Production of Gold

Background

A feasibility study on the production of gold at a fictitious mine (Moapa mine) in Elko County, Nevada is to be performed. The mine is capable of producing 325,800 tons of high-grade ore per year for 8 years. The deposit contains 0.12 ounces of gold per ton of high-grade ore and can be acquired at a cost of $10 per ton of ore (cost of mining ore at site). A sodium cyanide process is used to extract the gold from the ore, and various other processing techniques are used to produce 99.9% pure gold bullion from the ore.

The results of the feasibility study show that the ore can be processed by agitation leaching, which is preferred over heap leaching due to the low recovery associated with the heap leaching technology. The problem is to find the break-even price of gold for this mining operation. The process is currently unprofitable with a gold price around $300 per ounce.

Process Description

<u>Unit 100 – Size Reduction of Ore</u>

The BFD of the overall process is shown in Figure 1. The PFD for Unit 100, shown in Figure 2, is designed to reduce 41.5 tons/hr of gold ore from a feed range of 2-5” to 160 microns. The mined ore is fed using a Grizzly Feeder, F-101, into a Jaw Crusher, J-101, where 80% of the ore is crushed to 1.75” or smaller. The remaining 20% are recycled back into F-101 (not shown on PFD).

The ore is then sent to Screen S-101 where the ore that does not pass through the first deck is sent to the Standard Cone Crusher SC-101. Ore passing through the first deck but not the second deck is sent to the Shorthead Cone Crusher SHC-101, while ore passing completely through is sent to the Ball Mill B-101.

The ore passing through the first deck is sent to a Standard Cone Crusher, SC-101, which has a closed-side setting of 0.5”. Within this crusher, the ore size is further reduced to 80% passing at 0.5”. The ore leaving the SC-101 along with the second deck ore is then sent to a Shorthead Cone Crusher, SHC-101, where it leaves the equipment with 80% passing at 0.2” or less.

The ore from SHC-101 is sent back to the Screen S-101. The screen has a 0.5” sieve opening for the first deck while the second deck is 3 mesh, where all particles at or below 0.25” are sent to the grinding section for further size reduction. The screen deck oversize, consisting of particles over 0.25”, is recycled back to SC-101.

The Ball Mill, B-101, grinds the 0.25” ore until it is in the range of 160 microns. The ore leaving the ball mill is sent to six hydrocyclones that separate the larger particles from the smaller particles. The top stream leaving the cyclone is 75% of the feed into it. This top product is 160 microns or less. The bottom stream is recycled back to the ball mill.

Unit 200 - Leaching

The sub-millimeter particles from Unit 100, Stream 15, are now mixed with a dilute aqueous solution of sodium cyanide, Stream 16, and a recycle stream, Stream 20a, from Unit 400. The resulting slurry, Stream 18, is fed into large mechanically stirred tanks where it is agitated with air. Here, leaching occurs, and the gold is transferred from the ore and forms a gold-cyanide complex. The complex is then sent to Unit 300 as Stream 19 where it is filtered.

Unit 300 – Filtering

Filters following the agitation leach are designed to separate the spent ore from the leachate. The filter section consists of 4 multi-compartment rotary drum vacuum filters in series. The spent ore is left behind on the filters and the gold remains in the leach filtrate.

Unit 400 – Carbon Adsorption and Elution

The adsorption of gold from the pregnant leach solution onto the activated carbon is the key step in the recovery process. This recovery begins when the leach filtrate is sent to the carbon columns, CIC-401, via Stream 29. Gold is adsorbed onto the activated carbon. The filtrate is then sent to the elution vessel, V-401, where the elution process begins. The gold is eluted into a water solution from the carbon by the American-Anglo Research Laboratories (AARL) method, leaving the barren carbon behind. Figure 5 shows the carbon adsorption and AARL elution processes. The loaded eluant, Stream 37, is then sent to the electrowinning cells and subsequently to the refining process.

Unit 500 – Electrowinning and Refining

Electrowinning Process

In the electrowinning cells the gold is deposited onto steel wool cathodes. An article about an electrowinning process at the Masbate Gold Mine gives information on how to establish a base-case design[1].

Refining Process

The overall refining process is shown in Figure 6. In the acid dissolution chamber, AD-501, a 10% sulfuric acid solution is added to the loaded steel wool cathodes at 60°C in order to oxidize the excess iron present to a soluble form. Hydrogen gas must be vented to a flare throughout the batch reaction's 12-24 hour residence time, and the acid solution with the dissolved iron must be drained and treated.

The calcination step of refining consists of spreading the loaded steel wool cathodes into thin trays and heating with excess air at 600-700°C for 12-18 hours in order to oxidize the remaining base metals. Using an economizer, E-501, the inlet air can be preheated by the exhaust gas from the smelter. This minimizes energy requirements for the calcinator. The outlet air is scrubbed to remove any gaseous oxidized metals. If a mercury retort is used, it can take the place of the calcination by heating the loaded steel wool to 600-700°C at a slightly negative pressure for 2-3 hours. This will remove the mercury as well as oxidizing the base metals in the cathodes[2].

