Tailings2025 | 11th International Conference on Tailings Management

THE ROLE OF RHEOLOGY TESTS IN THE DESIGN AND OPERATION OF LONG-DISTANCE SLURRY TRANSPORT SYSTEMS

Cristian Giner[1]*, Alexander Manos[2] , Gonzalo Laciar[1] , Stuart Flett[2] , Cristian Bertolo[1]

1. *Mechanical and Piping Engineering, Knight Piésold, Argentina*
2. *Mechanical and Piping Engineering, Knight Piésold, USA*

ABSTRACT

Mineral-rich regions are often concentrated in defined geographic areas where multiple mining operations under common ownership may be established. In such cases, operations at specific development stages may share common tailings storage facilities, offering increased operational flexibility during facility expansions. In these configurations, long transport distances and rugged, uneven terrain present significant challenges to the design and operation of tailings pipeline systems, with implications of both, initial capital expenditures and long-term operational costs. Although the system's final design focused on compliance with standard design criteria, operational deviations from those guidelines were identified; nevertheless, the system met its performance objectives. The findings suggest that rheological properties obtained through non-representative laboratory testing can lead to conservative hydraulic design evaluations that do not accurately reflect site-specific conditions. This article presents a case study demonstrating how the rheological characteristics of tailings, especially those influenced by sample preparation and properties such as rheomalaxis and thixotropy can play a critical role in informing and optimizing key design decisions.

Keywords: long distance tailings transport, mining, pipeline systems, hydraulic evaluation, design criteria, rheology specifications.

INTRODUCTION

Knight Piésold's mechanical division, in collaboration with its international offices, conducted a hydraulic evaluation of a 9 km mine tailings transport system. Originally conceptually designed and partially constructed by a third party, the pipeline was developed under constraints related to time, budget, land availability, and equipment. These factors led to a compromised configuration, with anticipated slurry flow not fully meeting standard industry design criteria. The system also utilized an existing pumping setup not originally designed for this 9km tailings pipe application, introducing further limitations in flow rate and pressure. The evaluation assessed slurry flow, considering transitions between turbulent and laminar regimes, and operating pressures under steady-state conditions. The findings indicated potential flow regime instability, suggesting possible operating implications. However, field performance demonstrated that the system operated within acceptable limits despite constraints anticipated during the original design.

METHODOLOGY

- **Transport Stability Analysis:** Transport stability was assessed using the Paste Stability Diagram developed by Dr. Donald J. Hallbom. The transition between laminar and turbulent flow was identified through the intersection of the Buckingham and Thomas & Wilson models (Thomas. & Wilson, 2007). Sedimentation behavior was evaluated using the Durand model, alongside five additional models in a sensitivity analysis (Miedema & Sape, 2017)**.**
- **Determination of Pressure Drops:** Pressure losses were calculated by considering the fluid as an industrial slurry, analyzing both the Warman model for heterogeneous flow (Grzina, Roudnev & Burgess, 2002) and the Buckingham and Tomas & Wilson models for non-Newtonian homogeneous slurries (Hallbom, 2008).
- **Rheology:** Rheological characterization was performed by third parties across various tailings concentrations. The tests identified key fluid parameters and confirmed that the Bingham Plastic model was the most suitable representation across the concentration range under study, providing corresponding yield stress and plastic viscosity values. The reports did not include details on pre-shearing of the sample, actual low shear rate data (eg. Vane Test), or time-dependent behaviors such as rheomalaxis and thixotropy (Sofrà,& Boger, 2011).

