

Phosphoric Acid Production from Phosphate Rock

Martin Team 6

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CHEG 4248

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Agenda



Problem Statement
Project Goals
Design Basis



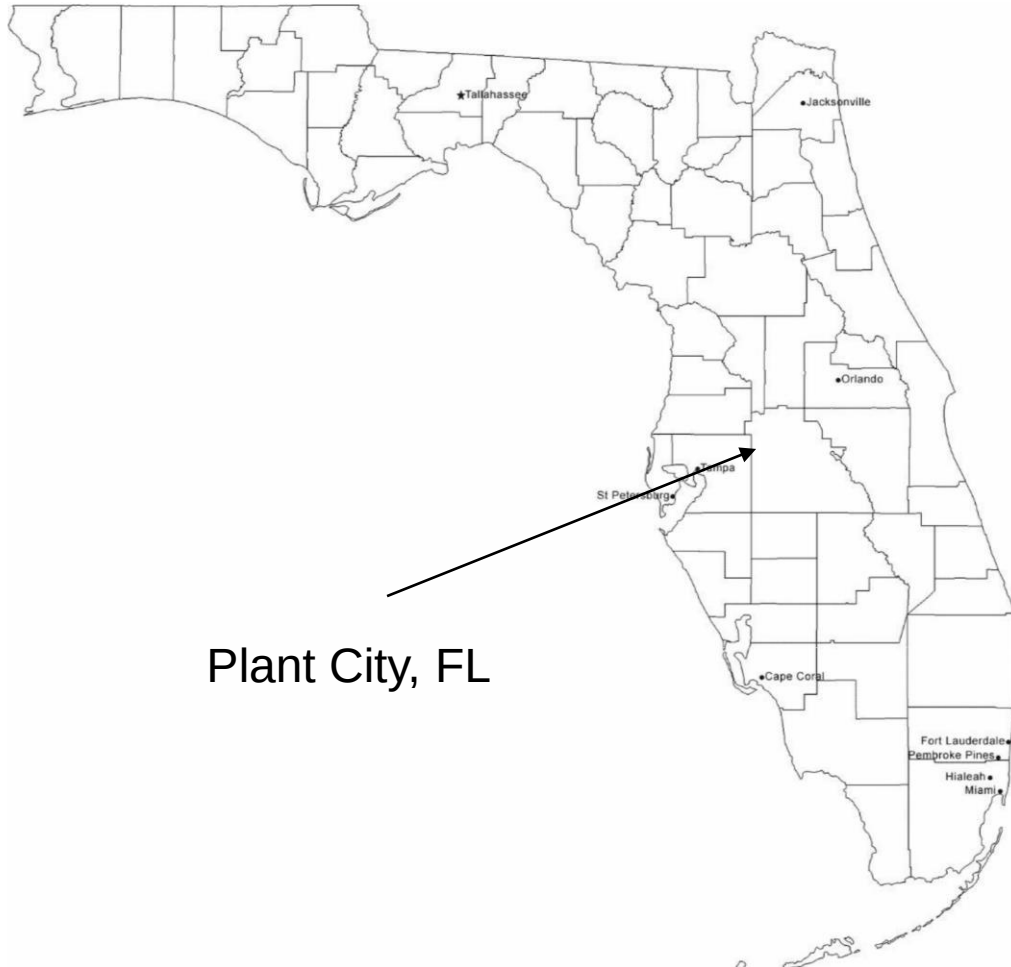
Project Schedule
Process Chemistry
Process Flow Diagram (PFD)
Material and Energy Balance
Major Equipment Design
Process Simulation (ASPEN)
Economic Analysis
Process Safety and Control
P&ID
HAZOP Analysis



Recommendations



Due to high demand of fertilizer, a local company requested us to design and evaluate a phosphoric acid production plant



