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CHLORIDE LEACHING FOR SILVER, COPPER, LEAD & ANTIMONY INDUSTRIAL EXPERIENCE IN THE 600 TONNE/DAY ITOS, BOLIVIA, PLANT

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ABSTRACT

The Itos Plant, located in Oruro, Bolivia, treats 600 tonnes per day of low grade silver ore (220 grams per tonne) using a hot, agitated chloride leach process. Leach solution contains 200 grams per liter sodium chloride, 10 grams per liter ferric iron and 10 grams per liter hydrochloric acid. A bulk metal precipitate is recovered by iron precipitation. The precipitate is smelted and then cupelled to produce a 95% silver doré bar.

The plant has processed nearly 600,000 tonnes of ore since startup in 1996. A Hargreaves Process hydrochloric acid plant was built in 1999 which resulted in a cost reduction of \$2.70 per tonne of ore treated (up to that time, acid had been imported from Peru). By late 2000, when operations were suspended due to low metal prices, costs had decreased to about US\$27.00 per tonne and overall silver recovery was 65%.

Itos is still in “development” mode. Planned modifications include switching from chlorine to air oxidation and installation of facilities for producing marketable-grade lead metal, antimony trioxide, and sodium sulfate. With these modifications, silver recovery will increase to 80% and costs will drop to US\$22.00 per tonne (\$3.20 per ounce of silver with byproduct credits).

INTRODUCTION

The 1.8 million tonne Itos tailings deposit is the result of several years of processing by Comibol of the San Jose and Itos Mine ores at Oruro, Bolivia. The historic flowsheet consisted of a flotation circuit in which silver-bearing galena and stibnite were concentrated. Approximately half the silver in the ore was not recovered, and the existing tailings contain 220 grams silver per tonne in the form of complex sulfides of silver, antimony, lead, and other metals as microveinlets inside grains of pyrite.

An extensive laboratory program was conducted to examine conventional processing methods such as cyanide leaching and regrinding followed by flotation. However, the silver-bearing sulfides are in intimate contact with the pyrite and the pyrite comprises 30% of the total tailings weight. Cyanide leaching recovers only 40% of the silver and the cyanide consumption is uneconomically high at 12 kg/tonne. Flotation produces an upgraded, but still uneconomic, concentrate.

For this reason, chloride leaching had been evaluated by Comibol, and in the mid-1980's Comibol undertook an innovative test consisting of two 300 tonne field heap leaches using a cold chloride solution. The tests were partially successful, but could not be applied to the bulk of the tailings which are already ground to 50% minus 200 mesh.

In 1992, Kappes, Cassidy & Associates undertook to develop a hot agitated chloride leach flowsheet. In 1995, KCA constructed a 600 tonne/day (15,000 tonne per month) treatment plant under a turnkey contract from a Bolivian company, Baremsa, S.A. Using this process, 81% of the remaining silver can be recovered, with significant by-product credits from antimony, lead, copper, and tin.

The company which owns the Itos project, Baremsa, is a closely held corporation with two principals, KCA and Barex Ltda. Barex is a metal trading firm with home offices in White Plains, New York. The Bolivian resident partner in Barex, Hans Tordoir, is also the business and public affairs manager of the project. Dan

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Kappes, of KCA, is the operations manager. Alberto Quinones, a Bolivian metallurgical engineer, is the plant manager. This three-pronged team has been very effective, necessary, and has resulted in an environment in which the Bolivian governmental authorities have been generally supportive and helpful.

The project features hot, agitated acidic chloride leaching. Silver is recovered as 95% bullion metal by furnace refining. Lead and tin are recoverable from the process solutions, and copper and antimony from refinery products. At this time, copper is the only by-product metal being commercially recovered. Lead and antimony are being stockpiled as intermediate products, and tin is lost to tailings. Operations were temporarily halted in November 2000 due to low silver prices. Investment in process optimization and in facilities for by-product recovery are planned, which will lower direct operating costs (net of by-product credits) to about US\$3.20 per recovered ounce.

paved road connects Oruro with the capital city of La Paz, three hours to the north.

