CONSTANCIA PROJECT PROCESS PLANT DESIGN AND START UP

*Steven Klohn[1] and David Stephenson[1], and Hugo Granados[2]

[1]Ausenco Services Canada
855 Homer Street
Vancouver, Canada V6B 2W2
*(*Corresponding author: steven.klohn@ausenco.com)*

[2]HudBay Minerals
Edificio Empresarial Cronos
Av. El Derby 055, Torre 3, Piso 4
Santiago de Surco
Lima, Peru

ABSTRACT

HudBay's Constancia project is a copper molybdenum concentrator located in southern Peru. In 2010 Ausenco was contracted to perform a feasibility study optimization review which resulted in an improved design with significantly increased throughput capacity at a minimal increase in capital cost. Construction began in 2012 with commercial operation commencing in May 2015. This paper outlines the process plant design as well as describing the plant's major equipment selections, start-up and early operations experiences.

KEYWORDS

Constancia, HudBay, Copper, Concentrator, Peru, Grinding, Throughput, Optimization

INTRODUCTION

HudBay Mineral’s Constancia project is located at 4200 meters above sea level (masl) in southern Peru, approximately 630 km south-east of Lima, Peru. The property can be accessed by road from Cusco, Peru, (approximately 110 km to the north), or from Arequipa, Peru (approximately 215 km to the south). Matarani, accessed via Arequipa, is the closest port.

Constancia is located within the Yauri-Andahuaylas metallogenic belt. The region contains several large copper-gold-molybdenum porphyry deposits such as Antapaccay (by Glencore) and Los Chancas (by Grupo Mexico), and copper skarn deposits such as Tintaya (by Glencore) and Las Bambas (by MMG). Constancia’s ore reserves contain copper and molybdenum with trace amounts of gold and silver.

Ore is mined by an open-pit operation. The process plant recovers copper and molybdenum concentrates, storing tailings in a conventional tailings management facility. Infrastructure at the site includes a grid power supply (via a 70 km overhead transmission line from Tintaya), water supply, workshops and an accommodation camp. Mine life is 22 years.

Site construction works began in 2012 with first copper concentrate produced in late 2014. The project was executed for approximately 1.75B$USD.

Ausenco’s design approach focussed on developing a capital efficient copper molybdenum concentrator. This paper outlines key features incorporated in the concentrator design, plant layout and equipment selection, as well as start-up experiences and early operational results.

Project timeline

GRDMinproc completed a Definitive Feasibility Study (DFS) on the Constancia project in 3Q2009 for Norsemont Mining. Ausenco was contracted by Norsemont to conduct a Feasibility Study optimisation review in 2010, which was completed with input from SRK and Knight Piesold, resulting in filing of a NI 43-101 Technical Report in February 2011. HudBay Minerals acquired Norsemont Mining in 2011 and subsequently contracted Ausenco to commence engineering work for permitting and front-end engineering and design (FEED). The principal beneficiation concession (construction permit) was granted in June 2012 with HudBay’s board approving construction shortly thereafter. Site earthworks commenced in October 2012 and first copper concentrate production was achieved in December 2014 with full commercial production following in April 2015.

GEOLOGY AND MINERALIZATION

Constancia’s reserves consist of two large-scale porphyry copper deposits: the Constancia and Pampacancha deposits. The process plant is located approximately 1 km west of the Constancia deposit, which is currently in production. The Pampacancha deposit, located 5 km to the south-east of the Constancia deposit, is expected to enter into production in 2016. Pampacancha exhibits higher grades of copper and gold than the Constancia deposit but also contains more hypogene ore, resulting in a harder ore body.

The majority of Constancia’s mineralization is associated with potassic alteration and quartz veining, occurring as chalcopyrite-bornite-pyrite mineralization in A and B Type veinlets. High-grade hypogene copper mineralization is found in A Type stockwork and exhibits a relatively low pyrite/chalcopyrite ratio, ranging from 1:1 to 2:1. The occurrence of molybdenite generally increases with depth and is associated with B Type veinlets.

Oxide mineralization occurs locally and is typically shallow and volumetrically small. Supergene enrichment occurs immediately below the oxide cap. The highest grade copper mineralisation is generally found in the supergene and skarn zones. Transition (mixed) mineralization is present over a limited interval where the supergene and hypogene mineralizations co-exist.