200,000 tons of phosphoric acid/year

Design Basis

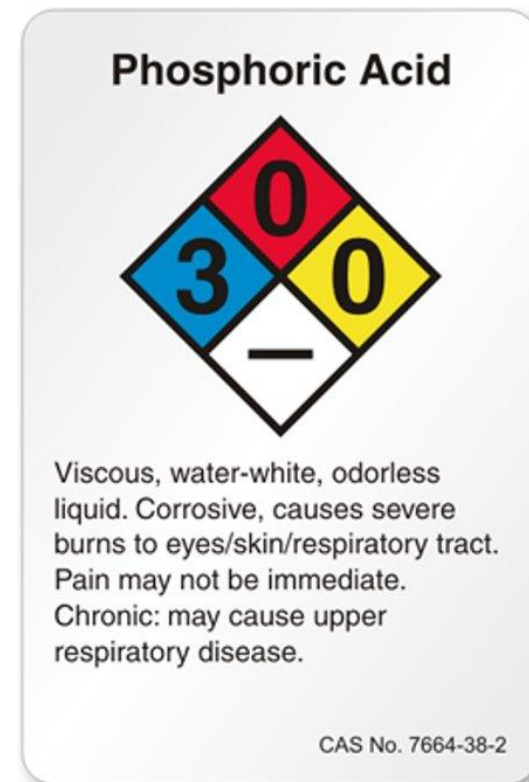
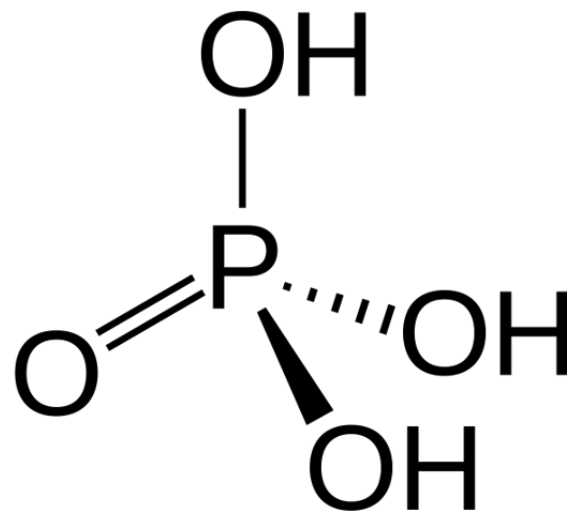
- Capacity
 - Design capacity: 200,000 tons/yr
 - Design operating time: 350days - 8400 hr/yr
- Raw materials
 - Phosphate rock (solid), grounded 0.0059 – 0.0787 in
 - Sulfuric acid (liquid, 93%)
- Product Specification
 - Liquid, 72% H_3PO_4 (52% available P_2O_5)

Project Scope

- Detailed Major Equipment Design
- Converged ASPEN Flowsheet
- Process Safety and HAZOP Analysis
- Detailed Economic Analysis
- Final Report

