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Fruta del Norte paste plant – case study

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Abstract

Lundin Gold's Fruta del Norte project, which is currently the largest gold deposit in Ecuador, achieved commercial production in February 2020. The project includes a mine plan that incorporates both bulk and selective mining methods. Most areas mined will use conventional transverse stoping and will be supported by the drift-and-fill mining method in zones of smaller dimension or with poor geotechnical quality.

Backfill is used as a ground support medium with the majority of voids to be filled using cemented paste fill. A paste plant, used to supply the required backfill tonnage, has been constructed directly over the orebody. The design of the paste plant is unique, accounting for challenges in topography, a sensitive local environment and challenging feed tailings.

The paste plant was successfully commissioned in quarter three 2020. In this case study, the design is described in how it caters for the unique requirements of the project. Further to this, construction and commissioning challenges faced and lessons learned are documented.

Keywords: *paste, plant design, commissioning, construction*

1 Introduction

In five short years, Lundin Gold successfully developed the Fruta del Norte (FDN) gold deposit into a world-class mining operation; the first of its kind in Ecuador. Overcoming several challenges along the way, first gold production was reached in December 2019 (Lundin Gold Inc 2019) and commercial production achieved in February 2020 (Lundin Gold Inc 2020). The project has delivered many firsts to Ecuador and the new paste backfill system (Figure 1) is just one example where best-practice principles and state-of-the-art technology were used to meet technical challenges head-on and provide the best long-term solution for the mine.

Paterson & Cooke (P&C) was involved from the beginning and performed the trade-off studies, testwork and engineering design to shepherd the backfill project through to a successful start-up in October 2020. Starting with the paste plant location, it was important to get the operation as close to the top of the orebody as possible. This meant constructing the plant remotely from the mill, but directly over the orebody, in order to achieve the best possible backfill recipes at the lowest possible operating cost.

Challenges that were overcome included developing the project in an environmentally sensitive remote rainforest setting; the Rio Manchinaza, which runs through the project site, a source tributary for the Amazon basin. Likewise, commissioning ran in two phases due to an interruption from the COVID-19 pandemic, but the paste plant was started up successfully in October 2020.

This paper documents the design, construction and commissioning challenges and achievements associated with the implementation of Lundin Gold's FDN paste plant system.

Figure 1 Paste plant at Lundin Gold's Fruta del Norte mine, Ecuador

2 Paste plant design

The FDN mine is located in the Cordillera del Cóndor region of Zamora-Chinchipe province, southeastern Ecuador. The FDN mine plan relies on backfill as a ground support medium with most voids being filled using cemented paste fill. The specified nominal capacity of the paste plant is 100 m³/h with a maximum flow rate of 115 m³/h.

2.1 Tailings material characteristics

The primary material properties, for both the whole and deslimed tailings, are summarised in Table 1.

Table 1 Tailings material characterisation summary

Parameter	Whole tailings (WT)	Deslimed tailings (DT)
Solids density (t/m³)	2.65	2.65
D_{90} particle size (µm)	94	108
D_{50} particle size (µm)	23	49
% passing 20 micron (%m)	25 to 48%m	25% ±5%
% passing 8 micron (%m)	Max 30%m	Max 15%m
Predominant minerals	Quartz: 77.1%m Muscovite: 22.9%m	–

The WT particle size distribution (PSD) is very fine with 48% passing 20 µm and 30% passing 8 µm. The WT contains a large portion of clay including muscovite which is a mica mineral. The presence of clays poses the following challenges:

- Dewatering: muscovite has a plate-like structure which packs against the filter cloth reducing the achievable loading rates.
- Rheology: all charged clay particles influence the rheology of the tailings and impacts at what mass concentration we can place the paste underground.
- Strength gain: muscovite has a plate-like structure resulting in a very weak particle matrix which causes 'bridging'. When a load is applied, the matrix collapses resulting in poor compressive strength. This in turn affects the paste fill strength.

Because of the challenges involved in using the WT in the production of paste, the paste plant was also designed to handle a DT product targeting 25% passing 20 microns.

2.2 Paste plant location

The process plant and the paste plant are approximately 2 km apart, separated by the Rio Manchinaza, with the paste plant being situated directly over the orebody (Figure 2). The paste plant site topography is relatively steep, with the natural ground slopes ranging from 30 to 70% (Figure 3) with significant cut-and-fill required to create the necessary platform area for the paste plant. In Figure 3, as reference, the filter building roof apex is ~23 m above ground level.

The reason for the selected site was twofold, namely:

- To allow paste to be transported to the underground stopes either by gravity or via paste pump.
- The tailings material properties highlighted in Section 2.1 show the significant presence of muscovite influences both rheology and strength gain. The paste mass concentration that could be placed underground was improved by placing the plant near the orebody. Even by optimising the paste plant over the orebody, the maximum paste density that could be achieved was approximately 64%m. This was increased to ~71%m when using DT (Figure 4).