Major ore types include skarn, hypogene and supergene mineralisation. Skarn mineralisation is sub-divided into skarn 1 and 2, where the latter's mineralisation is high in zinc and close to supergene mineralisation. High zinc was assigned as a further ore category (zinc greater than 0.16% and Zn:Cu ratio greater than 0.66) for use in the mining block model. High zinc ore is essentially a subset of the skarn 1 and skarn 2 mineralisation. Table 1 shows the abundance of each of the major ore types within the deposit.

Table 1 – Abundance of major ore types

Ore type	Relative Abundance (%)
Hypogene	63
Supergene	20
Skarn 1	5
Skarn 2 / High Zinc	12
Total	100

High zinc ores were recognised during the DFS as being potentially problematic during treatment, with zinc (as sphalerite) reporting to the copper concentrate as a penalty element. To optimise metallurgical performance and copper concentrate quality, the simultaneous treatment of high zinc and supergene ores would need to be minimised with blends of supergene and hypogene, or skarn and hypogene ore, being preferred. A combination of mining strategies and ore control practices were nominated as essential for managing zinc levels in plant feed.

The first five years of plant operation are characterised by the processing of mixed and supergene ores that are relatively soft with low competency. After year five, the plant will need to run greater percentages of hypogene ore which is significantly more competent.

TESTWORK

The metallurgical testwork programs for the DFS were managed by Lima-based Transmin Metallurgical Consultants. Testwork programs were conducted by C.H. Plenge Laboratory in Lima and SGS Minerals Chile. Testwork included comminution testing (Bond Ball Mill tests, Bond Abrasion tests and SMC tests), and flotation testing (variability testing and locked cycle testing). A total of 50 samples (taken from the various ore types) were used for the lab-scale testwork which was comprised of 50 comminution tests, 40 flotation variability tests, and 45 head grade tests.

Pilot scale flotation testing was also completed during the DFS. Approximately 25 t of feed material was fed to the pilot plant to confirm laboratory metallurgical design criteria and produce material for: rougher concentrate regrinding testing, copper concentrate rheology, thickening and filtration testing, and final tailings rheology and thickening testing.

No further confirmatory testwork was undertaken during the feasibility study optimisation review or FEED phase. Table 2 shows ore properties for the different mineralization types that were used to design Constancia's grinding circuit.

Table 2 – Ore competency and hardness values used in comminution circuit design

Ore type	A*b value		BMW$_i$ (kWh/t)	SG	Dw$_i$ (kWh/t)
	75th percentile	50th percentile	75th percentile	75th percentile	75th percentile
Hypogene	38	42.5	15.9	2.54	7.3
Supergene	77	90	12.8	2.47	3.7
Skarn	76	120	11.5	3.73	3.8

DESIGN BASIS

The Constancia design basis was derived through testwork analysis and benchmarking. Major elements of the design basis are listed in Table 3.

Table 3 – Constancia design basis

Description	Units	Data
Plant throughput, both grinding lines operating	Mt/a	25.3
Plant throughput, both grinding lines operating	t/d	76,000
Plant throughput, per grinding line	t/h	1584
Average copper feed grade	%Cu	0.39
Average molybdenum feed grade	g/t	105
Average annual copper production (contained metal in concentrate)	t Cu/a	82,000
Crusher availability	%	70.0
Grinding and flotation availability	%	91.3
Concentrate filter availability	%	82.2
Copper recovery	%	90
Copper concentrate grade	%	26
Molybdenum recovery	%	55
Molybdenum concentrate grade	%	45

DESIGN OPTIMIZATION

A key objective in Constancia's design was to maximize capital efficiency (minimizing capital and operating costs) without compromising safety, operability and maintainability. During the DFS optimization Ausenco identified several opportunities to add value to the Constancia project through improvements in plant throughput and layout.

Plant Throughput and Grinding Circuit Design

Plant throughput is constrained primarily by ore competency. The DFS called for the use of a single gearless SAG mill with 21,500 kW of installed power (at the time of the study this was the highest power available for a gearless drive at Constancia's altitude) and two ball mills with 13,000 kW of installed power each. This would have allowed for a grinding P_{80} of 106 microns at a throughput of 76,000 t/d in the first five years followed by a reduction to 50,000 t/d due to increasing percentages of competent hypogene ore in the plant feed.