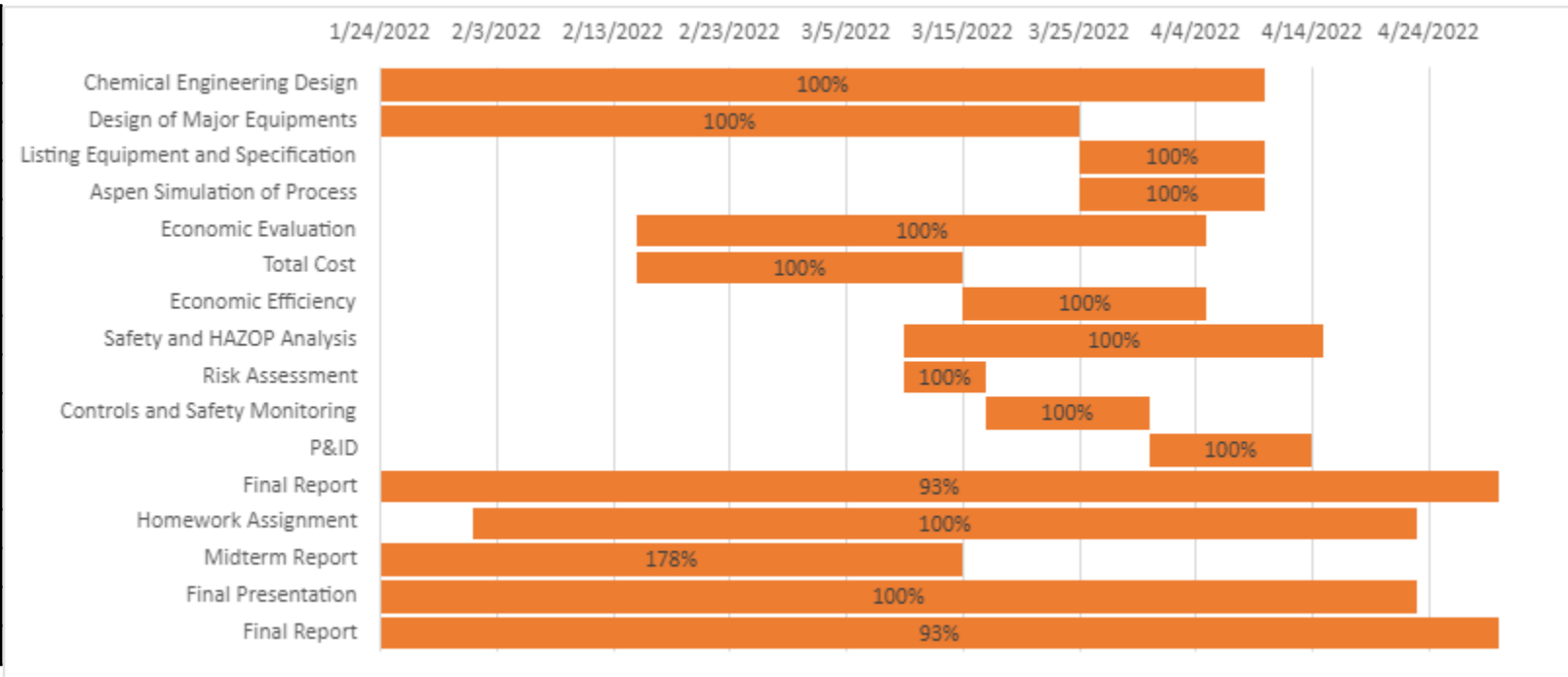
Properties of Phosphoric Acid

- Molecular formula: H_3PO_4
- Molecular Weight: 98 g-mol/mol
- Physical State: Liquid, green
- Melting Point: 108°F
- Boiling Point: 316°F
- Weak Acid

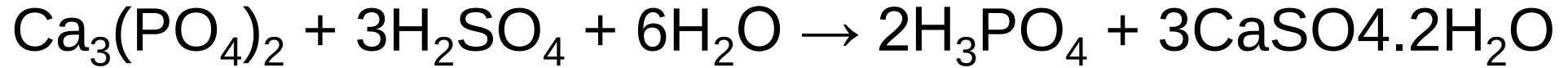


Project Schedule

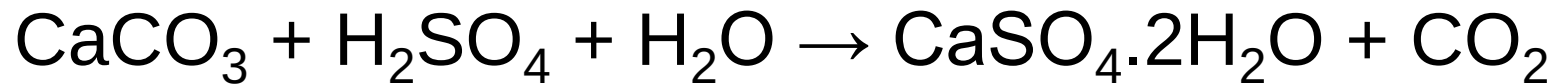
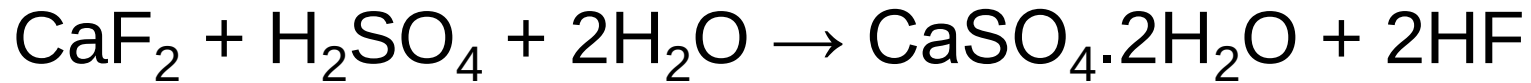
Task		Start Date	End Date
Phase 1	Chemical Engineering Design	1/24/2022	4/10/2022
	Design of Major Equipment	1/24/2022	3/25/2022
	Listing Equipment and Specification	3/25/2022	4/10/2022
	Aspen Simulation of Process	3/25/2022	4/10/2022
Phase 2	Economic Evaluation	2/15/2022	4/5/2022
	Total Cost	2/15/2022	3/15/2022
	Economic Efficiency	3/15/2022	4/5/2022
Phase 3	Safety and HAZOP Analysis	3/10/2022	4/15/2022
	Risk Assessment	3/10/2022	3/17/2022
	Controls and Safety Monitoring	3/17/2022	3/31/2022
	P&ID	3/31/2022	4/14/2022
Phase 4	Final Report	1/24/2022	4/30/2022
	Homework Assignment	2/1/2022	4/23/2022
	Midterm Report	1/24/2022	3/15/2022
	Final Presentation	1/24/2022	4/23/2022
	Final Report	1/24/2022	4/30/2022