Oruro is a town of about 150,000 inhabitants which was founded to exploit the San Jose mine in about 1590. The San Jose and Itos mines are adjacent to each other and contain narrow near-vertical silver veins. Since 1953 (and until the mine closed in 1992) the ore from both mines was treated in the Itos flotation plant which is the source of the Itos tailings. The mine is currently 500 meters deep and is maintained in good standby condition. When the mine is re-opened, the ore from the mine can be processed directly in the Itos chloride leach plant without the need to make a flotation concentrate.

Because of the low silver recovery in the historic Itos flotation plant, and the low value of the concentrate produced, it is estimated that Comibol received net payments of only 35% of the value of silver in the ore at the mine head. This poor economic situation is not uncommon for mines treating complex South



Figure 1. The 600 tonne/day Itos Bolivia chloride leach plant for silver. Leach tanks can be seen in the center of the photo. The tailings filter building is on the left, process building in the rear, and the pyrometallurgical plant on the right.

LOCATION & HISTORY

Bolivia is a landlocked country in the center of South America. Its economy is centered on the mining industry and its primary exports are tin, zinc, silver, and gold. Natural gas will soon become a major export commodity. The government is democratic and has been stable since the early 1980's.

The western half of the country is a high plain between two arms of the Andes Mountains, known as the Altiplano. The Itos project site is located in the town of Oruro approximately in the middle of the Altiplano at an elevation of 3700 meters (12,300 feet). A good

American silver ores. With direct hydrometallurgical treatment on site, a net return (after deducting operating costs and adding by-product credits) of 55% of the silver value is possible.

PROCESS DESCRIPTION

Primary Feed & Leach Solution Composition

The "ore", actually tailings from a flotation plant, contains about 30% iron pyrite with minor arsenopyrite in a rhyolite gangue. Silver occurs as "sulfosalts" (complex sulfides of silver with semi-metals), minerals such as pyrargyrite and polybasite (silver-antimony

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sulfides), proustite (silver-arsenic sulfide), andorite (lead-silver-antimony sulfide) and franckeite (lead-antimony-tin sulfide). These sulfides occur as coatings and fracture fillings in the pyrite.

The tailings are "mined" with a front end loader and screened to discard oversize material. All 6 mesh undersize (600 tonnes per day) is fed to an attritioning tank where it is mixed with barren process solution. Acid (275 tonnes HCl per month) and salt (750 tonnes per month) are added along with the ore. The attritioning tank is located on the tailings deposit, and the 45% solids slurry is pumped 0.75 kilometers to the processing plant.

The process solution has the following active components:

- Sodium chloride (salt) 200 grams/liter
- Iron chlorides 30 grams/liter
- Hydrochloric acid 15 grams/liter

As measured on a standard pH meter, the process solution shows a pH of 0.3. All equipment exposed to process solution is made from plastic, fiberglass/epoxy composites, rubber, or titanium. Because of the abrasive nature of the relatively coarse pyrite and the high temperature, hot slurry pumps have solid silicon carbide internals. Cold slurry and process solution pumps are urethane-lined steel.

Control of Reagent Addition

Due to the reactive nature of many of the dissolved salts, it has proven difficult in practice to measure free hydrochloric acid in solution. Hydrochloric acid is added at a pre-determined amount, up to 15 kilograms per tonne of ore.

The chloride level is maintained above 180 grams per liter (sodium chloride basis), based on analysis of the solutions in the first leach tank.

Oxidation is controlled by the addition of chlorine diluted with compressed air to the first and second leach tanks via submerged sparger tubes. Although the chloride bubbles are fairly large, chlorine odor is observed above the leach tanks only when the leach temperature is well below normal. The degree of oxidation and rate of chlorine addition are easily controlled by visual observation of the pregnant solution as it exits the tailings filters. A medium yellow color indicates a ferric content of two to four grams per liter, which is sufficiently in excess to accomplish leaching. If the solution becomes pale yellow or colorless, chlorine addition is increased. A yellow-orange color indicates excessive chlorine use.