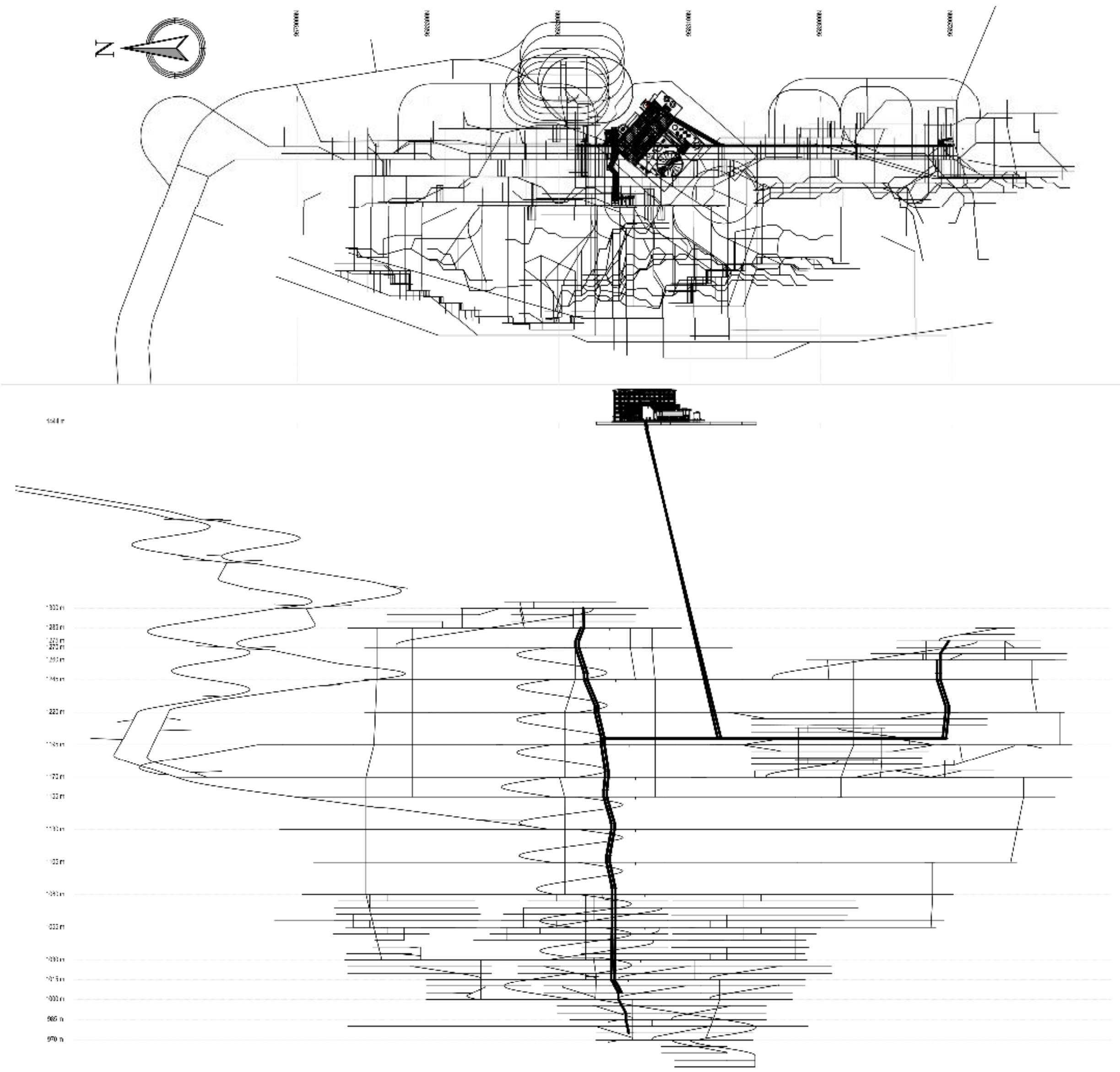

Figure 2 Long section showing location of paste plant relative to the orebody

Figure 3 Photo of paste plant showing extent of cut made to create the paste plant platform area

