening plant may convey either WT or O/F. Both non-thickened slurries will be transported through the same DN450 HDPE SDR 11 pipeline of about 782 m in length, following typical pipeline design guidelines (ASTM International 2008). A contingency pipeline was also implemented to discharge WT directly to the tailings deposit. The main elevations of the pipeline are displayed in Table 7.

Table 7 Pipeline main elevations, concentration plant to thickening plant

Parameter	Value	Unit
Initial elevation	4,208	m a.s.l.
Final elevation	4,235	m a.s.l.

3.1.1 Whole tailings

Initial data for the pumping system and pipeline calculations for this operation are shown in Table 8.

Table 8 Hydraulic parameters, non-thickened whole tailings pumping

Parameter	Value	Unit
Nominal slurry flow rate	780	m^3/h
Design slurry flow rate	936	m^3/h
Nominal dry mass flow rate	4,523	tph
Design dry mass flow rate	5,427	tph
Solids specific gravity	3.14	–
Solids concentration by weight	21	%m

The hydraulic gradient of the pipeline during WT transport is shown in Figure 3.

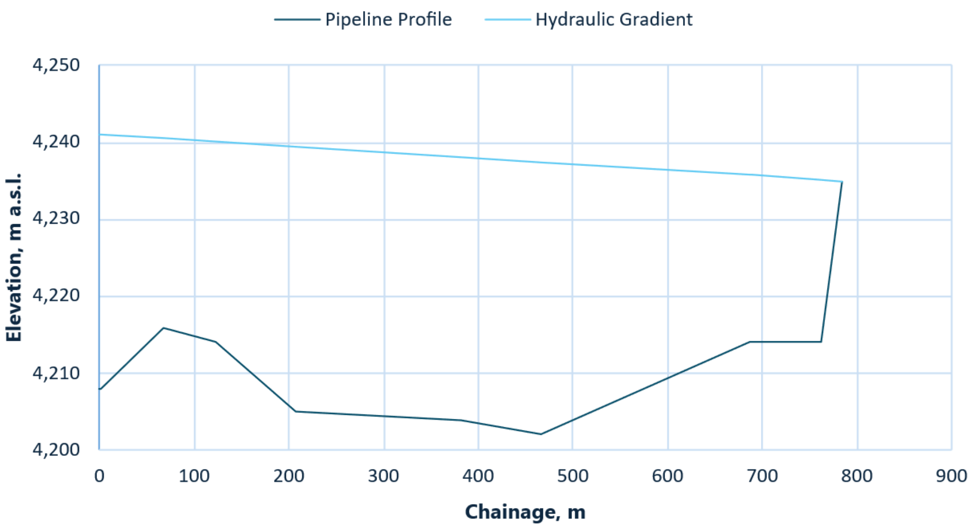

Figure 3 Hydraulic gradient, non-thickened whole tailings pumping

Results of the pumping system and pipeline calculations for this operation are shown in Table 9.

Table 9 Hydraulic calculation results, non-thickened whole tailings pumping

Parameter	Nominal value	Design value	Unit
Velocity in pipeline	2.03	2.43	m/s
Critical sedimentation velocity in pipeline	1.71	1.71	m/s
Friction head loss	4.7	7.8	m/km
Total dynamic head	33.7	36.4	m
Absorbed power	143.8	179.9	kW

3.1.2 Cyclones overflow

The hydraulic calculations for O/F transport will be similar to the WT transport calculations. Initial data for the pumping system and pipeline calculations for this operation are shown in Table 10.

Table 10 Hydraulic parameters, non-thickened cyclone overflow pumping

Parameter	Value	Unit
Nominal slurry flow rate	734	m^3/h
Design slurry flow rate	880	m^3/h
Nominal dry mass flow rate	2,488	tph
Design dry mass flow rate	2,985	tph
Solids specific gravity	3.03	–
Solids concentration by weight	13	%m

The hydraulic gradient of this pipeline during cyclones overflow transport is shown in Figure 4. The resulting gradient is similar to the one calculated for WT transport; however, the lower flow rate is reflected in a lower head required for pumping. As a result, the gradient shown in Figure 4 has a slightly lower slope than the one in Figure 3.

