hands-on training on the simulator. Only employees with proven competence are selected for the tasks that their positions require.

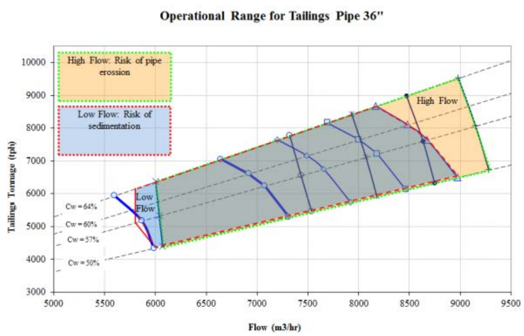


**Figure 8.** Operational Range for Tailings Pipe 36".

When operating a mineral pipeline it is important to:

1. Maintain the operation inside the volumetric flow vs. Mass flow window (ref. Figure 8).
2. Be able to start and stop relatively fast but assuring that the transients will generate the smoothest shock wave possible.

There are also certain constrains to the specific pipe case considering the following:

- Gravitational flow vs. forced flow; forced flow tends to make it easier to maintain the minimum flow.
- Tailings vs. Concentrate: Concentrates tend to avoid settling due to a smaller PSD and homogeneity; coarser material like tailings tend to settle faster.
- The possibility to operate a dissipation station with orifice plates and different CVs. This was mainly the case of the concentrate pipe at MLP.
- Replacing slurry with water or vice versa. The MLP tailings pipes have to be fully replaced to avoid plugging when stopped for more than 2 hours. MLP Concentrate pipe takes around 22 hours to flow from the peak to the harbor, and it typically contains several water batches inside the pipe.
- When the slurry pushes water, the higher weight tends to accelerate the flow and vice versa when water is behind the slurry. On the MLP concentrate pipeline, there is a second mountain chain that the pipe has to climb and hence there are more acceleration/deceleration phenomena.
- This is not a full list but a short summary of the issues which the operator will have to manage during a normal operation.
- The operators were exposed to different scenarios like the following:
  - Changes of slurry quality imply changes in rheology rheology, PSD, Cw, etc.
  - Changes on production requirements.
  - Forced shut downs, some coordinated some as fast as a black-out.
  - Finally, leaks were also simulated in diverse locations, some large and wide opening and some small and slowly growing.

## SIMULATOR RESULTS

The OTS was fully connected and the actual control logic allowed 100% of the IOs to interact at a scan rate of 1 second, and for some selected signals, even faster, which was enough to make the responses realistic, such that the operator could believe he/she was operating a real pipeline. Since the simulation is mainly based on first principles, it was possible to start an empty pipe and going through the whole start-up procedure until arriving at a steady state; also, when confronted with any abnormal situation, the responses were natural and the dynamic was almost identical when compared with actual operation.

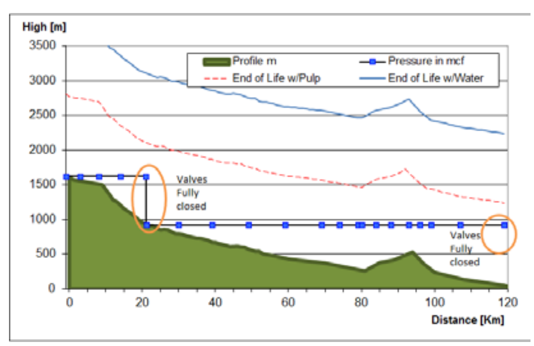


**Figure 9.** Concentrate Pipe profile stopped with Slurry.

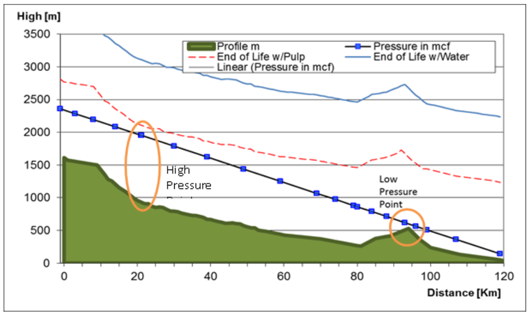


**Figure 10.** Concentrate Pipe profile full production with Slurry.

Figure 11 was also selected to show the visualization of the Slurry/Water Interface. We can observe a dynamic situation when starting slurry flow (already at Km 30) and at the same time the booster station running and the water dissipation ring in service. This example shows the complexity of the situation; on one side there is the need to dissipate high pressure at the booster station; on the other hand, the feed was maintained at the lowest possible pressure, almost gravitational, but which starts generating vacuum at Km 8 (High Point).