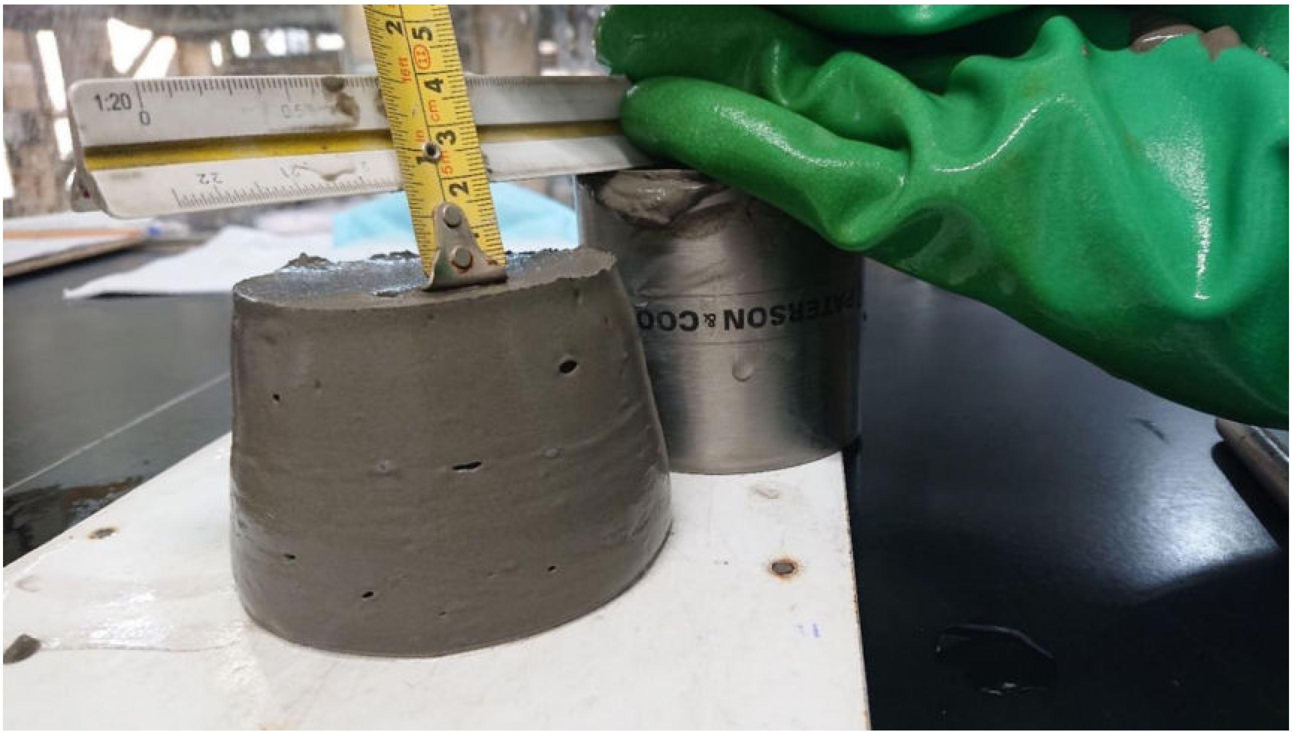

Figure 4 Paste sample leaving the mixer (deslimed tailings, 71%m)

2.3 Process description of paste plant facility

A simplified flow sheet of the paste plant is shown in Figure 5. Figure 6 shows a 3D model of the internal equipment and structure within the paste plant platform area.

