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Design Review for a Distributed Tailings Deposition System

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ABSTRACT

There has been an increasing move towards high-density thickened tailings systems over the last decade, mainly driven by the need to save water, meet environmental regulations and project specific demands.

A typical tailings distribution system on a Tailings Storage Facility (TSF) consists of a main pipe with multiple discharges operating simultaneously, to distribute the slurry across an extended length over a specific area of the TSF at a time. A potential limitation of these systems is an uneven distribution of slurry flow rate and solids concentration between multiple spigot discharges, where an inadequate design can lead to laminar pipeline flow conditions resulting in particle segregation, and an increased risk of pipeline blockage. An operation with unbalanced flow rates could result in an uneven distribution of solids that could impact the formation of beach slopes and/or cause difficulties for the dam construction.

Paterson & Cooke (P&C) has previously developed several thickened tailings distributed systems, where the discharge points are located on a distribution pipeline which branch off a main pipeline. This previous experience has allowed P&C to develop a methodology for the hydraulic modelling and implementation of these types of systems. This paper presents the methodology for distribution system deposition design review and its implementation of a TSF located in Southern Europe.

INTRODUCTION

General

High-density thickened tailings systems have become more frequent in the past years, mainly driven by the need to save water and to mitigate environmental concerns, meet corresponding local regulations and specific project requirements.

Targeted beach slopes are best achieved using a distributed tailings deposition system comprising of multiple simultaneously operating discharges which are spaced sufficiently far apart to ensure the individual discharges do not combine on the beach (McPhail G. et al, 2018).

Experience has shown that it is possible to design a successful high-density thickened tailings distribution system with multiple equal flow rate discharge spigots operating at the same time, considering a long distance deposition front (Martinson R. et al, 2015).

TAILINGS DISTRIBUTION SYSTEMS

When designing a distributed tailings deposition system there are two main slurry classifications that are considered, depending on the material process properties and slurry mixture flow behavior:

- Conventional tailings; or
- High-density thickened tailings transport.

Conventional Tailings Distribution Systems

Conventional tailings are generally in the ~20%m to 50%m solids mass concentration range and the fully-sheared slurry mixture yield stress of 0 to 10 Pa. A *conventional tailings distribution system* (CTDS) consists of a distribution pipeline, typically with the same pipe diameter, around the perimeter of the TSF. From this distribution pipeline there are several spigots in operation at the same time, equally separated and usually including an open-end discharge of same/similar diameter as the distribution pipeline. The open-end pipe is used to start the system operation and to minimize the risk of solids settling by maintaining enough slurry mixture velocity in the distribution pipe when possible. The objective of CTDS is to facilitate the coarser particles settling closer to the spigot discharge at the TSF. However, this type of systems could present the following downsides when not designed properly:

- Uneven distribution of slurry flow rate and concentration through the spigots in operation (higher flow rates and coarser particle size distributions through the initial spigots compared with downstream spigots);
- A major part of the slurry is discharged through the open-end pipe; and
- End section of the distribution pipeline operates at low velocities when spigots are in operation, leading to particles settling.

Figure 1 presents a standard arrangement of a conventional tailings distribution system, showing spigot discharges in operation and an open-end discharge:

Figure 1 Conventional tailings distribution system reference

Thickened Tailings Distribution Systems

Thickened tailings (high rate and high-density) are generally in the ~50%m to 70%m solids mass concentration range and the fully-sheared slurry mixture yield stress of 10 to 60 Pa. A *high-density thickened tailings system* (TTDS) requires pipe selection to verify turbulent flow regime over the entire distribution pipeline to avoid laminar flow regime, and solids settling in the bottom of the pipe that could lead to obstruction and blockage of pipelines (Cooke R. et al, 2002). The objective of TTDS is to maximize the beach slope while maintaining a non-segregating TSF. Figure 2 presents an arrangement of a high-density thickened tailings distribution system:

Figure 4 High-density thickened tailings distribution system reference

CTDS and TTDS Tailings Storage Facilities

The following Figure 3 presents a schematic diagram showing a conceptual comparison between CTDS and TTDS tailings storage facilities. TTDS have proven to achieve steeper beach slopes when compared to CTDS ($i_2 > i_1$), this implies that a TTDS demands lower volume for TSF containment wall construction ($Vol_1 >> Vol_3$). Conventional tailings present a higher water content than thickened tailings, consequently there is a larger volume of water in the TSF that needs to be managed by site operators ($Vol_2 > Vol_4$).