ANALYSIS

The evaluation of pipeline size began with an assessment of transport velocity limits, considering both the threshold for turbulent sedimentation and the transition from laminar to turbulent flow. The Paste Stability Diagram, (Hallbom DJ, 2024) served as a key tool for evaluating and selecting pipeline sizes for tailings transport for both the original design and the extended new 9km pipeline design under assessment. Figure 1 shows that the originally selected NPS 6 SCH 40 steel, 51 bar(g) rating pipeline, selected by the tailings pump station designer, for discharge to the original TSF, falls within the stable turbulent zone for the complete range of flows around the nominal design point. In contrast, for the new 9km pipeline differently sized NPS 8 SCH 80 steel 51 bar(g) rating pipeline, a significant portion of the original tailings pump station's operating range lies within the unstable laminar zone, indicating potential transport challenges. The analysis, and the graph in Figure 1, also presents a third scenario, in which the operation of the NPS 8 pipeline was reevaluated with a reduced range of tailings concentrations - thus increased volumetric flow - to achieve an upper concentration limit that still allows operation within the stable turbulent regime. Despite the increase in volumetric flow, which is associated with a decrease in solids concentration, the pressure loss analysis indicates that the lower density and reduced flow velocity resulted in more efficient transport conditions, leading to a pressure loss reduction of approximately 65%. Operation at high concentration and partial solid deposition was not considered, due to the high slopes of the pipeline, ranging from 20%, resulting in a high risk of solid avalanching and pipe clogging. Figures 2 and 3 present the pressure loss curves for both pipeline sizes, calculated using homogeneous and heterogeneous flow models, along with the system parameters summarized in Table 1.

Table 1 System parameters

Parameter	Symbol	Value	Unit
Solids Density	SG	2.82	-
Average particle size	D_{50}	29	μm
Concentration Range by Weight	$Cw_{\%}$	50 – 56	-
Tailings Production Range	T	3612 – 4300	tpd
Maximum flow rate pumping system	Q_{max}	160	m^3/h
Rheology – Yield Stress	Ys	4.81 – 10.23	Pa
Rheology – Coefficient of Stiffness	μ_b	10.91 –11.17	mPa.s