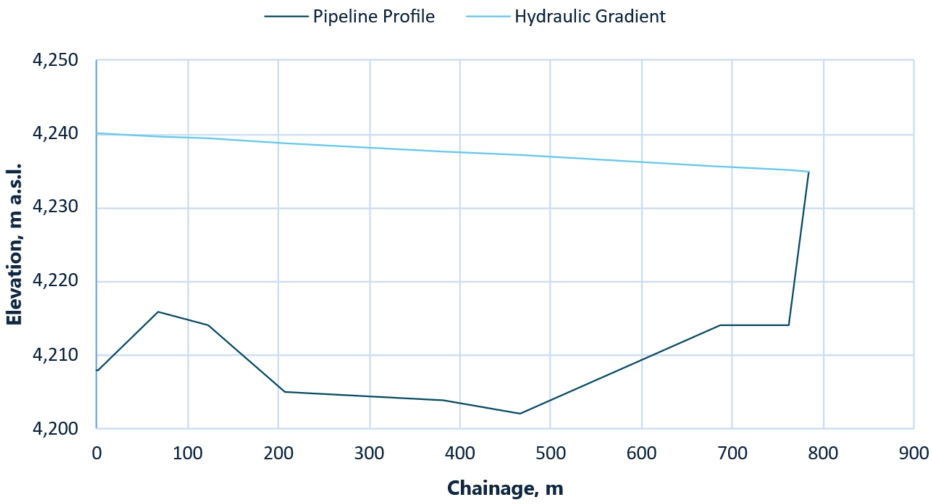

Figure 4 Hydraulic gradient, non-thickened cyclone overflow pumping

Results of the pumping system and pipeline calculations for this operation are shown in Table 11.

Table 11 Hydraulic calculation results, non-thickened cyclone overflow pumping

Parameter	Nominal value	Design value	Unit
Velocity in pipeline	1.91	2.28	m/s
Critical sedimentation velocity in pipeline	0.95	0.95	m/s
Friction head loss	3.9	6.6	m/km
Total dynamic head	33.0	35.3	m
Absorbed power	124.5	159.7	kW

3.1.3 Contingency line

In the event where the thickening plant cannot be operated due to any emergency, the slurry is pumped directly to the tailings deposit. The calculation results for that pipeline are summarised in Table 12.

The pipeline designed is similar to the one used for normal operation, a DN450 HDPE SDR 11, reaching 962 m in length, following typical pipeline design guidelines (ASTM International 2008).

Table 12 Hydraulic summary, non-thickened whole tailings. Contingency transport to tailings deposit

Parameter	Nominal value	Design value	Unit
Slurry flow rate	780	936	m^3/h
Total dynamic head	27.4	30.3	m
Absorbed power	128.4	170.5	kW

3.1.4 Selected pumping system

The existing system, comprised of Warman 200 MCC pumps, was evaluated and found to be able to fulfill all operation points. Additionally, the existing electric motors, rated for 250 hp (186.4 kW), can cover the power demand of the pumps during all operating scenarios.

3.2 Thickener dimensioning

Several laboratory tests were conducted to ensure the required parameters of the thickeners, using samples from both WT and O/F.

3.2.1 Flocculant selection

Eleven different flocculants were tested in the laboratory for both WT and O/F thickening. Of all flocculants, Floerger 60 Plus showed the fastest initial settling velocity, while Orifloc 305 achieved the greatest overflow clarity at 45 min. Underflow density measurements for all flocculants were very close at around 40%. Floerger 60 Plus was selected, and all further tests were performed using this flocculant.

3.2.2 Thickening laboratory testing

A summary of the results for all tests performed with both thickened WT and thickened O/F is displayed in Table 13. These tests were performed in accordance with ASTM (2010) standards.

Table 13 Test results summary, tailings thickening

Parameter	Value, whole tailings	Value, cyclone overflow	Unit
Feed solids concentration	20.7	17.4	%m
Feedwell solids concentration	8	7	%m
Flocculant dosage	30	40	g/t
Underflow solids concentration	62–70	59	%m
Unsheared yield stress	250	216	Pa
Overflow turbidity	20	22	NTU
Overflow total suspended solids	100	111	ppm
Thickener unit area	0.06–0.09	0.11	m^2/t·d
Bed height	2	2	m
Residence time	4	5	h

3.2.3 Thickener dimensioning parameters and selection

Given the test results, the parameters that the chosen thickener must comply with are summarised in Table 14.

