Cyan-ara Final Presentation

Cyanide Treatment Using Pure SO_2

Group P1

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Introduction

Scope, Goals and Benefits, Market

Gold Scenario

22% increase in Gold price over last 5 years [1]

Cyanide commonly used in the Gold leaching process [2]

Recent advances and development such as SART and NORAM Oxy-Sulphur Furnace

Improper treatment of cyanide leads to negative social, economical and environmental consequences

The Solution

Cyanide Destruction

Ensure destruction to < 1 ppm cyanide [3]

+

Cyanide Recovery

Recover Free Cyanide to re-use in leaching process, recover metal in leach solution.

→

Cyan-ara

1. Cyanide treatment using combined process utilizing pure Sulphur Dioxide
2. Production and Sale of Sulphur Dioxide and Recovery By-Products

Goals and Benefits

Reduce social, economical and environmental impacts caused by untreated tailings

Reduce overall plant size leading to lower capital costs and operational costs

Recycle cyanide from leach solution to reduce costs of purchasing new cyanide

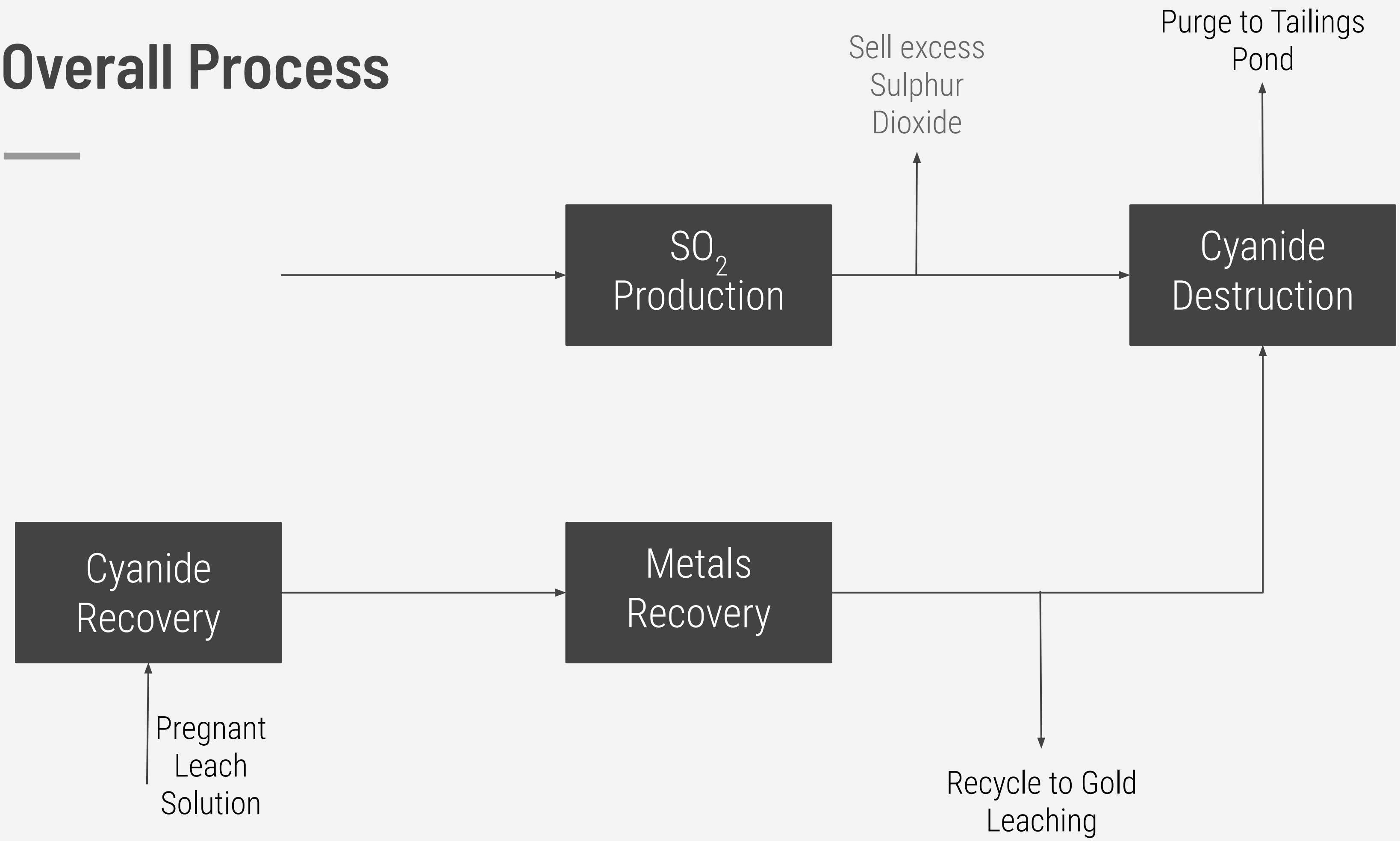
Treatment Capacity

730,000 m^3/year

Location: Sonora, Mexico

Process Overview

Overall Process



Sell excess Sulphur Dioxide

Purge to Tailings Pond

SO_2 Production

Cyanide Destruction

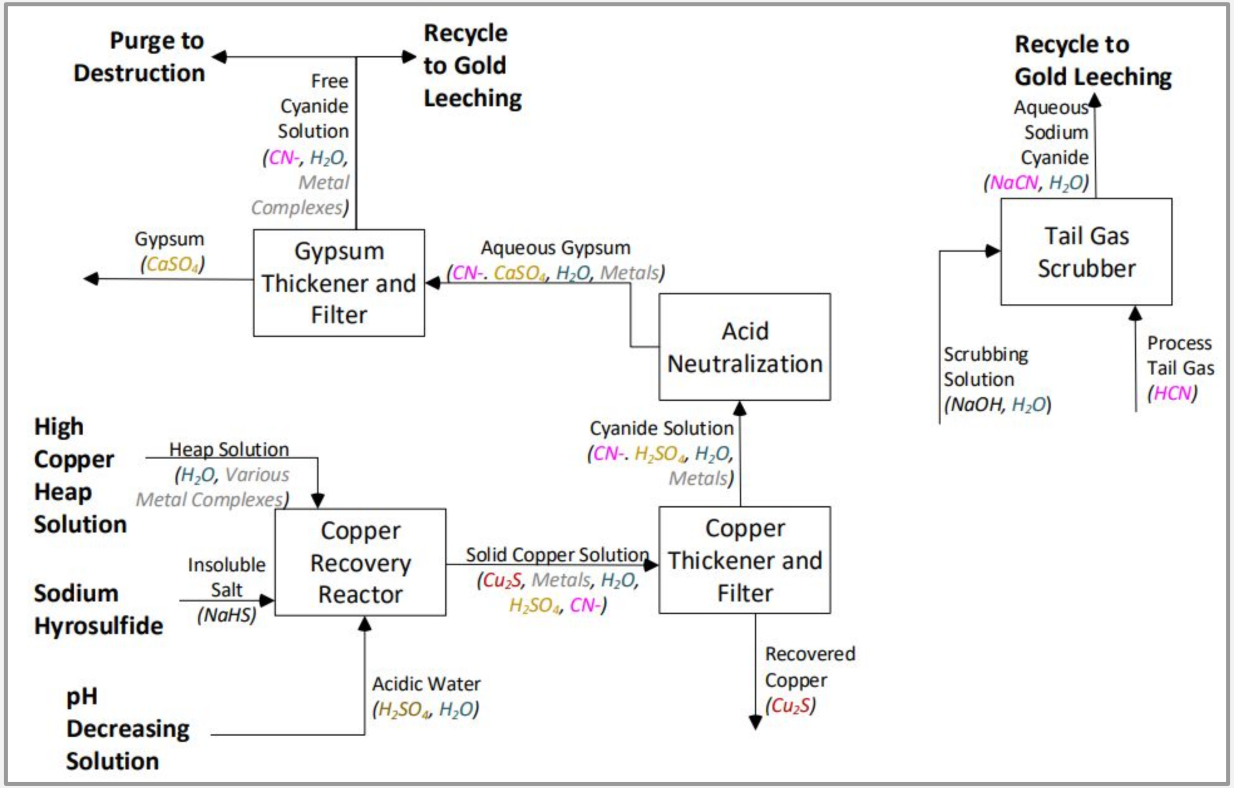
Cyanide Recovery

Metals Recovery

Pregnant Leach Solution

Recycle to Gold Leaching

Recovery Section



Purge to Destruction

Recycle to Gold Leeching

Free Cyanide Solution (CN^-, H_2O, Metal Complexes)

Gypsum ($CaSO_4$)

Gypsum Thickener and Filter

Aqueous Gypsum (CN^-. $CaSO_4$, H_2O, Metals)

Acid Neutralization

Recycle to Gold Leeching

Aqueous Sodium Cyanide ($NaCN$, H_2O)

Tail Gas Scrubber

Scrubbing Solution ($NaOH$, H_2O)

Process Tail Gas (HCN)

High Copper Heap Solution

Heap Solution (H_2O, Various Metal Complexes)

Cyanide Solution (CN^-. H_2SO_4, H_2O, Metals)

Copper Recovery Reactor

Solid Copper Solution (Cu_2S, Metals, H_2O, H_2SO_4, CN^-)

