Milling and Cyanidation at Pachuca

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Developments in Cyanidation, 1907 to 1934

The Compañía de Real del Monte y Pachuca started a 10-ton pilot plant in March, 1906. The distinctive features of the first cyanide installations at Pachuca were: grinding in cyanide solution, all-sliming and filtration of ore in which silver constituted the major value.

Loreto started with a 300-ton "all-sliming" plant, using jaw crushers, grinding in stamps, Chilean mills and pebble mills in cyanide solution, concentrating with Wilfley tables and Johnson vanners, classification by cones and Dorr classifiers, intermittent thickening by decantation, mechanical agitation in flat tanks by stirrers and centrifugal pumps, filtration in Butters filters and precipitation by zinc shavings. The "San Francisco" mill No. 1 was contemporaneous, using a rather similar flow sheet. We shall trace the main developments in the three large mills of the district to their present practice.

Developments in Large Mills of District

Crushing and Grinding.—The trend of development in this part of the work has been the same as throughout the milling world; viz., an increase in the degree of comminution of the ore in dry-crushing machines, the advance from pebble mill to rock mill and then to ball mill and the elimination of the stamp battery through the encroachment upon its field on the one side by finer dry crushing and on the other by more efficient wet grinding.

The single-stage crushing in jaw type crushers, used at the start, has been replaced by two stages; at first, both stages by gyratory type and later the present practice, which is the same in all three mills, consisting of gyratory as primary followed by cone as secondary and delivering a product that may be rated at ½ to 1 inch.

Primary wet grinding, at first performed by stamps and Chilean mills, is now by ball and/or rod mills; present practice differing widely in the three mills. Santa Gertrudis uses a 7 by 15 ft. rod mill, San Rafael

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uses one rod mill 5 by 10 ft. in parallel service with one ball mill 6 by 8 ft. Loreto uses large-diameter peripheral-discharge grate-mills in parallel service with center-discharge mills of smaller diameter, all using balls.

Secondary wet grinding has always employed the tube mill, but the grinding media have been successively pebbles, mine rock, iron or steel balls. Peripheral-discharge rock mills were used on this service at Loreto, which at one time practiced three-stage wet grinding. Present practice differs mostly in the character of the balls used, San Rafael employing a local, white-iron ball, Santa Gertrudis a local, cast-steel

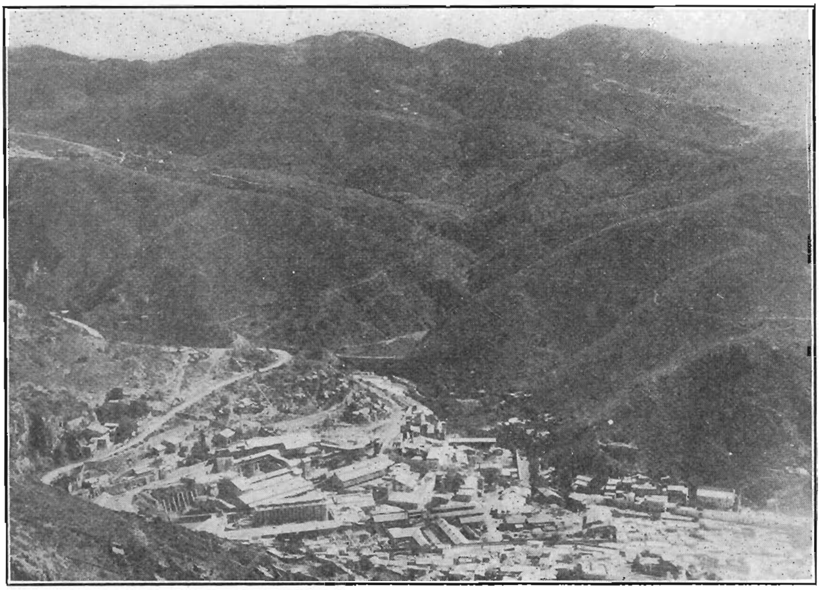

FIG. 1.—BIRD'S-EYE VIEW OF LORETO.

ball made in an electric furnace, and Loreto purchasing a tempered forged-steel ball.

