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THE DESIGN OF THE CENTURY ZINC CONCENTRATE PIPELINE – THE LONGEST SINGLE PUMP STATION SLURRY PIPELINE IN THE WORLD

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1. INTRODUCTION

The Century zinc/lead deposit near Lawn Hill in NW Queensland was originally discovered in the 1880's as a silver-lead deposit. It was rediscovered a century later by CRA (now Rio Tinto) in the late 1980's - hence the name Century. From the early days it was realised that a slurry pipeline was likely to be the most feasible transport option. The Gulf Country is subject to flooding in the wet season making road or rail transport options very expensive. From 1992 onwards, Slurry Systems was involved in various scoping studies, pre-feasibility studies, testwork at the bulk sampling plant, pipeline route selection, pipeline hydraulic design, commissioning, and on-site testing and reviews up until 2008. A number of different pipeline routes were initially considered including one heading north from Century to a proposed deep water port to be built on an island in the Wellesley group in the Gulf of Carpentaria. The final route selected was NE to Karumba where the filtered concentrate is trans-shipped to barges for subsequent loading onto ships moored off shore in the Gulf of Carpentaria.

The hydraulic design of the Century pipeline was by Slurry Systems Pty Limited with detailed design by a Joint Venture between Pasminco, Minenco and Bechtel. Construction was by Bechtel. The pipeline was commissioned on zinc concentrate in November 1999 by a team comprising Bechtel representatives and the author of this paper. The pipeline was subsequently commissioned on lead concentrate in July 2000.

The 304 km Century pipeline is the longest single pump station slurry pipeline in the world and was the first slurry pipeline to incorporate batching of different concentrates (zinc and lead). A conventional slurry pipeline design would typically have involved velocities around 1.6 m/s in this size pipe and the resulting pressure gradients would have required a booster station, since there is only 150 m elevation advantage over the 304 kms. However a remote booster station would have had to be diesel driven and could be cut off by flood waters during the wet season and so there was a strong incentive to achieve a single pump station design. Considerable time was spent in desk top studies to determine whether this was possible. The studies were based on slurry properties measured in Slurry Systems' laboratory and no loop tests were conducted. Eventually, given that the concentrates are much finer than most typical concentrates, it was concluded that an operating velocity of 1.2 m/s (in the thinnest wall pipe) was viable.

2. SINGLE PUMP STATION POSSIBLE BECAUSE OF FINE PARTICLE SIZE

Century zinc concentrate has a p80 around 7.5 microns and the lead concentrate a p80 around 15 microns with a maximum 22 microns. Conventional concentrates are significantly higher with p80 typically in the range 50 to 70 microns. Figure 1 shows the predicted deposit velocity in a 300 mm pipe versus mean particle size for a solids SG 4.0 assuming typical rheology.