Leaching & Leach Chemistry

The ore is fed continuously to the first of three leach tanks in series, where it is leached at a temperature of 75°C for a total effective residence time of eight hours (leaching appears to be complete in about four hours). Each tank is 5.5 meters in diameter and eight meters high (seven meter slurry level). The flowrate is 600 tonnes of ore per day in a 45% solids slurry (by weight), or approximately 38 cubic meters of slurry per hour (30 cubic meters of solution per hour).

Chlorine is fed into the leach tanks at the rate of 10 kilograms per tonne of ore in order to oxidize the iron (II) chloride to iron (III) chloride. The iron chloride then reacts to oxidize the silver minerals. Less than 3% of the feed weight is dissolved during leaching.

The essential reactions which take place in the leach tanks are shown below:

- (1) $24\text{FeCl}_3 + 2\text{PbS} \cdot \text{Ag}_2\text{S} \cdot 3\text{Sb}_2\text{S}_3$ (andorite, typ.) \rightarrow $24\text{FeCl}_2 + 2\text{PbCl}_2 + 2\text{AgCl} + 6\text{SbCl}_3 + 12\text{S}^\circ$
- (2) Oxidation, as shown above, only with cupric-cuprous rather than ferric-ferrous
- (3) $\text{AgCl} + 3\text{Cl}^{-1} \rightarrow (\text{AgCl}_4)^{-3}$
- (4) $\text{FeCl}_2 + \text{O}_2 + \text{HCl} \rightarrow \text{FeCl}_3 + \text{H}_2\text{O}$
- (5) $\text{FeCl}_2 + \frac{1}{2}\text{Cl}_2 \rightarrow \text{FeCl}_3$

The reactions shown above are simplified, or course, but are representative of what is actually experienced in the plant. There is a very extensive body of literature on various chloride leaching processes for base metals, which discuss many possible reactions. For instance, it is possible to form sulfate rather than elemental sulfur. In practice, Itos does not experience a significant buildup of sulfate in the leach solution. Other metals including copper, arsenic, bismuth, tin, and zinc dissolve along with the metals shown in equation (1).

In batch-scale tests, about 15 grams of ferric chloride per liter are required to dissolve the target minerals. In the continuous production leach tanks, where oxidation of ferrous to ferric takes place simultaneously with leaching, the level of ferric seldom exceeds three grams per liter.

Pyrite (iron sulfide) and arsenopyrite (iron arsenic sulfide) remain essentially unreacted under the leach conditions employed. Since the leach solution always contains several grams per liter ferrous iron (in addition to ferric), no free chlorine is present. By increasing the use of chlorine to the point where all dissolved iron is converted to ferric, it would be possible to create conditions to leach the pyrite.