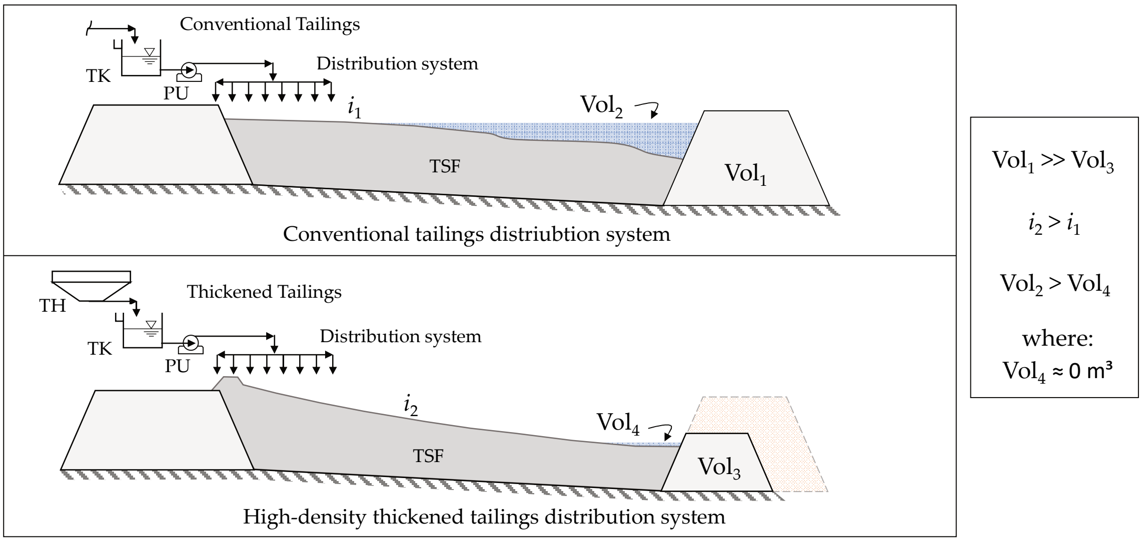

Figure 3 CTDS and TTDS tailings storage facilities

Table 1 presents a summary of the project objectives, risks to be considered in the design, operational challenges, and pump energy requirements for tailings distribution systems:

Table 1 Tailings distribution systems summary

Item	Conventional Tailings	High-density Thickened Tailings
Project Objectives	• Tailings distribution from the different walls around the perimeter of the TSF, to control the storage facility growth and facilitate the coarser particles settling closer to the spigot discharge. • Possibility to cover longer distances with lower pump requirements when compared to thickened tailings.	• Increase the facility storage capacities. • Higher slurry dewatering and reduced water management in the TSF. • Allow for the development of reasonably steep beach slopes, demanding lower volume for TSF containment wall.

<table>
<tr><th>Item</th><th>Conventional Tailings</th><th>High-density Thickened Tailings</th></tr>
<tr><td rowspan="2">Design and Operational Challenges</td><td colspan="2">• Equal distribution of slurry flow rate through spigots and solids.</td></tr>
<tr><td>• Slurry mixture velocities above solid deposition velocity.
• Extensive water management in the TSF.
• Slight beach slopes demanding larger containment walls.</td><td>• Higher rheology demands operating at higher velocities compared to conventional tailings, pipe material selection preventing premature wear.
• Requirement for trained personnel with general knowledge of thickened tailings.
• Experienced designers, beach slope estimates.</td></tr>
<tr><td>Risks</td><td colspan="2">• Solid particles settling and obstruction of distribution pipeline.
• Attention to oversized solids or foreign material in the slurry (mill balls, lining from pipes and trash in general) that may get trapped in spigots and/or smaller diameter pipes.</td></tr>
<tr><td>Costs</td><td>• Lower Capex when compared to thickened tailings systems.
• Higher Opex for containment wall construction.</td><td>• Higher Capex (thickeners, pumps, pipes, valves, instruments).
• Lower Opex for containment wall construction.</td></tr>
<tr><td>Pump Energy Requirements [1]</td><td>• Medium to low (Less than 50 m head of slurry typically).</td><td>• High (over 50 m head of slurry).</td></tr>
</table>

TAILINGS DISTRIBUTION SYSTEM DESIGN PROCEDURE

System Duty Definition

For the hydraulic modelling, it is necessary to understand the TSF elevations over project life time and pipeline routing. Mine production information must also be established, including solids tonnage production (and variation), solids concentration range, temperature range, stand by capacity, site conditions and mass balance.

