InLine Pressure Jig Pre-Concentration Plant at the Pirquitas Mine

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ABSTRACT

Gekko Systems Pty Ltd engaged in the test work, design, manufacturing and commissioning of the pre-concentration plant at Silver Standard Resources Inc's Pirquitas mine in the north western Jujuy province of Argentina. Testing of the ore at coarse feeds of between 2 and 12mm returned probable recoveries of up to a total of 95% silver into 50% of the mass fed to the InLine Pressure Jigs (IPJ's). The plant has been designed and built based on the test results to include a preparation screen to bypass the fines that are naturally higher in grade and repulping of the coarse which is then pumped to three parallel trains of 2-stage IPJ roughing-scavenging. The target 50% yield to concentrate passes over a dewatering screen and the solids are returned back to the mill feed conveyor. The IPJ tails are transferred to a dewatering screen and solid rejects are stockpiled off the end of a transfer conveyor. All dewatered underflow products are processed via hydrocyclones to recover dirty water for use back into the IPJ circuit and return entrained fines to the fines bypass line.

With the sulphide orebody being processed, the results from operations to date have shown that plant performance is matching the original laboratory sulphide ore testwork data. The objective of the pre-concentration step is to both reject gangue and achieve grades between 300-400g/t Ag to the float circuit as flotation recoveries are maximised within this range. The plant currently achieves overall upgrades of approximately 150% of feed grade with the IPJ only circuit producing an average 180% increase from calculated feed grade.

INTRODUCTION

Gekko Systems Pty Ltd (Gekko) were requested by Silver Standard Resources Inc (Silver Standard) in 2006 to investigate the use of the InLine Pressure Jig (IPJ) to pre-concentrate the silver, zinc, tin ore from their Pirquitas deposit. Silver Standard had previously carried out jigging test work to pre-concentrate the ore and found it to be very successful (Hatch, 2006).

The following sections of this paper describe the test work program, results, plant design, manufacture and commissioning of an InLine Pressure Jig based pre-concentration plant. Recent plant performance data is compared to the test work data.

BACKGROUND

Pirquitas Mine

Silver Standard Resources Inc (Silver Standard) acquired the Pirquitas mine in October 2004 when it completed the purchase of 100% of Sunshine Argentina Inc.

The Pirquitas mine is a silver, zinc and tin deposit located in the extreme north west of Argentina in the province of Jujuy as shown in Fig. 1. The project is located in mountainous terrain at altitudes ranging between 4000m to 4520m above sea level.

Fig. 1: Location of Pirquitas Project (Google Maps)

According to the Feasibility study (Hatch, 2006) eighty to ninety percent of the potentially economic material is made up of siliceous non-sulfide gangue composed of intergrown quartz and feldspar grains in a micaceous matrix. Five to twenty percent of the mineralization is made up of sulfides, which is mostly pyrite, and is commonly associated with silver, zinc and tin. From mineralogical studies, the silver was reported as being present primarily as silver sulphides and sulphosalts, containing high concentrations of silver, with most of the silver mineral grains in the range of 20 to 100µm in size. The zinc occurs primarily as medium to coarse grained sphalerite. Grain sizes up to 800µm were reported with 30 to 150µm the more typical size range. Tin occurs as aggregates of cassiterite crystals ranging from 5 to 15 µm, often intergrown with pyrite.

In 1997 and 1998 gravity concentration test work was carried out and indicated pre-concentrating the Pirquitas ore by jigging, after crushing to ½ inch was expected to recover approximately 50% of the crushed ore as mill feed, while only losing three to five percent of the silver and tin.

The benefits of pre-concentration to the Pirquitas project included keeping equipment smaller due to the issues with construction and operation at high altitudes, avoidance of smelter penalties when lower mine grades are processed and more metal production from the plant.

After the 2006 feasibility study by Hatch Engineering (Hatch, 2006), it was expected the ore would be processed by sequential crushing, screening and pre-concentration jigging (gravity). The jig concentrate and fines would be treated by grinding, selective silver flotation and sulphide/zinc flotation from which the zinc can be floated to a saleable grade concentrate. The sulphide/zinc tailings are then treated by gravity and flotation circuits for tin recovery to a saleable grade tin concentrate (Fig. 2).