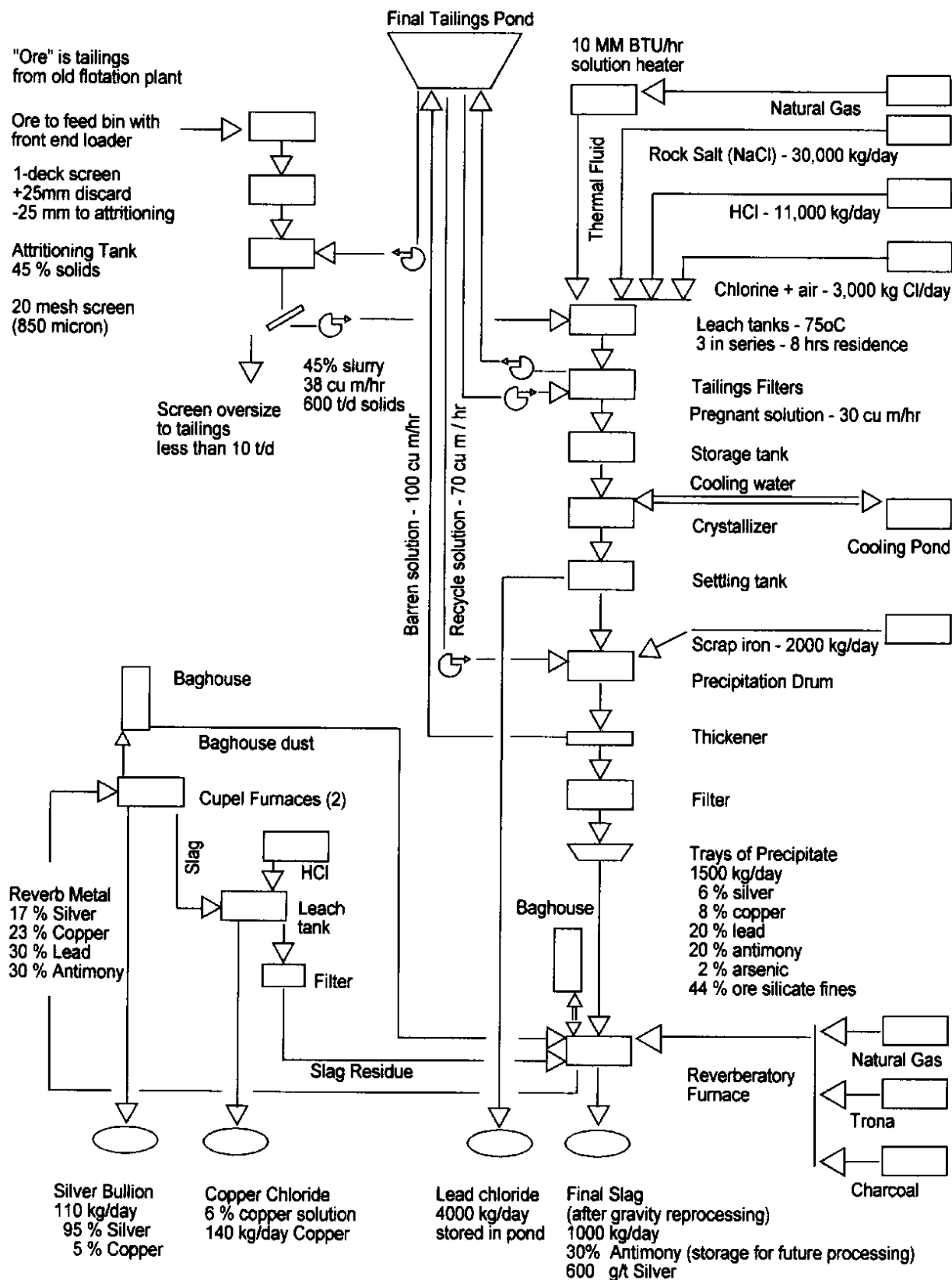


Figure 2. Itos process flowsheet.

Buildup of sulfate above 30 grams per liter inhibits the dissolution of antimony and silver. Sulfate levels in solution can be controlled by the addition of lime, but so far this has not been necessary. Minor soluble impurities, primarily zinc, aluminum, magnesium, and sulfate, are naturally controlled by inclusion within the normal moisture contained in settled tailings. Buildup of iron, commonly noted in literature as a problem in chloride leach circuits, has not occurred.

The Role of Hydrochloric Acid in Silver Recovery

As shown in the above equations, and discussed later in this paper, the chief function of hydrochloric acid is to participate in the oxidation reaction. Hydrochloric acid plays another role of enhancing the dissolution of silver. The exact mechanism by which it does this is unknown, but it probably has to do with the fact that higher acid strength results in better dissolution of iron oxides and other compounds which coat and passivate the silver minerals. The response of the Itos ores to acid strength is shown in below in Table 1.

Table 1 - Acid Strength vs. Silver Recovery

Acid Strength gpl HCl	Laboratory Batch % silvery recovery	Consumption HCl kg/tonne of ore
1.0	76	1.2
3.0	78	3.7
5.0	79	6.1
10.0	83	12.2
15.0	88	18.3

The data indicate that of an acid strength above five grams per liter hydrochloric acid (100% HCl basis), an additional nine grams silver per tonne of ore (3.6% of total fire assayable in the ore) is recoverable with the marginal increased consumption of about six kilograms hydrochloric acid per tonne of ore. The extra silver production is worth \$1.45 per tonne of ore with silver valued at \$5.00 per ounce. Until early 2000, when the on-site acid plant came online, the cost of acid was US\$910 per tonne of HCl delivered to Itos. In the on-site acid plant, the production cost is US \$40.00 per tonne of HCl. At a marginal consumption rate of 6 kilograms HCl per tonne of ore, the acid cost is US \$5.46 and US \$0.24 per tonne of ore, respectively. For this reason, for most of the operating time of the Itos plant we chose to accept a low percentage recovery.