Ausenco performed a number of trade-off studies to determine which arrangement would return the optimum project net present value (NPV). These studies considered the use of a single gearless SAG mill, with installed power between 20,000 and 26,000 kW, against two lines of pinion-driven SAG mills, with installed powers between 13,000 and 16,000 kW each. The optimum NPV was achieved with the latter option resulting in the selection of a grinding circuit consisting of two lines of pinion-driven SAG mills, with installed powers of 16,000 kW each, followed by pinion-driven ball mills, with installed powers of 16,000 kW each. This yielded a total of 64,000 kW of installed grinding power, a significant increase over the DFS grinding power, and allowed the plant to maintain a throughput of 76,000 t/d, with a P_{80} of 106 microns, throughout the mine's life.

Due to the increase in SAG mill power pebble crusher installation could be deferred until after year five. The size of the primary crusher was also increased to ensure it would not act as a bottleneck once greater amounts of hypogene ore were being processed.

Although the grinding circuit was designed at 76,000 t/d, Ausenco determined that the circuit would be capable of treating up to 86,000 t/d in the first five years of operation due to softer, less competent ore in the plant feed during this time. Minor modifications were made to downstream circuits to match this capacity, allowing for maximization of overall plant throughput. Based on the plant feed composition, current forecast plant throughput is 85,000 t/d at an availability of 93-94%, resulting in a plant capacity of approximately 29 Mt/yr.

Layout

The DFS layout was modified with the following key objectives in mind: minimize plant footprint, take full advantage of the site's natural ground contours, minimize the use of fully enclosed buildings, minimize the height of all structures, optimize the location of sub-stations and motor control centres (MCCs), and allow for the use of tower cranes (mobile and permanent) to support construction and operations. Figure 1 shows the Constancia plant in February 2015, after construction had been completed.

Constancia's grinding circuit layout was significantly altered from the DFS. In the optimized design, the grinding reline floor is common to both grinding lines and is accessed from ground level via a drive-on ramp. SAG mill feed conveyors are oriented perpendicular to the axis of the SAG mills in order to minimize foot-print; although uncommon in North and South American installations Ausenco has successfully implemented this design on previous projects and it is relatively common in Australian designs. Grinding area MCCs are located underneath the grinding floor along with mill lubrication units, which are adjacent to their respective mills. A 3D representation of the grinding floor arrangement can be found in Figure 2.

The primary crusher was relocated to a nearby hill that provided the necessary height for the circuit with minimal earthworks. This allowed the primary crusher and stockpile to align with the grinding circuit along a relatively flat spur, which further reduced overall project earthworks quantities.

The copper flotation circuit was relocated and the footprint was made more compact. Rougher cell tailings were allowed to flow down-grade to the tailings thickener, which was placed at a local low point. Reagent make-up equipment was moved closer to dosing locations to further reduce overall footprint.