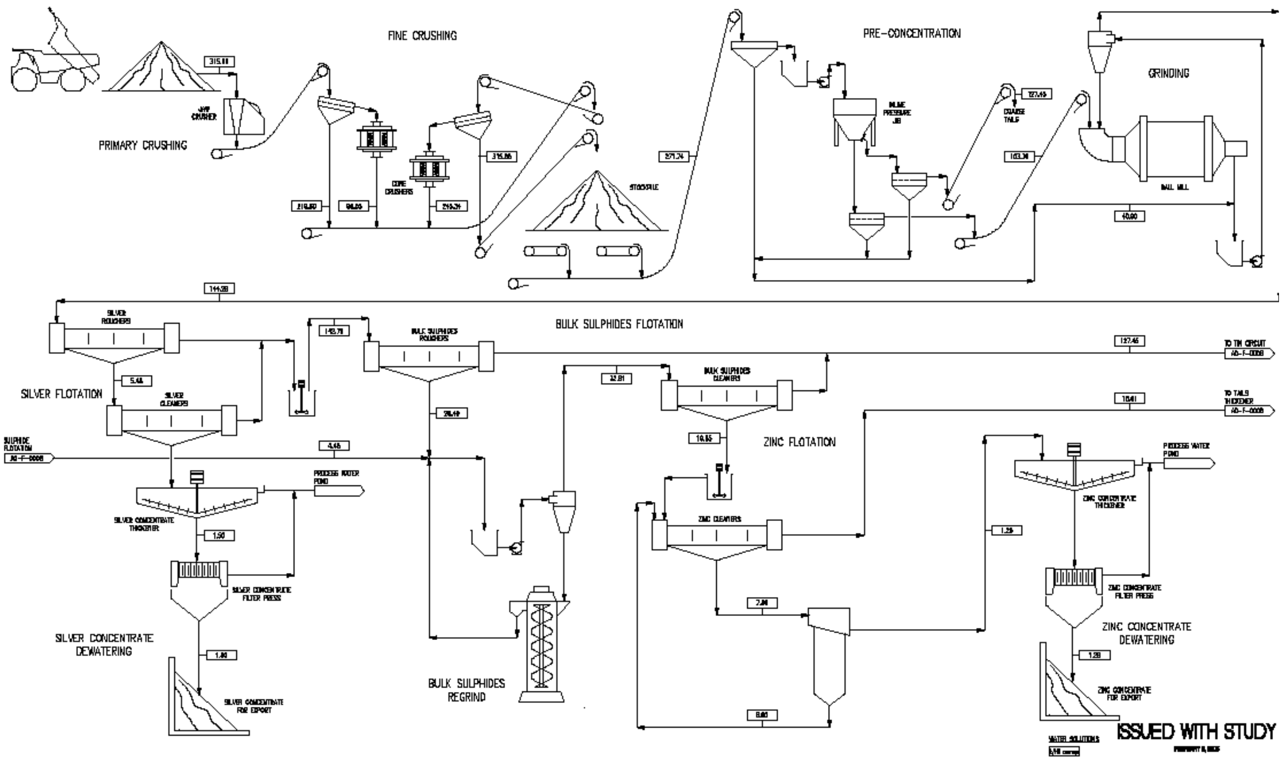

Fig. 2: Overall Pirquitas Flowsheet (MacRae and McCrea, 2008)

Pirquitas Proven and Probable mineral reserves (MacRae and McCrea, 2008) were estimated in house to be 30.4 million tonnes grading 199.6g Ag/t, 0.82% Zn and 0.22% Sn including the historical jig tailings. At a processing (crushing) rate of 6000tpd, planned mine life is 15 years.

Silver Standard commissioned the milling/flotation circuit on December 1st, 2009 at 4000tpd. The commissioning of the pre-concentration IPJ circuit in the 3rd quarter 2010 has resulted in an increase in processing rate to 6000tpd. Forecast (Silver Standard Resources Inc, 2011) silver production for 2011 is 8.5 million ounces of silver.

InLine Pressure Jig

The InLine Pressure Jig (IPJ) has been described in numerous papers (Gray and Hughes, 2008) and a brief summary follows:

- The IPJ is unique in its design and use of jigging concepts in that the unit combines a circular bed with a moveable sieve action.