Because of the other plant losses, the percent silver recovery shown in Table 1 is about seven percent higher than that actually achievable in the operating plant.

Alternative Oxidation Methods

As indicated above in equations (4) and (5), there are two possible routes for converting ferrous to ferric iron. The ore consumes about 15 kilograms of ferric iron per tonne, so the cost of conversion is a significant operating cost. Until mid-2000, when the hydrochloric acid plant came on line on-site at the plant, both chlorine and hydrochloric acid were purchased in Lima. Transportation to the mine site involves a 20-day round trip, which is both very expensive and a logistical nightmare. The purchase price of chlorine is higher than that of hydrochloric acid FOB at the Lima factory (both cost approximately US\$250/tonne). But, because hydrochloric acid is transported as a 35% HCl solution in water, the cost delivered to the mine site is US\$560 per tonne of chlorine and US\$910 per tonne of HCl (100% HCl basis). It is therefore less expensive to get "oxidation credits" by using chlorine (reaction 5) rather than by using acid and air (reaction 4).

Approximately three tonnes of liquid chlorine are consumed per day. This is vaporized in an on-site vaporizer of KCA design. The system has run for our years with only minor chlorine excursions and only minor, rare worker exposure to chlorine gas. Chlorine cost averages above US\$4.50 per tonne of ore.

In late 2000, in-process tests using air spargers indicated that the required amount of ferric could be created in situ using reaction (4). With on-site generated acid, this will reduce operating costs by approximately US\$2.50 per tonne. This will be one of the first modifications to be made once the plant is re-started.

Solution Heating & Leaching

At ambient temperature, recovery of only about 40% of silver is possible even with extended leach time. At the elevation of the plant (3700 meters, or 12,300 feet above sea level), the boiling point of the brine (and therefore the maximum operating temperature) is about 83°C. Fortunately, batch tests and plant practice indicate that 75% is sufficient to accomplish the leach reactions.

Slurry enters leach tank one on a continuous basis, at a temperature of less than 15°C. Temperature in all leach tanks is maintained at 75°C to 80°C using titanium tube heat exchangers immersed in the slurry. A 4 kilometer long natural gas line, extended from the Oruro city network, delivers gas at 300 psi to the plant. Gas is burned to heat thermal heating oil to 200°C, and this oil is pumped through the heat exchangers.

The plant is processing floatation tailings, and, as such, there is sufficient frother remaining in the material to cause the formation of a two inch froth cover in the leach tanks. This prevents heat loss from the solution



Figure 3 Ore Slurry is fed to the leach tanks at 45% solids. Leach tanks are rubber lined and externally insulated. The system that is barely visible on the right hand side of the photo is a hot thermal fluid heater used to raise the process solution to 75°C.

surface. The sides of the tanks are insulated with a 3-inch external flexible urethane foam blanket.

Filtration & Tailings Disposal

Leached slurry, at an average flowrate of 38 cubic meters per hour, is filtered in a bank of three recessed plate filters. Each filter contains 120 plates, 1500 by 1500 millimeters, with a 50 millimeter recess. The filter cake discharges into a plastic-lined "basement", where it is re-slurried and pumped to a new tailings dam which is fully lined with 40 mil PVC. Because each wet cake weighs over 200 kilograms, discharge of the cake is automatic once the plates are separated. Three men can open and clean a filter in approximately 20 minutes. Typical cycle times are 20 to 40 minutes for cake formation and 20 to 40 minutes for discharge. Three filters are used and typical duty is 12 cycles each per 24 hour day. The polypropylene filter cloths are replaced every six months.