The smelting step of refining consists of heating the loaded steel wool to melt the gold at 1300°C, with fluxes of silica, feldspar, and borax, to remove impurities. Complete separation occurs within 1.5 hours, at which point the slag is poured off and the molten gold is poured into anode casts and cooled. The anodes are approximately 99% pure and are submerged with 99.9% pure rolled gold cathodes in an electrolytic solution with 100g/L each of gold and hydrochloric acid. A current density of 800 A/m^2 is applied at 60°C, and the gold collected on the cathodes is rinsed several times with a hot sodium thiosulfate solution before the 99.9% pure cathodes are melted and recast as final products.

Unit 600 - Waste Treatment and Tailings Disposal

Waste Treatment

All cyanide and sodium hydroxide is recycled back into the leaching section. The hydrochloric acid leaving the elution vessel is the only solution treated. The HCl is neutralized by adding limestone to raise the pH from 3.0 to 7.0.

Tailings Impoundment

The design consists of two units, both helping to ensure that no seepage penetrates through the liners and enters the ground water. The main unit in this design is the impoundment area where 44 acres of land are used to store the hazardous filter cake. The liner system employed by this unit consists of a geotextile layer, a sand drain layer, a high-density polyethylene (HDPE) liner, and a clay layer. A monitoring well was also included in the design in order to determine the amount of seepage through these layers.

The second unit involved with this design is the leachate collection pond. This unit is considerably smaller than the impoundment area and is used to collect any seepage that collects in the drainpipes of the impoundment unit and any rainwater that runs down the embankment. The liner system associated with the leachate collection pond, however, actually provides better containment than the impoundment section because liquids increase the leakage value of liners. This liner design consists of a geotextile layer, two sand drain layers, two HDPE liners, a clay layer, and a monitoring well. Any seepage that gets collected in these drainpipes is then sent to the waste treatment unit.

Necessary Information and Simulation Hints

Gold is leached from ore by a dilute aqueous solution of sodium cyanide. The overall reaction thought to be mostly responsible for this is

$$2Au + 4CN^- + O_2 + 2H_2O \rightarrow 2Au(CN)_2^- + 2OH^- + H_2O_2 \quad (1)$$

This reaction was modeled as a shrinking core in a spherical particle with large pores. The rate determining step is the mass transfer of reactants through a fluid film around the particle and then through the ash layer of leached ore (operated at cyanide concentrations high enough so oxygen transfer was limiting). For this reaction, a resistance in series expression can be developed and then used in a first order rate of reaction expression developed by Habashi[3].

The adsorption of gold from the pregnant leach solution onto activated carbon is a key step in the recovery process. Van Deventer has proposed a simplified driving force, dual-rate adsorption model based upon the "systematic lack of fit" in the single-rate models proposed by other researchers[4]. This model exhibits excellent correlation with experimental data.

Van Deventer also gives some criteria for the selection of activated carbon for use in the adsorption process, as well as values for all of the adsorption constants for each of the nine carbons that he presents[4].

The reaction of HCl and limestone is

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l) \quad (2)$$

Equipment Descriptions

F-101	Grizzly Feeder
J-101	Jaw Crusher
SC-101	Standard Cone Crusher
SHC-101	Shorthead Cone Crusher

S-101	Screen
B-101	Ball Mill
CY-101 A/F	Hydroclones
C-201 A/B	Compressor
P-201 A/B	Slurry Pump
AT-201	Agitation Tank
P-202 A/B	Slurry Pump
AT-202	Agitation Tank
P-203 A/B	Slurry Pump
AT-203	Agitation Tank
P-204 A/B	Slurry Pump
AT-204	Agitation Tank
P-205 A/B	Slurry Pump
AT-205	Agitation Tank
P-206 A/B	Slurry Pump
AT-206	Agitation Tank
F-301	Rotary Drum
P-301 A/B	Slurry Pump
F-302	Rotary Drum
P-302 A/B	Slurry Pump
F-303	Rotary Drum
P-303 A/B	Slurry Pump
F-304	Rotary Drum

P-304 A/B	Slurry Pump
C-301 A/B	Vacuum Compressor
E-401	Economizer
V-401	Elution Vessel
CIC-401	Carbon in Columns
AD-501	Acid Dissolution
C-501	Calcination
MR-501	Mercury Retort
S-501	Smelter
ST-501	Slag Treatment
E-501	Economizer
EL-501	Electrolytic Refining
F-501	Casting Furnace
N-601	Neutralization Unit
TI-601	Tailings Impoundment

References

1. "Gold and Silver Leaching, Recovery, and Economics," *Proceedings from the 110th AIME Annual Meeting*, Chicago, Feb. 22-26, 1981, (W.J. Schlitt, W. C. Larson, and J. B. Hiskey, eds.)