Copper Thickener and Filter

Sodium Hyrosulfide

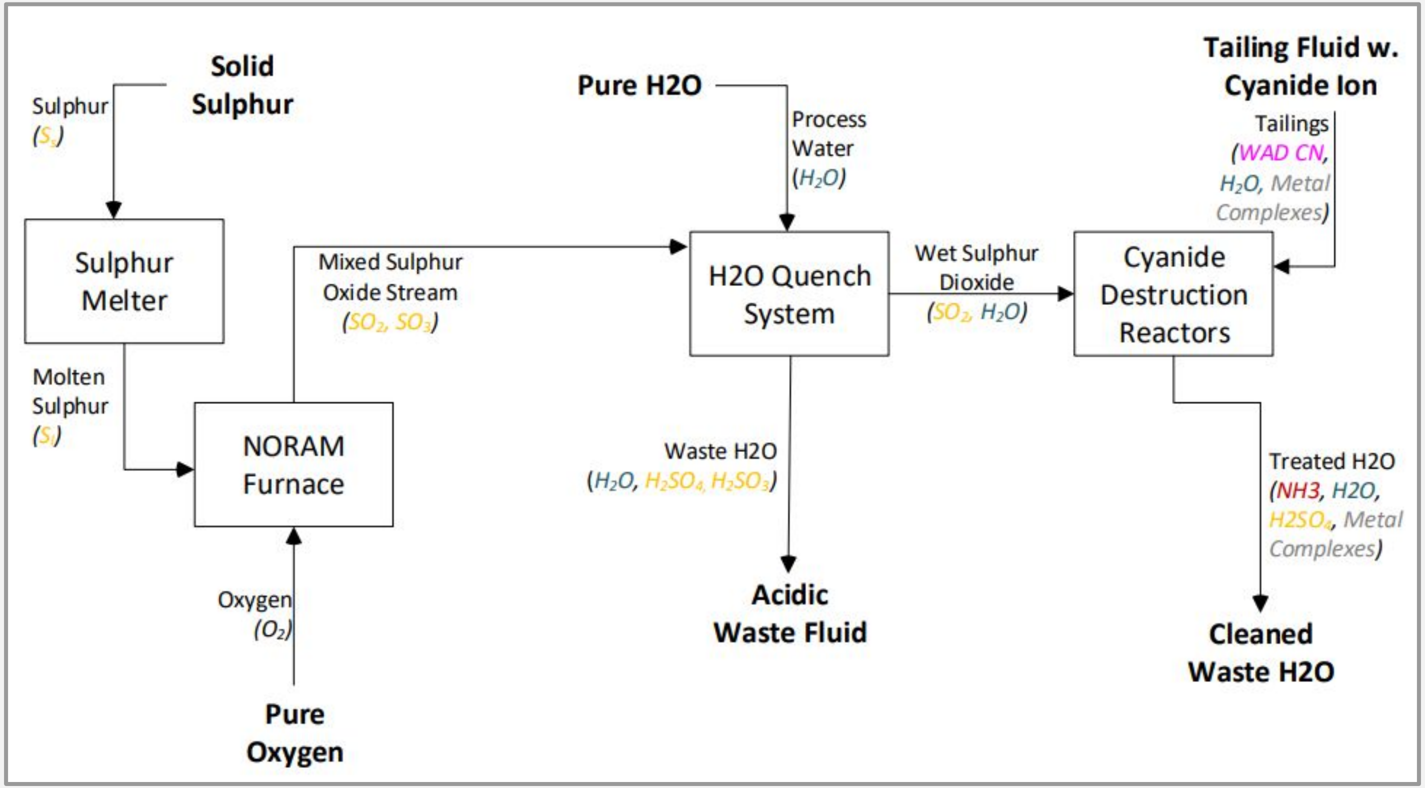
Insoluble Salt ($NaHS$)

Acidic Water (H_2SO_4, H_2O)

pH Decreasing Solution

Recovered Copper (Cu_2S)

Destruction Section



Solid Sulphur

Sulphur (S_s)

Sulphur Melter

Molten Sulphur (S_l)

NORAM Furnace

Oxygen (O_2)

Pure Oxygen

Mixed Sulphur Oxide Stream (SO_2, SO_3)

Pure H2O

Process Water (H_2O)

H2O Quench System

Waste H2O (H_2O, H_2SO_4, H_2SO_3)

Acidic Waste Fluid

Wet Sulphur Dioxide (SO_2, H_2O)

Tailing Fluid w. Cyanide Ion

Tailings (WAD CN, H_2O, Metal Complexes)

Cyanide Destruction Reactors

Treated H2O (NH3, H2O, $H2SO_4$, Metal Complexes)

Cleaned Waste H2O

General Reaction Schemes

Leach Component	Processing Agent	Processing Section	Removal Reaction
Metal/Cyanide Complexes	Sulphide	Recovery	$2Cu(CN)_3^{2-} + HS^- + 5H^+ \rightarrow Cu_2S + 6HCN$
Metal/Cyanide Complexes	Sulphuric Acid	Recovery	$Zn(CN)_4^{2-} + SO_4^{2-} + 4H^+ \rightarrow ZnSO_4 + 4HCN$
Metal/Cyanide Complexes	Sulphur Dioxide/ Cu^{2+} Catalyst	Destruction	$Ni(CN)_4^{2-} + 4SO_2 + 4O_2 + 4H_2O \rightarrow 4OCN^- + 4H_2SO_4 + Ni^{2+}$
Cyanate (OCN^-)	Sulphuric Acid	Destruction	$OCN^- + H^+ + 2H_2O \rightarrow HCO_3^- + NH_4^+$
Strong Complexed Cyanide (Fe^{2+} and Co^{3+})	Sulphur Dioxide	Destruction	$2Fe(CN)_6^{3-} + SO_2 + 2H_2O \rightarrow 2Fe(CN)_6^{4-} + 4\,H_2SO_4$ $2Cu^{2+} + 2Fe(CN)_6^{4-} \rightarrow Cu_2Fe(CN)_{6\,(s)}$

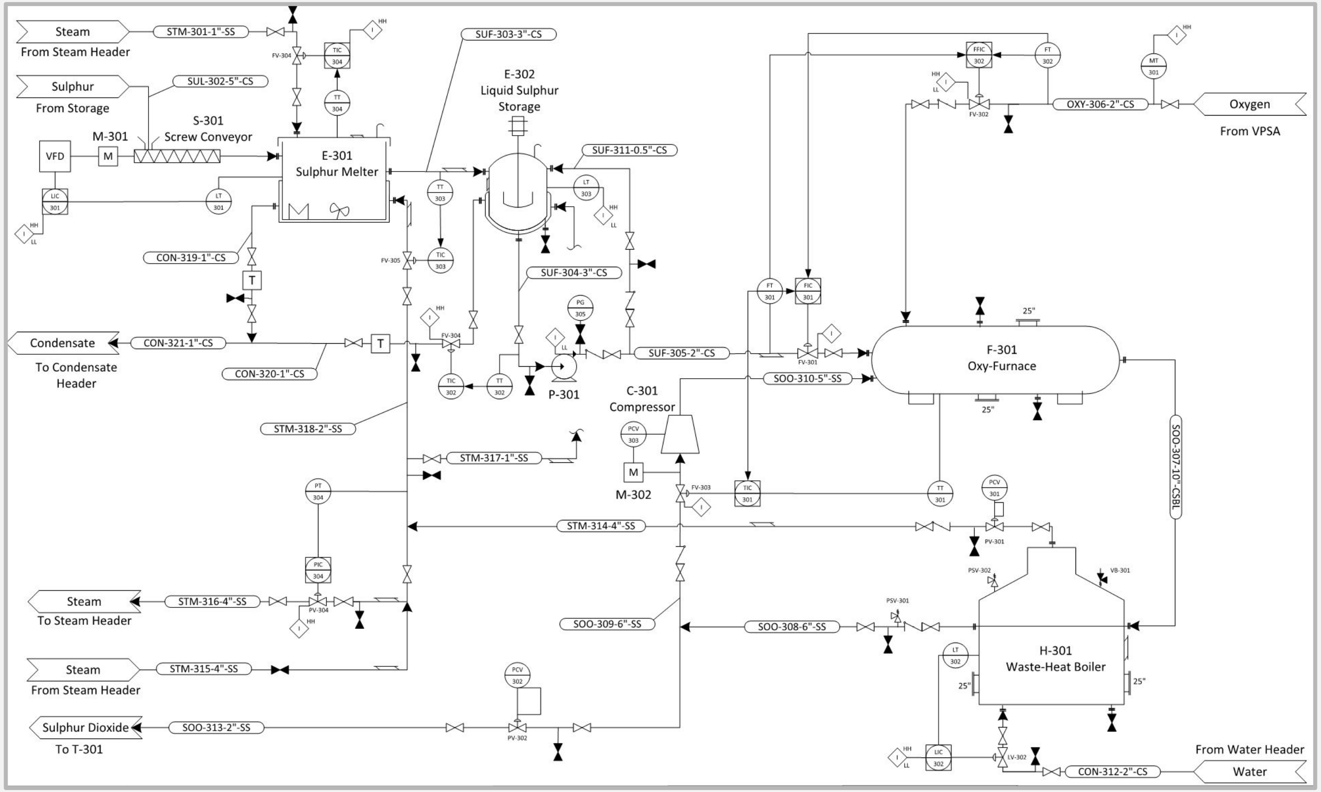
[2] [4]