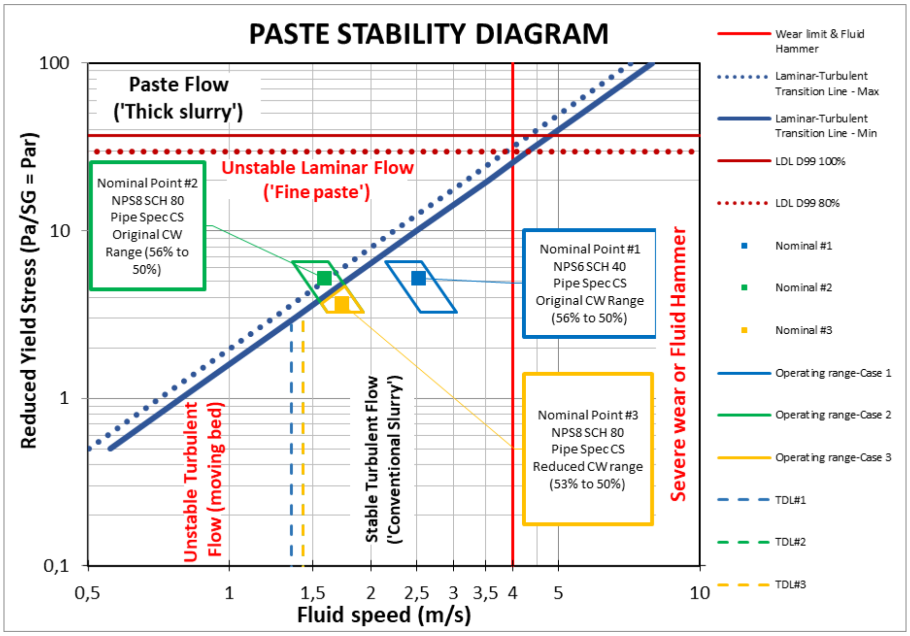

Figure 1 – Paste stability graph

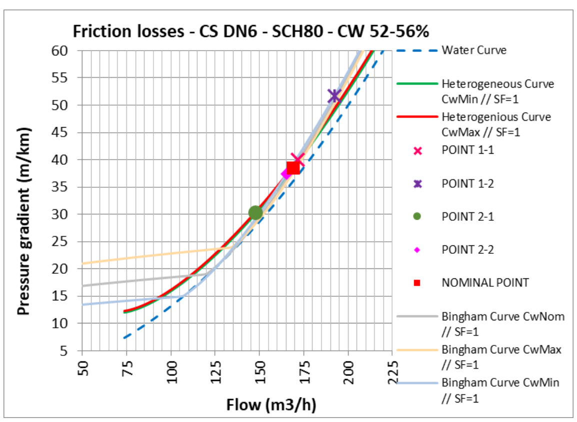

Figure 2 – NPS6 hydraulic gradient

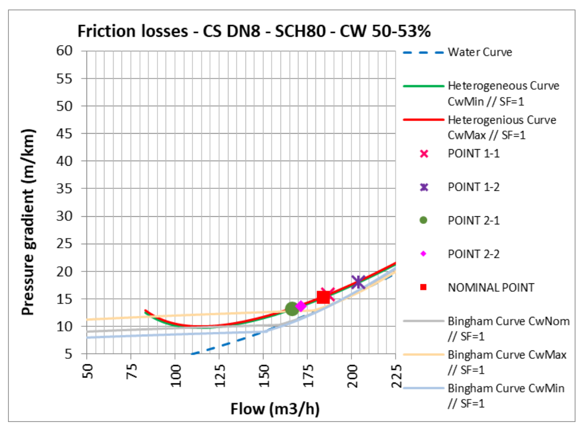

Figure 3 – NPS8 hydraulic gradient

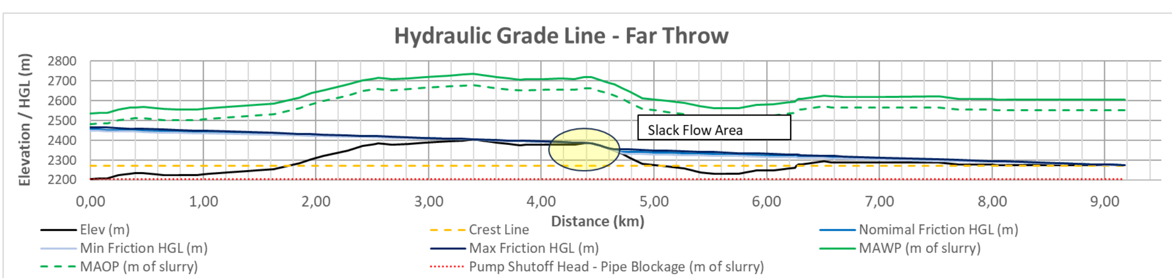

Figure 4 – Hydraulic gradient lines – NPS8 Distant discharge

RESULTS AND DISCUSSION

Pressure demands for the pumping station and pipeline were assessed for both pipe sizes and varying concentrations using hydraulic gradient lines. The NPS 6 pipeline exceeded equipment limits, requiring Class #600 components and new infrastructure. In contrast, the NPS 8 pipeline operated within existing system limits. A slack flow zone (Figure 4) was identified, where flow transitions to free-surface behaviour, helping to buffer pressure fluctuations and maintain stable discharge conditions across the TSF. The initial operating flow range for the Tailings Pump Station and NPS 6 pipeline (highlighted in Figure 4) largely fell within the laminar zone of the NPS 8 pipeline requiring dilution. To shift into turbulent flow, reducing solids concentration was recommended increasing flow rate and lowering yield stress. However, practical limitations arose due to the positive displacement pumps' flow and pressure capacity, which couldn't handle the full range of diluted conditions required for NPS 8, especially under high production. For that situation, a high-pressure dilution system was recommended at the pump discharge, but was not correctly implemented at the time, resulting in a faulty and unreliable system. Despite failures in the dilution system, the client continued operating the pipeline, reporting stable pressures, even at low flows, while operating in conditions expected to produce laminar flow (see field data on Figure 6) with consequent pressure fluctuations. No operational issues were observed over prolonged periods; pressure was stable over days of operation (Figure 5). Though sedimentation couldn't be totally ruled out, there were no signs of increased pressures or pipe clogging in steep pipeline sections. This suggests the system may have been operating more often, if not consistently, in a stable turbulent regime, minimizing laminar-turbulent transitions.