- The screen is pulsed vertically by a hydraulically driven shaft with the length of the stroke and speed of the up and down stroke varied to suit the application.
- Screen aperture, ragging dimension and ragging material can also be altered for the application.
- Inside the IPJ, the particles are kept submerged in the slurry thus eliminating the loss of hydrophobic fine particles at the air/slurry interface of conventional jigs.
- The submerged slurry also acts as a pseudo heavy media suspension above the jig bed greatly assisting the separation performance of the IPJ.
- Separation of valuable minerals from gangue particles occurs based on relative density as well as particle size and shape.
- High specific gravity particles are drawn into the concentrate hutch during the suction stroke of the bed and are continuously discharged while the lighter gangue is continuously discharged over the tailboard to the outer cone.

An overview is shown in Fig. 3.

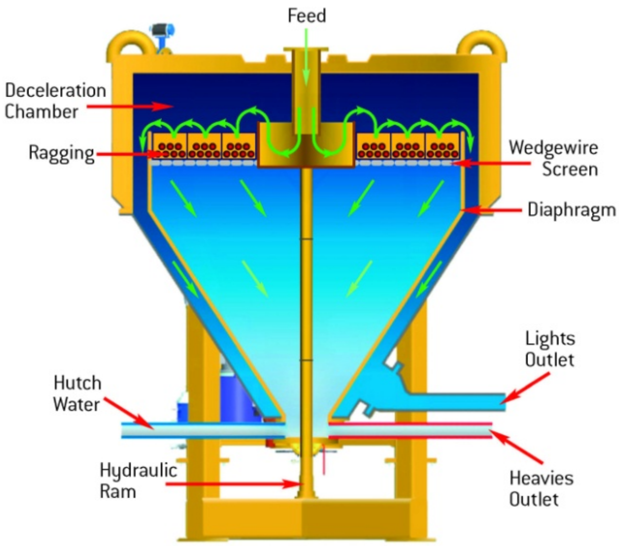

Fig. 3: IPJ cross sectional view.

TEST WORK PROGRAM AND RESULTS

Extensive gravity characterisation testwork was conducted at Gekko's laboratory in Ballarat. The test work flow sheet is presented in Fig. 4. Key tests conducted during the program include size distribution analyses, single pass tabling tests of a +1.7mm -3.35mm size fraction and dense media "Viking Cone" testing of +3.35mm -13.32mm and +3.35mm -9.5mm size fractions.

Fig. 4: Flowsheet for Pirquitas continuous gravity recovery test work

Three sulphide ore samples (#40, #26 and #17) of varying grades (Table 1) were tested for Ag, Zn and Sn recovery using Gekko's Viking Cone dense media separator. The Viking cone is similar to an Ericsson cone and uses a dynamic process to determine the sink float characteristics of an ore. The test is particularly suited to determining the recovery and mass yield that can be obtained using the IPJ at coarse sizes. The mass yield to concentrate from these tests is used to specify the required mass pull from the IPJ.

Table 1: Pirquitas test work sample characteristics (concentrations in ppm)

Sample	**#40**	**#26**	**#17**
Location	Level 5, ¾" crush	Level 2, coarse rock	Level 2, ¾" crush
Silver	250	157	337
Zinc	404	754	2909
Tin	13326	5592	12209
Sulphur	70638	75258	75413

The test results for the +3.35 and -13.5mm secondary crushed material were particularly good. Both silver and tin reported to the concentrate at mass yields less than 50%.

The results for Ag and Sn recovery in Figs. 5 and 6, show that recoveries in excess of 95% are achievable for all three samples, at a mass yield of approximately 50%. Zinc recovery was lower as show in Fig. 7 indicating poorer liberation of the zinc minerals at the crush size tested.