Safety

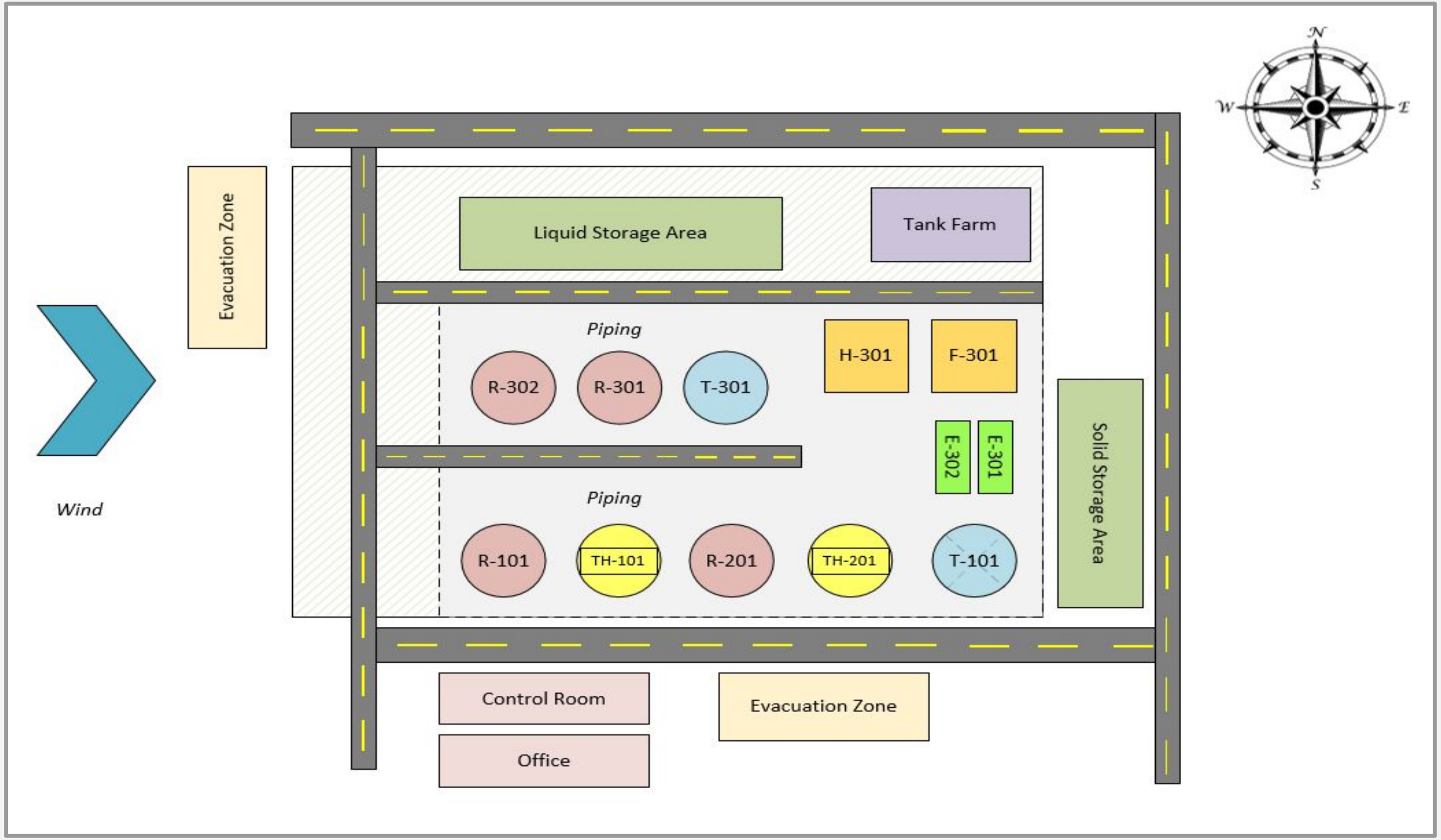
P&ID, Control Narrative, HAZOP,

Plant Layout, Cause & Effect Matrix

P&ID A-01-300


Steam
From Steam Header
STM-301-1"-SS
FV-304
TIC 304
HH
TT 304
SUF-303-3"-CS
Sulphur
From Storage
SUL-302-5"-CS
S-301
Screw Conveyor
M-301
M
VFD
E-301
Sulphur Melter
LIC 301
LT 301
HH
LL
E-302
Liquid Sulphur
Storage
SUF-311-0.5"-CS
TT 303
LT 303
TIC 303
FV-305
CON-319-1"-CS
T
SUF-304-3"-CS
PG 305
Condensate
To Condensate
Header
CON-321-1"-CS
CON-320-1"-CS
FV-304
TIC 302
TT 302
P-301
SUF-305-2"-CS
STM-318-2"-SS
C-301
Compressor
PCV 303
M
M-302
FV-303
STM-317-1"-SS
PT 304
PIC 304
STM-314-4"-SS
Steam
To Steam Header
STM-316-4"-SS
PV-304
Steam
From Steam Header
STM-315-4"-SS
SOO-309-6"-SS
PCV 302
Sulphur Dioxide
To T-301
SOO-313-2"-SS
PV-302
FFIC 302
FT 302
MT 301
FV-302
OXY-306-2"-CS
Oxygen
From VPSA
FT 301
FIC 301
FV-301
SOO-310-5"-SS
25"
F-301
Oxy-Furnace
25"
SOO-307-10"-CSBL
TIC 301
TT 301
PCV 301
PV-301
PSV-302
VB-301
PSV-301
SOO-308-6"-SS
LT 302
H-301
Waste-Heat Boiler
25"
25"
LIC 302
LV-302
CON-312-2"-CS
From Water Header
Water

Floor Layout



HAZOP: Oxy-Furnace

Node

Inlets and outlets of the Oxy-Furnace

This Node is used to show the main control scheme of the most dangerous unit of the plant

Deviations

Total of 11 deviations in the defined node

Range of mechanical, pressure, temperature, control and maintenance problems are discussed

Risk Rating

Risk Ratings of 2, 3 and 4 are determined in this node:

- Two 2’s
- Seven 3’s
- Two 4’s

Example of a Major HAZOP Deviation

Deviation	Consequence	Cause	Safeguard	RR
1.1 Temperature Runaway	Damage to refractory. Damage to piping. Explosion risk. Pressure buildup.	1.1.1.1 Insufficient sulphur dioxide recycle flow rate due to valve failure.	19 Interlock to stop fuel injection and flush system with pure oxygen	4
		1.1.1.2 Insufficient sulphur dioxide recycle flow rate due to compressor failure.	19 Interlock to stop fuel injection and flush system with pure oxygen	
		1.1.1.3 Increase in sulphur dioxide production	20 TIC 301 controller to increase/decrease how much recycle sulphur dioxide is fed into Furnace F-301.	
		1.1.1.4 Deviation from target fuel to oxygen ratio.	1 FIC 301 Ratio Controller	
			2 Sufficient maintenance	
			3 Oxygen Inlet Flow interlock	

Major Control Loops

Oxy-Sulphur Furnace Temperature

- Recycle cooled sulphur dioxide to furnace to control temperature
- Ensure temperature does not exceed 1500 degrees Celsius

Feed Ratios

- Ensure 3% excess oxygen is maintained in furnace
- Interlock sulphur flow in case temperature reaches High-High level

Liquid Level in Waste Heat Boiler

- Ensure sufficient water is supplied to cool gas from Oxy-Sulphur furnace
- Ensure water level is not too high to prevent overflow

Cause and Effect Matrix

			FV-301	FV-303	PV-302
			Sulphur Flow Control Valve	Temperature Recycle Flow Valve	Sulphur Dioxide Pressure Valve
Tag Number	**P&ID**	**Description**			
F-301	A-01-300	High High Temperature in Furnace	I	I	I

Start-up / Shut-down

Plant

- Addresses a general Start-up and Shut-down for the entire plant
- Every part of the plant still needs a detailed plan

P&ID

- Addresses Start-up and Shut-down in detail for PFD-300
- Main concern is pre-heating of Oxy-Sulphur furnace

Environmental Analysis

Air Emissions

Main Gas Emissions

HCN and SOx gas generation

Pollutant	**Expected Pollutant Generation**	**Emission Limit**
HCN	**1 -11 ppm**	**4.7 ppm [5]**
SO_2	**Negligible**	**0.7 ppm [6]**

Liquid Permitting

Main Concerns - Cyanide (all forms), Ammonia/Ammonium, Copper (and other metals)

Tailings Ponds are not regulated but any discharge to the natural environment has federally imposed limits.

Effluent requires further processing in conventional treatment units for non-cyanide species.

Substance	Expected Discharge to Pond (mg/L)	Tailings Pond Limit (mg/L)	Environmental Limit (mg/L)
Cyanide	**31.96**	**50 [3]**	**1 [7]**
NH_3/NH_4^+	**660**	**-**	**24.3 - 1450* [8]**
Copper	**38.30**	**-**	**0.3 [7]**

*Discharge limit dependent on effluent pH. A range of 6 - 8 was considered.