Classification.—Dorr classifiers were introduced at the start of cyanidation and are the exclusive means of classification today. Cones were continued in use for some years. Esperanza drag classifiers and Callow screens found application at Loreto for some time.

Thickening.—When the first cyanide mills started operations the charges were thickened by settling and decantation, a three to one pulp being the usual result. In 1908 the San Rafael mill started with the first Dorr thickeners and was soon followed by the other mills.

Concentration.—The early practice stressed gravity concentration to the point of recovering as much as 37 per cent of the silver and 33 per cent of the gold with a concentration ratio of 50 to 1. Santa Gertrudis mill, built in 1911, did not provide for concentration. San Rafael discontinued concentration in 1913, and Loreto in 1921.

Flotation has been given fairly thorough trials, but has not succeeded in equaling the economic results of cyanidation.

Agitation.—The first agitation was mechanical, using stirrers and centrifugal pumps to circulate the pulp through relatively low, large-diameter tanks, referred to as "flat tanks." The importance of more air was soon recognized and the Brown agitator, using an air-lift instead of a centrifugal pump, was introduced in 1907 at the San Francisco mill and gained rapid favor under the name of "Pachuca tank." At present, much of the compressed air is introduced through perforated rubber or canvas diaphragms.

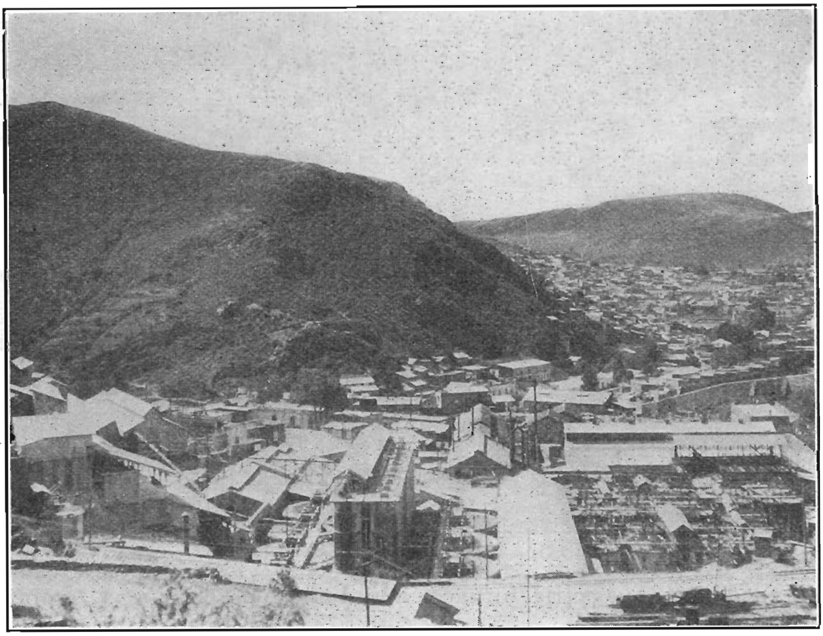

FIG. 2.—LORETO IN 1934.

Thin pulps, 3:1, were used at first. The Dorr thickener made a one to one pulp available, and that dilution is in use today. At first, the individual tanks were operated on charges or batches. The present continuous flow through a series of agitators was begun in 1911.

High lime, practically saturation, has always been carried and cyanide strengths have varied from 0.15 per cent to 0.35 per cent NaCN, depending on grade and character of ore.

Filtration.—Loreto originally installed Butters vacuum filters; San Rafael, the Moore vacuum filter and Santa Gertrudis, Merrill sluicing filter presses. Loreto and San Rafael have not changed their types of filters; Santa Gertrudis, when enlarging its capacity in 1920, installed

Butters filters ahead of the Merrill presses, thereby gaining a more efficient double filtration but at increased cost.

Clarification.—At the start, solutions were not clarified and precipitates were correspondingly low in grade. The first efforts to remedy this were by means of sand clarification, which progressed to present practice of either pressure or vacuum-type filtration.