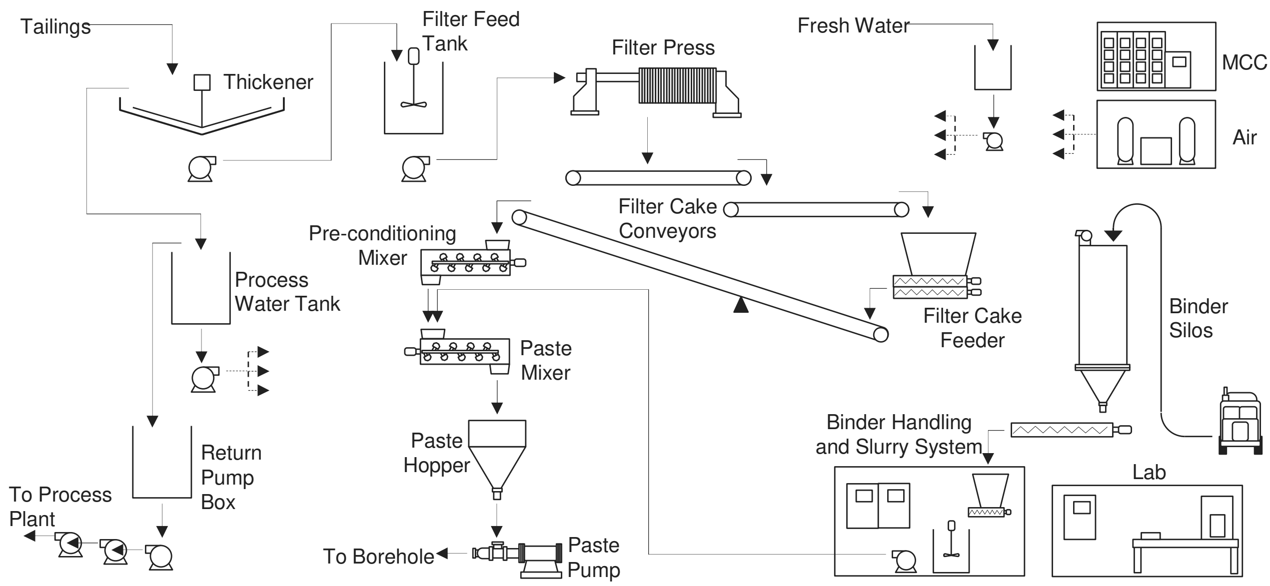

Figure 5 Simplified flow sheet of existing paste plant

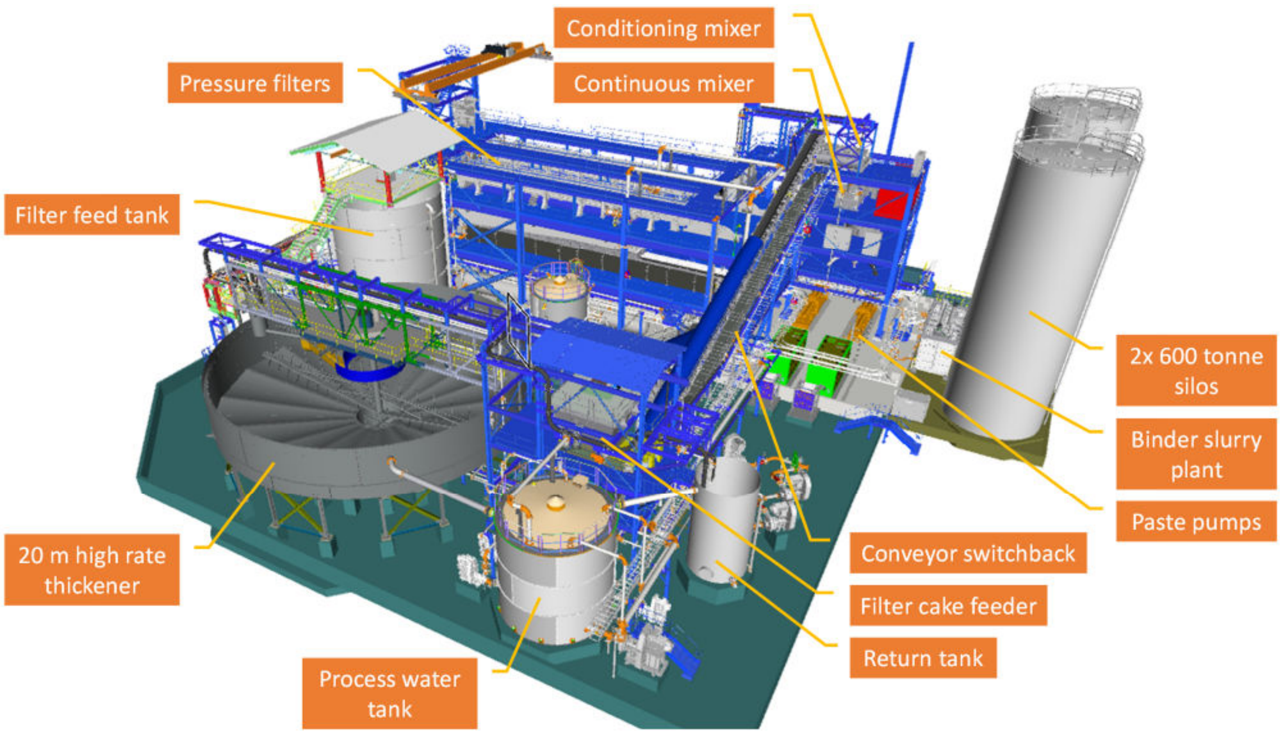

Figure 6 3D model of paste plant (filter building structure removed to show equipment inside building)

WT or DT from the process plant is received at the paste plant via a 2 km overland pipeline. The tailings first undergo a series of dewatering steps which includes thickening (20 m high rate thickener) and filtration (pressure filters complete with 90 chambers and 1,500 × 1,500 mm plates) to achieve a final target filter cake moisture of ~20%.

Filter cake from the pressure filters is discharged onto dedicated collector conveyors. A series of transport conveyors and a filter cake feeder in a switchback arrangement transport the filter cake to the top of the mixing tower.

The pressure filters may also be bypassed from the filter feed tank. In this instance, the filter feed bypass is used as trim slurry in the mixer operation to aid effective paste mixing. The amount of bypass is no greater than 40% of the filter feed.

As filter cake discharges off the last transport conveyor into the Simem MDC 501 L conditioning mixer, both the tailings bypass stream and process water are added to re-pulp the filter cake into a manageable mixture and ensure clay clumps are mixed in. The paste discharges through the bottom of the conditioning mixer and into the second mixer, a Simem MDC 501 L continuous mixer.

A binder system consisting of silos, screw conveyors and a Simem Vortimix VM1500 colloidal continuous production binder slurry plant (capacity of 30 m^3/h) is used to feed binder to the continuous mixer. The binder slurry is pumped from the binder slurry plant to the continuous mixer using binder slurry pumps. Each silo has a 600 tonne capacity. The two silos have a combined storage capacity of five days for a nominal paste backfill recipe using 8.6% cement.