Table 14 Test results summary, tailings thickening

Parameter	Specified value	Unit
Feed type	Whole tailings or cyclone overflow	–
Thickener type	Paste thickener	–
Thickener unit area	0.09	m^2/t·d
Nominal tailings tonnage	4,523	tpd
Feed dilution (solids content)	7–8	%m
Flocculant	Foerger 60 Plus	–
Flocculant dosage	30	g/t
Underflow solids concentration by weight	63–70	%m
Overflow total suspended solids	<50	ppm

Several thickener offers were received with these parameters, and a deep cone paste thickener (FLSmidth 2014) was selected. This thickener has a diameter of 19 m, a height of 21 m, and a design capacity of 188 tph using 65.2 kW, for an installed power of 75 kW. A picture of the thickener installed on site is shown in Figure 5.

Figure 5 Deep cone thickener in situ

Once the dimensions and requirements were established, a thickening plant was designed, containing all auxiliary systems for the process. Figure 6 shows an isometric view of the designed plant, including a flushing system, flocculant plant, compressed air room and electrical room.

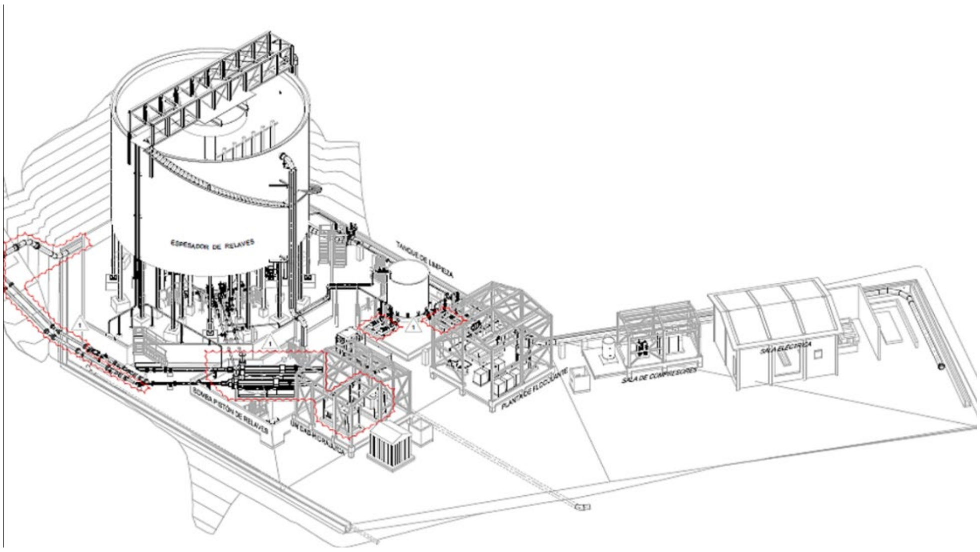

Figure 6 Thickening plant, isometric view

3.3 Nearly paste tailings transport

The system designed to pump the high-density tailings to the deposit must be able to transport thickened tailings made from either WT or O/F. Both slurries will be transported through the same 1,120 m long DN200 CS SCH 80 pipeline and deposited through several spigots of DN250 HDPE SDR 9 pipe up to 380 m in length. Longer spigots will require an initial portion of carbon steel pipe to hold the high pressure, according to ASME (2012) pipeline guidelines, and only one spigot will be operational at once. The analysis of the results shows the worst-case discharge scenario; for the farthest spigot from the pumps, located on the southern end of the pipeline. A contingency pipeline was also installed to discharge the high-density tailings to the deposit through the first spigot, the discharge closest to the thickener in the tailings storage facility. The elevations of the main pipeline are displayed in Table 15.

Table 15 Pipeline main elevations, thickening plant to tailings deposit

Parameter	Value	Unit
Initial elevation	4,213	m a.s.l.
Final elevation	4,230	m a.s.l.

3.3.1 Whole tailings

Initial data for the pumping system and pipeline calculations for this operation are shown in Table 16.

Table 16 Hydraulic parameters, thickened whole tailings

Parameter	Nominal value	Design value	Unit
Slurry flow rate	146	186	m^3/h
Dry mass flow rate	188	226	tph
Sheared yield stress	118	250	Pa
Solids specific gravity	3.14	3.14	–
Solids concentration by weight	68.5	70	%m

The hydraulic gradient of the pipeline during WT transport is shown in Figure 7.