Figure 1

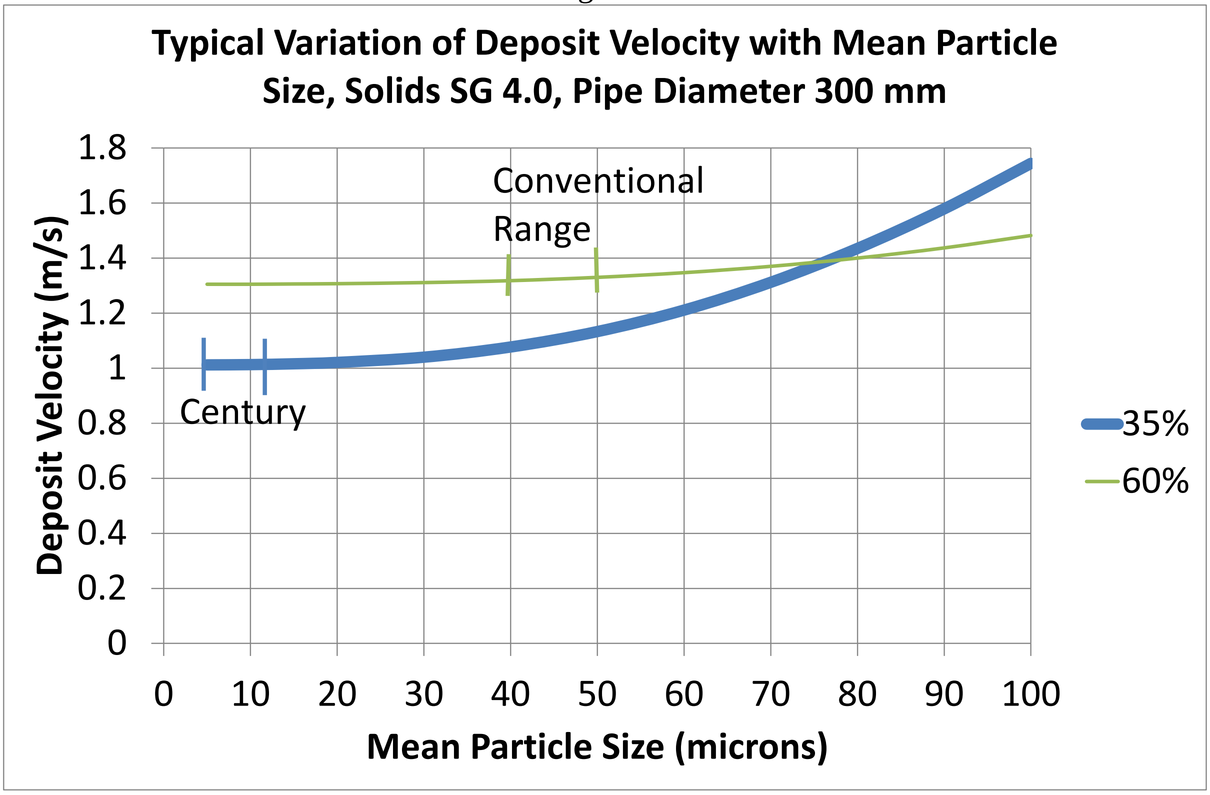


Figure 1 indicates a deposit velocity around 1.3 m/s for conventionally sized concentrate whereas the deposit velocity for Century concentrates is around 1 m/s. Allowing for a velocity margin above deposition the conventional concentrate pipeline operates at around 1.6 m/s whereas Century operates at 1.2 m/s. As a result the pressure gradient in the Century pipeline is about half that for a conventional concentrate pipeline of the same 300 mm pipe size.

The finer Century particle size translates to a higher rheology than conventional concentrates and the concentration must be lowered to ensure flow remains turbulent.

3. SLURRY PROPERTIES AND TRANSITION VELOCITY

Some typical slurry properties adopted during the design phase are summarised in Table 1 (Thomas et al, 2002).

Table 1
Century pipeline – typical slurry properties

	Zinc Conc.	Lead Conc.
Concentration (wt%)	35	37
Solids SG	4.1	4.8
Particle Size (Microns) p_{95}	14	33
p_{80}	7.5	20
Yield Stress (Pa)	1.0	0.5
Plastic Viscosity (mPas)	4.0	3.5

Note the very low concentrations compared with other concentrate pipelines which typically operate around 60% concentration. The low concentration is required to ensure the yield stress remains below about 1.5 Pa. The laminar-turbulent transition velocity is largely determined by the yield stress. For example the following equation (Wilson and Thomas, 2006) predicts the transition velocity for Century concentrates.

$$Vt = 25 \left(\tau_y / \rho_{sl} \right)^{0.5} \qquad (1)$$

where Vt = transition velocity (m/s)
τ_y = yield stress (Pa)
ρ_{sl} = slurry density (kg/m^3)

The slurry density for the zinc concentrate of Table 1 is 1360 kg/m^3 and Eqn 1 predicts Vt = 0.68 m/s. For the zinc concentrate the deposit velocity generally coincides with the transition velocity. If the yield stress is increased to 1.5 Pa then Vt increases to 0.83 m/s which is about the maximum to provide an adequate margin below the minimum operating velocity of 1.20 m/s.

The lead concentrate is coarser, has a higher solids SG and lower rheology than the zinc concentrate and the deposit velocity for the lead concentrate is generally controlled by heterogeneous effects. A maximum p_{80} of around 22 microns generally applies to the lead concentrate to ensure the deposit velocity is a safe margin below the 1.2 m/s operating velocity.

As is discussed in the following section, Century zinc concentrate typically contains about 15% air in the form of micro-bubbles. Under pressure in the pipeline all this air is dissolved and does not affect pipeline operation. However rheology tests are necessarily conducted at atmospheric pressure and the measured rheology is higher than the rheology applying under pressure in the pipeline. The micro-bubbles increase the rheology in an analogous manner to how spheres increase the viscosity of a fluid. Laboratory rheology results are adjusted to compensate for the air content.