Figure 1 – Constancia plant overview

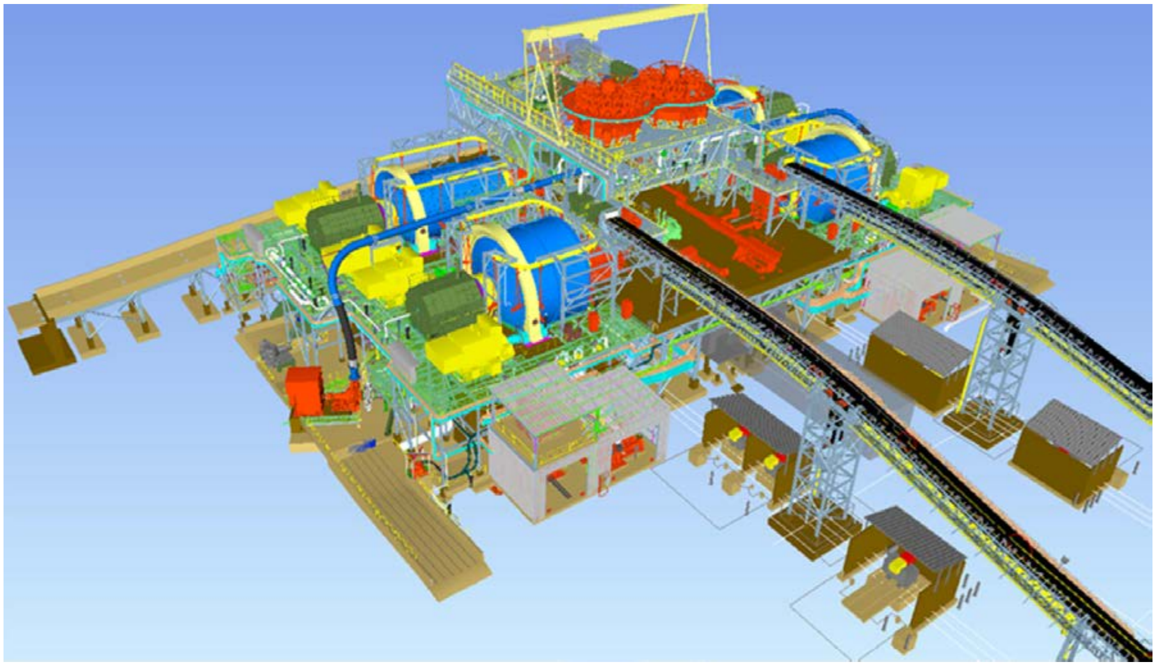

Figure 2 – Constancia grinding circuit layout

The contact water collection pond was placed at the low point in the plant, allowing for site-wide drainage to a single settling pond. Modifications were also made to the location of the main sub-station and warehouses which reduced bulk quantities.

FLOWSHEET

Constancia's overall flowsheet can be found in Figure 3.

Run-of-mine (ROM) ore is processed in a single primary crusher before being stockpiled. Ore is reclaimed from the stockpile and sent to parallel lines of SAG and ball mill (SAB) grinding. Primary grinding cyclone overflow reports to parallel lines of rougher flotation. Both roughing lines send concentrate to a single regrind mill followed by a single line of cleaner flotation. Final tailings consist of rougher tailings and first cleaner scavenger tailings and are thickened and pumped to a conventional tailings management facility. The product of this process is a bulk copper molybdenum concentrate, which is thickened to remove residual reagents before undergoing molybdenum flotation.

Molybdenum flotation conditioning occurs in two stages; the first stage lowers slurry pH, which optimizes copper sulphide depression, while the second stage mixes reagents (NaHS and molybdenum collector) into the slurry. Slurry pH is adjusted with liquid CO_2 due to preferred safety characteristics. Molybdenum flotation incorporates a single train of rougher flotation cells followed by five stages of cleaner flotation and one stage of cleaner scavenger flotation. Final molybdenum concentrate is dewatered and dried prior to bagging. Copper concentrate, consisting of molybdenum rougher tailings and molybdenum first cleaner scavenger tailings, is thickened and filtered prior to stockpiling and loadout.

Services, such as water, compressed air, and reagent distribution were also part of the project scope. Reclaimed water from the copper plant is kept separate from the molybdenum plant's water supply to ensure that residual copper flotation reagents do not contaminate molybdenum flotation.

MAJOR EQUIPMENT SELECTION

Primary Crushing, Stockpile and Reclaim

Constancia's primary crushing circuit was designed for a maximum Crushing Work Index (CW_i) of 20 kWh/t. One 1,000 kW FL Smidth 1600 x 3000 (60 x 113 inch) TSU gyratory crusher is fed via a dump pocket capable of accommodating two 250 t haul trucks. The crusher is a top service unit and the facility includes a permanent overhead crane for maintenance.

An open crushed ore stockpile with a design live capacity of 16 hours provides feed to the grinding circuit. Feed for Constancia's two grinding lines is reclaimed by four 1,600 t/h apron feeders that are housed in free-draining tunnels. Each tunnel acts as the emergency escape route for the other tunnel and a common ventilation system is used for both tunnels.

Grinding

Both grinding lines at Constancia consist of a 10.97 m by 7.31 m, 16,000 kW dual pinion-driven SAG mill followed by a 7.92 m x 12.36 m, 16,000 kW dual pinion-driven ball mill in an SAB circuit. This design provides 64,000 kW of total installed grinding power (considering both grinding lines). SAG mill specific energy is 8.8 kWh/t and ball mill specific energy is 9.7 kWh/t. In order to minimize the height requirement between mills and the pump boxes, trommels were selected over screen decks for mill discharge.