The paste in the continuous mixer is discharged into the paste hopper. This hopper has a total volume of 8.3 m^3 which provides for a continuous flow of paste to the underground. Paste is discharged from the paste hopper to a Putzmeister HSP 25100 50 bar rated hydraulic piston type paste pump which pumps the paste to the first of two boreholes located adjacent to the paste plant building. As an alternative, for selected stopes, the paste flows by gravity from the paste hopper to the second borehole. During the design, an allowance was made for a second paste pump to be installed. After completion of commissioning, the second paste pump was installed.

3 Design considerations

3.1 Flexibility

During the initial studies, P&C conducted extensive test campaigns at P&C's Sudbury laboratory in Ontario, Canada. The FDN tailings are not a generic gold tailings typically used to produce paste. As such, the design approach could not be a typical design with an 'off-the-shelf' solution. The preparation and mixing process needed to produce a suitable homogeneous paste using the available tailings (WT and DT) with the tailings material characteristics described in Section 2.1.

Desliming the tailings allows a significant portion of the clay materials to be removed and was demonstrated to improve both the rheological and strength characteristics of the paste. However, to obtain a suitable DT product, approximately 50% of the tailings by mass is lost. At the time of the project conception, the remaining cyclone underflow product was only able to produce ~78 m^3/h of paste and was not able to keep up with the mine's paste volumetric requirements. As such, it was decided that the paste plant equipment must be capable of handling both the whole and deslimed tailings. This decision was further validated once commissioning occurred as the tailings received by the paste plant were finer than the original samples received and tested during the design phase.

The main risk to the process is the fact the tailings exhibit cohesive properties within the range of anticipated moisture contents. Because of the large portion of clay particles, even with DT, the cohesive properties of the tailings could result in clumps of tailings material not being broken down and thoroughly mixed with the other paste fill ingredients before entering the underground distribution. This would result in heterogeneous paste fill being transported to the underground which will lead to unpredictable and inadequate paste fill strength, and potential pipeline blockage issues.

The design included two steps in ensuring the tailings used would produce a high-quality homogeneous paste. The first step includes a filter cake feeder. The purpose of the filter cake feeder is threefold:

- Due to the cohesive nature of the tailings material, the bottom of the feeder was fitted with augers to load the tailings in a controlled manner onto the transport conveyor feeding the mixing tower. The auger motors are fitted with a variable speed drive and are controlled via a setpoint determined by the mixers and the level of paste in the paste hopper.
- The filter cake feeder augers break up the large sheets of filter cake produced during pressure filtration.
- The filter cake feed is fitted with a hopper and provides a surge capacity linking the batch pressure filter process with the continuous mixing process.

The second step in producing a high-quality homogeneous paste is the two-stage mixing process. The first stage mixer is a conditioning mixer. Thickener bypass tailings and process water are added along with the filter cake to re-pulp the filter cake prior to adding the binder. The additional mixer also significantly increases the residence time available to mix the paste recipe. The conditioned paste from the conditioning mixer discharges into the second stage mixer which produces the cemented paste at the correct consistency. The binder is added to the second mixer along with thickener bypass tailings and process water. Both mixers operate on a continuous basis. The operator can select the amount of bypass tailings and process water that reports to either mixer.

3.2 Binder system

Due to the remote location of the mine site and due to the abnormally high binder requirements for the paste recipes, two 600 tonne silos were included.

The mine site is located above the North Andean portion of the South American subduction zone. A seismic hazard evaluation indicated that the site may be subjected to future strong ground shaking generated by large earthquakes from numerous seismic sources in the region. For this reason and to limit the platform footprint required, a wet binder slurry system was included for the paste plant (Figure 7).