Solid Storage and Disposal

Solids for the process will be transported in a truck and stored in closed, dry containers

Proper handling and disposal of solids such as sodium hydrosulphide, sulphur and the copper catalyst needs to be maintained throughout the operation

Economic Analysis

$10.6 million USD

Capital Cost investment required for the project

Economic Summary

Operating Expenses

Raw Materials Cost ($/yr)	1,700,000
Total Operating Labor and Maintenance Cost ($/yr)	910,000
Total Utilities Cost ($/yr)	280,000
Plant Overhead ($/yr)	460,000
General and Administrative Costs ($/yr)	480,000
Total Operating Cost ($/yr)	3,830,000

Sale Streams

Copper Sulphide ($/yr)	1,200,000
Sulphur Dioxide ($/yr)	1,100,000
Recycled Cyanide ($/yr)	1,100,000
Total Products Sales ($/yr)	3,400,000

Comparison

- Configuration 1 performs INCO process in Tanks
- Configuration 2 performs INCO in tailing ponds
- Costs in Table do not include Operator and Maintenance Costs, Plant Overhead, or G/A costs

Our Process vs other Composite Processes [9]

	Cyanisorb and INCO Process Configuration 1* (2.4 TPD Cyanide)	Cyanisorb and INCO Process Configuration 2* (2.4 TPD Cyanide)	Cyan-ara Process (2.6 TPD Cyanide)
Capital Cost ($)	14,000,000	12,500,000	10,600,000
Net Cost ($/yr)	-1,400,000	-1,000,000	+1,400,000

***Prices inflated from 2004 to 2020 prices**

Conclusion

Project is viable and compares well to other

Attractive Economics for leach solutions
above 200 mg/L

Future work and challenges
More detailed engineering and economic
analysis needed to bring costs down

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Applied Science

NORAM

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Questions?

References

[1] Macrotrends LLC, "Gold Prices - 100 Year Historical Chart," Macrotrends LLC, 2020.

[2] M. M. B. A. S. Terry I. Mudder, Chemistry and Treatment of Cyanidation Wastes, London: MINING JOURNAL BOOKS LTD, 2001.

[3] K. H. T. I. M. Mark J. Logsdon, "MANAGEMENT OF CYANIDE IN GOLD EXTRACTION," International Council on Metals and the Environment, Ottawa, 1999.

[4] S. M. Services, "Cyanide Recovery," SGS, 2013.

[5] The National Institute for Occupational Safety and Health, "HYDROGEN CYANIDE," Centers for Disease Control and Prevention, 1988.

[6] British Columbia Ministry of Environment, "New National Air Quality Standards for SO2," Canadian Council of Ministers of the Environment, Vancouver, 2016.

References

[7] Government of Canada, "Justice Laws Website," 25 06 2019. [Online]. Available: https://laws-lois.justice.gc.ca/eng/regulations/sor-2002-222/page-10.html#docCont. [Accessed 15 02 2020].

[8] Government of Canada, "Guideline for release of ammonia in wastewater effluents: guide," 03 2003. [Online]. Available: https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/publications/guideline-release-ammonia-wastewater-effluents/guide.html#appa. [Accessed 10 03 2020].

[9] G. P. D. a. T. C. Cheng, "A case study of CIP tails slurry treatment: comparison of cyanide recovery to cyanide destruction," *The European Journal of Mineral Processing and Environmental Protection,* vol. 4, no. 1, pp. 1-9, 2004.

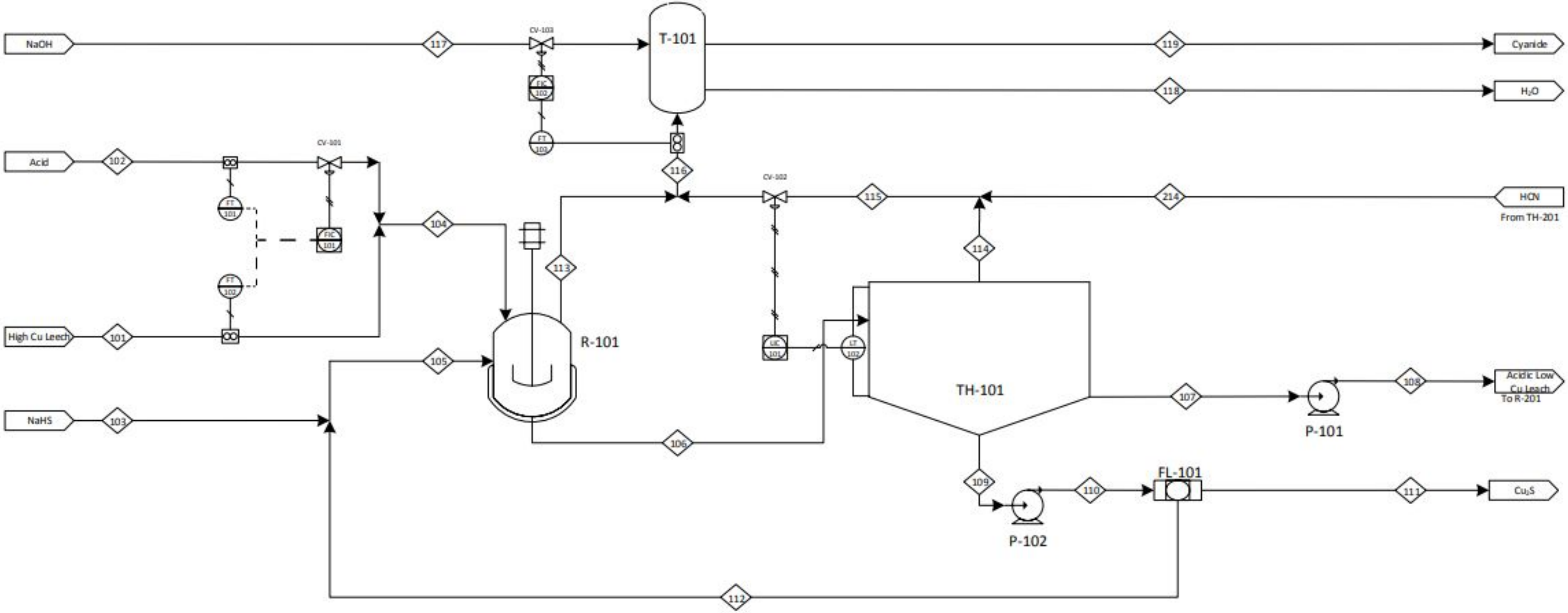
[10] T. P. H. &. D. J. Burkey, Encyclopedia of Inorganic Chemistry, First Edition, Hoboken: John Wiley and Sons, 2006.

[11] En-Wiki, "Prussian Blue," Wikipedia Commons, 27 11 2005. [Online]. Available: https://en.wikipedia.org/wiki/Prussian_blue. [Accessed 27 03 2020].

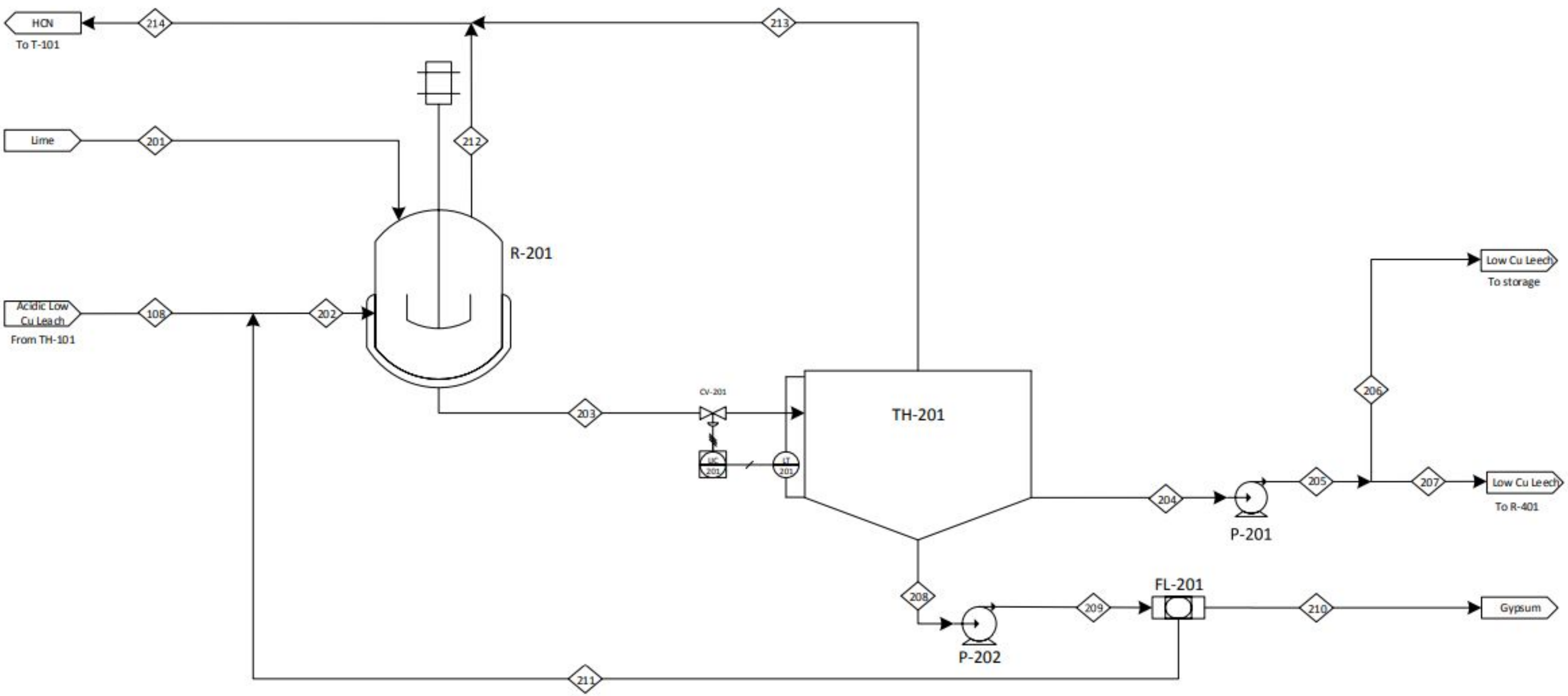
[12] Science Direct, "Metal Sulphides," Science Direct, 23 05 2016. [Online]. Available: https://www.sciencedirect.com/topics/chemistry/metal-sulfides. [Accessed 30 03 2020].

