Paste and Thickened Tailings Transportation: Design Aspects Overview

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ABSTRACT

Tailings transport is an integrated element in any wet tailings storage facility (TSF). Tailings from the process plant are often thickened to a moderate or relatively high (but still pumpable) solids concentration, depending on several parameters mainly the TSF deposition requirements and strategies, process plant water security status and the dewatering technology utilised.

This paper overviews the transportation of paste and thickened tailings and discusses various aspects and considerations in the hydraulic design of the system. Material characteristics, flow behaviour assessment (rheological behaviour measurement and interpretation) and the basis of design definition are discussed.

The recent developments in environmental authorities' regulations associated with the tailings pipeline burst and leakage management are also reviewed in this paper. The tailings leakage and spillage to the environment is one the main concerns for any tailings hydraulic transportation system, therefore as part of the tailings pipeline design, the pipeline integrity failure (due to pipe wear, overpressure bursting etc.) should be thoroughly analysed to propose proper mitigation measures. The paper discusses a methodology to assess the potential tailings volume release to the environment in an event of the pipeline integrity failure which would be of interest to the operators and designers.

INTRODUCTION

Tailings transport is an integral element of most wet tailings storage facility (TSF) that involves pumps, pipelines or open channel (if terrain allows) to hydraulically convey the tailings from the process plant to the TSF. Tailings are often thickened to a moderate or relatively high transportable solids concentration, depending on several parameters mainly the TSF deposition requirements and strategies, process plant water security status and the dewatering technology utilised. This paper provides an overview on various aspects of the thickened tailings transport system and the recent developments in the requirements for the tailings pipeline leakage management strategies that might be interested to the operators and designers.

Failings to adequately investigate and study these aspects of the tailings transport at the design stage can result in a transport system with high maintenance and operating costs, facing face frequent shutdowns and loss of production.

DESIGN CONSIDERATIONS

The thickened tailings transport pipeline is often designed in a way that the system to operate in a turbulent regime with an average velocity exceeding the transitional velocity. Given the moderate to relatively high yield stress (i.e. 25-50Pa) and plastic viscosity of the thickened tailings at the range of operational solids concentrations, the pipeline Minimum Allowable Transport Velocity (MATV) is dominated by a transitional velocity rather than a deposition velocity. Figure 1 shows the various flow regimes and locus of the transitional velocity and MATV in the plot of pressure drop vs average velocity.

Therefore, the pipes sizing should be based on the fact that the tailings pipelines have to operate at a velocity above the transitional velocity, while running at nominal tonnage and nominal solids concentration. The analysis should also account for the stationary bed formation in the extreme low flow cases. Some designers may accept a stationary bed in the extremely low flow, albeit if the tailings is re-suspendable.

Based on the estimated transitional and deposition velocities, a MATV is defined for the operation of the pipeline with a reasonable safety margin.
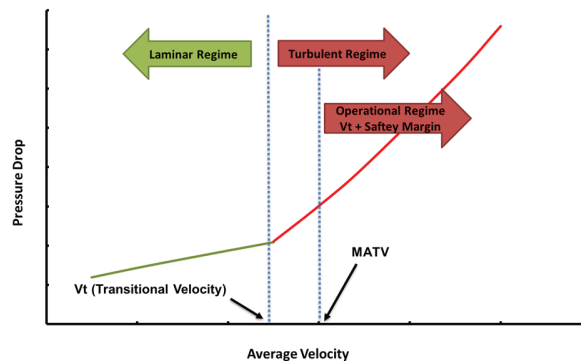
Figure 1 Example of Tailings and Return Water Pipeline Bunded Corridor

MATV can be estimated using semi-empirical models which have been validated against the small/large scale pipeloops and the operational data. The method defined by Slatter-Wasp (2000) and further updated by Wilson-Thomas (2006) is often employed for prediction of the laminar-turbulent transition in large pipe. Based on these models, for all values of He greater than about 10^5 the relative transition velocity is effectively equal to a constant value that can be predicted as follows:

$$V_t = A \sqrt{\frac{\tau_y}{\rho}} \tag{1}$$

Alternatively, similar to the Newtonian fluid, the Reynolds number proposed by Slatter (2011) can be used to discriminate the onset of the turbulent. However, this model has not been extensively investigated against various non-Newtonian slurries.