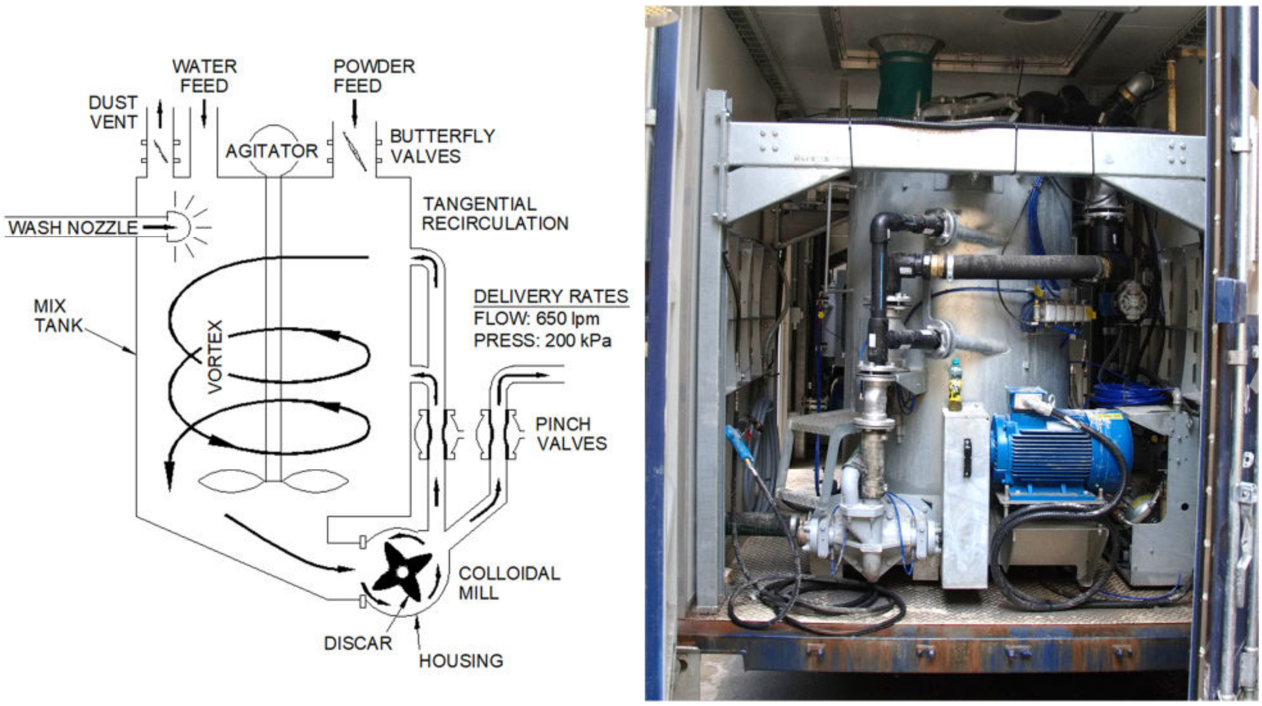

Figure 7 Binder slurry plant colloidal mixer

The colloidal binder system assists with efficient pre-mixing of cementitious components with water before blending with the tailings. Two colloidal mixers work in tandem supplying a continuous supply of homogeneous slurry binder to the continuous mixer.

Wet binder slurry plants are typically not used in backfill applications. The addition of water with cement prior to the mixing process means more process equipment encounters cement creating a potential maintenance headache. The colloidal mixers are designed to be self cleaning. The inside of the tank is scoured with fresh water after every batch, pressure washing the inside of the vortex chamber. The water used to clean is used in the next batch cycle.

This system was installed knowing there would be the traditional challenges that come with mixing cement powder and water. Pumps and pipelines were sized and routed to promote adequate flow velocities and self-drainage; however frequent and thorough maintenance cannot be avoided. It took some time for the operators and maintenance crew to work through the most efficient flushing and cleaning procedures. Some plugs were encountered initially and overcome with higher flush volumes, tweaks to the programming, as well as more frequent maintenance and inspection (Figure 8).

Figure 8 Initial challenges with the binder slurry plant; examples of cement blockages

3.3 Layout

Keeping the plant layout compact to reduce the overall footprint was a key priority (Figure 9). The paste plant consists of a single multilevel building, a thickening area and a service area. To enable the pressure filter equipment and the mixing tower equipment to be housed in a single compact paste building, the filter cake conveyor (#1) collecting filter cake from the collector conveyor and feeding the filter cake feeder and the filter cake conveyor (#2) receiving filter cake from the feeder were placed in a switchback configuration (Figure 10).

The binder slurry system has a small footprint, and because the slurry is pumped to the end destination, proximity of the cement silos to the main paste fill system was not a factor. As a result, the layout of the paste fill system was flexible and allowed easy integration into the paste plant building.

Figure 9 Compact plant layout

Figure 10 Tailings feeder with switchback conveyor arrangement

3.4 Filtration system

Vacuum filtration was initially considered with extensive testing carried out. Significantly low filtration rates were measured and attributed to the large quantity of muscovite in the tailings (Section 2.1). Because of the very poor performance, vacuum filtration was excluded as a possible means of dewatering.

Pressure filtration testing was carried out at four separate target feed densities, spanning 51 to 68%m solids, for both WT and DT. The range of filter feed densities tested reflect the underflow densities achieved during dynamic thickening testwork. The testwork showed that a target cake moisture content of less than 20% was required to eliminate long filter plate washing requirements and to reliably transport filter cake using the various conveyors.

The testwork also showed that the target moisture of 20% and less by mass can be achieved either by recessed chamber pressure filtration configuration using a form step with air blow step or by membrane filter press configuration using a partial form step followed by a press step and/or air blow step.

Two FLSmidth AFP-IV™ Filter Press pressure filters complete with 90 chambers and 1,500 × 1,500 mm plates were installed in a duty/standby configuration (Figure 11).