Precipitation.—The Merrill zinc-dust process was a feature of the new Santa Gertrudis mill, started in 1911, and it rapidly replaced the original

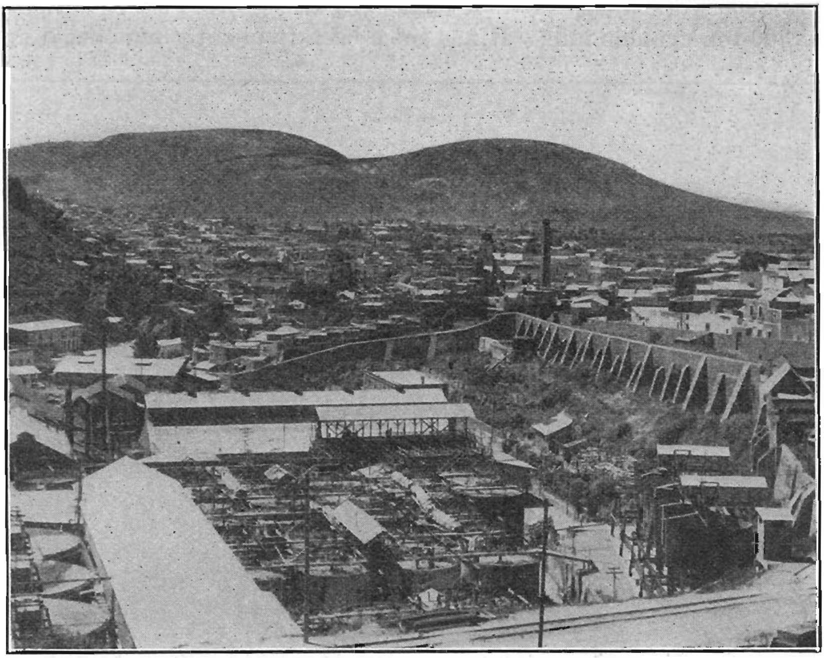

FIG. 3.—LORETO IN 1934.

zinc-shavings precipitation in the other mills. The Crowe vacuum treatment was started in 1918. Zinc dust, emulsified in a small stream of barren solution, is pumped into the stream of pregnant solution coming from the main pumps. Loreto uses centrifugal pumps for both of these services while the other mills use plunger pumps.

Melting Precipitate.—Melting was first done in graphite crucibles, then in tilting furnaces, and finally in oil-fired reverberatory furnaces. Both aluminum dust and electrolytic precipitation were tried and abandoned.

Cyanide Regeneration.—In 1924, cyanide regeneration was introduced at both the Santa Gertrudis mill and the Guerrero mill of Compañía de Real del Monte y Pachuca, accomplishing a considerable saving in the mechanical loss of cyanide.

Compared to the earlier processes, cyanidation has demonstrated the following advantages: lower operating costs, much higher gold recovery, and adaptiveness to a wider range of ores.

The district has a comparatively small tonnage of refractory manganese ores, upon which considerable pilot-plant work has been done using SO_2 and the Caron-Clevenger reduction. So far these special treatments have not proved economically justifiable.

Loreto Cyanide Mill, 1934 Operations

In 1906 work was started on converting Loreto from a 150-ton patio to a 300-ton cyanide mill. It has since been frequently remodeled and