[1] Assumptions: 50 000 tpd tonnage and 2 000 m length pipeline. Conventional tailings 30%m mass concentration and fully sheared slurry mixture yield stress of 0.0 Pa. Thickened tailings 65%m mass concentration and fully sheared slurry mixture yield stress of 20.0 Pa.

Slurry Characterization

The minimum test work that should be conducted for the mass balance and hydraulic modeling is basic material properties (PSD, solids density), carrier fluid properties (viscosity, process water chemistry), slurry mixture density and rheological properties. Depending on the project, pipe loop tests for deposition velocity, pipeline restart, pipeline pressure gradients, pump derating and pipe material wear tests could be included.

Hydraulic Design

Figure 4 presents a flow diagram and a typical arrangement of a tailings transport and deposition system general design:

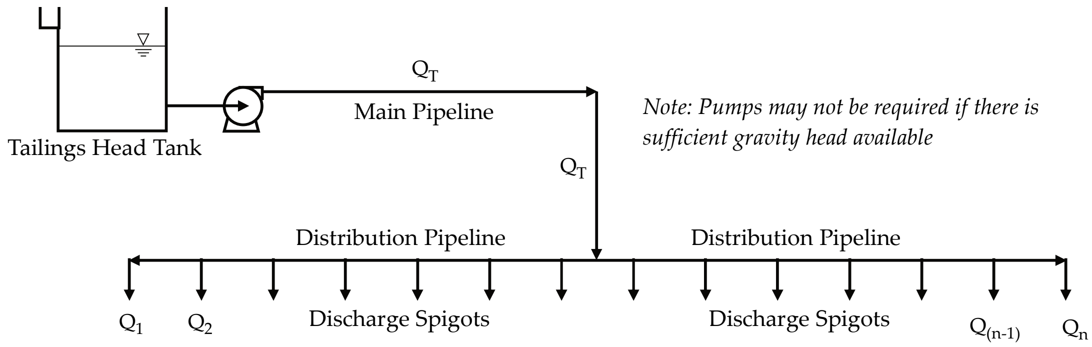

Figure 4 Distributed tailings deposition system

A hydraulic model is built with the previous collected data, developing piping alignment and profiles (length, changes of direction and elevations). This activity considers:

- **Pipeline sizing and material selection -** to determine sufficient operating velocities, calculate pipeline friction losses, develop hydraulic grade lines for all operating conditions, slurry head requirements and check pipeline pressure rating.
- **Pump station design -** pump type selection and materials, establish pump operating limits and derating factors, check pump NPSH and suction requirements.

In a typical spigot discharge arrangement, assuming equally sized spigots with no other flow control accessories, the flow rate from each spigot will be in proportion to the local pressure at the spigot take-off (energy), generally resulting in a higher flow rate at the spigots closer to the main pipeline and decreasing downstream to the last discharge in the distribution pipeline [2].

[2] This occurs when spigots are spaced far apart. If spigots are closely spaced without a flow control mechanism, it could be that the opposite results; that a higher flow rate discharges from the spigots closer to the end of the distribution pipeline.

To equalize the spigot discharge flow rates, a flow control mechanism in the form of a localized head loss is required upstream of the spigot discharge.

$$Q_i = \frac{Q_T}{n} \quad (1)$$

$Where;$

$Q_T \quad = \quad total\ flow\ rate\ of\ the\ system$

$Q_i \quad = \quad initial\ discharge\ spigot\ flow\ rate$

$n \quad = \quad total\ number\ of\ discharges$

The number of spigots operating at the same time will define the flow rate of each discharge and the hydraulic balance on the distribution pipeline. Number of spigots is a key parameter, defined by the civil/geotechnical specialist and is intended to improve the beach slope in the TSF (for TTDS) and to develop the tailings filling plan (for CTDS and TTDS).