Plant Water Balance

The water (actually process solution) for the slurry cake discharged from the filters makes a continuous loop from the new tailings dam. Oruro experiences a four-month summer rainy season with a total annual rainfall of only 300 millimeters, and excess water accumulated during this period is stored in the tailings pond. Because of the high altitude and dry winter conditions, solar evaporation can be very intense and the annual water balance is negative. Well water of relatively low quality (high TDS) is used for plant makeup.

During the rainy season, flooding occurs on the natural salt flats located in southern Bolivia, which are the

source of the sodium chloride used in the process. Salt usage increases during rainy season since the rainwater must be brought up to process solution strength, but it's often not available at this time of year. To overcome this problem, stockpiles of several thousand tonnes of salt are seasonally maintained at the plant.

Solution Processing

Pregnant solution from the leached tailings filters, nominally at 75°C after filtration, is cooled in a heat exchanger to precipitate about 4 tonnes per day of lead chloride. Lead chloride crystals are collected and stored for future processing. The solution is then warmed in a second heat exchanger and proceeds to metals precipitation.

Silver, antimony, arsenic, copper and residual lead is precipitated in a rotating drum using two tonnes per day of scrap iron. Drum feed rate is approximately 100 cubic meters per hour of clear solution, consisting of about 28 cubic meters per hour of pregnant solution assaying 120 ppm silver and 72 cubic meters per hour of tailings return solution assaying 30 ppm silver.

Precipitation efficiency in the drum is 90% to 95% for silver and 30% to 50% for other metals. All residual ferric is converted to ferrous. Barren solution exiting the drum (after thickening to remove suspended precipitate) is sent to the plant feed section where it is slurried with new ore to begin the process again, or it is returned to tailings.

The precipitated metals exit the drum as a fine suspension in the process solution. The metal powder is flocculated, thickened, and filtered. An average of 1500 kilograms of filter cake is produced per day. This

cake contains about 6% silver, 20% antimony, 20% lead, 10% copper, and 1% to 3% each of bismuth, arsenic, and iron. The remaining 38% of the cake consists of mineral fines (silica and silicates) which escape the tailings filtration circuit.

Pyrometallurgy

The metal precipitate, which is in the form of a damp filter cake, is dried in a gas-fired tunnel oven. It is then briquetted using a roll-type briquetting press to form cylindrical briquettes approximately 6 millimeters in diameter and 25 millimeters long. Briquetting is necessary because damp bulk metal powder can explode if placed in a hot furnace. The briquetting process creates sufficient porosity to prevent the buildup of steam which accelerates the oxidation to explosive rates.

The briquettes are melted and partially refined in a reverberatory furnace using sodium carbonate (trona), borax, and charcoal. Arsenic, iron, non-metallic impurities, and a portion of the antimony are removed in the slag. Some antimony is removed as baghouse fume which is recycled. The furnace, 1.2 meters wide and 1.8 meters long, can smelt one tonne of precipitate in a ten-hour campaign.

The "reverb metal" typically assays 20% silver, 20% copper, 30% lead, and 30% antimony. This metal is transferred to a cupel furnace where it is blown with air. Crude antimony oxide is produced and collected in bag filters. During a two to four-day campaign, the silver content of the metal in the cupel increases from 10% silver to 95% silver. The final bullion assays 95% silver, 5% copper, and less than 0.2% of any other

metal. Antimony is fumed off and collected as antimony trioxide in a baghouse. Copper and lead form a slag which is re-dissolved for copper recovery; slag residue is recycled to the reverberatory furnace.

Approximately 30 tonnes of slag per month are generated in the reverberatory furnace. This slag contains about 15% of the silver entering the furnace, in the form of impure metal as small prills dispersed in the slag. This slag contains about 15% of the silver entering the furnace, in the form of impure metal as small prills dispersed in the slag. This material is currently sent to a local outside contractor, who grinds and concentrates in on a gravity table. Table concentrate, containing about 75% of the silver in the slag, is returned to the reverb. Tests indicate that the slag can be floated to recover about 90% of the contained silver. Currently, the final slag loss amounts to about 2.5% of the silver entering the plant; this is the only refinery loss.