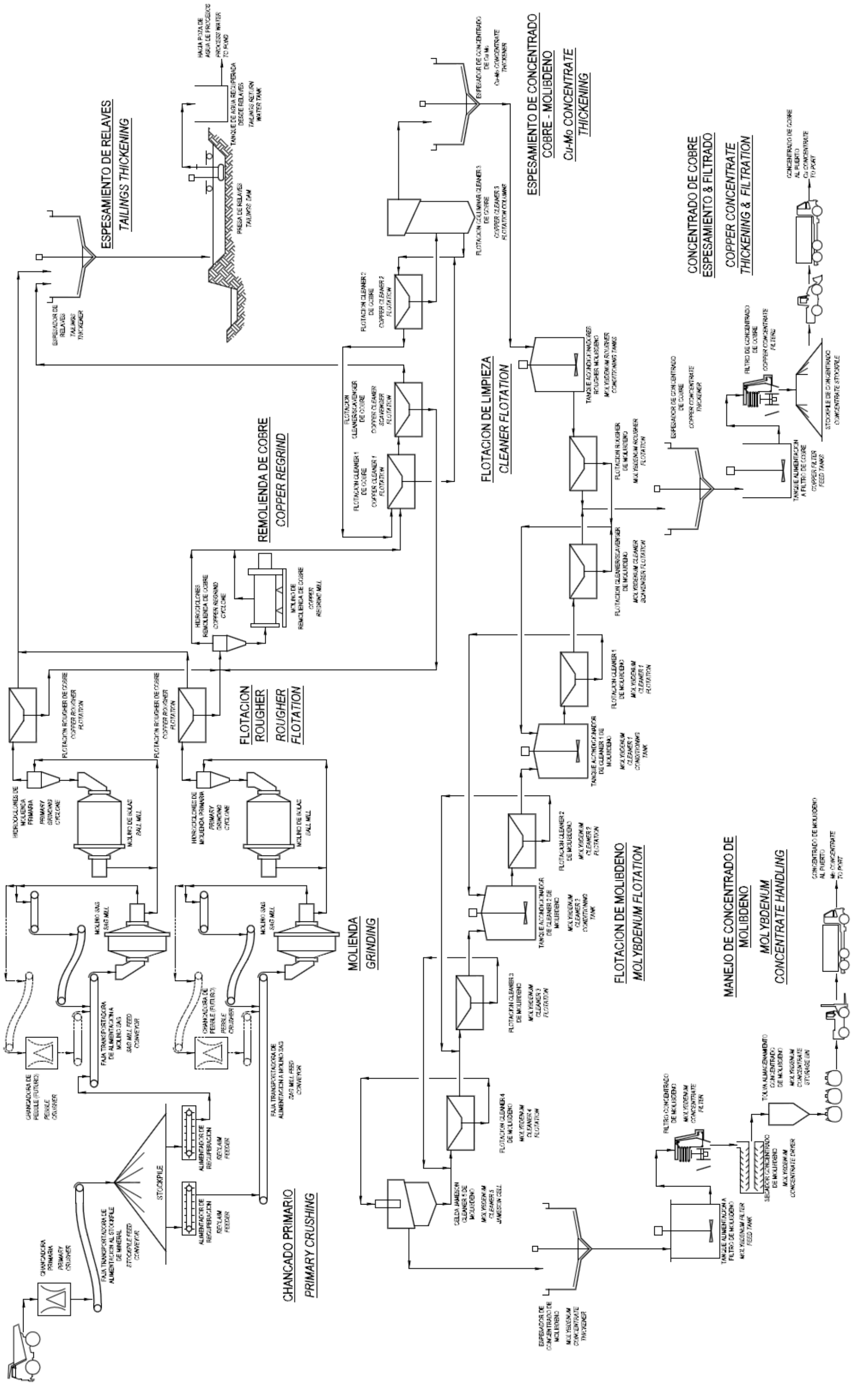

Figure 3 – Constancia overall flowsheet

The selection of pinion drive over gearless drive systems contributed to reducing project risk: gearless drives typically required more complex maintenance systems and had experienced reliability issues on installations prior to 2011. Additionally, spreading the grinding duty across two lines created less risk on start-up than a single line.

Primary grinding cyclone overflow P_{80} is 106 microns at 36% solids. Classification is provided by Krebs gMax26 hydrocyclones fed by 2,000 kW Warman 650 cyclone pumps.

Cyclone service and grinding media additions are completed using a gantry crane. Relining is accomplished using separate SAG and ball mill liner handlers and a mill feed chute transporter; all mills have dedicated reline hoists and bolt hammers.

Copper Flotation and Copper Concentrate Handling

Copper roughing is performed in two parallel lines each consisting of seven 300 m^3 Outotec forced-air mechanical cells with dual level control dart valves and 250 kW direct drive mechanisms. Rougher flotation recovers 94% of the feed copper into 9% of the mass with a residence time of 25 minutes.

Rougher concentrate from both lines is reground to a P_{80} of 25 microns using a single 3,000 kW M10,000 IsaMill in open circuit. Regrind specific energy is 8 kWh/t. The regrind mill is fed by an agitated surge tank with a residence time of 20 minutes; substantial surge capacity allows the regrind and cleaner circuits to maintain stability during fluctuations in plant head grade and rougher flotation mass pull. Layout allowances have been made for installation of a second, identical mill in the future due to increased hypogene ore hardness. The regrind mill is serviced by a dedicated jib crane.