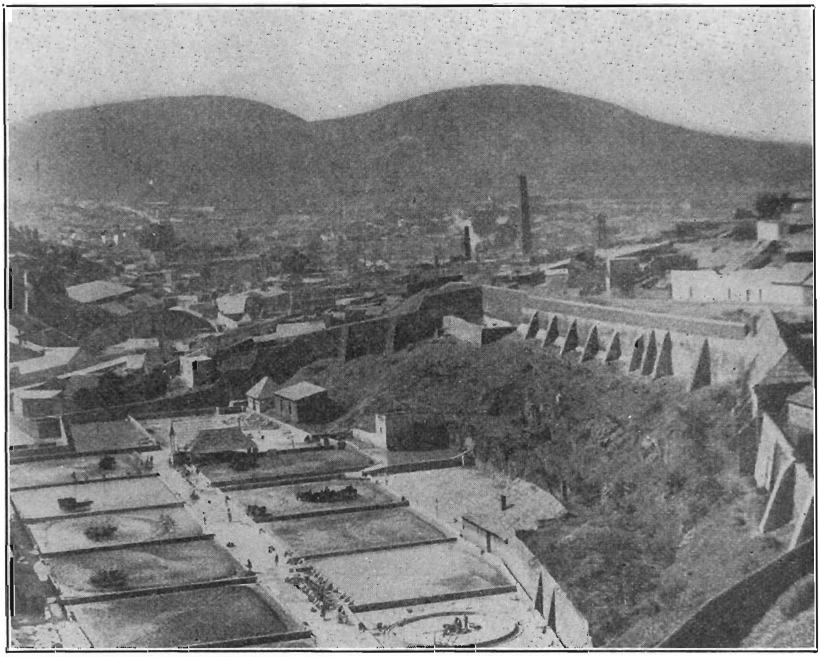

Fig. 4.—Loreto horse patio in 1891.

enlarged, and today it is the world's largest silver-cyaniding plant. The mill site is hemmed in by mountains and the city of Pachuca, but it is conveniently situated for ore delivery from various mines. Much ingenuity has been required to effect enlargements within the original walls and without interrupting operations.

Crushing.—The crushing plant operates six days per week and 22 hr. per day, at an average rate of 200 tons per hour. The mine ore, maximum size 12 in., passes over a Miami grizzly, 40° slope, 4-in. clear openings. The oversize is crushed to a 4-in. product in a 20-in. Traylor gyratory crusher, belt-driven by 100-hp. motor using 28.5 hp. Cost of

TABLE 1.—*Grinding Data*

	Primary Grinding		Secondary Grinding	
Type mill	Grate	Trunnion	Trunnion	Trunnion
Make	Marcy	Traylor	Traylor	Local
Size, ft.	8 × 6	6 × 12	6 × 10	5 × 10
Number in operation	3	4	8	8
Horsepower per mill, installed	225	150	150	75
Horsepower per mill, used	246	160	134	77
Speed of mill, r.p.m.	23.2	23.1	23.1	28.0
Breast liners: material	Mn steel[a]	Mn steel[a]	Iron	Iron
Kg. per set	9650		10,000	7,300
Life, days	160	300	250	365
Grate bars, kg. per set	1560			
Chrome steel life, days	180			
Feed end liners: material	Mn St	Iron	Iron	Iron
Kg. per set	2259	1360	1360	820
Life, days	190	120	250	350
Classifiers: size, ft.	6 × 22	6 × 22	8 × 22	6 × 22
Strokes per minute	27.2	27.2	22.6	20.3
Per cent solids, overflow	64	64	20	20
Balls: size new, in.	5	5	2¾	2¾
Consumed per ton feed, kg.	0.662	0.647	0.732	
Original feed, tons per day per mill	660	450	310	165

SCREEN ANALYSIS, PER CENT

Mesh		Original Feed to Primaries	Product of Primaries, or Feed to Secondaries	Final Product of Secondaries
On				
Inch	1.050	7.36		
	0.742	23.50		
	0.525	24.03		
	0.371	15.38		
Mesh	3	7.68	0.43	
	4	6.21	1.36	
	6	3.44	2.38	
	8	2.36	4.10	
	14	2.92	19.37	
	28	1.97	19.61	
	35	0.29	6.46	
	48	0.69	6.82	2.20
	65	0.53	4.41	7.90
	100	0.55	5.46	9.17
	150	0.55	4.73	13.13
	200	0.29	3.01	8.09
Through 200		2.25	21.86	59.51

[a] Scrap manganese-steel liners weigh 36 per cent of original weight.

supplies, including liners and mantles, is ₱0.011. (Costs, unless otherwise stated, are on a basis of total metric tons of ore milled and not on tons through the particular machine.) The product from the primary crusher, combined with the undersize of the first grizzly, passes over another grizzly of 40° slope, 2-in. clear openings, oversize direct to secondary crushers, undersize to a Traylor vibrating screen, 4 ft. by 6 ft. 6 in. with 1¼ by 1¾-in. clear openings, the oversize going to secondary crushers and undersize to fine-ore storage. Secondary crushing is performed by two Symons cone crushers, 5½ ft., set to give a ⅞-in. product, each driven by a 225-hp. motor through V-belt drives using 172 hp. each. Mantles and bowl liners are of manganese steel. The mantles weigh 1850 kg. new and 700 kg. worn, and last 85 days. The bowl liners weigh 2200 kg. new and 800 kg. worn, and last 87 days. Supplies, not including liners and mantles, cost ₱0.036 per ton, the main items being repair parts, oil and zinc.