Appendix A - PFDs

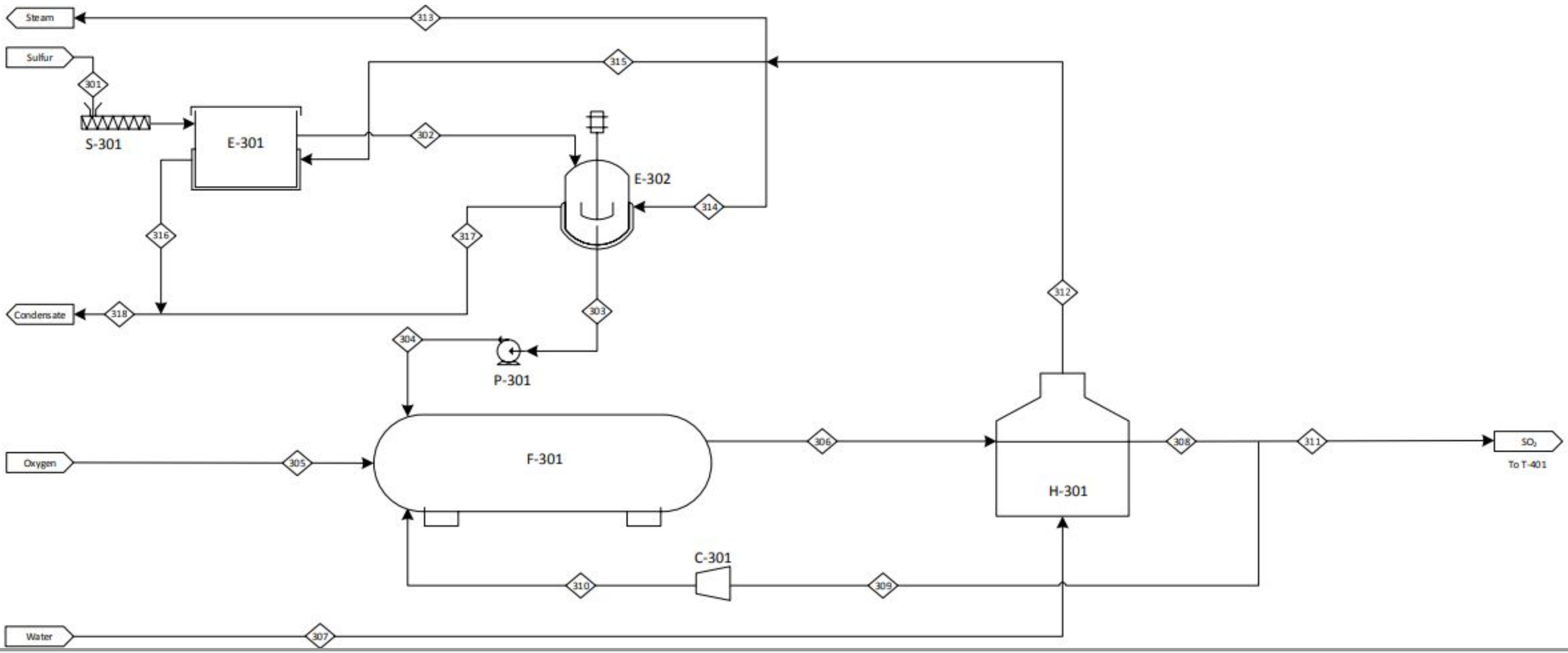
R-101	TH – 101	T-101	FL-101	P-101	P-102
Cyanide Decomplexation Reactor	Copper Precipitate Thickener	Tail Gas Scrubber	Copper Filter	Centrifugal Pump	Slurry Pump



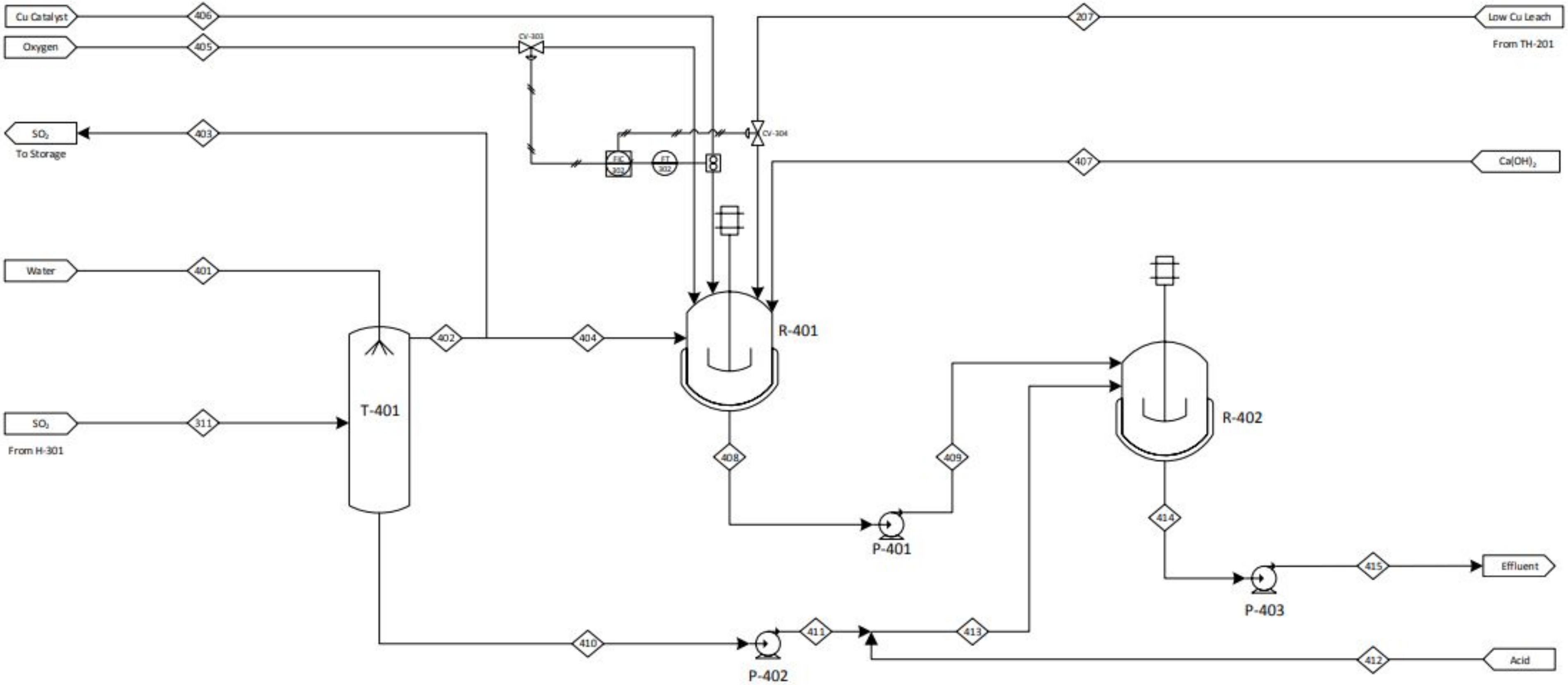
R-201	TH-201	FL-201	P-201	P-202
Acid Neutralizer	Gypsum Precipitate Thickener	Gypsum Filter	Centrifugal Pump	Slurry Pump



S-301	E-301	E-302	P-301	F-301	H-301	C-301
Screw Conveyor	Sulphur Melter	Liquid Sulphur Sotrage	Centrifugal Pump	Oxy-Sulphur Furnace	Waste Heat Boiler	Compressor



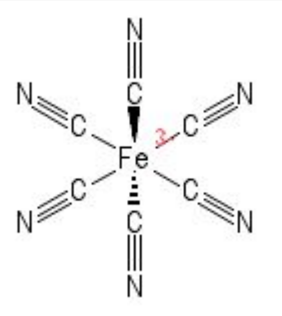
T-401	R-401	R-402	P-401	P-402	P-403
Water Quench Tower	Cyanide Reactor	Cyanate Neutralizer	Centrifugal Pump	Centrifugal Pump	Centrifugal Pump