The first stage of cleaning occurs in four 130 m^3 cleaner cells with five 130 m^3 scavenger cells. Cleaners and cleaner scavengers are Outotec forced-air mechanical cells with dual level control dart valves and 160 kW direct drive mechanisms. Residence time for cleaner flotation is 12.5 minutes while residence time for cleaner scavenger flotation is 15 minutes resulting in stage recoveries of 85% Cu and 92% Cu, respectively. Second cleaning occurs in three 130 m^3 Outotec forced-air mechanical cells, with dual level control dart valves and 160 kW direct drive mechanisms, with a residence time of 8 minutes. Stage recovery in second cleaning is 80% Cu. Selection of first and second cleaner equipment was driven by the froth carrying capacity.

The third and final stage of copper cleaning uses two 4.87 m by 12.0 m Eriez CPT column cells equipped with cavitation air spargers. Stage recovery for third cleaning is 80% Cu with a carrying capacity of 2 t/m^2h, superficial gas velocity of 1.5 cm/second, and wash water bias ratio of 0.2. Column cells were selected due to their inherently deeper froth depth and enhanced ability to reject silicate materials compared to mechanical cells. Final copper molybdenum concentrate has an average grade of 25.8% Cu and 0.5% Mo.

As the copper flotation area is not enclosed in a building, crane service is provided by a centrally located tower crane. Maintenance stands allow for service of flotation mechanisms. Flotation air is provided by low pressure blowers for the mechanical cells and dedicated compressors for the column cells. A nine stream Courier on-stream analyser provides feedback for operations staff and is intended to inform the expert control system in the future.

Copper molybdenum concentrate (copper flotation product) is thickened to 60% solids in a 24 m high-rate thickener. Thickener design is based on a unit settling rate of 0.2 t/m^2h. Final copper concentrate (molybdenum plant product) is also thickened to 60% solids in an identical 24 m high-rate thickener. Final copper concentrate grade is 26% Cu. Due to concerns about high losses of concentrate fines, froth skimmers were installed on both thickeners to improve recovery. A Jameson flotation cell is installed on the bulk copper molybdenum thickener overflow stream to minimise the loss of fine molybdenum.

Final copper concentrate dewatering occurs in two Larox PF 108-144 M60 160 filters. The filters are fed by two filter feed tanks with a total residence time of 24 hours, allowing for adequate surge capacity and filter cloth maintenance. The filters discharge final copper concentrate directly to a loadout shed with seven days of storage capacity.

Tailings Handling

Final tailings (copper flotation tailings) are thickened to 55% solids in a 75 m high rate thickener before being pumped to the tailings storage facility. Thickener design is based on a unit settling rate of 0.75 t/m^2h. Pumping is provided by a single duty set of five Weir Warman 20/18 centrifugal pumps using a single 750 mm diameter HDPE-lined steel pipeline. Layout allows for the future installation of a standby tailings pump set.

Molybdenum Plant and Molybdenum Concentrate Handling

Table 4 summarizes the equipment selected for molybdenum flotation. Cleaner flotation units and pumps were selected to accommodate the high recirculating loads expected. Agitated conditioning tanks provide for Eh and pH control prior to the rougher, first cleaner, and second cleaner stages.

The mechanical flotation cells are WEMCO inert gas cells that are used to minimize the consumption of NaHS. Supplementary nitrogen (from a membrane-type N_2 generator) is used to maintain the inert atmosphere.

Hoppers, tanks and flotation cells are enclosed and vented to a caustic gas scrubber to mitigate hazards from unintended release of H_2S gas. As additional safety measures, H_2S and O_2 gas sensors are installed at all points where NaHS addition occurs and an H_2S sensor is installed on the caustic scrubber exhaust stack.

Final molybdenum concentrate is thickened in a 4 m high-rate thickener before undergoing filtering in a Larox PF 4.7/6.3 filter press to a moisture content of 15%. A Metso D1216-5 Holoflite dryer completes concentrate dewatering by drying the final product to 5% moisture before the molybdenum concentrate is bagged for transport. A wet gas scrubber removes harmful off-gas from the dryer exhaust; an SO_2 sensor is installed on the scrubber exhaust stack as a safety precaution.