LAMINAR OR TURBULENT REGIME?

Laminar regime transportation of the thickened tailings is often refrained due to the risk of pipeline blockage, in particular for a moderately thickened tailings transport via a long pipeline. In the laminar transport regime an ultra-thickened bed may form on the pipe invert as the particles settle under the shearing, resulting information of a density profile decreasing from bottom to top [Paterson, 2011]. This packed bed requires a significant pumping pressure to move along the pipeline.

On this basis, to reduce the risk of   pipe blockage in the laminar regime, the pumping system are designed such that to have a minimum installed pumping pressure to be able to slide the bed along the pipe invert. This minimum pumping pressure is largely independent of the pipe diameter and is recommended to be in the range of 1.5-2 kPa/m [Pullum, 2007].

Nevertheless, for slow settling materials (i.e. paste or high density fine tailings), the laminar regime transportation can be adopted for relatively short distances since the likelihood of a density profile formation is expected to be relatively low.

For the thickened tailings materials, there will be a maximum pipeline length (i.e. a Critical Length) that the material can be transported in the laminar regime before the formation of the packed bed starts which requires a significant pumping pressure to slide through the pipe. However to the knowledge of the authors, a reliable methodology to assess and predict the Critical Length for laminar transport has not been yet developed.

Laminar regime transport can bring several benefits to the transport system. Comparing these two flow regimes for thickener tailings transport, a significantly lower pumping pressure and less pipe wear due to a moderate transport velocity with minimized eddies make the laminar regime very cost effective (Yánez & Tapia, 2018).

Figure 2 compares the initial and operating costs of a transport system in the laminar and turbulent regimes. This analysis has been undertaken for a real transport case which was designed based on a turbulent regime to deliver paste material to the TSF. As can be seen, in this case study, the CAPEX and OPEX associated with a turbulent regime are approximately double of those for a laminar regime transportation. Also, the laminar regime transport net present cost saving would be about $47M (111-64) over the project life which is 20 years.

Basically, the lower velocity associated with the laminar regime will reduce the pressure drop and subsequently the total pumping pressure (i.e. number of pump) can be considerably diminished. This may also result in selection of the transport components (i.e. piping, valves and inline instrumentation etc) with a lower pressure class. The reduced velocity is more likely to elongate the pipe lining/pipe life as well. The basis of this cost analysis is presented in Table 1.
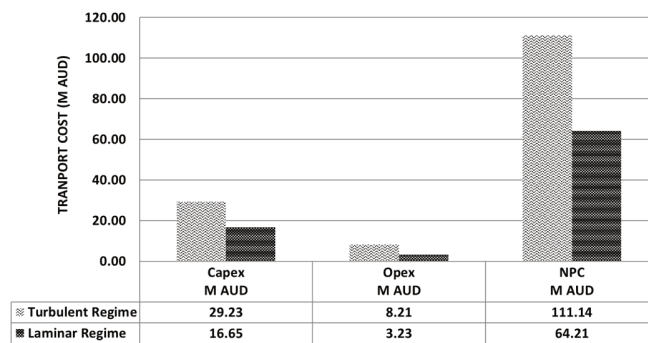
	Capex M AUD	Opex M AUD	NPC M AUD
Turbulent Regime	29.23	8.21	111.14
Laminar Regime	16.65	3.23	64.21

Figure 2 Laminar Regime vs Turbulent Regime Cost Comparison

Table 1 Cost Analysis Basis (Life=20years)

Item	Laminar Regime	Turbulent Regime
Average Velocity (m/s)	2	4.4
Pressure Drop @ Nominal Flow (m slurry/km)		
Section (1)/Section (2)/ Section (3)	9.64/9.55/8.99	20.63/25.05/18.05
Pumps (running in series)	2 off Centrifugal Pumps	4 off Centrifugal Pumps
	2000kW installed	5000kW installed
Average Absorbed Power	460×2 kW	630×4 kW
Pipeline		
Pipe Section (1)	1.0km CS NB650 Sch60	1.0km CS NB500 Sch80
Pipe Section (2)	2.0km HDPE DN800 PN16	2.0km HDPE DN630 PN25
Pipe Section (3)	1.5km HDPE DN800 PN12.5	1.5km HDPE DN630 PN16
Wear Rate	0.45 mm/y CS Pipe	1.34 mm/y CS Pipe
	0.76 mm/y HDPE pipe	2.22 mm/y HDPE pipe

