

Case Study: Paste Tailings Transport Optimization, Model Calibration and Concentration Sensitivity

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ABSTRACT

This paper presents a case study on the optimization of a paste tailings transport system for a tailings storage facility located in Zacatecas, Mexico. The study focuses on hydraulic performance, model calibration using field data, and sensitivity to solids concentration under varying operating conditions. The system consists of a combined pipeline configuration, including a 12-inch HDPE ramp section and 10-inch HDPE distribution lines delivering tailings to multiple discharge points across two storage cells. A steady-state hydraulic analysis was carried out over a wide operational envelope defined by variations in throughput and solids concentration to determine the operating pressures. Although laboratory testing suggested a Bingham fluid model, field measurements showed stronger agreement with a Casson-based approach. Hydraulic loss models were therefore calibrated against field data, yielding improved head loss prediction reliability. The study also highlights the influence of field data in calibrating the hydraulic gradient models and slurry properties. Calibrating the model with operational data provided the technical justification to safely maintain the existing HDPE infrastructure for new TSF elevations, avoiding a costly upgrade to carbon steel piping. Ultimately, the outcomes of this study supported informed decision-making, allowing capital investments to be minimized while maximizing the utility of the existing pumping system.

INTRODUCTION

This paper focuses on a Case Study TSF located at Fresnillo, Zacatecas, Mexico . The infrastructure currently relies on a pipeline system that transports process tailings up to the deposition points (spigots) distributed across two cells: Cell 1 and Cell 2. As the project advances to Stage 5, the project TSF is planned to be raised. This expansion requires the distribution system to be optimized, as the selected pipeline configuration did not consider the stage 5 pressure requirements and includes a 12-inch HDPE (DR 7.3) ramp section that transitions into 10-inch HDPE (DR 11) distribution lines along the perimeter of the cells. The primary technical challenge involves managing a tailings slurry characterized by high yield stress and high solids concentration, ranging from 53% to 57% by weight under nominal conditions.

The objective of this study is to evaluate the hydraulic behavior of these distribution pipelines during the Stage 5 raise to ensure reliable operation under a variety of operational scenarios. To achieve this, a steady-state analysis was conducted to determine a safe operational envelope based on the limits of throughput and concentration. The remainder of this paper is structured as follows: First, the Methodology describes the rheological modeling of the tailings, introducing the Bingham (Bingham, 1922) and Casson (Casson, 1959) fluid approaches, alongside the criteria for hydraulic stability and sensitivity analysis. Next, the Results and Discussion section contrasts the theoretical models against field data calibration, and defines the safe operational pumping limits. Finally, conclusions and recommendations for the TSF Stage 5 expansion are presented.

METHODOLOGY

Rheological Modeling and Field Data Calibration

Extensive laboratory testing was performed on mixed tailings samples to determine the physical and rheological properties of the slurry prior to system modelling. Initial rheological characterization in the laboratory suggested that the paste behaviour could be modelled using a Bingham plastic fluid approach. The Bingham model characterizes the slurry utilizing a linear relationship defined by the equation

$$\tau = \tau_y + \mu_B \dot{\gamma} \quad (1)$$

where τ_y represents the yield stress and μ_B represents the Bingham plastic viscosity and $\dot{\gamma}$ the shear rate.

However, due to the shear-thinning characteristics typical of highly concentrated mineral slurries at lower shear rates, the hydraulic loss formulas for the HDPE piping networks were calibrated against field data utilizing the Casson fluid approach. The Casson model is expressed by the following equation:

$$\sqrt{\tau} = \sqrt{\tau_y} + \sqrt{\mu_c \dot{\gamma}} \quad (2)$$

Consequently, the hydraulic loss formulas for the HDPE piping networks were calibrated against the field data utilizing the Casson approach.

Hydraulic Stability Assessment

System stability was assessed using paste stability diagrams tailored for the specific internal diameters of the 10-inch and 12-inch HDPE pipes. The limit to maintain a stable, non-settling flow regime was setup applying a simplified Gillies model (Hallbom, 2008; Gillies, 2000; Gillies, 2004).

Concentration Sensitivity and Pumping Limits Modeling

To support safe operation without exceeding the structural limits of the HDPE pipelines, a robust sensitivity analysis of flow rate (throughput) and maximum pumpable solids concentration was conducted. The hydraulic analysis modelled the maximum permissible concentration limits for each specific discharge spigot in Cell 1 and Cell 2, applying a safety factor (FS) of 1.2 to standard operating pressures.

RESULTS AND DISCUSSION

Rheological Characterization Outcomes

Sieve analysis indicated a finely ground material, with 80% of the particles passing 40 μm and 99.5% passing 150 μm . However, the transition from theoretical modelling to operational reality required careful calibration. When comparing the laboratory-derived Bingham models with actual field measurements supplied by the operator, significant discrepancies were observed. The Bingham model failed to perfectly map the pressure gradients and friction losses across the varied operational shear rates present in the field (Figure 1).