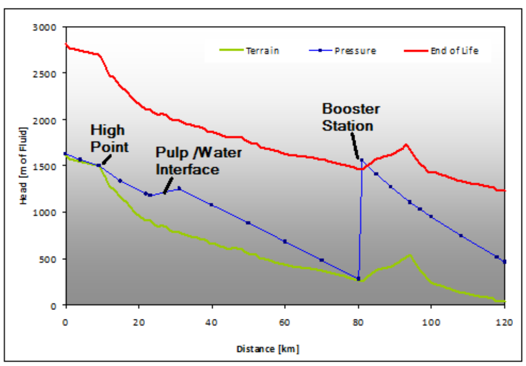


**Figure 11.** Concentrate replacing Water and booster pumps running.

In order to have a realistic operation at the OTS control room, historical data was added its trends were displayed on a wide screen and also a leak detection system was included. Data from an actual mill were obtained. The pressure transmitter's noise results varied (3 sigma) from 2.5 to 7.5 psi, depending on the probe location. The noise was included into the simulation and was forced to the leak detector to filter it like on the real control.

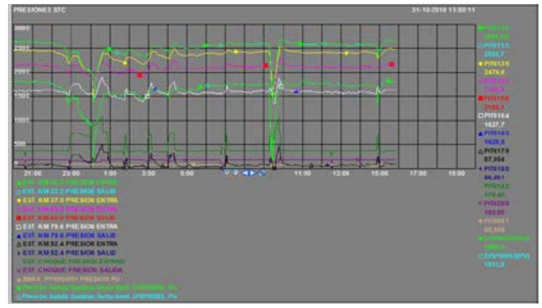

**Figure 12.** Concentrate Pipe Pressure trends, example of Historization.

On scenarios, the operator ability was tested on the following type of abnormal situations:

1. Failure of a pump
2. Solid sedimentation in a section
3. Rupture of disk brake
4. Loss of a pressure transmitter
5. Small leakage
6. Large leakage
7. Load Shedding

All consultants, supervisors and operators, agreed upon how realistic the responses become in all tested cases. Operators were asked to give a test before training and at the end of it. On an average, the start competencies were at the level of 35% and after 2 weeks of hands-on training, the test results showed it as above 80%.

One of the most relevant experiences was related to leakages. Once the operator was confronted with a large leak, the leak detector alarm was activated, and he/she was required to evaluate the situation, make an estimate of the leak location, and act accordingly. After training, all operators were able to react immediately, and in less than 10 minutes start the shut-down procedure. When the small leak scenarios were started (the scenario represented a pitting which starts from nil until it reached a full 2" hole in 50 minutes). This scenario would not trigger the leak detector alarm as the changes in dP are smaller than the filter on pressure transmitters. In the first test, it takes up to 8 hours for the operator to conclude there was a leak. After training, it took them one to two hours to arrive at the same result. We concluded that only a well-trained operator is prepared to find out a small leak situation and that there is no technology available to replace his experience.

## NOMENCLATURE

| | |
|---|---|
| a | wave speed in m/s |
| aii | correlation factors |
| A | pipe cross-section area in m2 |
| Cv | Solids volumetric percent |
| Cw | Solids mass percent |
| D | pipe diameter in m |
| dP | Pressure drop in mcl |
| e | Wall thickness in mm |
| E | Modulus of elasticity of pipe material |
| f | Friction factor adimensional |
| g | Gravity acceleration: 9.81 $m/s^2$ |
| H | Piezometric head in mcl |
| Kl | Bulk modulus of elasticity of liquid in Kg/m s2 |
| Ks | Bulk modulus of elasticity of solid in Kg/m s2 |
| L | Pipe Length in m |
| Q | Volumetric flow rate in m3/s |
| R | coefficient = f/2DA in 1/m3 |
| ρ | density in kg/m3 |
| t | Time in seconds |
| μ | viscosity in Pa s |
| v | Fluid speed in m/s |

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