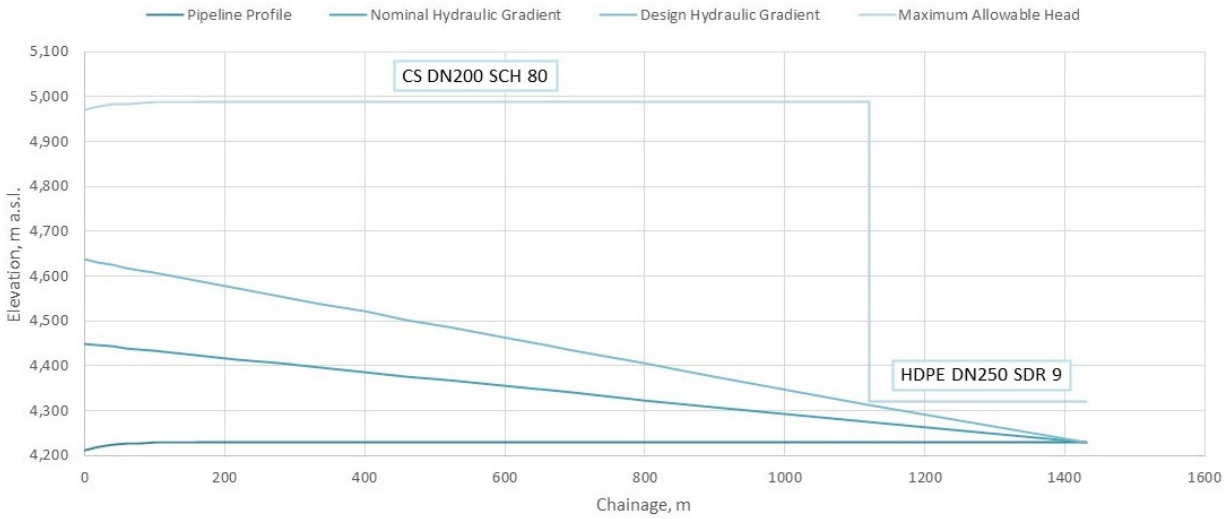

Figure 7 Hydraulic gradient, thickened whole tailings pumping

Results of the pumping system and pipeline calculations for this operation are shown in Tables 17, 18, and 19.

Table 17 Hydraulic calculation results, thickened whole tailings. Main pipeline, CS DN200 SCH 80

Parameter	Nominal value	Design value	Unit
Velocity in pipeline	1.37	1.75	m/s
Friction head loss	156.2	289.3	m/km

Table 18 Hydraulic calculation results, thickened whole tailings. Spigot pipeline, HDPE DN250 SDR 9

Parameter	Nominal value	Design value	Unit
Velocity in pipeline	1.18	1.51	m/s
Friction head loss	125.9	234.3	m/km

Table 19 Hydraulic calculation results, thickened whole tailings. Pumping system

Parameter	Nominal value	Design value	Unit
Total dynamic head	237	425	m.s.c.
Total dynamic head	464	777	m.w.c.
Absorbed power	225.0	523.4	kW

3.3.2 Cyclones overflow

Initial data for the pumping system and pipeline calculations for this operation are shown in Table 20.

Table 20 Hydraulic parameters, thickened cyclone overflow

Parameter	Nominal value	Design value	Unit
Slurry flow rate	95	122	m^3/h
Dry mass flow rate	104	124	tph
Sheared yield stress	121	207	Pa
Solids specific gravity	3.03	3.03	–
Solids concentration by weight	63	60.8	%m

The hydraulic gradient of this pipeline during cyclones overflow transport is shown in Figure 8.