Instead, field data demonstrated stronger alignment with a Casson-based fluid approach (Figure 2). Unlike the Bingham model, the Casson model more accurately captures the shear-thinning characteristics of the paste at lower shear rates, a phenomenon typical for highly concentrated, fine-particle mineral slurries. This recalibration proved critical, yielding significantly improved prediction reliability for the existing pipeline design, head requirements, and stability limits.

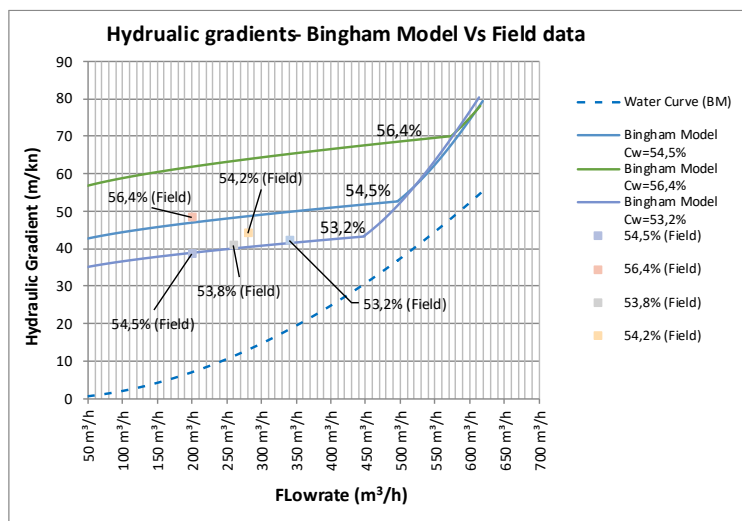


Figure 1 Bingham Model (curves) vs Field data (dots)

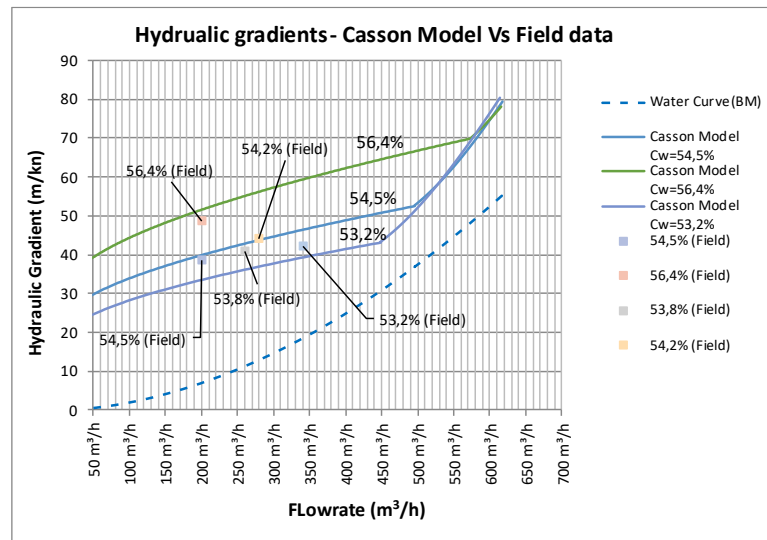


Figure 2 Casson Model (curves) vs Field data (dots)

Hydraulic Stability and System Performance

The analysis confirmed that stable transport is achieved purely under laminar flow conditions. Under laminar flow conditions, hydraulic gradient is highly affected by yield stress instead of the flow speed, in contrast of the turbulent flow conditions, where the flow speed is one of the critical variables. Due to the considerably high yield stress of the paste, particle settling is suppressed, and the system relies entirely on "viscous drag" to move the thick slurry safely.

A critical minimum yield stress threshold of approximately 19 Pa was established as a requirement to maintain this stable, non-settling flow regime (Hallbom. 2008). While viscous drag ensures stability, it heavily influences system pressure. For nominal concentrations (around 55%), the working pressures approach, but do not exceed, the allowable safety limits of the piping. However, at the upper limits of operation (approaching 57 wt% concentration), the pipeline pressure borders the absolute maximum threshold of the HDPE infrastructure.

Concentration Sensitivity Limits

The results demonstrated that maximum pumpable concentration is dependent on both the system flow rate and the linear distance to the active discharge spigot. Figure 3 shows the discharge points locations on both cells. Figure 4 and Figure 5 summarize the operational limits dictated by pipeline friction losses for each cell of the TSF.