2. Marsden, John and Iain House, The Chemistry of Gold Extraction, Ellis Horwood Ltd., Chichester, West Sussex, England, 1992.

3. Habashi, Fathi. *Kinetics and Mechanism of Gold and Silver Dissolution in Cyanide Solution*. Montana College of Mineral Science and Technology. Butte, Montana. April 1967.

4. Van Deventer, J. S. J., "Criteria for Selection of Activated Carbons Used in CIP Plants," *Reagents in the Minerals Industry, Inst. Min. and Metall.*, (M.J. Jones, ed.,) pp. 155-160, 1984.

Gold Production Stream Table

Unit 100 – Size Reduction

Stream	1	2	3	4	5	6	7	8
Total Flow (tons/hr)	41.5	41.5	41.5	31.4	31.4	36.4	5.0	36.4
Component Flowrates (tons/hr)								
Ore	41.5	41.5	41.5	31.4	31.4	36.4	5.0	36.4
Water	--	--	--	--	--	--	--	--

Stream	9	10	11	12	13	14	15
Total Flow (tons/hr)	77.9	41.5	10.4	17.3	69.2	69	52
Component Flowrates (tons/hr)							
Ore	77.9	41.5	--	13.8	55.3	55.3	41.5
Water	--	--	10.4	3.5	13.8	13.8	10.4

Unit 200 – Leaching

Stream	15	16	17	18	19	20a
Total Flow (tons/hr)	46.66	0.0014	0.5403	93.33	93.33	46.67
Ore Flow (tons/hr)	37.33	--	--	37.33	37.33	--
Water Flow (tons/hr)	9.33	--	--	55.99	55.99	46.66
Component Flows (kg/hr)						
Gold	0.1528	--	--	0.1528	0.0019	--
Oxygen	--	--	113.45	0.4480	0.4480	0.3733
CN-	--	0.5185	--	2.9117	2.8719	2.3932
OH-	--	0.1587	--	0.9519	0.9519	0.7933
Na+	--	0.6733	--	4.0397	4.0397	3.3664
$Au(CN)_2$	--	--	--	--	0.1907	0.0016
Water	9332	--	--	55994	55994	46662
Nitrogen	--	--	426.80	--	--	--

Unit 300 -- Filtration

Stream	19	20b	21	22a,b,c	23	24
Total Flow (tons/hr)	93.33	9.33	46.66	3.11	46.66	46.66
Ore Flow (tons/hr)	37.33	--	37.33	--	37.33	37.33
Water Flow (tons/hr)	55.99	9.33	9.33	3.11	9.33	9.33
Component Flows (kg/hr)						
Gold	0.0019	--	0.0019	--	0.0019	0.0019
Oxygen	0.4880	0.0747	0.0747	0.0249	0.0747	0.0747
CN-	2.8719	0.4786	0.4786	0.1595	0.4786	0.4786
OH-	0.9519	0.1587	0.1587	0.0529	0.1587	0.1587
Na+	4.0397	0.6733	0.6733	0.2244	0.6733	0.6733
Au $(CN)_2$	0.1907	0.0002	0.0318	0.0001	0.0239	0.0180
Water	55994	9332	9332	3111	9332	9332

Stream	25	26	27	28	29	30
Total Flow (tons/hr)	46.67	3.11	3.11	3.11	9.33	46.66
Ore Flow (tons/hr)	--	--	--	--	--	37.33
Water Flow (tons/hr)	46.66	3.11	3.11	3.11	9.33	9.33
Component Flows (kg/hr)						
Gold	--	--	--	--	--	0.0019
Oxygen	0.3733	0.0249	0.0249	0.0249	0.0747	0.0747
CN-	2.3932	0.1595	0.1595	0.1595	0.4786	0.4786
OH-	0.7933	0.0529	0.0529	0.0529	0.1587	0.1587
Na+	3.3664	0.2244	0.2244	0.2244	0.6733	0.6733
Au $(CN)_2$	0.1589	0.0080	0.0060	0.0045	0.0184	0.0135
Water	46662	3111	3111	3111	9332	9332

Unit 400 – Carbon Adsorption and Elution

Stream	20a	20b	25	29	31
Total Flow (kg/hr)	46669	9334	46669	9334	4.30
Ore Flow (kg/hr)	--	--	--	--	--
Water Flow (kg/hr)	46662	9332	46662	9332	4.30
Component Flows (kg/hr)					
Gold	--	--	--	--	--
Oxygen	0.3733	0.0747	0.3733	0.0747	--
CN-	2.3932	0.4786	2.3932	0.4786	--
OH-	0.7933	0.1587	0.7933	0.1587	--
Na+	3.3664	0.6733	3.3664	0.6733	--
$Au(CN)_2$	0.0016	0.0002	0.1589	0.0184	--
Water	46662	9332	46662	9332	4.30
HCl	--	--	--	--	0.0001
Carbon	--	--	--	--	--