4. SYSTEM DESCRIPTION

The Century pipeline has a single pump station with three Wirth TPM 83/4 x 14 piston diaphragm type pumps each driven by a 1130 kW motor. Design pressure is 18 MPa. There are pressure monitoring stations along the pipeline to provide Hydraulic Gradient Line information and leak detection monitoring. The pipeline is 323.9 mm OD, API 5L X70 with steel wall thickness varying from 8.4 mm to 4.8 mm, lined with 7.5 mm of HDPE. The normal operating flow rate is 305 m^3/h and the design was based on 6% higher flow rate (323 m^3/h). Figure 2 is a view of the pump station.

There are four 12.5 m high x 12 m diameter agitated storage tanks at the pump station, three for zinc concentrate and one for lead concentrate. Each tank has a live capacity of approximately 1150 m^3 representing about 4 hours pumping capacity.

A well-equipped testloop is provided which consists of two 100 m long straight legs with a 5D radius bend at the end. The test loop is fitted with a magnetic flow meter, a nuclear density gauge mounted at 45^0 across the horizontal pipe and a differential pressure transmitter. Sampling tubes are mounted at top, middle and bottom of the pipe. The test loop was used during commissioning to assess slurry pumping suitability and confirm design parameters. During normal operation the test loop is not used for zinc concentrate but is generally used to assess lead concentrate suitability for pumping.

Figure 2
View of Century Pump Station

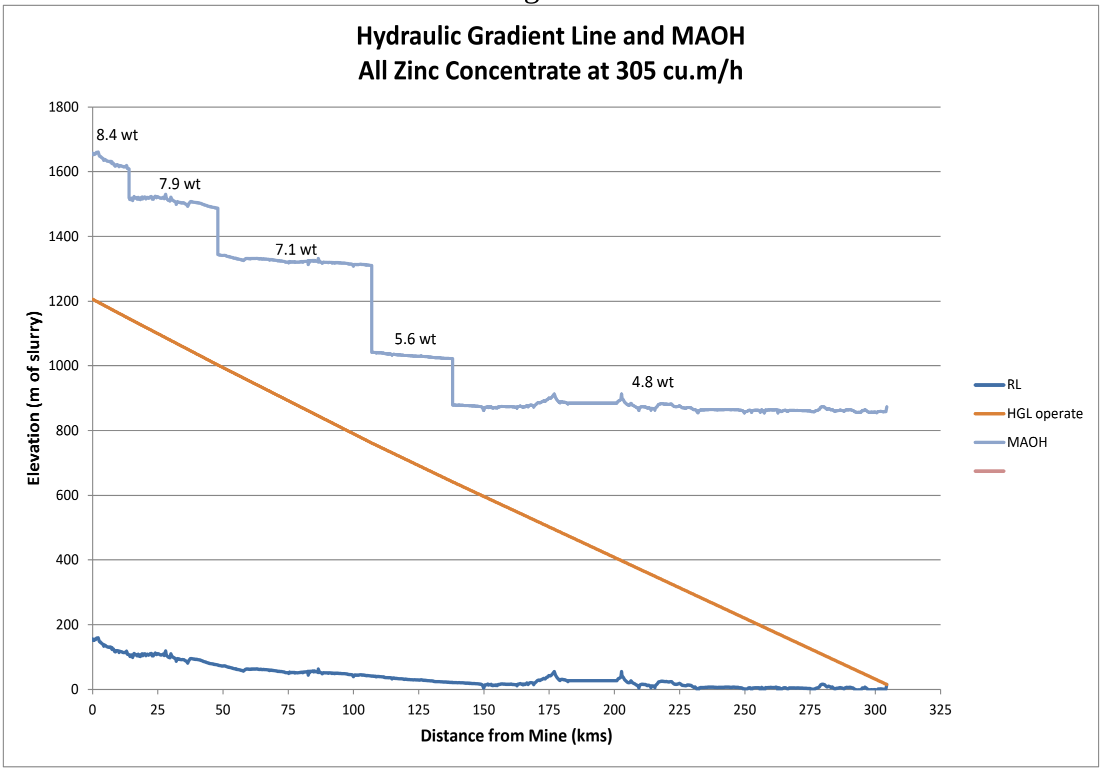
Main pipeline instrumentation includes a magnetic flow meter, nuclear density gauge and pressure transmitter. The deposition velocity in the pipeline is mainly controlled by laminar-turbulent transition, and because of the lower than normal operating velocity, it was considered prudent to provide an on-line viscometer to monitor the slurry yield stress. The Slurry Systems On-Line Viscometer controls water dilution into the suction of the centrifugal charge pump. The water dilution can also be controlled to a density set point. The On-Line Viscometer is particularly useful at Century because variable quantities of air entrained in the zinc concentrate (typically 15% air by volume) affect laboratory rheology determination. The On-Line Viscometer measures the Yield Stress at approximately 500 kPa charge pump pressure where most of the air is dissolved and any remaining free air is compressed to a very small volume concentration. It is therefore measuring the slurry at conditions very close to those in the high pressure pipeline where all air is dissolved.