As highlighted in the sensitivity tables, the existing system can comfortably pump concentrations up to 58% at proximal discharge points across all tested flow rates. However, the cumulative frictional losses across the longer distribution paths to the furthest spigots act as a severe operational constraint. At peak flow rates, the tailings concentration must be actively diluted and reduced for the most distal spigots to avoid over-pressurizing and damaging the piping network.

Figure 3 Cell 1 and Cell 2 discharge points locations



Figure 4 Maximum pumpable solids concentration (%) vs. Flow Rate (m³/h) for selected discharge points in Cell 1 (FS = 1.2)

Q (m ³ /h)	Punto 6	Punto 5	Punto 4	Punto 3	Punto 2	Punto 7	Punto 8	Punto 9	Punto 10	Punto 11	Punto 12	Punto 1
150	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	57%	55%
175	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	56%	55%
200	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	56%	54%
225	58%	58%	58%	58%	58%	58%	58%	58%	58%	58%	56%	54%
250	58%	58%	58%	58%	58%	58%	58%	58%	58%	57%	55%	54%
275	58%	58%	58%	58%	58%	58%	58%	58%	58%	57%	55%	54%
300	58%	58%	58%	58%	58%	58%	58%	58%	58%	57%	55%	53%
325	58%	58%	58%	58%	58%	58%	58%	58%	58%	56%	54%	53%
350	58%	58%	58%	58%	58%	58%	58%	58%	58%	56%	54%	53%
375	58%	58%	58%	58%	58%	58%	58%	58%	58%	56%	54%	53%
400	58%	58%	58%	58%	58%	58%	58%	58%	57%	56%	54%	52%

Figure 5 Maximum pumpable solids concentration (%) vs. Flow Rate (m³/h) for selected discharge points in Cell 2 (FS = 1.2)

Q (m ³ /h)	Punto 11	Punto 12	Punto 1	Punto 5	Punto 3	Punto 7	Punto 9	Punto 8	Punto 6	Punto 4	Punto 2	Punto 13	Punto 10	Punto 14
150	58%	58%	58%	58%	58%	56%	58%	58%	58%	58%	58%	58%	58%	57%
175	58%	58%	58%	58%	58%	55%	58%	58%	58%	58%	58%	58%	58%	57%
200	58%	58%	58%	58%	57%	55%	58%	58%	58%	58%	58%	58%	58%	56%
225	58%	58%	58%	58%	57%	55%	58%	58%	58%	58%	58%	58%	57%	56%
250	58%	58%	58%	58%	57%	54%	58%	58%	58%	58%	58%	58%	57%	56%
275	58%	58%	58%	58%	56%	54%	58%	58%	58%	58%	58%	58%	57%	56%
300	58%	58%	58%	58%	56%	54%	58%	58%	58%	58%	58%	58%	56%	55%
325	58%	58%	58%	57%	56%	54%	58%	58%	58%	58%	58%	57%	56%	55%
350	58%	58%	58%	57%	56%	53%	58%	58%	58%	58%	58%	57%	56%	55%
375	58%	58%	58%	57%	55%	53%	58%	58%	58%	58%	58%	57%	56%	55%
400	58%	58%	58%	57%	55%	53%	58%	58%	58%	58%	58%	57%	55%	54%

CONCLUSIONS

The optimization of the paste tailings transport system hydraulic calculations for the TSF Stage 5 successfully balanced hydraulic performance requirements against the mechanical limits of the piping network. The following conclusions and recommendations were established:

- *Model Calibration is Critical:* The study of paste rheology is extremely complicated due to its high concentration, the complexity of paste slurry materials, and the “three non” engineering characteristics (Wu, 2022). Calibrating the theoretical rheological model using field data and shifting from a Bingham plastic to a Casson-based approach proved essential in this case study. This transition allowed for accurate predictions of pressure losses across varied flow regimes, ensuring reliable operation of the existing HDPE pipe instead of the carbon steel upgrade required by the test-based Bingham Model pressure calculations.
- *Project specific operational tools:* Calibrated model allowed to provide project specific operation tools. These tools resulted very useful for the operation team, to match the deposition / filling plan of the TSF with the best efficient operation (highest concentration possible).
- *Operational Control & Monitoring:* Stable transport fundamentally depends on viscous drag and the maintenance of a minimum yield stress of 19 Pa. Because operating near 57 wt% closely approaches the HDPE pipeline limits, continuous pressure monitoring and rigorous concentration control are mandatory, particularly when activating distant discharge points. Tailings rheology is known affected by mineralogy, design factor of 1.2 is considered for typical process variations. Nevertheless, diligent and live monitoring, interlocks and control system protections are recommended.
- *Project positive impact:* The insights derived from this study function as a critical decision-making tool, enabling operators to minimize future capital investments while safely maximizing the utility of the existing pumping and HDPE pipeline infrastructure for stage 5 TSF elevations.

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