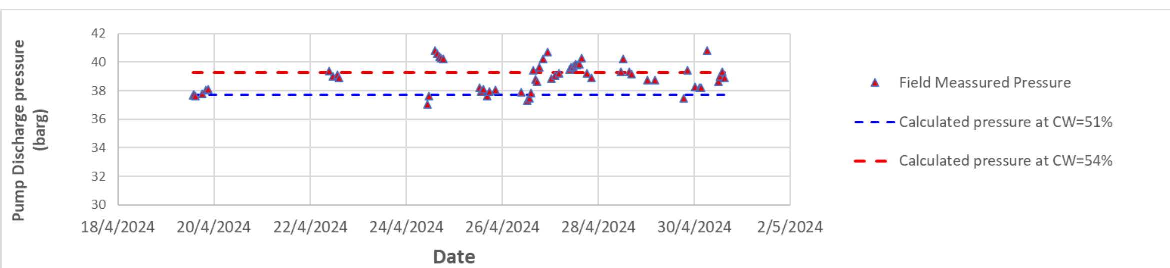

Figure 5 – Calculated vs measured pipeline working pressure at 160 m3/hr and Cw= 51 to 54%

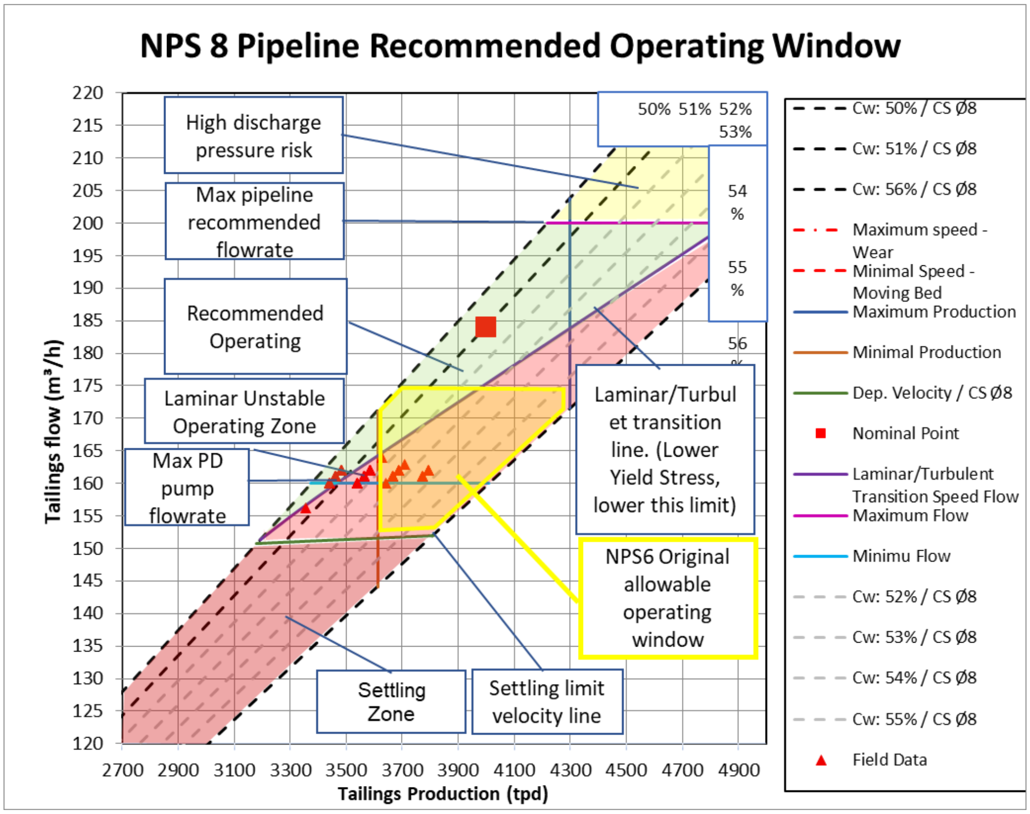

Figure 6 – System recommended Operating Window and Measured Field Data

CONCLUSION

Theoretical models effectively predicted operating conditions and supported revised operations at higher flows (i.e., with dilution) for the larger pipe. However, hydraulic models appeared conservative in defining system flow limits. This was evident when comparing pipeline sizes and observing the 9 km pipeline's operation without pressure fluctuations or clogging. System performance exceeded predictions due to lower effective yield stress values, reflecting high shear effects not captured in baseline rheology. These gaps underscore the risks of designing slurry systems based on poor rheological testing, which can misinform decisions and result in suboptimal designs.

RECOMMENDATIONS

To improve accuracy, detailed rheological testing protocols should be developed, considering recent techniques (Sofrà & Boger, 2011), particularly nothing the following:

- **Sampling & On-Site Testing:** Lab samples from dry solids often fail to reflect actual slurry behavior, considering water chemistry, pH, and additives (e.g., flocculants/coagulants) which play a key role. Mobile labs allow real-time testing of fresh samples from critical points (e.g., thickener underflow, pump discharge), improving insight into system behavior.
- **Shear Behavior & Comprehensive Analysis:** Even with fresh samples, pre-shear and time-dependent effects (thixotropy, rheomalaxis) must be considered to capture yield stress behavior. Testing both full slurry and carrier fluid (<45 μm) with methods like vane rheometer, cup-and-bob rheometers, and pipe loop tests (for coarser slurries, P80 > 212 μm) can enable more accurate, multi-scale modeling.