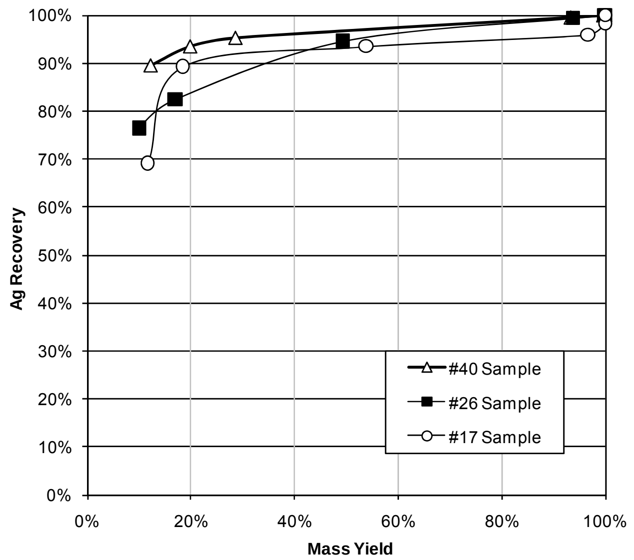

Fig. 5: Silver recovery versus mass yield from Gekko test work

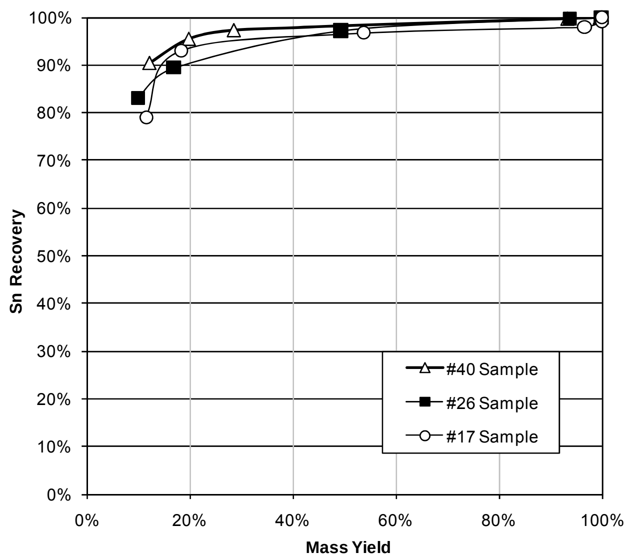

Fig. 6: Tin recovery versus mass yield from Gekko test work

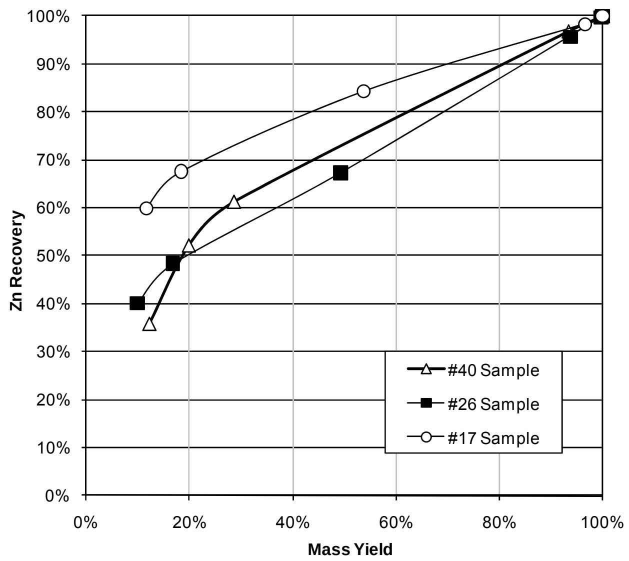

Fig. 7: Zinc recovery versus mass yield from Gekko test work

The test work also showed a natural concentration of silver in the fines (-1.7mm) after crushing to minus 12mm with its grade typically twice that of the head grade.

Overall the test work indicated treating plus 1.7mm minus 12mm will result in 95% recovery of silver into 50% mass.

PLANT DESIGN

The main design parameters for the plant after communication with Silver Standard were 95% recovery of silver and tin into 50% of the mass from the +2mm to -12mm stream. Throughput to the IPJ's was specified as 214 tph.

The recovery needed to be maximised and mass pull to concentrate was too high for a single pass jigging stage so a two stage rougher-scavenger jigging circuit was used. This type of circuit was used very successfully at the former Lihir Gold Ballarat Goldfields Project in Australia (Gray and Hughes, 2007). The final design consisted of two stages of three IPJ2400 model InLine Pressure Jigs connected in parallel in a rougher scavenger configuration as indicated in the Process Flow Diagram shown in Fig. 8. The throughput rate for the IPJ2400 was de-rated from a nominal 100tph to 75tph due to the high mass pull to concentrate required in this application and resulted in the use of three parallel trains of IPJ's.