Weighing and Sampling.—After secondary crushing the entire ore stream comes together on a 42-in. belt conveyor, inclined 18°, speed 310 ft. per min., passing over a Merrick weightometer having a capacity of 300 tons per hour. This weightometer is checked both by usual chain method and by passing weighed tonnages of ore over it. The ore stream is sampled by a chain-bucket cutter; the sample is successively cut by another chain-bucket and by two Snyder samplers, passing two sets of rolls for size reduction. The final sample is reduced by riffles and sample grinders.

Grinding.—Two-stage grinding in cyanide solution is practiced and two types of primary and secondary mills are in use. The principal data for both primary and secondary grinding will be found in Table 1.

Tempered steel balls are now used in both primary and secondary grinding. The first efforts to use tempered balls in 1932 were immediately successful with the small balls used in the secondaries, but the large balls used in primaries required a longer time to work out a successful technique. There is still considerable breakage of the large tempered balls, but these are now worked up by forging into small balls in our own shop at low cost. The consumption of steel balls before tempering and the present consumption of tempered balls is given in Table 2.

TABLE 2.—*Consumption of Balls*

	Consumption of Balls, Kg. per Ton	
	Untempered	Tempered
Primary mills	0.816	0.656
Secondary mills	1.240	0.732
Total ball consumption	2.056	1.388

Pulp Elevation.—In the remodeling and enlargements of 1929, local conditions made it impossible to obtain a gravity flow from primary to secondary milling and these departments had to be located on the same level and some distance apart. The pulp from the primary classifiers is pumped by one 8-in. Wilfley pump, V-belt driven by a 75-hp. motor, through a 10-in. pipe 196 ft. long. The screen analysis of material handled is given Table 1 under Product of Primaries. The pump handles 3800 tons solids and 2600 tons solution, or total of 6400 tons, pulp per day. The specific gravity of pulp is 1.55, so the pump is handling 757 gal. per min. The lift is 42 ft., which makes the static head 65 ft. of water, and the friction head is 23 ft., making a total head of 88 ft. The average continuous horsepower consumed is 72½ and the speed of pump is 810 r.p.m. All wearing parts are of white iron cast at Pachuca; runners last 7 days, follower plates 5.4 days and casings 30.5 days. Operating costs, exclusive of labor, amount to ₱ 0.012 per ton of ore.

Thickening and Agitation.—The pulp from the classifiers of the secondary grinding circuit is thickened to 48 per cent solids in nine thickeners, 48 ft. 9 in. by 15 ft. 3 in.

Two types of agitators are in use. The Pachuca, or Brown, agitator has been retained because of limited floor space, although showing higher operating costs than the flat agitators which have been used for all increases in agitation capacity. The flat agitator is a tank equipped with a Dorr thickener mechanism and air jets.

Total agitation capacity now consists of 20 Pachuca tanks, 15 ft. in diameter by 60 ft. high and 30 flat tanks, all of which are 30 ft. in diameter, 18 being 20 ft. high and 12 being 24 ft. high. The Pachucas are operated as two circuits and the flats as three. The compressors used to supply air for agitation have a total displacement of 13,550 cu. ft. per min. The Pachucas consume 290 cu. ft. free air per min. per tank at a pressure of 35 lb. per sq. in. and the flats consume 260 cu. ft. per min. per tank at 18 lb. The time of agitation is 73 hr. in the Pachucas and 70 hr. in the flats. The cost of air for agitation is ₱ 0.147 per ton of ore.

A study of the consumption of oxygen shows that 210 grams is consumed in agitation for the dissolution of 292 grams silver per ton of

TABLE 3.—*Free Air Supplied at Pachuca*

	Free Air Used per Dry Ton Slime, Cu. Ft.	Utilization of Oxygen, Per Cent
Pachuca agitation	7850	0.49
Flat-tank agitation	4070	0.96
Laboratory-bottle agitation	335	11.5

ore. This is 9.75 times the amount called for by Elsner's equation. To supply this amount of oxygen would require 38½ cu. ft. free air at Pachuca. The amount of air actually supplied per ton of ore in three different types of agitation is shown in Table 3.