A five stream Courier on-stream analyser provides feedback to plant operators. As the molybdenum plant cannot be reached by the copper flotation area tower crane, layout allowances were made for access by forklift and mobile crane.

Table 4 – Molybdenum plant flotation equipment

Description	Units	Data
Molybdenum circuit Mo recovery	%	85.7
Rougher feed density	%solids	15
Rougher cell type		mechanical
Rougher cell model		FL Smidth WEMCO
Number of rougher cells	#	6 x 28 m^3
Rougher mass recovery	%	10
Rougher stage recovery	%	95
First cleaner cell type		mechanical
First cleaner cell model		FL Smidth WEMCO
Number of first cleaner cells	#	5 x 14 m^3
First cleaner stage recovery	%	90
First cleaner scavenger cell type		mechanical (open circuit)
First cleaner scavenger cell model		FL Smidth WEMCO
Number of first cleaner scavenger cells	#	4 x 14 m^3
First cleaner scavenger stage recovery	%	85
Second cleaner cell type		mechanical
Second cleaner cell model		FL Smidth WEMCO
Number of second cleaner cells	#	4 x 14 m^3
Second cleaner stage recovery	%	60
Third cleaner cell type		mechanical
Third cleaner cell model		FL Smidth WEMCO
Number of third cleaner cells	#	5 x 9 m^3
Third cleaner stage recovery	%	50
Fourth cleaner cell type		mechanical
Fourth cleaner cell model		FL Smidth WEMCO
Number of fourth cleaner cells	#	4 x 4 m^3
Fourth cleaner stage recovery	%	40
Fifth cleaner cell type		Jameson
Number of fifth cleaner cells	#	1 x Z1200
Fifth cleaner stage recovery	%	40

START-UP AND OPERATION

Start-Up

The commissioning team was mobilized in mid-2014 with first ore to the primary crusher on October 24th, 2014. This was followed by first ore through grinding line two on December 16th, 2014 and first copper concentrate production on December 27th, 2014. On January 24th, 2015 grinding line two was taken off-line due to bearing damage on the ball mill, however production was able to resume shortly thereafter with start-up of grinding line one on February 1st. In March of that year grinding line two was brought back on-line and the plant met design throughput of 76,000 t/d for three consecutive days on March 29th, 2015.

The start-up effort was characterised by collaboration between the project team, construction and commissioning crews, and the owner's operations group allowing for an effective transfer of knowledge between all parties. The result was an efficient ramp-up curve for the plant which is shown in Figure 4.

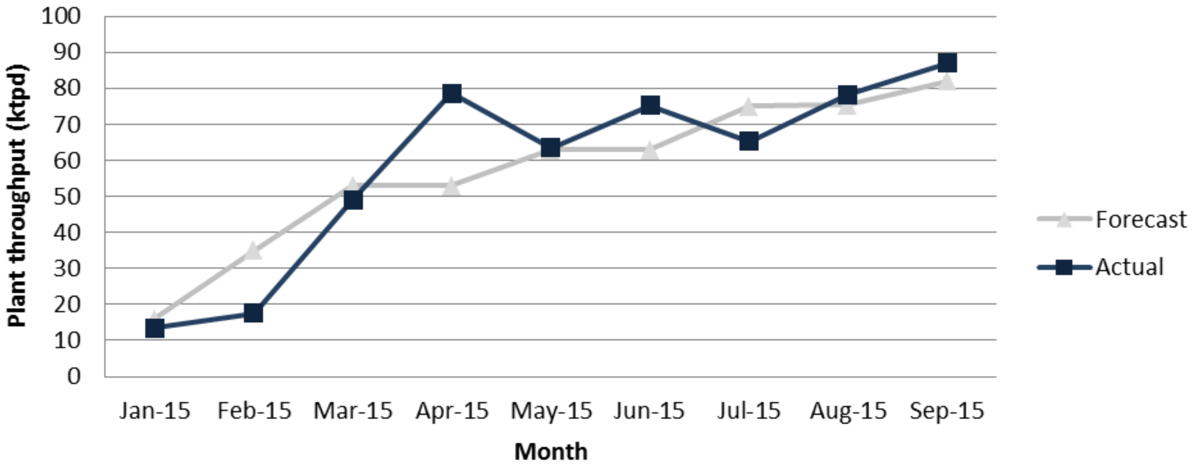

Figure 4 – Throughput ramp-up

Current Operations

Currently, the plant is processing supergene and mixed ore that exhibits higher copper oxide content than expected. This material cannot be recovered in the flotation circuit and is therefore reducing the plant's metallurgical recovery (relative to total copper head grade). However, average daily throughput and head grade have both exceeded forecasted values by at least 5%, which has resulted in the plant exceeding forecasts for copper production, as shown in Figure 5. The oxide content in the ore is expected to decrease until mid-2017 when the oxide material will be exhausted, at this point copper recovery is expected to return to design levels. Figure 6 shows the plant's copper recovery ramp-up.