Acid Plant

In September 1999, a Hargreaves Process plant was commissioned to make hydrochloric acid on site. In this plant, briquettes of salt (sodium chloride) are reacted at 600°C with sulfur dioxide gas (made by burning sulfur), air, and water vapor to produce HCl vapor and sodium sulfate. The hydrochloric acid vapor is absorbed in the barren plant solution to raise the level of hydrochloric acid to the normal 10 grams per liter operating level.

Once the acid plant is operating at its full design level, acid costs will drop from \$90,000 per month, using imported acid to \$30,000 per month. The plant

Figure 4. Precipitation drum and precipitate filter. Two tonnes per day of scrap iron are added to the discharge end of the drum. Drum discharge is pumped to a thickener behind the plant and the thickened metal slurry is filtered in the foreground filter.



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currently runs at about 60% of the design level. The salt/SO₂ reaction is a function of temperature, catalyst addition, and briquette permeability, all of which are being optimized. Low temperature is the main reason for the current performance shortfall, with installation of additional gas heaters planned.

By-Products

By-products include copper, lead, antimony, tin, and sodium sulfate. Depending on the relative market prices for these materials, the value of these by-products is equal to between 20% and 30% of the value of the recovered silver. Zinc and bismuth could be recovered economically, but there is very little of either in the Itos feed material.

Copper

Approximately 120 kilograms of copper per day is recovered in the metal precipitate and is transferred to the pyrometallurgical plant. There, when concentration in the cupel furnace slags, it can run as high as 20% copper. Copper is currently recovered by dissolving the slag in hydrochloric acid to produce a concentrated cupric chloride solution. This solution is sold as a flotation reagent.

Antimony

Approximately 1000 kilograms of antimony per day is recovered in the metal precipitate and reports to the baghouses in the pyrometallurgical plant as impure antimony trioxide. Future plans include a two-stage volatilization furnace to produce a marketable-grade antimony trioxide. Currently, the baghouse dusts are recycled to the reverb furnace and the antimony is stored as high grade slag.

Lead

The majority of the lead, about four tonnes per day, reports as crystalline lead chloride in the first stage of solution purification following the tailings filters. This material is currently stored in a lined pond. Future plans include a smelting furnace to directly reduce the lead chloride metal. Bench-scale tests indicate the resulting lead will be market-grade without further purification.

Tin

Approximately one kilogram of tin per tonne of ore enters the leach solution, primarily from the oxidation of silver-tin sulfides. Tin is not precipitated by the scrap iron in the precipitation drum. Laboratory tests indicate that the tin can be recovered by solvent extraction and precipitation of a high grade tin oxide. Although the value of tin, exceeding US\$5.00 per tonne of ore, is significant, the technology is considered a bit complicated, so detailed design and cost studies have not yet been undertaken.

The ore contains about five kilograms per tonne of tin as cassiterite (tin oxide), which is not leached. Unfortunately, it does not appear possible to achieve a high recovery or a high grade concentrate, by either gravity concentration or flotation.

Sodium Sulfate

Sodium sulfate is a by-product of the hydrochloric acid plant. It can be recovered in commercial form by a single-stage dissolution and recrystallization process, followed by filtration and drying. Currently it is being stockpiled.

ENVIRONMENTAL BENEFITS

The process system is designed for zero discharge and all process solutions are continuously recycled. At the end of the operation the new tailings pond will be sealed with a PVC and earth cover. The feed material, the "Itos tailings," now exists as an exposed mound of oxidizing pyrite. Transfer of this material to the new tailings pond will result in a significant, permanent improvement of the environment in the southern part of the city of Oruro.

ECONOMICS

Total capital cost of the physical installations including civil works, infrastructure, and construction management services, was about US\$9,000,000. Capital costs were higher than expected and startup was longer than expected. This resulted in a chronic shortage of startup and operating capital which prolonged the startup period. Total capital invested through the end of 1999 including startup capital and financing costs has been \$17 million.