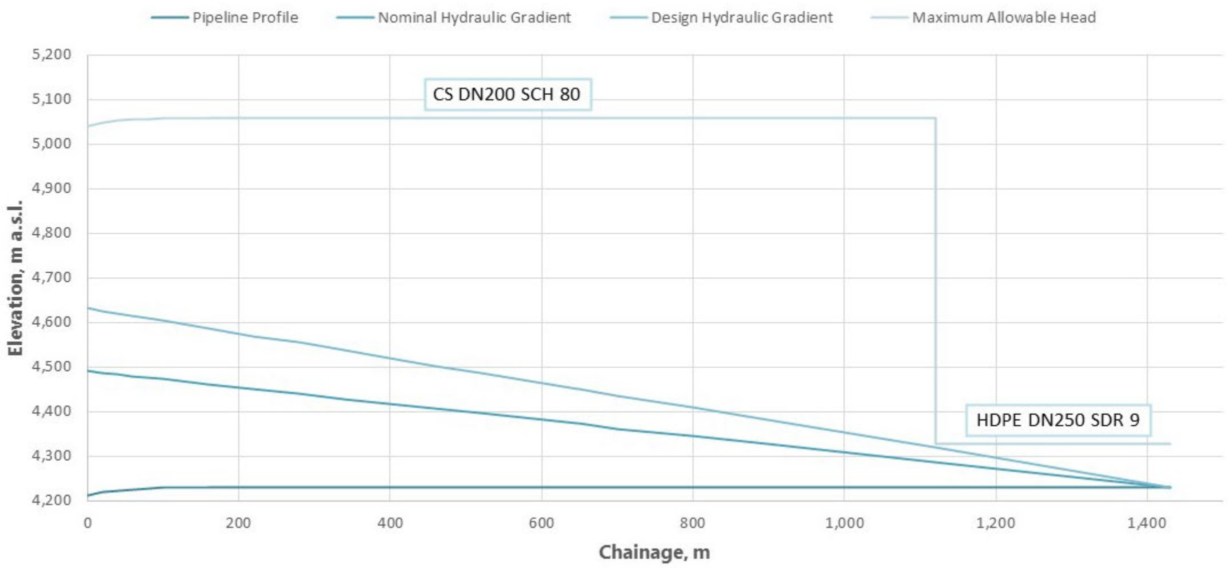

Figure 8 Hydraulic gradient, thickening plant to tailings deposit, cyclone overflow pumping

Results of the pumping system and pipeline calculations for this operation are shown in Tables 21, 22, and 23.

Table 21 Hydraulic calculation results, thickened cyclone overflow. Main pipeline, CS DN200 SCH 80

Parameter	Nominal value	Design value	Unit
Velocity in pipeline	0.82	1.15	m/s
Friction head loss	180.7	278.2	m/km

Table 22 Hydraulic calculation results, thickened cyclone overflow. Spigot pipeline, HDPE DN250 SDR 9

Parameter	Nominal value	Design value	Unit
Velocity in pipeline	0.71	0.99	m/s
Friction head loss	166.2	255.0	m/km

Table 23 Hydraulic calculation results, thickened cyclone overflow. Pumping system

Parameter	Nominal value	Design value	Unit
Total dynamic head	279	420	m.s.c.
Total dynamic head	499	708	m.w.c.
Absorbed power	159.4	312.9	kW

3.3.3 Contingency line

In the event where the main pipeline is obstructed, the slurry is pumped through an additional pipeline connected to the first (closest) spigot. The calculation results for that pipeline are summarised in Table 24.

The pipeline designed is made of DN250 CS SCH 80, reaching 300 m in length until the first HDPE spigot.

Table 24 Hydraulic summary, thickened whole tailings. Contingency transport to first spigot

Parameter	Nominal value	Design value	Unit
Friction head loss on main pipeline	115.5	215.4	m/km
Slurry flow rate	146	185	m^3/h
Total dynamic head	97	166	m
Absorbed power	92.1	204.1	kW

3.3.4 Selected pumping system

Given the necessary pressure to be reached in the pumping system, it was deemed necessary to employ positive displacement pumps. A pair of KSP 220 piston pumps (Schwing Bioset 2014) was selected, working in parallel, each with a design capacity to pump 92.5 m^3/h at 95 bar. The hydraulic unit for the operation of these pumps has 372 kW of installed power per pump.

4 Conclusions

The design and optimisation of the tailings beach slope in the existing tailings deposit was a success. The specific conclusions are subdivided into 4 parts: tailings transport to the thickening plant, the tailings thickening plant, transport of thickened tailings to the deposit, and the achieved beach slope.

4.1 Tailings transport to the thickening plant

The tailings transport system from the concentration plant to the thickening plant was evaluated, for both WT and O/F pumping. Parameters, results, and further conclusions of this evaluation include:

- Slurry flow rate ranges between 734 and 936 m^3/h.
- The pipeline designed for the main transport shall be made of DN450 HDPE SDR 11, with an estimated length of 782 m.
- For WT transport, the pumping system shall achieve a total dynamic head of 33.1 m, which results in a power consumption of 180 kW.
- For O/F transport, the pumping system shall achieve a total dynamic head of 32.2 m, which results in a power consumption of 160 kW.
- An additional contingency pipeline will convey WT directly to the deposit, using 962 m of a similar DN450 HDPE SDR 11 pipe. During this contingency, the pumps will work at 30.3 m, with absorbed power of 171 kW.
- The existing pumping system comprised of Warman 200 MCC pumps and 250 hp (186.4 kW) pumps will be able to fulfill all new operating points.
- Lesson learned: fine tailings consume less power, around 80% of the motor's capacity, while coarse tailings consume more, around 95%, meaning that higher particle size increases power consumption.
- Lesson learned: because the required pressures in the piping system to the thickener are less than 50 psi, HDPE pipe is used.