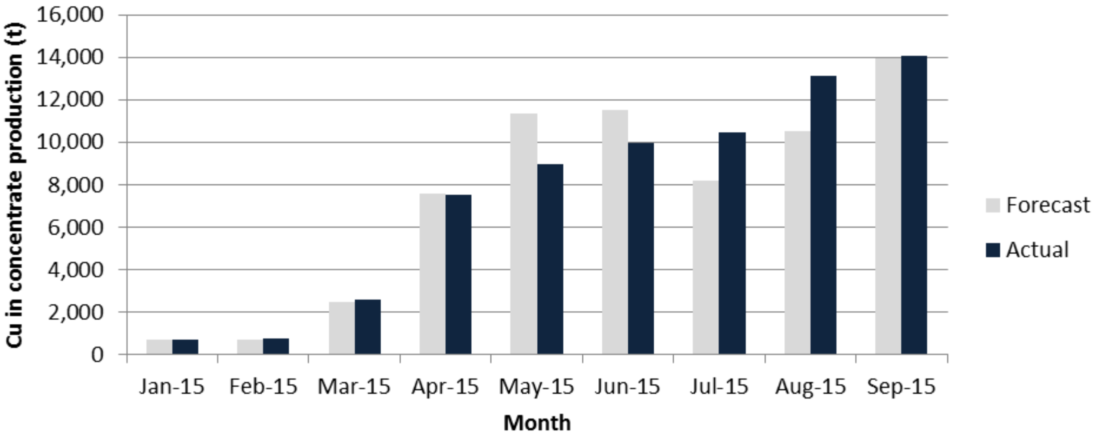

Figure 5 – Copper in concentrate production ramp-up

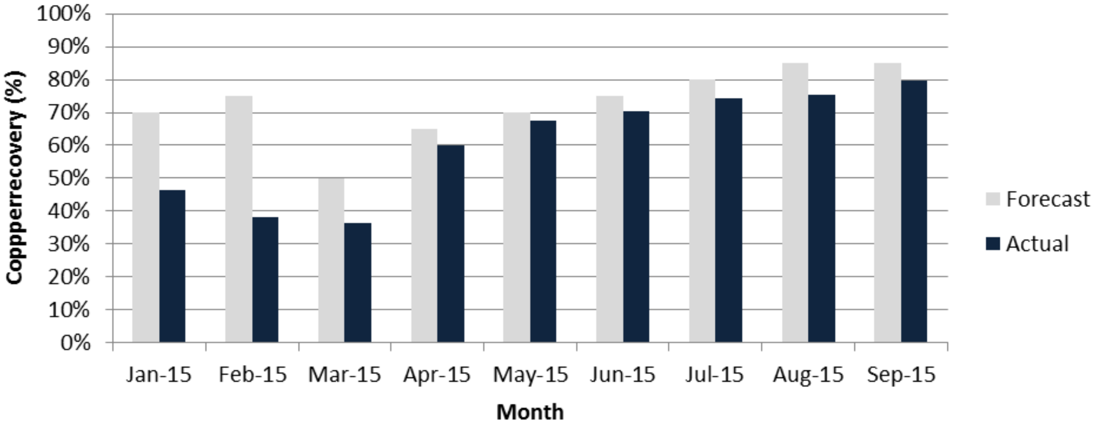

Figure 6 – Copper recovery ramp-up

Constancia's design has a nominal throughput of 76,000 t/d at a grinding circuit P_{80} of 106 microns, however during recent operations the plant has been able to achieve throughputs of 95,000 t/d with softer supergene ore by allowing the grinding circuit P_{80} to rise to 150 microns. Although the higher P_{80} reduces recovery in the copper flotation circuit, overall copper production has increased.

Availability of the process plant has generally been high. The plant has been able to exceed target monthly availabilities of 93% in several months, however year-to-date average availability is still slightly below target. Because the plant throughput is higher than design, maintenance planning and logistics are critical to ensure spare parts are available in the event of early equipment failures. As the plant continues to operate maintenance crews will improve their understanding of the wear characteristics of the equipment and continue to improve availability.

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