Operating costs in late 2000 were about \$27.00 per tonne of ore treated, or \$5.20 per ounce recovered. Once acid consumption is optimized and by-product facilities are in place, operating cost (with by-product credits) will be below \$3.20 per ounce.

STAFFING LEVELS & COSTS

Total staffing including the acid plant is 210 personnel, including: 140 operators and operating foremen (35 per shift), 50 maintenance personnel, 10 support (office and lab) personnel, and 10 Bolivian engineers/senior managers. Skilled operators and mechanics earn Bs1100 per month, including fringe benefits, equal to US\$160 per month.

CONSTRUCTION EXPERIENCE

Equipment and piping installations were done under the supervision of a team of five U.S.-based KCA engineers and a senior Bolivian engineer, with a staff of 35-50 Bolivian employees. Bolivian-based subcontractors were used to erect buildings and to

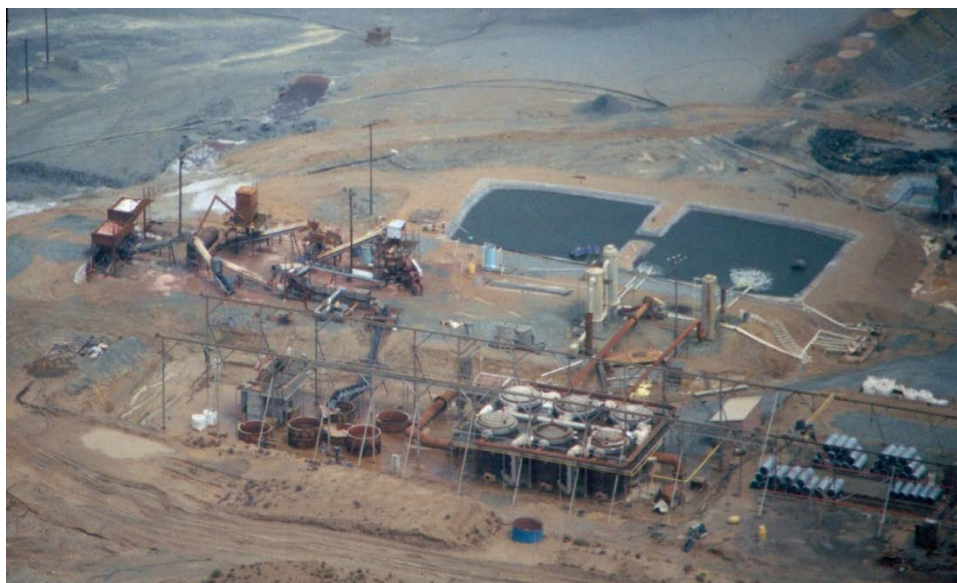


Figure 5. Hargreaves process plant for making hydrochloric acid. The salt preparation facility can be seen on the left. It consists of feed bins, a dryer, a hammer mill, and a briquetting machine. The six Hargreaves reactors containing 12 tonnes each of briquetted salt can be seen in the foreground. The process plant chlorine addition facility, which uses one-tonne tanks, is shown on the right.

provide specialty services such as electrical installations, tank coatings, and installation of natural gas distribution systems. The performance of Bolivian workers and subcontractors has been excellent.

TIME SCHEDULE

Laboratory testing to develop the process (based on an extensive history of chloride process evaluations) was begun in early 1992 and continued until mid-1993. The feasibility study was completed in October 1993. Financing was completed in early 1994, and detailed engineering design began at that time. Groundbreaking for the civil works and buildings took place in December 1994. Installation of equipment began in mid-April 1995. The plant achieved startup in March 1995, and reached full tonnage throughput in September

1998. As of late 2000, the process had not yet reached percent recovery targets due to economic restrictions on acid consumption. By-product facilities still need to be installed.

CONCLUSION

The Itos plant is one of the few commercial attempts to treat a low value silver and base metal ore (with recoverable metal content of less than \$40 per tonne) using the chloride lead process. Technically, the project has developed with very few surprises. Economically, the project has developed slowly, but experience indicates that it will be able to achieve commercial success.