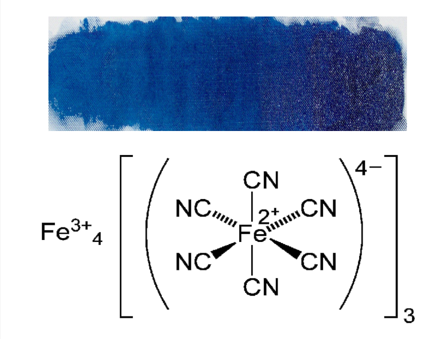
Appendix B - Further Chemistry Details

Cyanide Metal Complexes

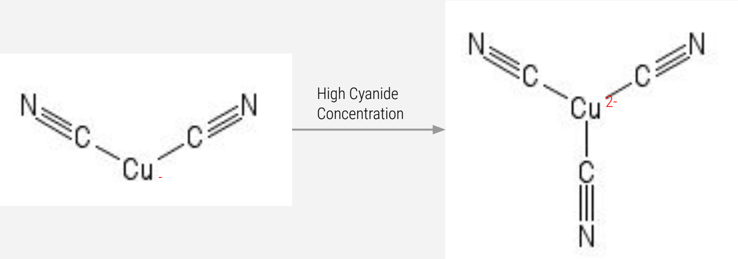
- Cyanide is a small and highly basic ligand, so it readily forms coordination complexes with metals.
- Coinage metals (Cu^{1+}, Au^{1+}, Ag^{1+}) form stable dicyanometallates.
- Forms strongly bonded octahedral complexes with many stable metals (Fe^{2+}, Fe^{3+}, Ti^{3+}, Co^{3+})
- Also forms weaker tetrahedral complexes with d^8 metals (Ni^{2+}, Pb^{2+}). [10]



Strongly Complex Fe(III) Cyanometallate



Prussian Blue: A Cyanometallate Derivative[11]



Copper Cyanometallates

Metal Sulphates and Sulphides [12]

- Most transition metals freely form compounds with sulphate and sulphide groups.
  e.g. CdS, Cu_2S, FeS_2, $ZnSO_4$, $PbSO_4$
- All transition metal sulphides are insoluble in water, so sulphidisation is a good option for removing metal ions form solution.
- Only lead and mercury for insoluble sulphates, so any metal sulphate formed is unrecoverable.
- Based on electronegativity ionic bond strength goes Zn>Cd>Fe>Co>Cu>Ni.

Cu_2S Chalcocite-
A Very Common
Copper Sulphide

Full Reaction Description For Non Trace Metals [2][4]

Leach Component	Processing	Removal Reaction	Value Added
Copper (Cu^+)	Recovery	$2Cu(CN)_3^{2-} + HS^- + 5H^+ \rightarrow Cu_2S + 6HCN$	High
Zinc (Zn^{2+})	Recovery	$Zn(CN)_4^{2-} + 2H_2SO_4 \rightarrow ZnSO_4 + 4HCN$	Moderate
Nickel (Ni^{2+})	Recovery	$Ni(CN)_4^{2-} + H_2SO_4 \rightarrow NiSO_4 + 4HCN$	Moderate
Cobalt ($Co^{2+/3+}$)	Recovery	$Co(CN)_4^{2-} + H_2SO_4 \rightarrow CoSO_4 + 4HCN$	Moderate
Cadmium (Cd^{2+})	Recovery	$Cd(CN)_4^{2-} + H_2SO_4 \rightarrow CdSO_4 + 4HCN$	Minimal
Thiocyanate (SCN^-)	Destruction (10-20%)	$SCN^- + 4SO_2 + 4O_2 + 5H_2O \rightarrow H_2SO_4 + OCN^-$	Very Minimal
Strong Complexed Cyanide (Fe^{2+} and Co^{3+})	Destruction	$2Fe(CN)_6^{3-} + SO_2 + 2H_2O \rightarrow 2Fe(CN)_6^{4-} + 4H_2SO_4$ $2M^{2+} + 2Fe(CN)_6^{4-} \rightarrow M_2Fe(CN)_{6\,(s)}$	None
Cyanate (OCN^-)	Destruction	$OCN^- + H^+ + 2H_2O \rightarrow HCO_3^- + NH_4^+$	None

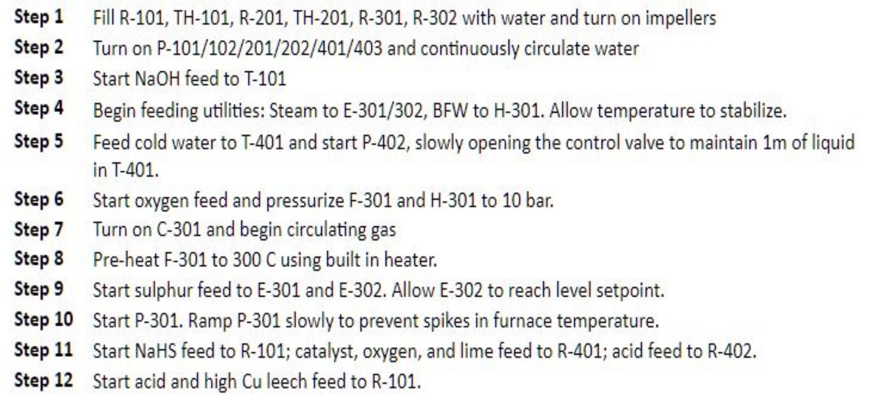
General Reaction Schemes

Leach Component	Processing Agent	Processing Section	Removal Reaction
Metal/Cyanide Complexes	Sulphide	Recovery	$M(CN)_n^{(n-m)-} + (m/2)*HS^- + (n-m/2)*H^+ \rightarrow MS_{m/2} + n*HCN$
Metal/Cyanide Complexes	Sulphuric Acid	Recovery/ Destruction	$M(CN)_n^{(n-m)-} +(m/2)*SO_4^{2-} + n*H^+ \rightarrow M(SO_4)_{m/2} + n*HCN$
Metal/Cyanide Complexes	Sulphur Dioxide/ Cu^{2+} Catalyst	Recovery	$M(CN)_n^{(n-m)-} + n*SO_2 + n*O_2 + n*H_2O \rightarrow n*OCN^- + n*H_2SO_4 + M^{m+}$
Thiocyanate (SCN$^-$)	Sulphur Dioxide	Destruction (10-20%)	$SCN^- + 4SO_2 + 4O_2 + 5H_2O \rightarrow H_2SO_4 + OCN^-$
Cyanate (OCN$^-$)	Sulphuric Acid	Recovery/ Destruction	$OCN^- + H^+ + 2H_2O \rightarrow HCO_3^- + NH_4^+$
Strong Complexed Cyanide (Fe^{2+} and Co^{3+})	Sulphur Dioxide	Destruction	$2Fe(CN)_6^{3-} + SO_2 + 2H_2O \rightarrow 2Fe(CN)_6^{4-} + 4\ H_2SO_4$ $2M^{2+} + 2Fe(CN)_6^{4-} \rightarrow M_2Fe(CN)_{6\,(s)}$

Appendix C - Startup and Shutdown

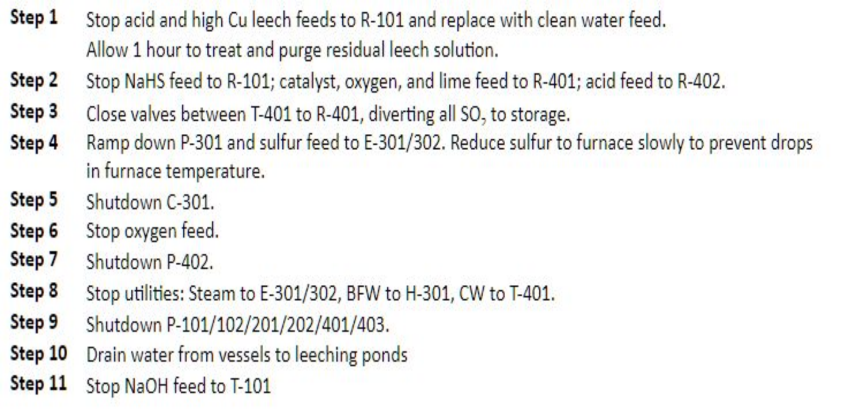
Start-up / Shut-down - General Procedure for Plant

Start-up Procedure



Step 1 Fill R-101, TH-101, R-201, TH-201, R-301, R-302 with water and turn on impellers
Step 2 Turn on P-101/102/201/202/401/403 and continuously circulate water
Step 3 Start NaOH feed to T-101
Step 4 Begin feeding utilities: Steam to E-301/302, BFW to H-301. Allow temperature to stabilize.
Step 5 Feed cold water to T-401 and start P-402, slowly opening the control valve to maintain 1m of liquid in T-401.
Step 6 Start oxygen feed and pressurize F-301 and H-301 to 10 bar.
Step 7 Turn on C-301 and begin circulating gas
Step 8 Pre-heat F-301 to 300 C using built in heater.
Step 9 Start sulphur feed to E-301 and E-302. Allow E-302 to reach level setpoint.
Step 10 Start P-301. Ramp P-301 slowly to prevent spikes in furnace temperature.
Step 11 Start NaHS feed to R-101; catalyst, oxygen, and lime feed to R-401; acid feed to R-402.
Step 12 Start acid and high Cu leech feed to R-101.