Stream	32,33	34	35	36	37
Total Flow (kg/hr)	37.02	4.00	3.66	4.00	35
Ore Flow (kg/hr)	--	--	--	--	--
Water Flow (kg/hr)	36.98	--	--	--	--
Component Flows (kg/hr)					
Gold	--	0.1389	0.0014	--	--
Oxygen	--	--	--	--	--
CN-	0.036344	--	--	--	--
OH-	0.000038	--	--	--	--
Na+	0.000094	--	--	--	--
$Au(CN)_2$	--	--	--	--	0.1738
Water	36.98	--	--	4	34
HCl	--	--	--	0.0001	--
Carbon	--	3.655	3.66	--	--

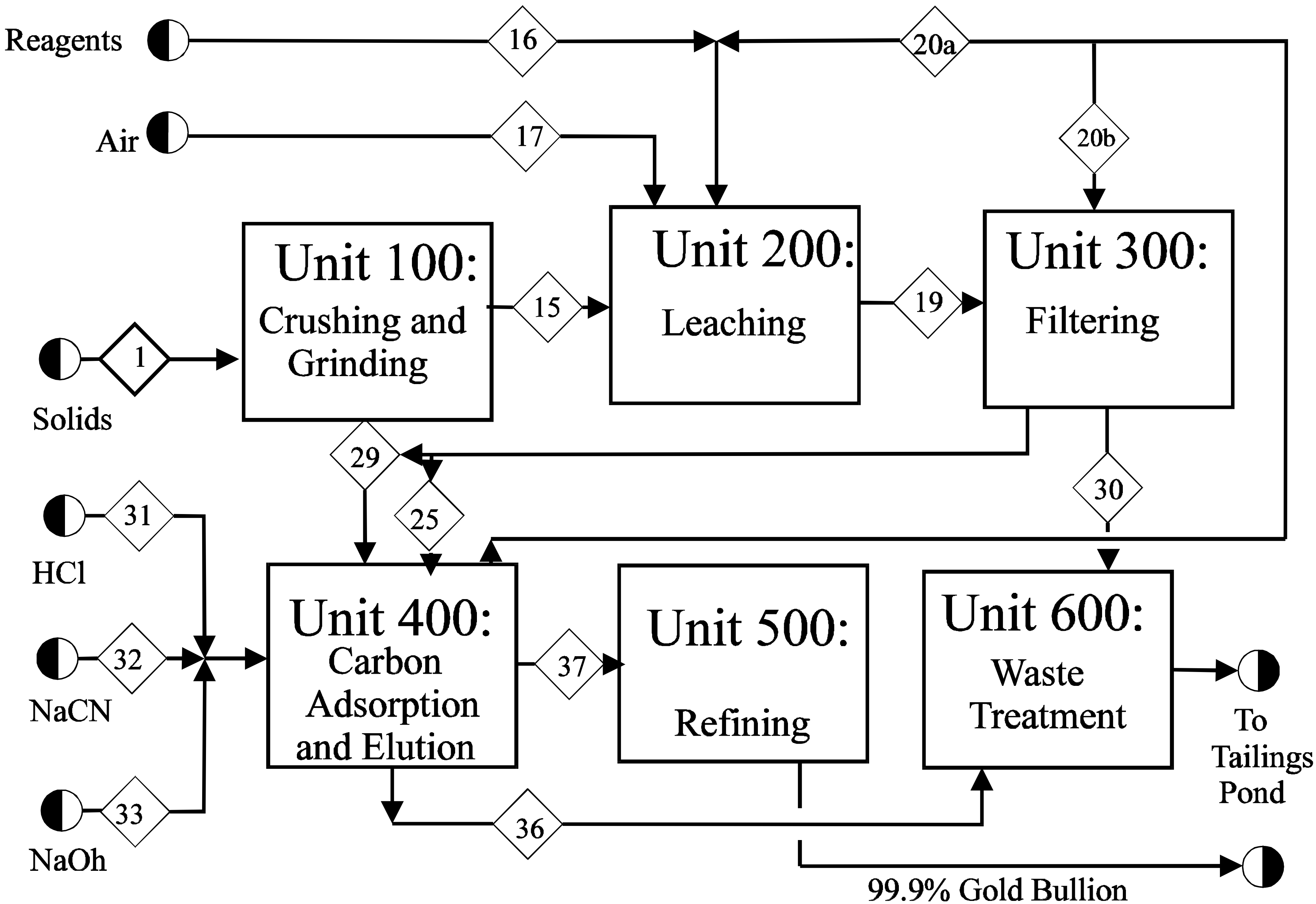

Figure 1: BFD of Gold Production Process

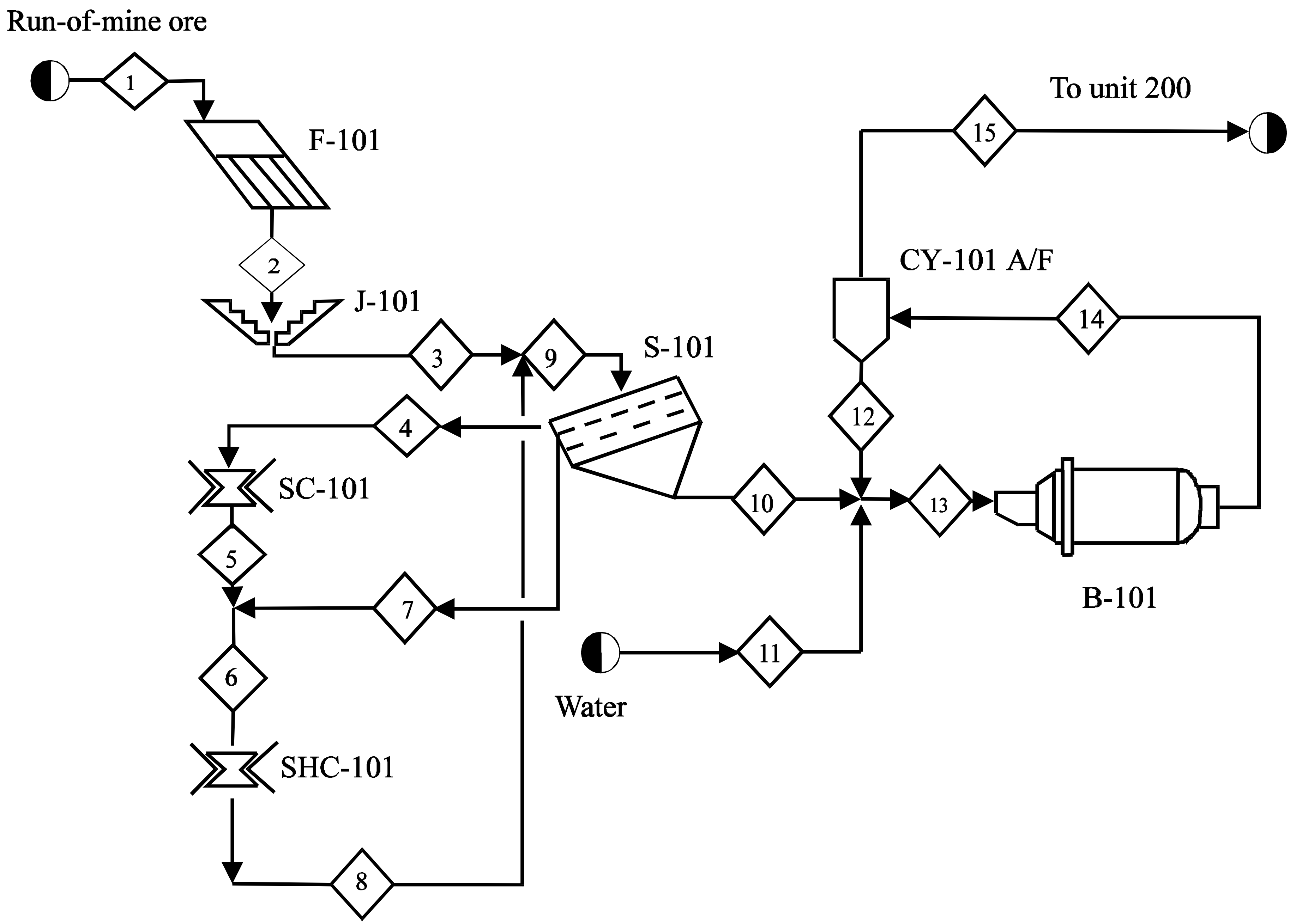

Figure 2: PFD for Unit 100--Size Reduction