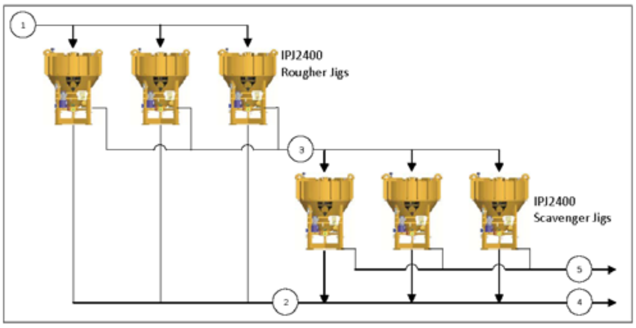

Fig. 8: Simplified PFD of Gekko pre-concentration process at Pirquitas

Crushed run-of-mine ore is fed to an existing fine ore screen. A diversion gate in the feed chute to the screen allows the feed to be bypassed around the pre-concentration process. The fine ore screen splits the feed at 2mm, producing material in the size range, +2mm to -12mm, as feed to the Gekko plant, at a rate of 214 tph. The dry feed is mixed with water recycled from the IPJ products to approximately 50% solids and is pumped to the Rougher InLine Pressure Jigs (Stream 1 – Fig. 8).

The IPJ Feed pump (Warman 6/6 gravel pump), feeds a distributor vessel on top of the IPJ platform. The pump's speed is controlled by a variable speed drive to ensure that the pipe velocity of the slurry is greater than the settling velocities of the coarse particles (>4 m/s).

The IPJs use an internal screen with 18mm apertures and the ragging used is 30mm in diameter and has a specific gravity (SG) of 3.2. The large ragging size was selected to allow the jigging bed to be open and free, which is necessary for the high mass pull.

The tails from the rougher IPJs (Stream 3) report to the in-series scavenger IPJs. The scavenger IPJs tails (Stream 5) flow to the tails dewatering screen. The dewatered tail particles (+1 mm) pass to the existing conveyor, while the water and fine solids pass to a combined screen undersize/cyclone feed sump. The concentrates from the rougher (Stream 2) and scavenger IPJs combined (Stream 4) flow to the concentrate dewatering screen and the water and fine solids also pass to the combined screen undersize/cyclone feed sump.

The water and minus 1mm particles are pumped to a cyclone cluster designed to remove any liberated fines from the recycled water. The cycloned water overflow is sent back to the gravity circuit's 40m^3 dirty water tank for re-use in the IPJ's. The cyclone underflow is directed to a sump along with a bleed of dirty water to reduce the build up of ultra-fines in the circuit. A pump transfers this fine material directly to the ball mill discharge hopper where it is then pumped to the cyclones in this grinding circuit.

The de-watered IPJ concentrates report to the ball mill feed conveyor.

The de-watered IPJ tailings report to the rejects stockpile for disposal.

The scope of Gekko's supply for the project was expanded from just the IPJ supply to frames, feed pump, product and tailings dewatering screens, water recycle circuit, PLC control and SCADA system and motor control centres. This enabled Gekko to control the way the circuit was engineered to ensure it matched the requirements of the IPJ's and allowed Silver Standard to have one supplier answerable for the performance of the circuit from pumping to de-watering. It also allowed the circuit to be installed independently of the main grinding circuit.

The overall pre-concentration plant layout as modelled by Pro-E 3D modelling software is shown in Fig. 9.

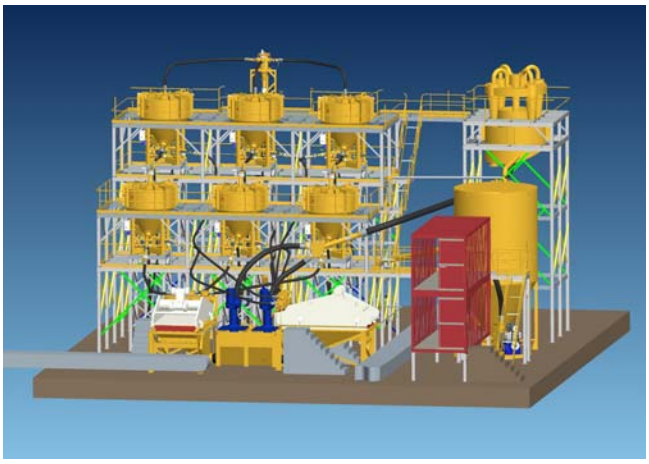

Fig. 9: 3D Model of Pirquitas two stage gravity concentration plant

PLANT MANUFACTURE AND INSTALLATION

The plant was fabricated, trial assembled and factory commissioned at the Gekko's factory in Ballarat, Australia in 26 weeks. Upon successful completion of factory commissioning (see Fig. 10), the plant was marked, disassembled, packed into containers and shipped to site.