To produce the same tail assay, the Pachucas require 73 hr., the flats 70 hr. and the laboratory bottle 36 hours.

About 35 per cent extraction is obtained in milling and thickening and 55 per cent in agitation, both referring to content of the original mill heads.

Aero brand cyanide, known locally as "surronide," is dissolved in barren solution to make a strong solution and this is added to the agitator heads in amount sufficient to bring them up to a strength of 0.25 per cent NaCN. Litharge is added to the cyanide in the dissolving tank to eliminate the soluble sulfides contained by the surronide. The addition of surronide amounts to 1 kg. equivalent NaCN per ton of ore and the cyanide recovered in the regeneration plant and returned to the mill solutions amounts to 0.62 kg., making the total consumption, without regeneration, 1.62 kilo NaCN per ton ore.

The consumption of lime is 6.0 kg. per ton ore. This lime is burned locally in vertical shaft furnaces, the product containing 70 per cent water-soluble alkalinity in terms of CaO. Each ton of lime produced requires 1.85 tons of limestone and 0.16 ton coke.

Filtration and Clarification.—Filtration is performed in six Butters vats containing a total of 1120 leaves each 67 by 117 in. giving 115,000 sq. ft. filtering area. Each vat averages 11 cycles per day of 128 min. each, leaving 32 min. per day lost time. The average cake is ⅞ in. thick and represents 0.308 ton dry slime per leaf. The cycle of 128 min. is divided into 20 min. for caking, 44 min. for barren wash, 5 min. for water wash to mill and 30 min. for water wash to regeneration, the remaining 29 min. being required for the various fillings, transfers and discharging. A vacuum of 18-in. mercury is maintained and each leaf passes about 0.01 ton solution or water wash per minute.

Each filter vat is operated by its individual wet vacuum pump. One dry vacuum unit was later installed for use on any one of the six vats, thereby avoiding filter delays while repairs are being made on wet vacuum pumps. This dry vacuum unit is superior to the wet system in faster caking, higher vacuum at all times and ease and simplicity of operation. The dry vacuum is supplied by one Ingersoll-Rand, type ER-1, 18 by 7-in. pump, operating at 350 r.p.m., piston displacement of 720 cu. ft. per min. and driven through V-belts by a 25-hp. motor. The pump is somewhat more than ample to operate one of the larger vats of 260 leaves and maintain a vacuum of 20 in. of mercury.

Filter leaves are cleaned by rotating brushes, and acid-treated every nine days in sulfurous acid of a strength equivalent to 12 kg. hydrochloric per ton, time in acid being 16 hr. Sulfurous acid was substituted for hydrochloric, eliminating the use of 0.26 kg. of 20° Bé. HCl per ton of ore. The sulfurous acid is made in a small tower in the regeneration plant through which the acid solution for the filter plant circulates and meets a great excess of SO_2 gas, the excess escaping to the acidification circuit of the regeneration plant. To prevent fouling, a constant amount of acid is bled from the acid-treating vats into the regeneration circuit and thus becomes effective in the acidification of the regeneration solutions. The consumption of sulfur is insignificant.

Clarification is performed in 11 Sweetland presses having a total area of 5080 sq. ft. filter leaf, the duty being 2.25 tons solution per day per square foot of filter area. Presses are discharged twice and cleaned once per 24 hr. and leaves are acid-treated every 10 days.

Precipitation.—Approximately three tons of solution is precipitated per ton of ore. Crowe vacuum system and Merrill presses are used. A departure from usual practice is the use of centrifugal pumps instead of plunger pumps for forcing the solution through the presses. The pumps used have been designed to give a relatively flat horsepower curve for their entire range of head capacities. Much pump and press trouble, due to the danger of the old system exceeding safe working pressures, has been eliminated. With the present system, pressure at the presses automatically regulates itself from 30 lb. minimum to 40 lb. maximum. In this range the pump efficiencies are 82 per cent.

The average consumption of zinc dust is 630 grams per kilogram of silver precipitated. Average analysis of the dried precipitate is:

	Per Cent		Per Cent
Silver	83.00[a]	Cu	0.10
Gold	0.46[b]	Insol	5.50
Fe	0.50	CaO	4.30
Pb	1.50	Se	0.25
Zn	2.20		
		Total	97.81

[a] 830 kg. per ton.
[b] 4.6 kg. per ton.