The air remains fully dissolved in the slurry under the high pipeline pressure until about the last 15 kms when it starts to come out of solution. By the time the slurry reaches the terminal all of the air has come out of solution and does cause problems with the magnetic flow meter at the pipeline terminal.

5. ROUTE PROFILE AND HYDRAULIC GRADIENT

Figure 3 shows the Hydraulic Gradient Line (HGL) on the route profile at the normal operating flow rate of 305 m^3/h with the pipeline full of zinc concentrate. However normally the pipeline will be full of zinc and lead batches separated by water batches. Also shown is the Maximum Allowable Operating Head (MAOH) for the various pipe wall thicknesses.

Figure 3



6. BATCHING AND INTERFACIAL MIXING

Normally the pipeline comprises batches of zinc and lead concentrate separated by water batches. The water batches are used to minimise contamination between batches. Turbulent mixing at the front and end of a slurry batch together with the degree of trailout of coarser particles at the end of a batch, determine the minimum water batch lengths required. Mixing and trailout lengths are generally increased if the pipeline is shut down and restarted and this is a major reason why continuous pipeline operation is preferred. To minimise contamination between different batches it is important to be able to predict both the interfacial mixing at the head of a batch and especially the trailout of solids at the rear of a batch.

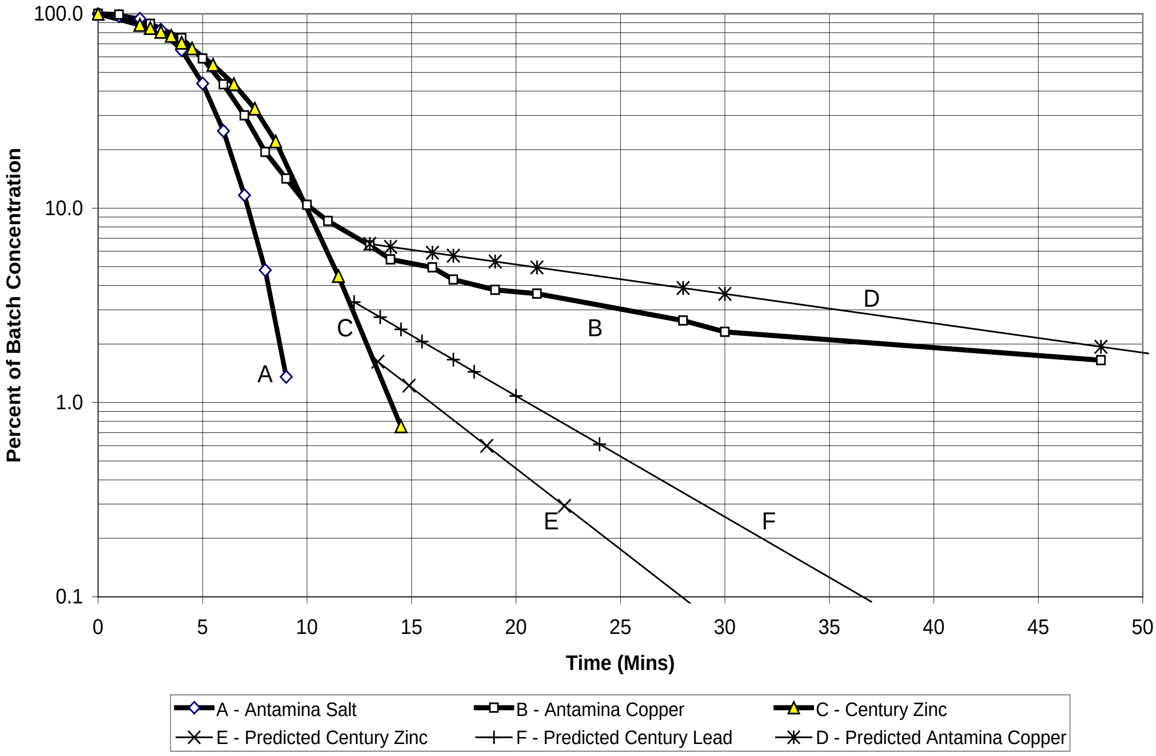
Even with homogeneous fluids, interfacial mixing occurs at the batch interface and knowledge of this mixing length is extensively used in batching products in oil pipelines. Smith and Schulze (1948) provide a method to predict the time required to reach 99% purity in terms of pipeline length and the Reynolds Number based on the average fluid properties of the two batches. With a slurry pipeline there is the additional effect of trailout of coarser particles from the tail of the slurry batch into the following water batch. Because of the lower density and viscosity of water compared with slurry, these solids travel in the lower portion of the pipe at a slower velocity than the average flow until they are re-suspended by the following slurry batch and become contaminants in that batch.