Fig. 10: Pirquitas two stage gravity concentration plant assembled at Gekko, Ballarat

After arrival at the Pirquitas mine site, a local team of construction personnel mechanically installed the majority of the hardware, including frames, equipment and pipe work, following a Gekko designed modular system that allowed them to construct in a Meccano-set style approach with little interaction from Gekko. Electrical instrumentation and drives were then installed under supervision and assistance from Gekko electricians.

Gekko provided services throughout the installation and commissioning period that included personnel with specific expertise in mechanical, electrical, process control, metallurgy and training. This enabled Gekko to provide the technical expertise to resolve issues rapidly and provide the essential knowledge sharing and relationships to ensure the project will be a long term success.

Despite language barriers, Pirquitas mine staff and Gekko worked together and provided the required resources from both sides with language skills that ensured focus and progress of the project was maintained at all times.

PLANT PERFORMANCE

During commissioning, throughput to the IPJ circuit was reduced to 130 tph to ensure that each bottleneck was identified and rectified prior to the next staged increase. It also allowed time for the crushing circuit to be upgraded to the design 6000tpd capacity. On several occasions the plant was taken to rates of up to 230-240tph for short periods or 165-170tph feed to IPJs, but these were for periods too short to monitor recovery performance.

The initial lower than designed crushing circuit throughput resulted in the opening up of the screens in the crushing circuit to increase crushing rates and resulted in material up to 25mm reporting to the circuit. Although the +12.7mm material was less than 1% of the feed to the IPJ's, occasionally stray rocks up to 100mm would enter the circuit and lead to immediate blockages and often significant delays in operation. This lead to the installation of a 25mm scalping screen on top of the 2mm banana screen and the blockage issues were resolved. Ultimately the mine should be targeting 20mm if not 15mm aperture screens to ensure that all feed has equal opportunity to report to concentrate and to minimise the hang up of coarse 20-25mm in the IPJ beds. The majority of these larger rocks were also noted to be heavily mineralised and should have gone to concentrate, but could not due to the internal IPJ screen size.

The IPJ 3.2 SG ragging used in the first fill was soon replaced with 5.5 SG ceramic and 7.0 SG steel as the heavily mineralised coarse rocks mentioned previously were found to displace the ragging out of the inner rings of the IPJ bed. Once the ragging was displaced there was no restriction of flow of feed to concentrate and the concentrate grade was subsequently diluted. In the end the beds all had a mixed bed of these ragging types, but they generally went from high densities in the inner rings to the lighter in the outer rings. The ragging size was generally 30mm for the 3.2 and 5.5 ragging, but the steel was commercially available ball bearing and grinding media at 25mm.

During November 2010, operational data was collected from the plant to provide an understanding of the performance of the process. A typical mass balance is shown in Fig. 11 and indicates the tonnage, silver grade and recovery expectations of the plant.

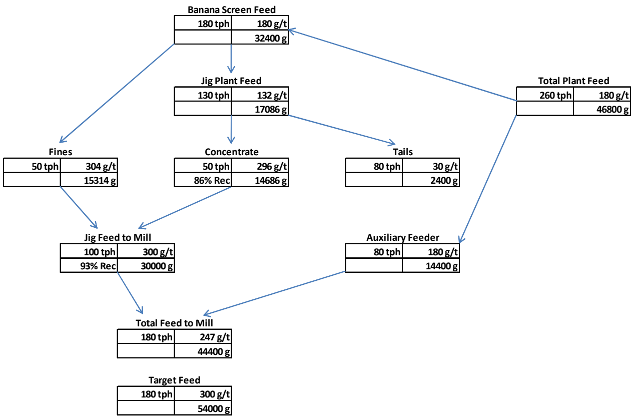

Fig. 11: Mass balance around IPJ circuit

Due to the lower tonnes produced from the crushing plant than designed, passing all of the ore through the IPJs would regularly produce insufficient feed to the grinding circuit and cause starved conditions that would produce finer grinds and in turn lower silver recoveries in the flotation circuit. In addition, the bypass of -2mm to the ball mill discharge increased the “efficiency” of the ball mill which also enhanced the grind produced. Recommendations were made to reduce the layers of ragging in the IPJ beds to provide higher concentrate production, however this was not supported by site as focus was to produce high grades from the IPJ circuit and proceed slowly on process changes to enable an improved understanding of the IPJ variables to be made.