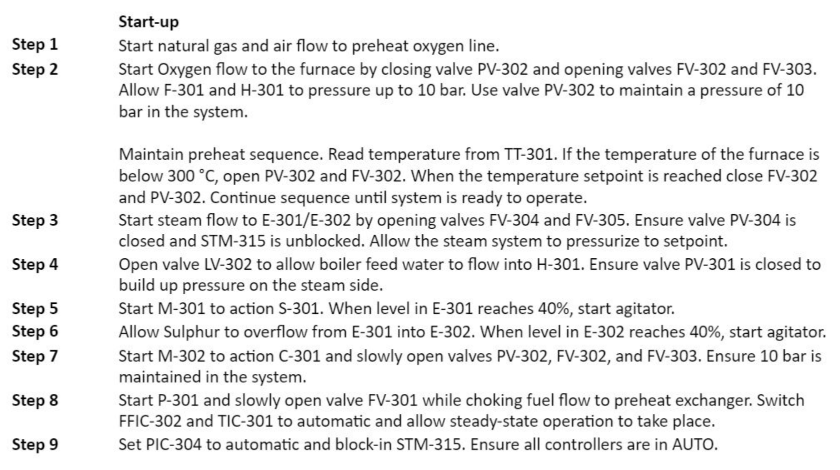
Shut-down Procedure



Step 1 Stop acid and high Cu leech feeds to R-101 and replace with clean water feed. Allow 1 hour to treat and purge residual leech solution.
Step 2 Stop NaHS feed to R-101; catalyst, oxygen, and lime feed to R-401; acid feed to R-402.
Step 3 Close valves between T-401 to R-401, diverting all SO_2 to storage.
Step 4 Ramp down P-301 and sulfur feed to E-301/302. Reduce sulfur to furnace slowly to prevent drops in furnace temperature.
Step 5 Shutdown C-301.
Step 6 Stop oxygen feed.
Step 7 Shutdown P-402.
Step 8 Stop utilities: Steam to E-301/302, BFW to H-301, CW to T-401.
Step 9 Shutdown P-101/102/201/202/401/403.
Step 10 Drain water from vessels to leeching ponds
Step 11 Stop NaOH feed to T-101

Start-up / Shut-down - Detailed Procedure for P&ID

Start-up Procedure ✓



Start-up

Step 1 Start natural gas and air flow to preheat oxygen line.

Step 2 Start Oxygen flow to the furnace by closing valve PV-302 and opening valves FV-302 and FV-303. Allow F-301 and H-301 to pressure up to 10 bar. Use valve PV-302 to maintain a pressure of 10 bar in the system.

Maintain preheat sequence. Read temperature from TT-301. If the temperature of the furnace is below 300 °C, open PV-302 and FV-302. When the temperature setpoint is reached close FV-302 and PV-302. Continue sequence until system is ready to operate.

Step 3 Start steam flow to E-301/E-302 by opening valves FV-304 and FV-305. Ensure valve PV-304 is closed and STM-315 is unblocked. Allow the steam system to pressurize to setpoint.

Step 4 Open valve LV-302 to allow boiler feed water to flow into H-301. Ensure valve PV-301 is closed to build up pressure on the steam side.

Step 5 Start M-301 to action S-301. When level in E-301 reaches 40%, start agitator.

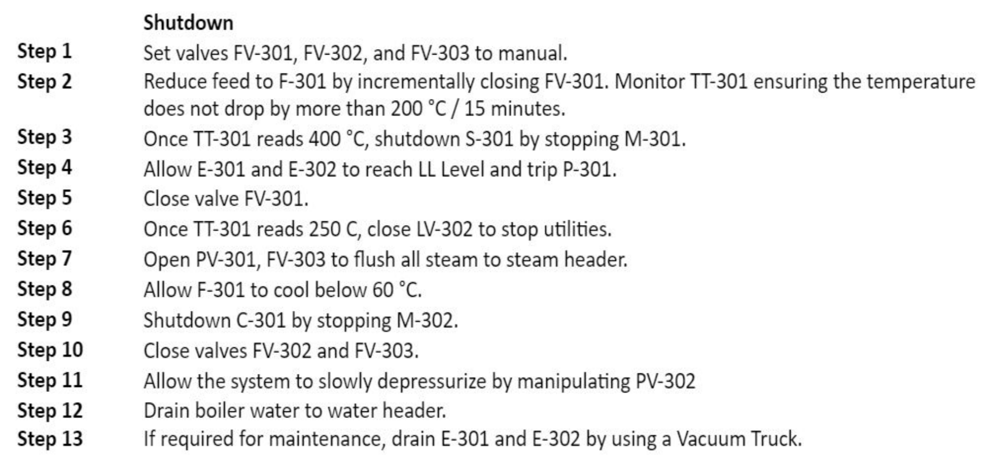
Step 6 Allow Sulphur to overflow from E-301 into E-302. When level in E-302 reaches 40%, start agitator.

Step 7 Start M-302 to action C-301 and slowly open valves PV-302, FV-302, and FV-303. Ensure 10 bar is maintained in the system.

Step 8 Start P-301 and slowly open valve FV-301 while choking fuel flow to preheat exchanger. Switch FFIC-302 and TIC-301 to automatic and allow steady-state operation to take place.

Step 9 Set PIC-304 to automatic and block-in STM-315. Ensure all controllers are in AUTO.

Shut-down Procedure ✖



Shutdown

Step 1 Set valves FV-301, FV-302, and FV-303 to manual.

Step 2 Reduce feed to F-301 by incrementally closing FV-301. Monitor TT-301 ensuring the temperature does not drop by more than 200 °C / 15 minutes.

Step 3 Once TT-301 reads 400 °C, shutdown S-301 by stopping M-301.

Step 4 Allow E-301 and E-302 to reach LL Level and trip P-301.

Step 5 Close valve FV-301.

Step 6 Once TT-301 reads 250 C, close LV-302 to stop utilities.

Step 7 Open PV-301, FV-303 to flush all steam to steam header.

Step 8 Allow F-301 to cool below 60 °C.

Step 9 Shutdown C-301 by stopping M-302.

Step 10 Close valves FV-302 and FV-303.

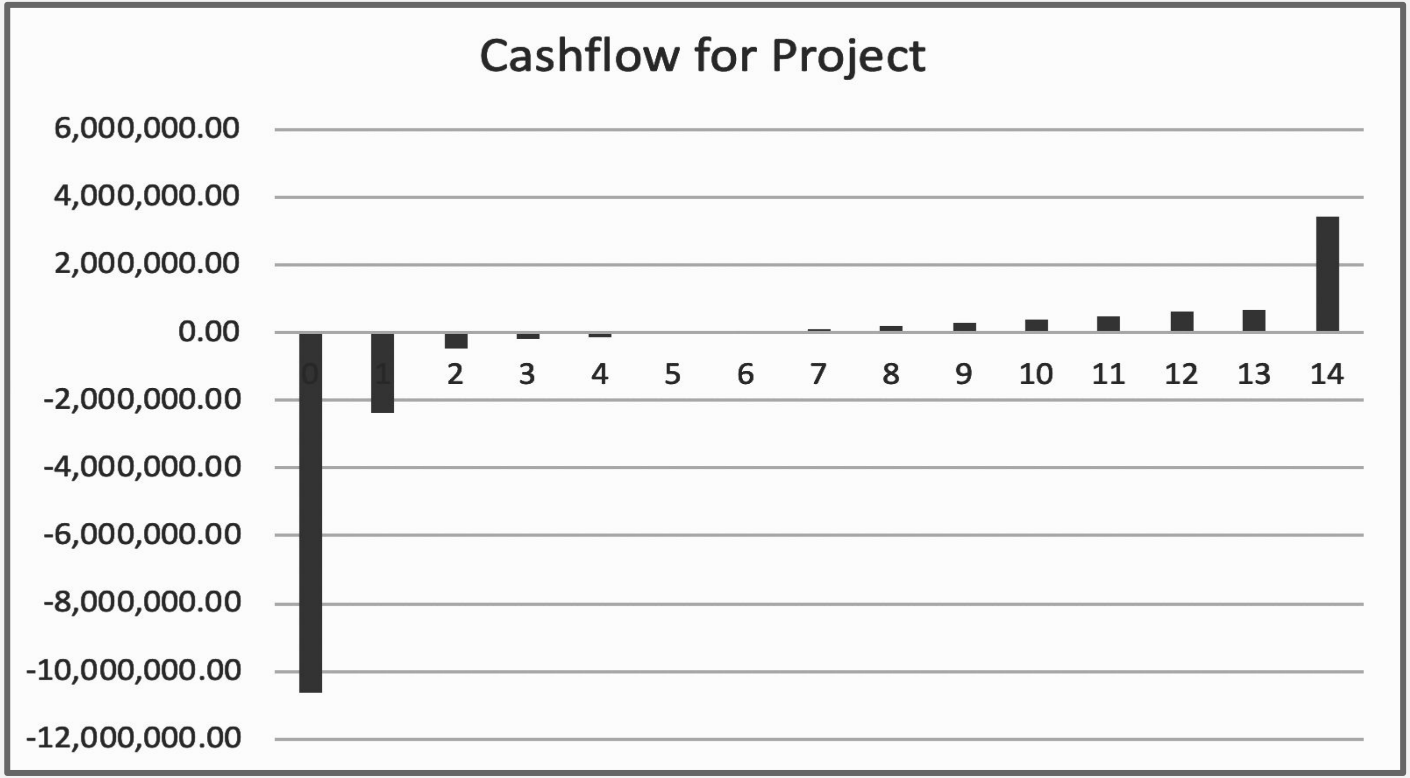
Step 11 Allow the system to slowly depressurize by manipulating PV-302

Step 12 Drain boiler water to water header.