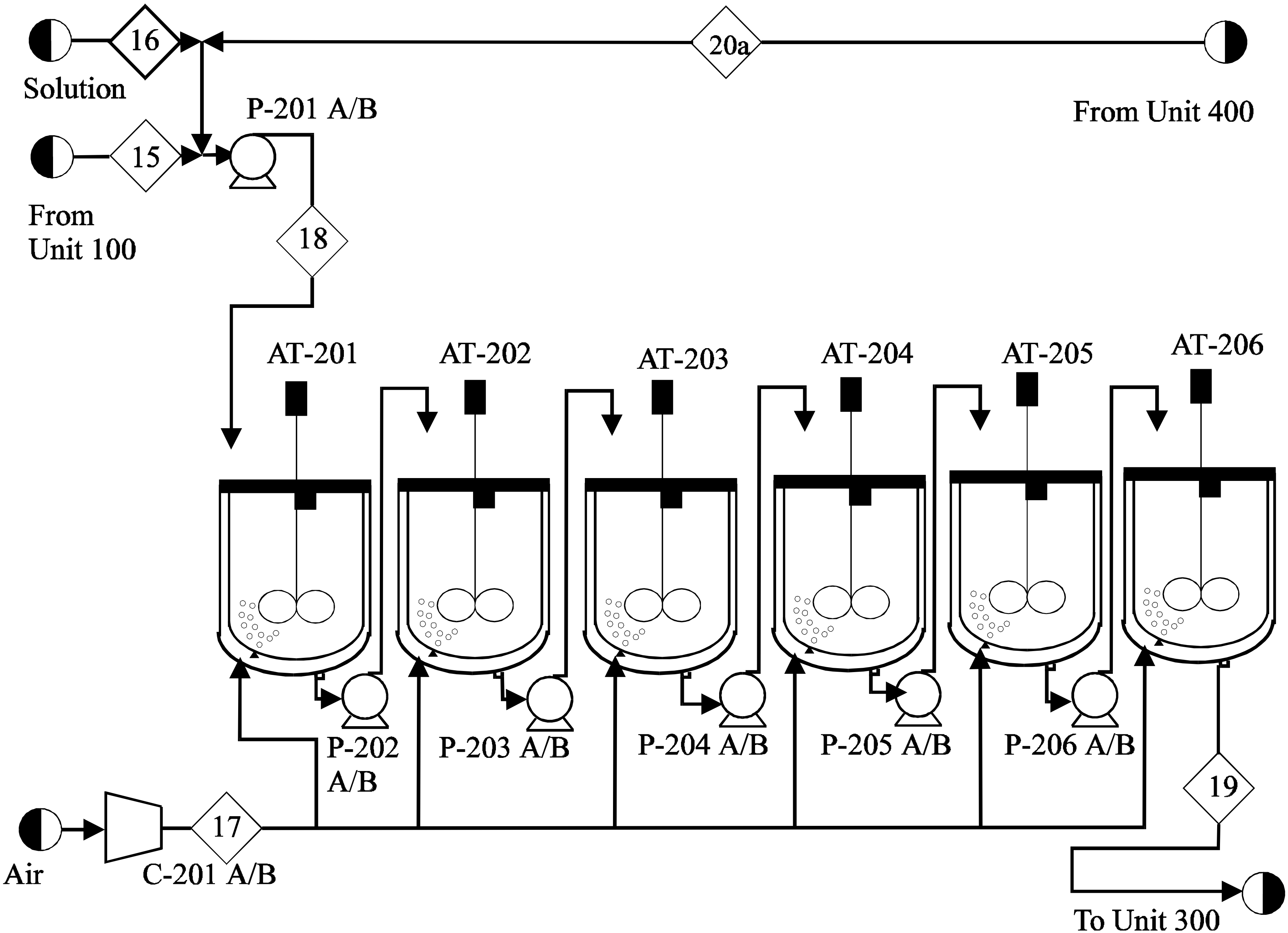

Figure 3: PFD for Unit 200--Leaching

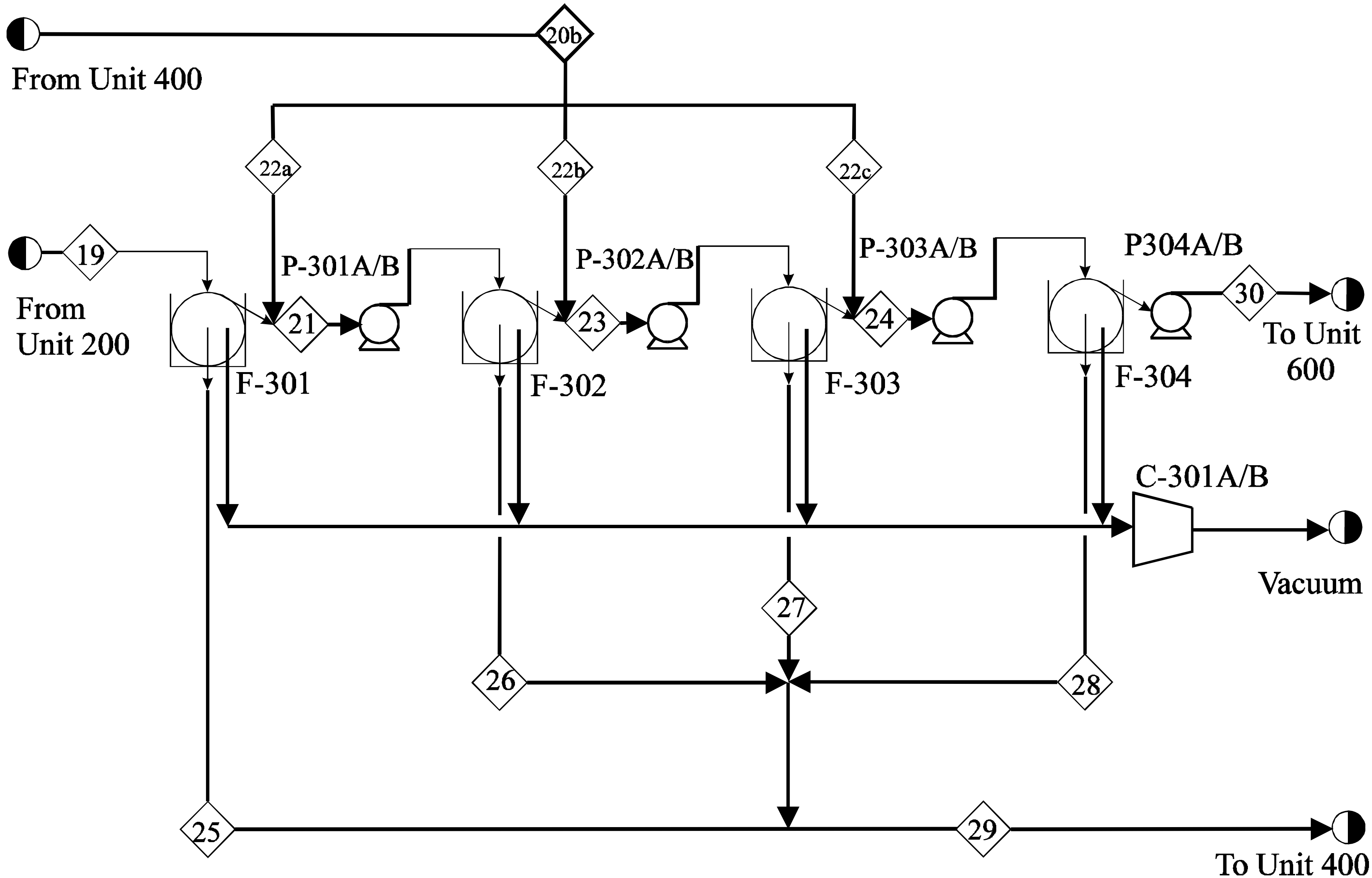

Figure 4: Unit 300--Rotary Drum Filtration of Leached Sludge