The splits or yields of the various products namely the fines bypassed directly to grinding circuit, concentrate stream and tails produced; are shown in Fig. 12. The actual grade to the grinding circuit is diluted by the auxiliary feed (as shown in the mass balance in Fig. 11 and depicted in Fig. 12) used to make up the tonnes for the appropriate ball mill load.

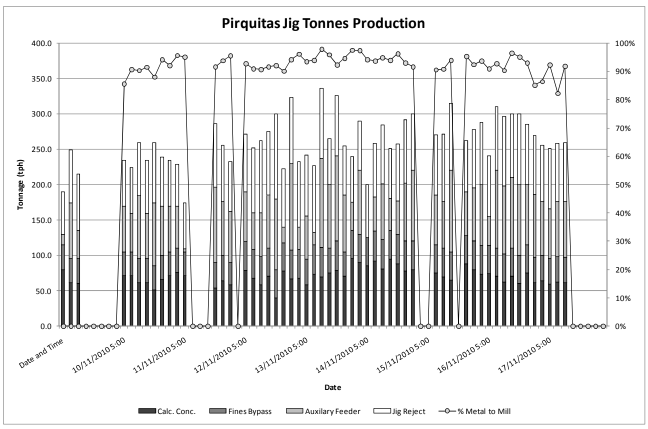

Fig. 12: Tonnes distribution in feed to the Pirquitas milling circuit

Fig. 13 shows the budget of silver metal production and the minimum target grade of the feed to the grinding circuit by the horizontal line. The vertical bars indicate the metal feed per hour to the grinding circuit inclusive of the diluted feed from the auxiliary feeder with recoveries in the 90-95% region (excluding auxiliary feeder material). The O to X shows the increase in grade to the grinding circuit which depicts an average of 153% grade increase (inclusive of auxiliary feeder), however the grade improvement across the IPJs alone shows an average 201% increase prior to auxiliary feeder dilution.

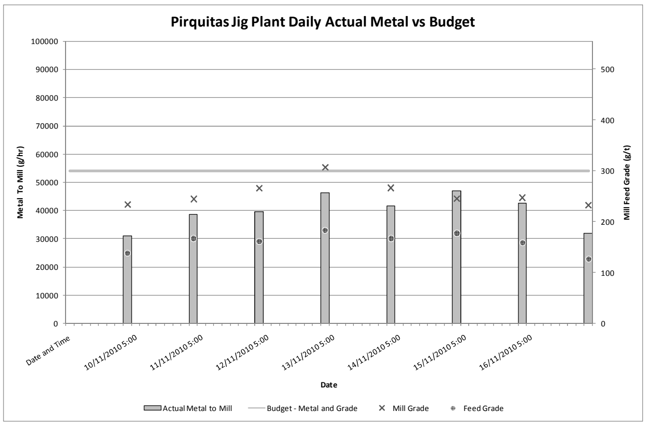

Fig. 13: Silver grade and metal feed rate to the Pirquitas milling circuit

The higher grinding circuit feed grade for Pirquitas was found to be very important for flotation recovery. Grinding circuit feed grades maintained in the 300-400g/t Ag range compared to the average 180g/t Ag mine production grade were found to produce superior flotation recoveries generally providing a 10-20% improvement in performance and at higher than planned flotation concentrate grades. This somewhat unexpected benefit reduced smelter penalties and improved overall economics.

The actual results are very encouraging as the data follows the main trend and stays within the variances seen in the Gekko testwork results (Fig. 14).