Moisture in undried precipitate is 32 per cent.

Cyanide Regeneration.—The mechanical loss of cyanide is reduced by means of cyanide regeneration. After the usual washes of the filter cake, including the permissible water wash to mill, the cake is given a further water wash of 30 min. and the values of cyanide and precious metals contained in this solution are removed in the regeneration plant, the cyanide being returned in a water-free form to the mill solutions; the silver and gold, as well as quantities of copper, are recovered in the form of a precipitate, which is shipped to the smelter.

The treatment of the solution is: (1) acidification with sulfur dioxide to neutralize lime and convert the cyanides to hydrocyanic acid, (2) vaporization of the hydrocyanic acid from this solution by means of a large current of air, (3) absorption of the hydrocyanic acid carried by this current of air in the regular mill solutions, (4) addition of zinc dust to precipitate the gold and (5) recovery of the precipitate of gold, silver and copper by means of filtration.

The regeneration plant treats 110,000 tons solution per month carrying 750 grams NaCN and 7 grams silver per ton. The tails assay 70 grams NaCN and a trace of silver. The consumption of sulfur is 2500 kilos per day and includes that used to make acid for the treatment of filter and clarifier leaves in the cyanide plant.

The cost per kilo of NaCN recovered is ₱0.22 without credit for leaf-treatment acid or for precious metals recovered.

Tailings Disposal.—Tailings leave the mill with 2.9 parts solution to one of ore and enter an 18-in. clay sewer-pipe line laid beneath the bed of the river, minimum grade 0.5 per cent. Emerging from the river at the lower end of the town of Pachuca, the tails are transported to one 8-in. Wilfley pump at the dam by means of an open ditch and then a flume 28 in. wide by 22 in. high, grade 0.35 per cent. Some solution is recovered from the dam by decantation and run through zinc boxes to recover the precious metals.

Having reached a height of 15 meters, the older parts of the dam have been abandoned for some time and dried out. During the windy season a great deal of dust arises from this part of the dam and considerable work has been done in an effort to abate this nuisance. The slopes have been planted with grasses and weeds and the top has been covered with a clay slime, classified from the tails. This slime dries, cracks and hardens into a suitable capping to reduce dusting.

TABLE 4.—*Loreto's Consumptions of Major Supplies, per Ton of Ore*

Cyanide purchased, in terms of kg. equivalent NaCN	1.00	Power, kw-hr., crushing and grinding	17.7
Grinding balls, kg.	1.39	Cyanidation, air	5.3
Zinc dust, kg.	0.26	Cyanidation, other	7.4
Lime, kgs.	6.00	Miscellaneous	1.4
Sulfur, kg.	0.66		
Labor, man-shifts (₱4.50 per 8 hr.)	0.11	Total	31.8

Recovery.—Recoveries in the district depend on economic considerations of metal prices, exchange rate, cost of cyanide and power, as well as on such refractory constituents of the ore as pyrolusite and excessive base sulfides. On "clean ores" the recovery reaches 93 per cent silver and 95 per cent gold. On heads of 400 grams silver and 2 grams gold, the present recovery in the district is about 90 per cent silver and 92 per cent gold.

Consumption of Supplies and Costs.—Loreto's consumption of major supplies, including labor and supplies, is given in Table 4.

FIG. 5.—SILVER BARS AND ANODES IN REFINERY AT LORETO.
1,500,000 oz. in sight (about 20 days production at refinery).

Because of Loreto's disparity in capacity, it is thought more appropriate to cite present costs in one of the smaller cyanide mills of the district (Table 5).

TABLE 5.—*Costs at a Small Cyanide Mill in the Pachuca District*
400 TONS PER DAY

	Pesos per Ton		Distribution, Pesos per Ton
Crushing and grinding	1.27	Labor	1.38
Cyanidation	1.75	Supplies	2.04
Precipitation and melting	0.30	Power	0.72
Water supply	0.14	Miscellaneous	0.24
General expense	0.92		
		Total	4.38
Total	4.38		

The prevailing rate of exchange in 1934 was 3.60 Pesos per U.S. dollar.