BASIS OF DESIGN DEFINITION

TONNAGE AND SOLIDS CONCENTRATION

For the design of a tailings transport system, an appropriate range of tonnage and solids concentration based on the upstream operations (i.e. process plant) should be defined. A range of variability is often expected in the tailings thickeners underflow tonnage and the solids concentrations and hence the transport system is required to be designed to handle the process variations. The expected range of the solids concentration is usually defined by the thickening testing and needs to be realistic adopted as the effect of the solids concentration variation is not only on the volumetric flowrate but also more importantly on the rheological behaviours of the material.

In case of designing the transport system for an existing thickener, it is recommended that the operational data of the existing system to be thoroughly analysed. The data is preferred to be instantaneous records rather than hourly or daily averaged records. Analysis of the operational data would provide valuable information such as the trend of the process fluctuations which can be utilised to define the design parameters more realistically, provided that the accuracy of the data is verified. Figure 3 shows a typical recorded operational data distribution from an iron ore tailings thickener and the recommended range for the design of the transport system.

The expected variations in the flow and solids concentration for different types of thickener, have been reported in previous research works (Seddon, Pirouz and Javadi, 2018), (Pirouz, Javadi and

Seddon, 2017), (Seddon and Fitton, 2011). For the operation of paste thickeners a Coefficient of Variation (C.V.) value between 0.030 and 0.085 is recommended for simulation of underflow solids concentration and mass flowrate variability respectively (Pirouz, Javadi and Seddon, 2017). For High-Rate thickeners it is recommended to use a C.V. value of 0.05 for underflow solids concentration and for simulation of slurry mass flowrate variation a "two-tailed" normal distribution with C.V. values of 0.12 for the lower tail and 0.07 for upper tail are suggested by Seddon and Fitton (2011) (Pirouz, Javadi and Seddon, 2017). These C.V. values are recommended based on the statistical analysis of the actual thickener data.
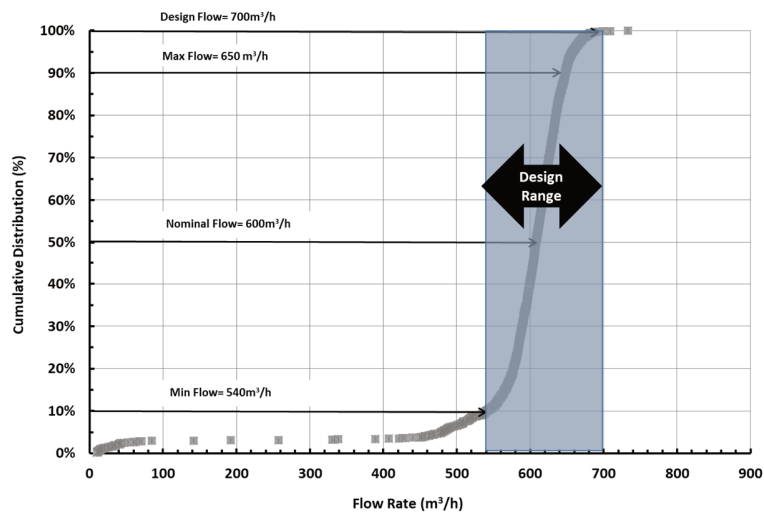

Figure 3 Thickener U/F Actual Operational Data

RHEOLOGICAL PARAMETERS

The rheological parameters are the key inputs for designing the transport system since the thickened tailings flow characteristics are represented by these parameters. The rheological properties which are different for different material, should be tested and measured by laboratory testing preferably before the conceptual or pre-feasibility stages of the transport system design.

Thickened tailings rheological testing is often undertaken by using a rotary viscometers or rheometers. The testing involves a rheometer with cup and bob geometry, preferably with a grooved surface to minimize the particle wall slip. It is also recommended to repeat the testing at least twice to ensure the result repeatability.