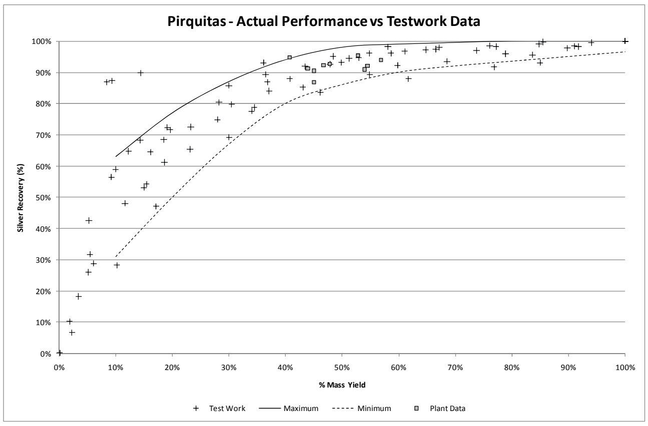

Fig. 14: Silver recovery versus mass yield for test work versus plant data

Fig. 15 depicts the distribution of silver metal at the Pirquitas project. The auxiliary feeder input is at the mined grade without any beneficiation, added to the post IPJ processing and the minus 2mm stream and fed directly to the grinding circuit. The fines were found to be naturally high in grade but are only generally around 20% of the feed material and are bypassed directly to the ball mill discharge hopper. The +2mm material is fed to the IPJ circuit and split approximately 50:50 to concentrate and tail and upgrades the concentrate by approximately 180% of jig feed grade. Tails are sent to the rejects pile at grades typically between 10 and 30g/t Ag.

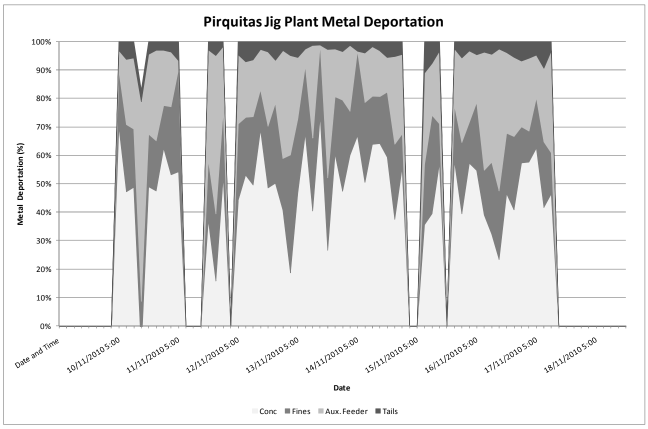

Fig. 15: Metal distribution at the Pirquitas plant

Apart from the lower than planned tonnage mentioned previously, the pre-concentration circuit operated as planned producing a higher grade to the grinding circuit for greater silver production and higher recoveries.

There were some challenges with the pre-concentration circuit experienced during commissioning and optimisation. These included:

- Excessively large rock entering the plant that contributed to low availability due to blockages and excessive wear to sections of the plant's pipe work. This issue was resolved by retrofitting a scalping screen strapped to the banana screen. Although not ideal it did perform OK and eliminated the blockage problems that were being experienced. However due to spatial limitations, the modification restricted flow and hence feed tonnes that could be fed to the banana screen. Eventually a properly installed safety scalping screen will need to be installed into this circuit to remove this bottleneck.

- Pumping of coarse gravel without any fines proved to be challenging as most pump models take into account the fines to assist in the transport of the coarser material. Higher than expected pipe velocities were required to maintain proper operation of the gravel pumps, but the higher velocities lead to accelerated wear. The high level of instrumentation and control in the plant logic system allowed a modified operational philosophy to operate the pumps according to this essential criterion. Severe wear was mainly found in the suction of the IPJ feed pump and extended life in this area was achieved with design changes to the flow pattern of the material to the pump's suction inlet and improved material selection to line these parts.

- Controlling the split of concentrate yield on high mass pull circuits is largely attributed to machine variables (i.e. screen size, ragging density and size, ragging depth) as opposed to traditional thinking where operating variables (i.e. stroke length and pulse frequency) play the larger role. In "through-bed" jigs, the machine variables make up 80% of the yield characteristics and the operating variables are used to fine tune the yield. This change in concept is difficult to transfer to operators that have experience in traditional jigging culture. This does not always provide the flexibility that some operations would like, but generally in relatively steady state plants these machine variables will not alter significantly once the right operating parameters are established.

CONCLUSIONS

The performance of Silver Standard Resources Inc's silver pre-concentration plant utilising InLine Pressure Jigs has verified the scale-up from test work to plant performance. The challenges of dealing with truncated coarse feeds have been overcome by mine and Gekko personnel and resulted in a robust operating plant that is exceeding its targets.

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