Step 13 If required for maintenance, drain E-301 and E-302 by using a Vacuum Truck.

Appendix D - Further Economic Analysis

Project After Tax Cash Flow



Sources of Capital

- ★ Average cyanide concentration treated - 500 mg/L
- ★ Our Operating cost - $3.8 million / yr

Cyanide Concentration (mg/L)	Gold Leached (kg)	Profit ($50/g of gold)
500	3650	$182,500,000
600	4380	$219,000,000
700	5110	$255,500,000

Area Equipment Cost Breakdown

Area	Function	Total Direct Cost ($ USD)
100	Copper Sulphide Recovery	827,500.00
200	Cyanide Recovery	738,600.00
300	Sulphur Dioxide Production	984,300.00
400	Cyanide Destruction	855,500.00

Area-100 Equipment Costs

Equipment Tag	Equipment Type	Total Direct Cost ($ USD)
TH-101	Thickener	157,000.00
R-101	Agitated Tank, Enclosed	367,900.00
P-103	Centrifugal Pump	52,200.00
P-102	Centrifugal Pump	54,400.00
P-101	Centrifugal Pump	31,300.00
FL-101	Rotary Drum Filter	164,700.00

Area-200 Equipment Costs

Equipment Tag	Equipment Type	Total Direct Cost ($ USD)
TH-201	Thickener	157,000.00
P-201	Centrifugal Pump	27,900.00
FL-201	Rotary Drum Filter	164,700.00
P-202	Centrifugal Pump	47,700.00
R-201	Agitated Tank, Enclosed	341,300.00

Area-300 Equipment Costs

Equipment Tag	Equipment Type	Total Direct Cost ($ USD)
H-301	Waste Heat Boiler	360,200.00
E-301	Agitated Reactor, Jacketed	328,900.00
P-301	Centrifugal Pump	87,000.00
F-301	Refractory Lined Pressure Vessel	208,200.00
R-201	Agitated Tank, Enclosed	341,300.00

Area-400 Equipment Costs

Equipment Tag	Equipment Type	Total Direct Cost ($ USD)
R-402	Agitated Reactor, Enclosed	342,800.00
R-401	Agitated Reactor, Enclosed	193,700.00
T-401	Quench Tower	220,400.00
P-401	Centrifugal Pump	27,200.00
P-402	Centrifugal Pump	35,700.00
P-403	Centrifugal Pump	35,700.00

Comparison

- ★ Average cyanide concentration treated - 500 mg/L
- ★ Our Operating cost - $3.8 million / yr

Effect of CN concentration on operating costs

Process	**Cyanide Concentration (mg/L)**			
	100	**150**	**200**	**400**
	$MM/year*			
INCO	1.5	2.25	2.74	5.48
Cyanisorb	1.3	0.85	0.41	1.37
Combined	2.8	3.1	3.15	6.85

Economic Analysis Parameters

Number of Weeks per Period	*Weeks/period*	52
Number of Periods for Analysis	*Period*	14
Duration of EPC Phase	*Period*	0.67
Duration of EPC Phase and Startup	*Period*	1.06
Working Capital Percentage	*Percent/period*	5
Operating Charges	*Percent/period*	25
Plant Overhead	*Percent/period*	50
Desired Rate of Return/Interest Rate	*Percent/period*	6.5
ROR Annuity Factor		15.38
Tax Rate	*Percent/period*	40
ROR Interest Factor		1.06
Economic Life of Project	*Period*	14
Salvage Value (Percent of Initial Capital Cost)	*Percent*	20
Depreciation Method		Straight Line
Project Capital Escalation	*Percent/period*	5
Products Escalation	*Percent/period*	5
Raw Material Escalation	*Percent/period*	3.5
Operating and Maintenance Labor Escalation	*Percent/period*	3
Utilities Escalation	*Percent/period*	3
Desired Return on Project for Sales Forecasting	*Percent/Period*	10.5
General and Administrative Expenses	*Percent/Period*	8
Duration of EP Phase before Start of Construction	*Period*	0.44

Appendix E - Project and Technology Development

Technology Development

Gold Cyanidation

- Many easy access deposits were quickly depleted
- Extraction from trace gold ores required
- Cyanide complexation developed in late 1800s

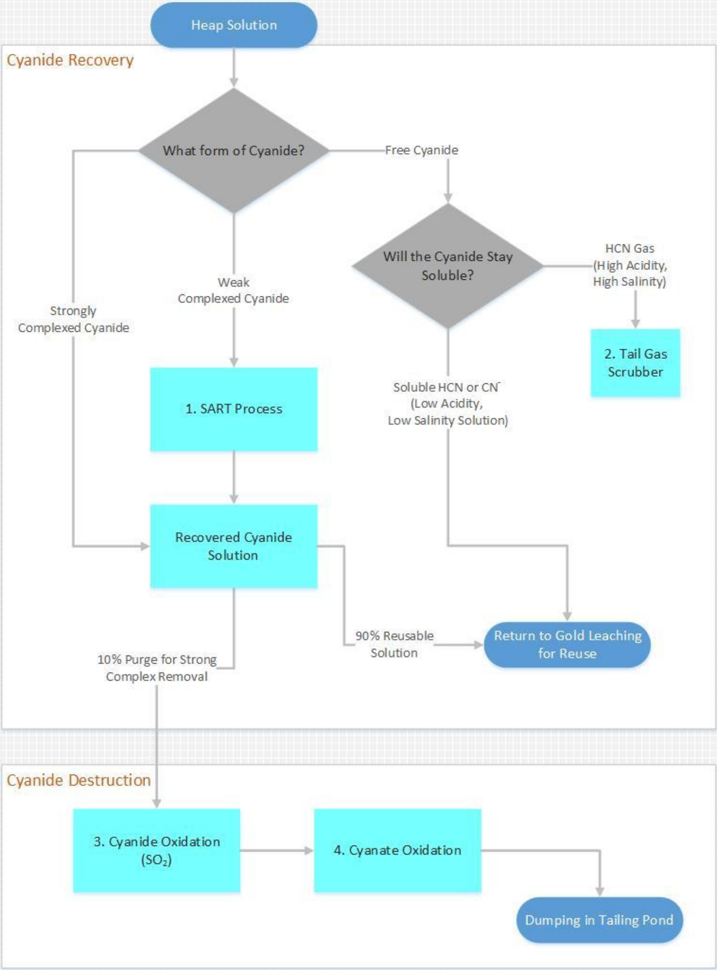
Destruction and Recovery

- Cyanide recovery creates a value added recycle stream
- Dependent on local mineralogy (ex. Not viable for iron rich areas)
- Destruction process guarantees cyanide removal

Pure SO_2 Reagent

- Downstream destruction of cyanide is a needed
- Many possible reagents: SO_2, Caro's Acid, H_2O_2.
- SO_2 has lowest reagent cost.
- Pure SO_2 reduces capital and operating costs

Gold Mining Decision Flowchart



Heap Solution

Cyanide Recovery

What form of Cyanide?

Free Cyanide

Will the Cyanide Stay Soluble?

HCN Gas (High Acidity, High Salinity)

2. Tail Gas Scrubber

Soluble HCN or CN^- (Low Acidity, Low Salinity Solution)

Weak Complexed Cyanide

Strongly Complexed Cyanide

1. SART Process

Recovered Cyanide Solution

90% Reusable Solution

Return to Gold Leaching for Reuse

10% Purge for Strong Complex Removal

Cyanide Destruction

3. Cyanide Oxidation (SO_2)

4. Cyanate Oxidation

Dumping in Tailing Pond

Key Decision Tree

1. Cyanide Recovery Process

No Cyanide Recovery
- *Waste of resources*
- *Simple and Cheap*

SART Process
- *Simple and Versatile Recovery Method*

AVR Process
- *Cannot Recover Weak Complex CN*

2. Tail Gas Treatment

Sodium Hydroxide
- *Cheap and Efficient*

Potassium Hydroxide
- *Very effective*
- *Expensive*

No Treatment
- *Cheapest*
- *Safety Hazard*

3. Cyanide Oxidation

SO_2 Oxidizing Agent
- *Low Reagant Cost*

H_2O_2 Oxidizing Agent
- *Highly Effective*
- *High Reagant Use*

Fe S Complexation
- *Low Reagant Cost*
- *Low Conversion*

4. Cyanate Oxidation

No Cyanate Treatment
- *Low Cost*
- *Environmental Impact*

Oxidation of Cyanate
- *Environmentally Responsble*
- *More Expensive*