To assess the effect of the shear on the rheological properties of the sample, the test can be carried out for both increasing shear rate and decreasing shear rate. The increasing shear rate is titled as "Up-Ramp" which means that the material shear stress is measured with the shear rate increasing from 1 s^{-1} to a maximum of 500 s^{-1} as opposed to the "Down-Ramp" where the shear rate reduces from the 500 s^{-1} to 1 s^{-1}.

Depending on a sheared or un-sheared material being handled by the transport system, the proper rheological data sets (i.e. "Up-Ramp" or "Down-Ramp") can be selected. The material discharging from the thickeners underflow are un-sheared, as such the thickener U/F pumps are selected and sized using the un-sheared rheological parameters, while if the transport system delivers the tailings which are already pre-sheared with shear-thinning pumps or sump pump agitators, the sheared data should be utilized.

It should be noted that the testing methodology described here is adopted by the designers for the purpose of the tailings transport as a generally accepted testing technique, despite the fact that there is not a unique testing methodology recommended by a Code or Guidelines. For the purpose of the transport system design, the rheological parameters reported by the thickeners suppliers should be avoided since the methodology more focuses on evaluation of un-sheared material flow behaviour at a very low shear rate using a vane geometry.

TAILINGS PIPELINE FAILURE RELEASE MANAGEMENT

Tailings pipelines leakage and spillage to the environment is one the main concerns for any tailings hydraulic transportation system, in particular for the above-ground installations. As such, a comprehensive pipeline integrity failure analysis should be undertaken during the design stage to assess the volume of the released tailings to the environment in case a failure occurs. Slurry pipelines failure with subsequent leakage can be caused by:

- Wear to the pipe wall due to solids particles' inherent erosive nature;
- Pipe burst;
- Pipe Welding Malfunction; or
- Severe external damage to the pipeline due vehicle collision, fire or similar.

To minimize the environmental impact of pipeline failure, the tailings and return water pipelines are often proposed to be installed in a containment bund to capture potential tailings spillage and prevent a subsequent spillage to the wider external environment in case of a failure. The containment bund also reduces the risk of external damage to the pipe due to vehicle collision, fire etc. Figure 4 shows a typical containment bund with tailings and return water pipelines.

Additionally, based on the volumes of tailings that can potentially be released to the bunded corridor, multiple containment/collection ponds may be needed along the pipeline length at different locations to store any potential leakage.
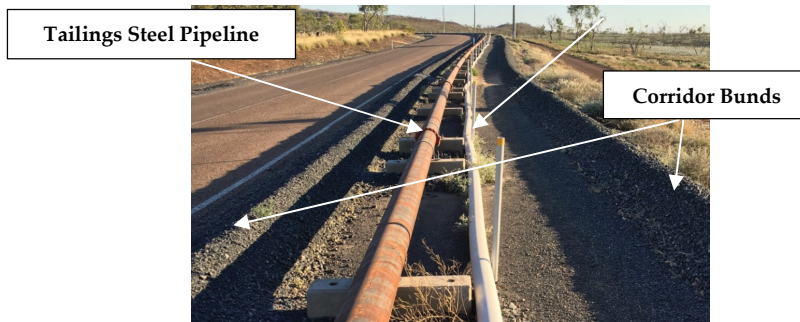
Return Water HDPE Pipeline

Figure 4 Example of Tailings and Return Water Pipeline Bunded Corridor

For monitoring of the pipeline failure, the tailings pipelines are also often proposed to be fitted with a Leak Detection System (LDS). LDS consists of two paired high accuracy flowmeters installed at the beginning and the end of the tailings pipeline. The flowmeters are specifically designed array-based sonar technology instruments which allows accurate, stable and drift-free flow measurements for leak detection in the pipelines.

The first flowmeter is installed on the tailings discharge pipeline next to the pump station and the second flowmeter on the other end of the tailings pipeline close to the TSF. The flowrate readings from the two flowmeters are transmitted to a Process Control System (PCS) and are constantly compared with each other to detect flowrate deference.

Based on the leak detection control and monitoring philosophy, three different failure modes can be defined as follows:

- Non-Detectable Failure;
- Minor Failure; and
- Major Failure.