The spigot pipe length is also considered in the hydraulic design; depending on the TSF filling plan, the spigot length could be extended and/or relocated together with the distribution pipeline following the TSF growth over the life time of the project.

Pipe selection should verify a minimum required operating velocity, based on either the solids deposition velocity *for conventional tailings* or the laminar-turbulent transition velocity *for high-density thickened tailings* as with most slurry pipeline designs.

Flow Rate Control

The required head loss for each spigot is determined by calculating the energy balance along the distribution pipeline, considering the decrease in total flow rate downstream the distribution line.

$$H_{Di} = \Delta h_{Si} \quad (2)$$

$Where;$

$H_{Di} \quad = \quad head\ calculated\ in\ the\ distribution\ pipeline$

$\Delta h_{Si} \quad = \quad head\ calculated\ in\ each\ spigot\ pipeline\ being\ evaluated$

Assuming equal flow rate is required for the spigots, the head loss requirements for each spigot are determined, the minor head loss coefficient 'K' is calculated for each spigot, then the flow control mechanism to be included in the system can be selected and sized. Figure 5 presents an example of an energy balance along the distribution pipeline:

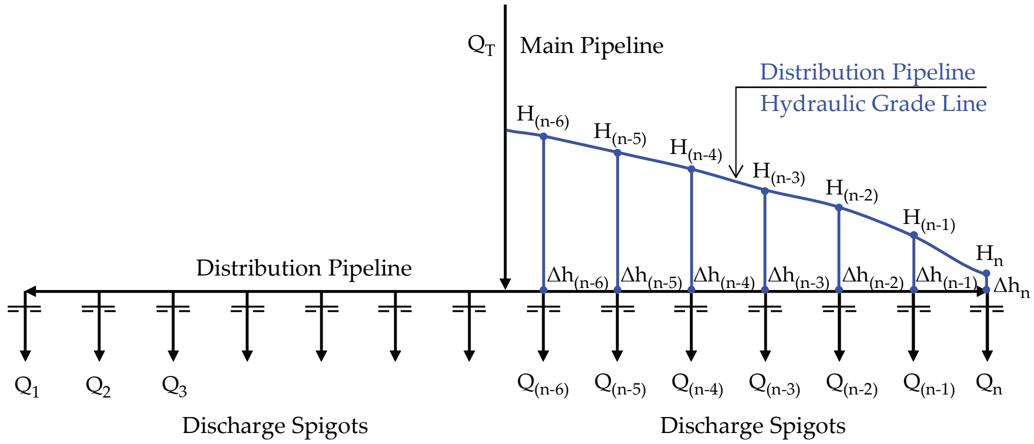

Figure 5 Distribution Pipeline Hydraulic Grade Line Example

The previous exercise is developed for the entire design operational flow rates envelope, including tonnage production and solids concentration variability. Depending on the spigots discharge flow rate required, nowadays a variety of flow control options are available, including:

- Slurry control valves, such as pinch or diaphragm valves.
- Using small diameter spigot piping to act as a "choke" restriction; or
- Small bore orifice plates at each spigot discharge. These are generally the preferred option when there is a high number of simultaneous discharges, for its simplicity of use and minimum control requirements for site operators, guarantee against mechanical failures, cost savings and reliability when compared to an active system.

The selection of the flow control option for the spigots discharges is dependent on the level of operator interaction preferred; in the case of valves these can be manually or automated actuated for opening and closure.

The following Figure 6 presents a flow chart for the design review methodology for a distributed tailings deposition system.