- **Mineralogical Sensitivity:** Analyzing samples from various ore sources can identify slurry rheology variations due to mineralogy to better support designs.

ACKNOWLEDGEMENTS

We thank all our colleagues from the specialist tailings transport teams of Knight Piésold USA, Mexico and Argentina, particularly Alexander Manos (KP USA), Gonzalo Laciar (KP Argentina), and Dr. Donald J. Hallbom, who supported with their time, knowledge and thoughts.

NOMENCLATURE

TSF Tailings Storage Facility

REFERENCES

Hallbom DJ, (2008), 'Pipe Flow of Homogeneous Slurry', a thesis submitted in partial fulfillment of the requirements of the degree of Doctor of Philosophy in the faculty of graduate studies of the university of British Columbia, Vancouver.

Hallbom DJ, (2024), 'Slurry Seminar', Part 3 and 4, stability maps and allowable velocity range, Vancouver, Canada.

Thomas, A.D. & Wilson, K.C.. (2007). Rough-wall and turbulent transition analyses for Bingham plastics - The 17th International Conference on the Hydraulic Transport of Solids. 77-86.

Miedema, Sape. (2017). Slurry Transport, Fundamentals, A Historical Overview, The Delft Head Loss & Limit Deposit Velocity Framework. 2nd Edition Preliminary Version.

Sofrà, F & Boger, DV (2011), 'Rheology for thickened tailings and paste — history, state-of-the-art and future directions', in R Jewell & AB Fourie (eds), Paste 2011: Proceedings of the 14th International Seminar on Paste and Thickened Tailings, Australian Centre for Geomechanics, Perth, pp. 131-133.

Grzina, A, Roudnev, A, Burgess KE, (2002) Slurry Pumping Manual, 1st Edition. Warman International LTD