Figure 11 Pressure filters

4 Construction and commissioning challenges and achievements

It can be a challenge to write about commissioning in a positive way. Troubleshooting and dealing with upsets is the nature of the work until all the bugs are worked out. For the record, the FDN paste system was commissioned successfully in September 2020 with the first paste stope filled by October (Figure 12). This achievement was reached by the team despite several interruptions from the COVID-19 pandemic and a host of new safety precautions that were needed to allow work to continue onsite.

Figure 12 First cemented paste pour at FDN

4.1 Operator training

Training began early in the project with in-person classroom training that educated the operators in paste material properties, rheology, strength gain and the hydraulic relationship between surface and underground. The backfill engineer(s) also received hands on work with the hydraulic model and paste quality testing. The classroom training eventually transitioned to the paste plant where the operators were assigned specific circuits to be responsible for (Figure 13). Thickening and filtration, mixing and binder, services and paste pumping were areas of focus in the early days of commissioning for the operators.

Figure 13 Operator training

4.2 Pre-commissioning

The first step in start-up was pre-commissioning, which was accomplished in two parts involving inspection and validation against the design drawings, verification of motor rotation, pump efficiency adjustments and general construction drawing adherence. This step helps to control costs by getting out in front of the commissioning crews and rectifying any misunderstandings that may have happened during construction. Technical reports were provided to help steer the construction crews and get the plant ready for start-up. Figure 14 provides an example of some modifications that were made early in the commissioning to improve performance.

Figure 14 Flush mounting instrumentation to eliminate cemented blockages

The laboratory within the paste plant was commissioned successfully, and the plant operators and civil technicians were trained. In the end, the site decided to task the civil technicians with the quality control testing since they had very similar experience testing all concrete onsite and were becoming available as construction was winding down.

One of the first challenges encountered at start-up was the inherent corrosion and damage to mechanical equipment that sat idle from the early days of the pandemic. Start-up was interrupted by about five months and the commissioning team spent considerable time and energy re-confirming the status of all equipment, bearings, screens and pumps before each circuit could be run reliably.

4.3 Pandemic

The original start-up was halted in March 2020 when the site, and everyone else, dealt with the COVID-19 pandemic. Limited operations continued at the mine, while the construction and commissioning teams left until further notice. As conditions became better understood, all teams re-grouped and the contractors, specialists and vendors returned to site and the dry, then the wet start-up were methodically executed. The first month of the re-started commissioning was spent discovering seized bearings or blockages that would interrupt progress and delay the team. Time was also lost when spare parts were not available for immediate replacement due to the pandemic. Eventually each individual circuit was returned to a state of readiness and slowly the availability of the entire system began to improve. The commissioning plan ran in parallel with the operator training program. It was important to prepare the operators and technicians for the paste production and quality control programs that followed.

4.4 Production

One of the lessons learned in hindsight is the impact that performance of the filters will have on the commissioning schedule. If the filters can be started and optimised quickly, the downstream process will commission smoothly. If the performance is not within spec early, there will be struggles with chutes, conveyors, bins and general performance of all equipment downstream (Figure 15). Once the filters became dialled-in with the help of an FLS site engineer, the remaining circuits fell into place fairly quickly. The paste plant needs that steady and reliable performance from its filters to create a baseline for tailings moisture content and high production rates of quality paste to underground.

(a) (b)

Figure 15 Early filter cake production. (a) Too dry; (b) Examples of tailings clumps on hopper screen

The main aspect affecting the plant production rate was the filter cycle time. Once commissioned, the filters performed reliably. However, they do not achieve the specified cycle time. At the time of purchase, the quoted cycle time was a little under minutes total. At the time of commissioning, this value was between 11 and 13 minutes. Reconciliation of the cycle time showed the total time for filling, pressing and cake drying was approximately 265 seconds, and aligned against the design value of 289 seconds. The cycle time delays were caused by the stated technical time not being achieved and not by the tailings material. The increased cycle time put a significant strain on the paste plant being able to achieve the nameplate production rate. The main tool used to offset the lower filter production was increasing the bypass tailing directly to the mixers thereby lowering the strain on the filters.

4.5 Investing in the underground distribution – diversion valves

The underground distribution system was designed to include several safety elements. These included pressure relief devices and diversion valves for re-directing the paste flow (Figure 16). One of the most important design features came in handy on the second day of pouring when a power failure led to an interruption in paste filling and a near plug of the line.

The underground team had rehearsed for such an event and had cycled the diversion valve to test it on the morning of the pour. Once paste was observed on the CCTVs to stop flowing out of the pipe at the stope, the emergency flush procedure was followed, and the valve was activated locally which released paste as intended into the isolated underground sump. The emergency flush procedure was enacted from surface, and the distribution system flushed multiple times until clean. This could have ended entirely differently if the cost of the valve had not been justified during the design and construction phase. It had certainly paid for itself in its short life.