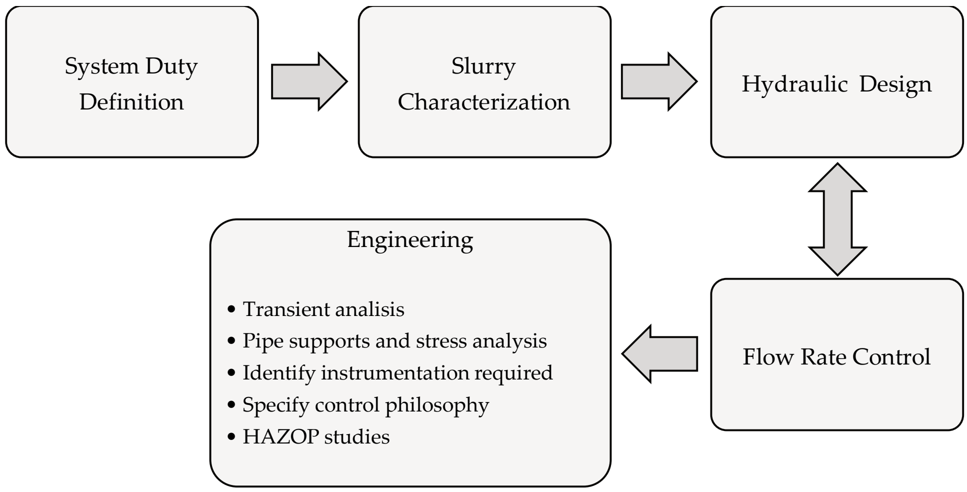

Figure 6 Design Review Methodology for a Distributed Tailings Deposition System

Case Study

Case study is a 310 tph polymetallic base metal operation in southern Europe, for a high-density thickened tailings distribution system. This consisted of a ~2 000 m length main pipe with 150 mm NB, from a new pump station to the TSF location. A distribution pipeline with 6 spigot operating at the same time, with equal flow rate and discharges spaced at 200 m each. The pipe selection for the distribution pipeline was designed in a range between 100 mm to 65 mm NB selected to ensure turbulent flow regime along the entire length. Spigot piping to the TSF considered 65 mm and 90 mm NB. The use of slurry pinch valves as a flow control element was selected in this case, due to client and site operators preference. The small spigot pipe diameter and the reduced number of spigots operating simultaneously (when compared to a large tonnage operation) also justified pinch valve selection. This tailings distribution system presented the following process requirements:

Table 2 Process requirements summary

Item	Value / Description	
Solids throughput	Nom / Min / Max	= 310 tph (±10%)
Solids mass concentration	Nom / Min / Max	= 70 %m / 67 %m / 72 %m
Solids density	4.5 t/m^3	

Item	Value / Description	
Slurry yield stress fully sheared	C 70%m	= 14 Pa
	C 67%m	= 8 Pa
	C 72%m	= 20 Pa
Number of spigots in operation	six operating simultaneously, equal flow rate	
Spigot spacing	200 m	
Spigot discharge flow control	Manual pinch valves	
Delivery system type	Centrifugal pumps	

CONCLUSIONS AND RECOMMENDATIONS

- Experience has shown it is possible to design a successful distributed tailings deposition system with the correct integration of slurry mixture flow behavior knowledge and system philosophy of operation, either if it is to transport conventional tailings or thickened tailings. Each type of slurry presents specific challenges from the design and TSF operation point of view.
- Capex and Opex of a tailings distribution system is sensitive to the solids concentration by mass operational range, as it defines:
  - Target beach slope estimates
  - TSF growth plan modelling,
  - Slurry mixture flow behavior, and
  - Mass balance, flow rates for the sizing of pipelines, pump station and system energy requirements.
- The use of thickened tailings with a single point discharge system does not assure steeper beach slopes in the TSF. Tailings distribution systems with simultaneous discharges operating simultaneously with equal flow rate allow for the development of reasonably steep beach slopes when considering thickened tailings with high rheology (i.e. yield stresses and Bingham plastic viscosity). This type of system could considerably reduce the costs associated with the construction of larger containment walls.
- The case study shows the implementation of the design review methodology approach in full scale application. This type of system has allowed operations to achieve the required tailings deposition method, over a range of slurry mixture process variables.

NOMENCLATURE

%m	solids concentration percentage by mass
C	solids concentration by mass
m	meter
mm	millimeter
m^3	cubic meter
NB	nominal bore
PSD	particle size distribution
TSF	tailings storage facility
t	tonne (metric)
tph	tonnes per hour (metric)
Pa	Pascal (yield stress unit)
Pa·s	Pascal per second (viscosity unit)

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