Non-Detectable Failure is associated with any leak which is beyond the accuracy of the LDS. This type of failure can be identified and verified by a detailed visual inspection of the pipeline corridor. The visual inspection is recommended to be at least once a day.

In the Minor Failure, the reported difference in flow is more than a H set-point and below a HH set-point. In this case, the PCS starts alarming to notify the operators to conduct a visual inspection along the pipeline, in order to confirm if there is a leakage, while the pumps are still in operating.

The Major Failure is defined as severe damage to the pipeline after which a leak greater than a HH set-point occurs. In this case, it is assumed that the pipe is burst or a joint has failed and a fully open pipe discharge to the corridor occurs. Once a major failure occurs, an emergency shutdown is initiated after few minutes and if a positive gradient is available the pipeline can then be drained by opening a scour valve at the pump station.

Based on the volume of the released tailings and the rainfall runoff, the containment pond and the containment bunds can be sized. The tailings volume releasing from the pipeline depends on the type

of failure, response time and the pipeline chainage at which the failure has occurred. The total released tailings volume is the sum of the following flows:

- Leakage while the Tailings Pump Station (TPS) is running; and
- Leakage after the TPS is stopped, but the pipeline has not been fully drained.

In Figure 4, as an example, the results of an analysis for released tailings volume and flow rate due to a Major Failure leakage is presented. In this case study, it is assumed that one or two of the coupling joints are fully broken and the tailings are discharged through a fully opened pipe. In this case the maximum volume of the released tailings to the corridor is estimated to be 265 m^3 if the failure point is located at the lowest section of the pipeline (i.e. Chainage 800 m).
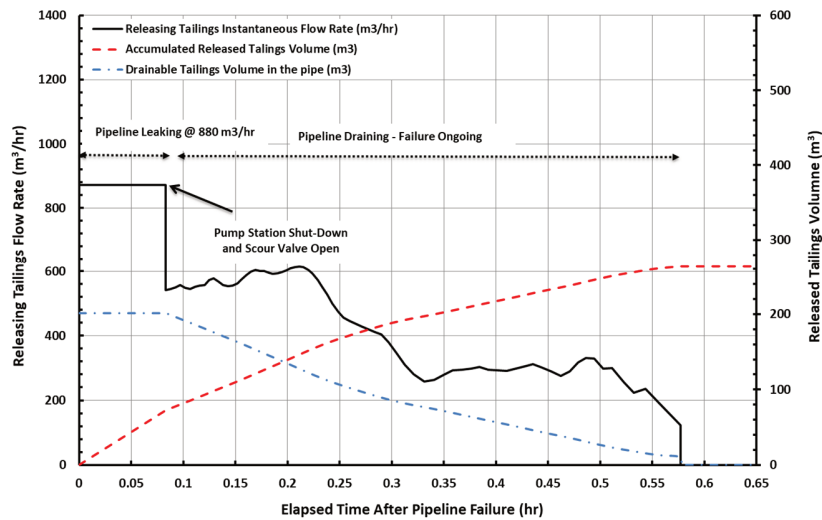

Figure 5 Major Failure Leakage Flow and Released Tailings Volume

The same analysis for other types of the failures described should be undertaken at various chainages along the pipeline length. The maximum released volume will dictate the size of the containment corridor and the ponds.

CONCLUSION

This paper gave an overall overview to the thickened tailings transportation system which is an integrated element in any wet tailings storage facility (TSF).

Multiple aspects of the transport system (pressurised or open channel) have been reviewed and the considerations for design of hydraulic transport system, including the flow regime, material characteristics, flow behaviour assessment (rheological behaviour measurement and interpretation), the basis of design definition, pipeline leakage monitoring system and failure analysis and management are discussed.

Failings to address these important topics adequately at the design stage can result in a malfunctioning transport system with high maintenance and operating costs which would inevitably face frequent shutdowns (i.e. loss of production) and can be a nightmare to operate.

NOMENCLATURE

V_t : transition velocity (m/s)

τ_y : Yield Stress (Pa)

ρ : Slurry Density (kg/m^3)

A   : Constant (Ranging from 19 to 26)

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