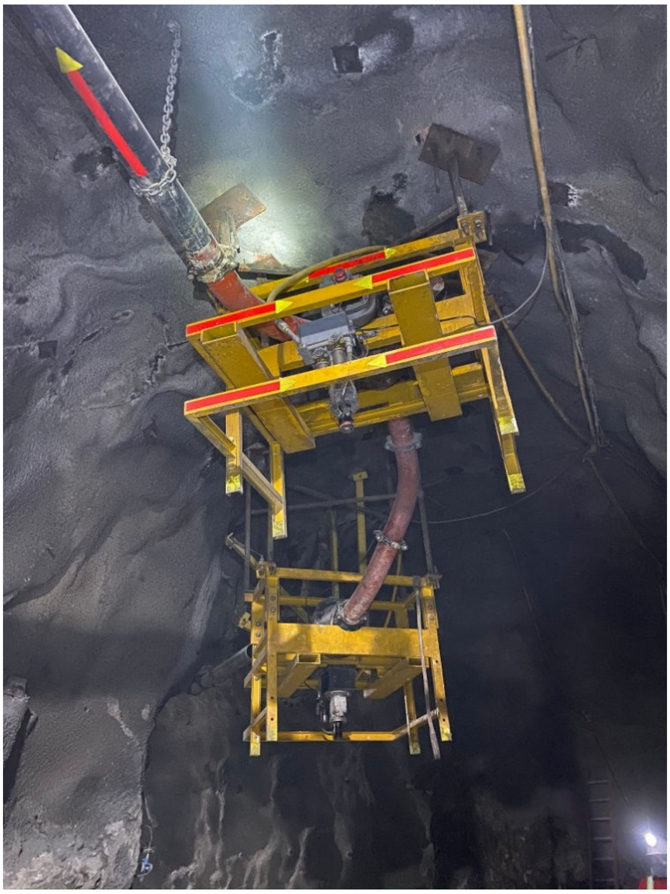

Figure 16 Paste diversion valves at FDN

4.6 Friction loss monitoring

One of the most useful streams of data that is incorporated into the design is the constant measurement of paste friction losses in the underground distribution system. Several pressure transmitters were installed throughout the system, both on-surface and underground. The pressure change was divided by the distance between instruments and corrected for elevation, to produce a 'live' delta P over delta L. This friction loss gave the operators a real-time indication of the paste quality, and more importantly it ran a live trend that showed the impact of immediate changes to the recipe, minus the known lag time between the mixer and the instrument, on the underground pressures.

4.7 Live feedback to operators

The evolution of communication infrastructure underground has lowered the cost and improved the ease of installation for camera surveillance and pressure monitoring of every pour. Great success was achieved using multiple pan-tilt-zoom (PTZ) cameras both at the pour point and the barricade. Operators can see firsthand the final quality and flow behaviour of the paste at the pour point, and safely monitor the integrity of a barricade from the control room on surface (Figure 17). Sample collection near the pour point can also be monitored and logged from the control room.

Figure 17 Live underground monitoring for paste operators

5 Conclusion

Lundin Gold recognised early in the project that the backfill operation was going to be critical to the mining cycle, and there would be challenges ahead in terms of tailings material properties and backfill quality. The entire scope of work was assigned to specialist engineers who managed the testing program, the design process and the training and commissioning assignments.

The importance of a comprehensive test program early (Figure 18) in the feasibility stage permitted the identification of risks with filtration rates and strength gain. This data supported the engineering and allowed for a suitably conservative design that incorporated:

- Both whole tailings and deslimed tailings production.
- Pressure filtration to manage known difficult material properties.
- Tailings slurry bypass to supplement filtration with additional tonnes of tailings when required.
- Dual stage mixing to ensure lump-free paste production from the pressure filter cake.
- Both gravity and pumped underground delivery of paste underground.
- On-premises laboratory testing facilities to support ongoing quality control and cost optimisation initiatives.

The project team received significant support from Lundin Gold when selecting equipment and processes. The importance of getting out in front of the mining cycle while also managing tailings placement underground in an optimal way was stressed to the project team from the start. Great care was taken to ensure a robust and operator-friendly design, that included redundancy for production and flexibility for recipes.

Figure 18 Sending paste to a test stope with berm during commissioning

Many setbacks were encountered during the pandemic, which were eventually overcome with proper planning and site safety precautions, which allowed the commissioning to proceed. Investment in modern control features and instrumentation proved valuable early in the commissioning. CCTV, high pressure wash systems and underground diversion valves all demonstrated their worth in the early days of commissioning. The switchback design feature handling filter cake outside the original building is a characteristic that has its place in this type of operating environment and is sure to be used again.

Through hard work and the desire to keep standards high and build an industry-leading facility, the FDN paste system took many turns and graduated into a robust and reliable backfill operation that is setting the mine up for expansion today.

The achievement of pouring paste backfill underground to satisfy the mining, while still deep in the commissioning stage (and learning stage for the operators) is an important milestone and the team should be commended.

Acknowledgement

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