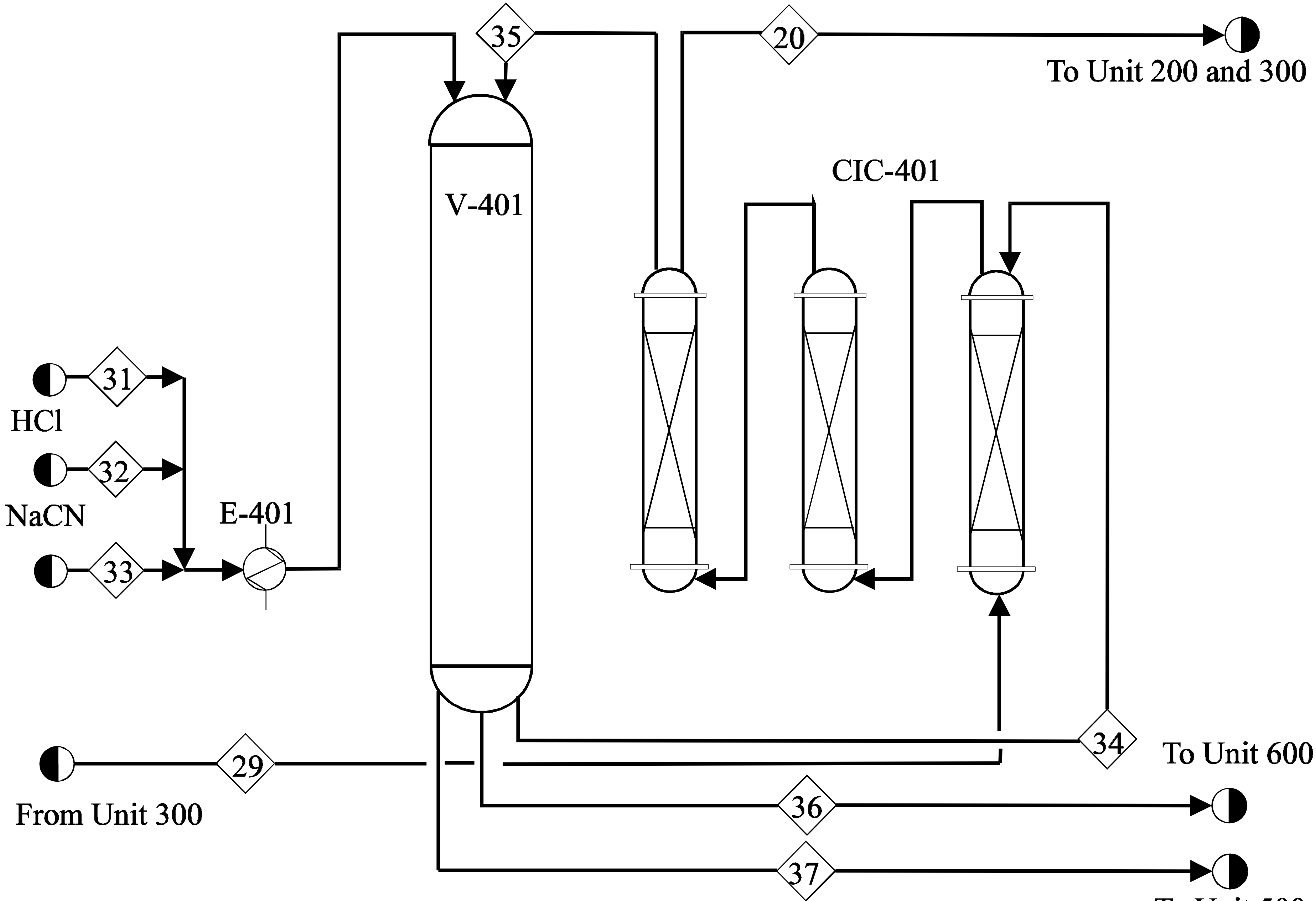

Figure 5: PFD for Unit 400--Carbon Adsorption and Elution

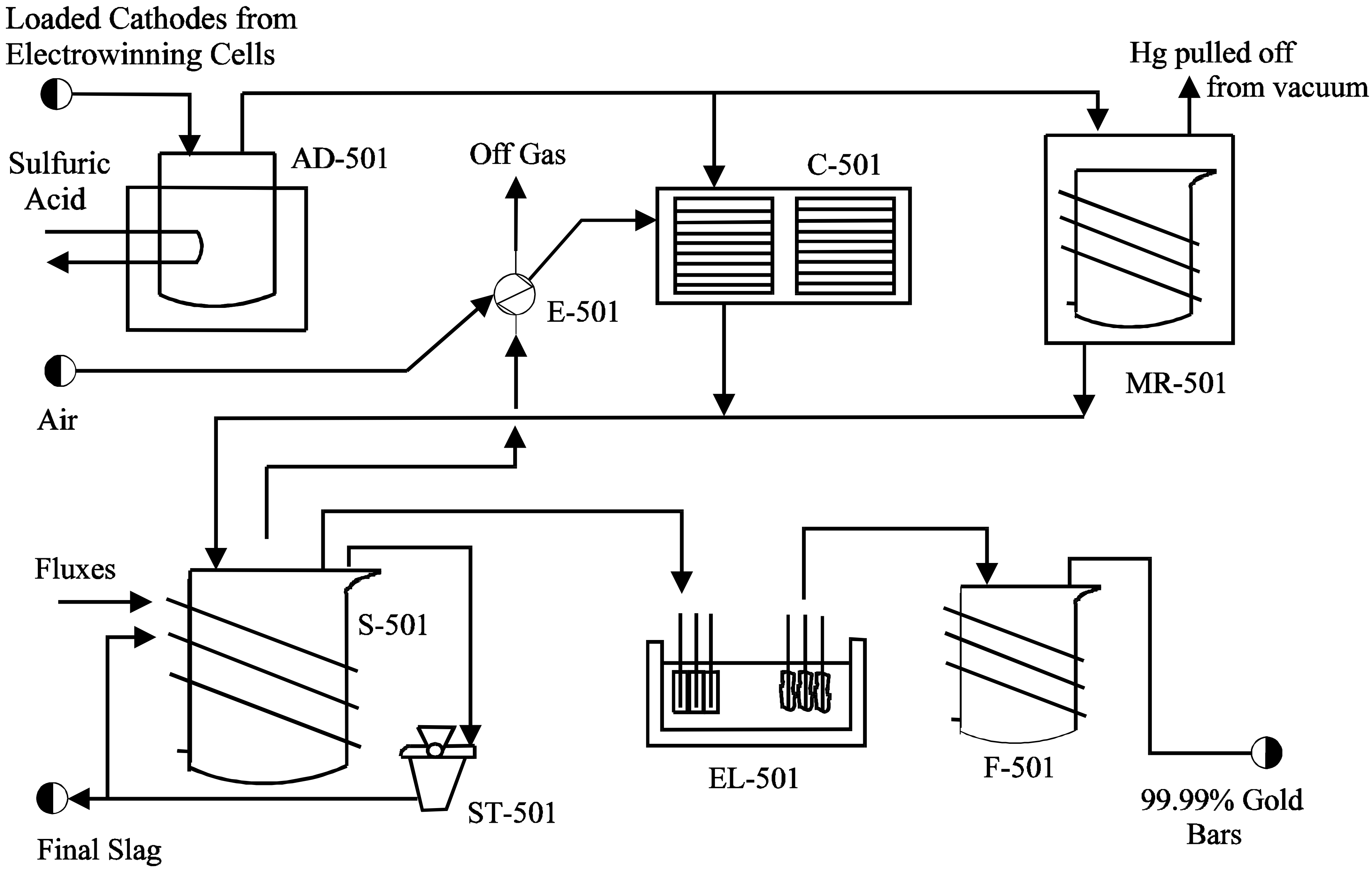

Figure 6: Process Flow Diagram for Unit 500--Refining