In 1992 the author carried out extensive tests on trailout and pipe wear in the 155 km Ok Tedi copper concentrate pipeline. Some of this work was reported by Venton and Boss (1996). It was found that about 20 minutes was required for the solids concentration to decrease to a few percent in the water batch although, in a particularly long water batch, trace quantities of coarser particles were still observed after 20 hours. During the design of the Century pipeline information from these Ok Tedi tests was used to develop a prediction method to predict trailout in the Century pipeline. An initial water batch length of 2 hours was specified.

Examination of trailout of a number of Ok Tedi batches indicated two distinct phases. The concentration decreases rapidly for about the first 10 to 15 minutes reducing to between 5% and 7% of the original concentration during this phase. The curve relating concentration to time during this first trailout phase follows a similar shape as that based on interfacial mixing between homogeneous fluids as predicted by the method of Smith and Schulz (1948).

Following the initial phase, the trailout behaviour changes significantly and becomes strongly dependant on the particle size. Thomas et al (2002) analysed in detail the trailout at the tail of slurry batches and compared results for the Century pipeline and the Antamina copper-zinc pipeline. During commissioning of the Antamina pipeline, a salt slug was injected at the pump station when the pipeline was pumping water. The results for this salt slug together with data for copper concentrate in the Antamina pipeline and zinc concentrate in the Century pipeline are shown in Figure 4 (Thomas et al (2002).

Figure 4
Trailout of Solids at Tail of a Slurry Batch



In Figure 4 the decrease in concentration at the end of a batch as it enters the terminal expressed as a percentage of the original batch concentration is shown. Data are shown for Antamina salt slug, Antamina copper concentrate and Century Zinc concentrate. Curve A is the result for the salt slug. The step decrease in salt injection at the pump station had spread out to about 10 minutes as the end of the salt slug entered the Antamina terminal. This decrease in salt concentration is well predicted by the method of Smith and Schulz (1948). The Century zinc curve C is of similar shape to the Antamina salt curve. The initial phase of the Antamina copper concentrate curve B also has a similar shape.

During the second phase the concentration decrease is approximated by a straight line on the log-linear plot indicating an exponential decrease with time as indicated by predicted curves D, E and F in Figure 4. A method of predicting these curves is detailed by Thomas et al (2002). They reported that at that time the Century pipeline utilised a one hour water batch behind each zinc concentrate batch and a two hour water batch behind each lead concentrate batch. Water batches of varying lengths were also inserted between zinc concentrate batches as required to match pipeline capacity with production with the aim of keeping the pipeline operating continuously.

7. CONCLUSIONS

The Century pipeline design presented two major challenges:

- Achieving a single pump station design for the 304 km pipeline length with limited elevation assistance.
- Designing for batching of the separate zinc and lead concentrates

Both challenges were successfully met and the pipeline has operated for 13 years.

8. REFERENCES

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