4.2 The tailings thickening plant

The required thickening operation was evaluated, and an appropriate thickening system was selected. The resulting design and further conclusions include:

- The selected thickener was a deep cone type, brand FLSmith with 19 m of diameter and 21 m of height, with a capacity of 188 tph that can handle up to 250 Pa slurry shear stress.
- The selected flocculant was Foerger 60 Plus. In addition, the overflow discharge has a recovered water quality of less than 50 NTU.
- Lesson learned: to select a deep cone thickener, it is necessary to implement a pilot test, preferably onsite at the mine, to evaluate the rheological range and the variability of the parameters

4.3 Transport of thickened tailings to the deposit

The tailings transport system to deposit thickened tailings from the thickening plant was evaluated, for both WT and O/F operation. Parameters, results, and further conclusions of this evaluation include:

- Slurry flow rate ranges between 88 and 186 m^3/h.
- The pipeline designed for the main transport shall be made of DN200 CS SCH 80, with an estimated length of 1120 m. Out of this pipeline, several spigots will emerge, discharging the tailings on the deposit through a DN250 HDPE SDR 9 pipe each. These spigots may be up to 380 m in length. Any spigot greater than this length shall have a CS portion at the beginning of the pipe to handle the pressure.
- For WT transport, the pumping system must achieve a total dynamic head of 425 m, which results in a power consumption of 523 kW.

- For O/F transport, the pumping system must achieve a total dynamic head of 420 m, which results in a power consumption of 313 kW.
- An additional contingency pipeline will convey WT to the deposit, shall the main pipeline be obstructed by poorly sheared tailings, using 300 m of DN250 CS SCH 80 pipe. During this contingency, the pumps will work at 166 m, with absorbed power of 204 kW.
- To achieve the pressure requirements, a pair of KSP 220 positive displacement piston pumps in parallel were selected, incurring in 372 kW of installed power per pump.
- Lesson learned: for high-rheology pumping, a piston-type pump must be used, and due to its higher flow rate, a parallel system was implemented.
- Lesson learned: furthermore, because the pumps are parallel, a synchronisation system must be implemented to calibrate the pulsations of each pump to prevent them from overlapping; this is due to the piston system.

4.4 Achieved beach slope

On the objective of increasing the beach slope of the tailings dam, it can be concluded that:

- With the increased percentage of solids in the thickener discharge, the rheology increases, therefore, increasing the beach slope at the discharge.
- The use of a piston pump after the thickener discharge is essential because this type of pump can handle high rheological conditions and high solids content.
- Along the pipeline from the thickener discharge to the spigot discharge point, the rheology decreases due to floc breakage. It is estimated that approximately 30% of the rheology leaving the thickener is lost. This data is based on rheology measurements at the thickener discharge and the spigot discharge.

References

ASME 2012, *Pipeline Transportation Systems for Liquids and Slurries (ASME B31.4)*, New York.

ASTM International 2010, *Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer (ASTM D854-10)*, West Conshohocken.

ASTM International 2008, *Standard Specification for Polyethylene Plastics Pipe and Fittings Materials (ASTM D3350-08)*, West Conshohocken.

Colebrook, CJ 1939, 'Turbulent flow in pipes with particular reference to the transition region between the smooth and rough pipe laws', *Journal of the Institute of Civil Engineers*, vol. 4, pp. 133–156.

FLSmidth 2014, *19m Deep Cone Paste Thickener*, apparatus, https://fls.com/en/equipment/filtration-and-dewatering/thickeners-and-clarifiers

Hallbom, DJ 2008, *Pipe Flow of Homogenous Slurry*, PhD thesis, The University of British Columbia, Vancouver.

Schwing Bioset 2014, *KSP 220 Tailings Pump*, apparatus, https://www.schwingbioset.com/municipal-products/piston-pumps

Wasp, EJ, Kenny, JP, Gandhi, RL 1978, 'Solid-Liquid flow slurry pipeline transportation', *Trans Tech Publications*, Clausthal.

Wilson, KC, Thomas, AD 2006, 'Analytic model of laminar-turbulent transition for Bingham plastics', *Canadian Journal of Chemical Engineering*, vol. 84, no.5, pp. 520–526.