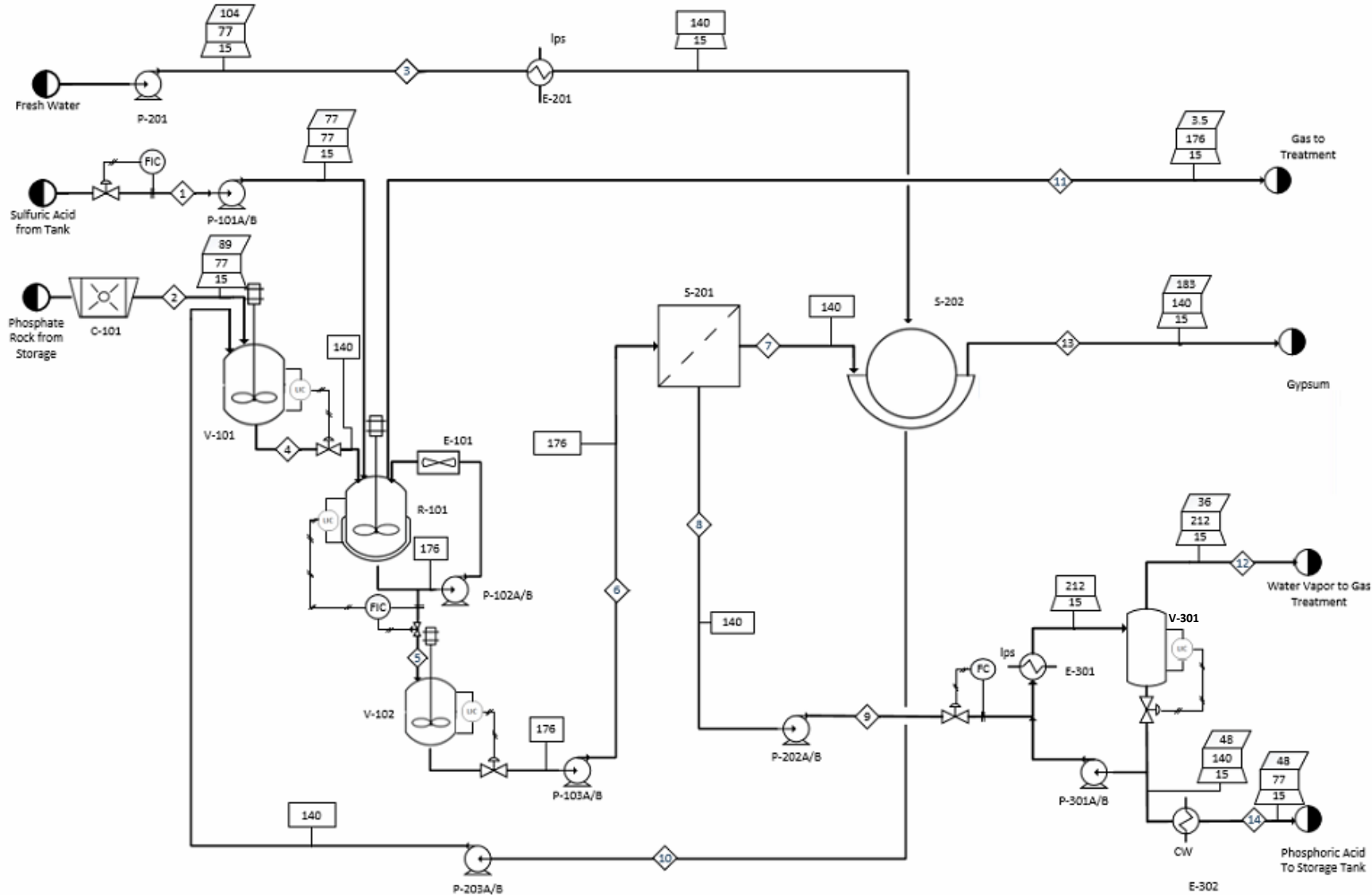
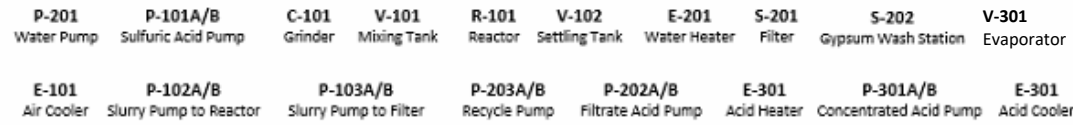
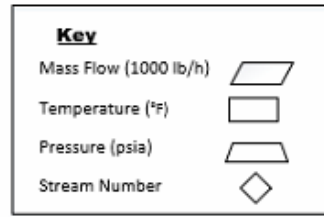
Process Chemistry



Side Reactions:



Process Flow Diagram



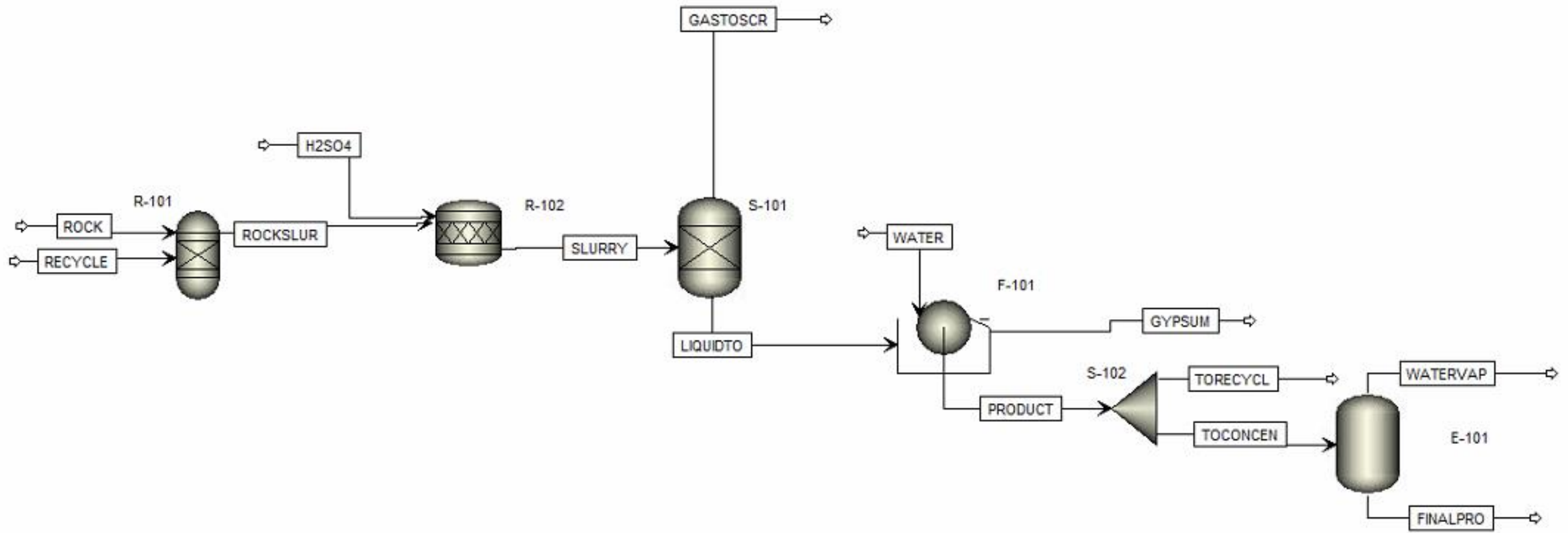
DABK Design – Phosphoric Acid Production

Drawn by: KH Date: 1/1/2022
 Checked by: AN Date: 3/15/2022
 Drawing Number: DABK_0001
 Revision: 2

Material and Energy Balance

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Temperature (°F)	77	77	77	140	176	176	140	140	140	140	176	212	140	77
Pressure (psia)	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Phase	Liquid	Solid	Liquid	Liquid/Solid	Liquid/Solid	Liquid/Solid	Liquid/Solid	Liquid	Liquid	Liquid	Vapor	Liquid/Vapor	Solid	Liquid
Mass Flow (lb/h)	77000	89000	104000	268900	342500	342500	2589000	83600	83600	179900	3540	35600	183000	48000
Composition Mass Flow (lb/h)														
P ₂ O ₅	0	26700	0	0	0	0	0	0	0	0	0	0	0	0
Ca ₃ (PO ₄) ₂	0	0	0	58300	2300	2300	2300	0	0	0	0	0	2300	0
CaO	0	43000	0	2800	0	0	0	0	0	0	0	0	0	0
CaCO ₃	0	0	0	7000	0	0	0	0	0	0	0	0	0	0
F	0	3200	0	0	0	0	0	0	0	0	0	0	0	0
CaF ₂	0	0	0	6600	0	0	0	0	0	0	0	0	0	0
SiO ₂	0	8500	0	8500	6000	6000	6000	0	0	0	0	0	6000	0
H ₂ SO ₄	71200	0	0	0	3000	3000	1800	1200	1200	0	0	0	1800	1200
H ₂ O	5800	0	104000	129400	112800	112800	66600	46200	46200	129400	0	35600	41200	10600
H ₃ PO ₄	0	0	0	50500	85100	85100	50500	34600	34600	50500	0	0	0	34600
CaSO ₄ ·2H ₂ O	0	0	0	0	123600	123600	123600	0	0	0	0	0	123600	0
SiF ₄	0	0	0	0	3900	3900	2300	1600	1600	0	440	0	2300	1600
CO ₂	0	3100	0	0	0	0	0	0	0	0	3100	0	0	0
Other	0	4500	0	5800	5800	5800	5800	0	0	0	0	0	5800	0

ASPEN Simulation



ASPEN Simulation Report

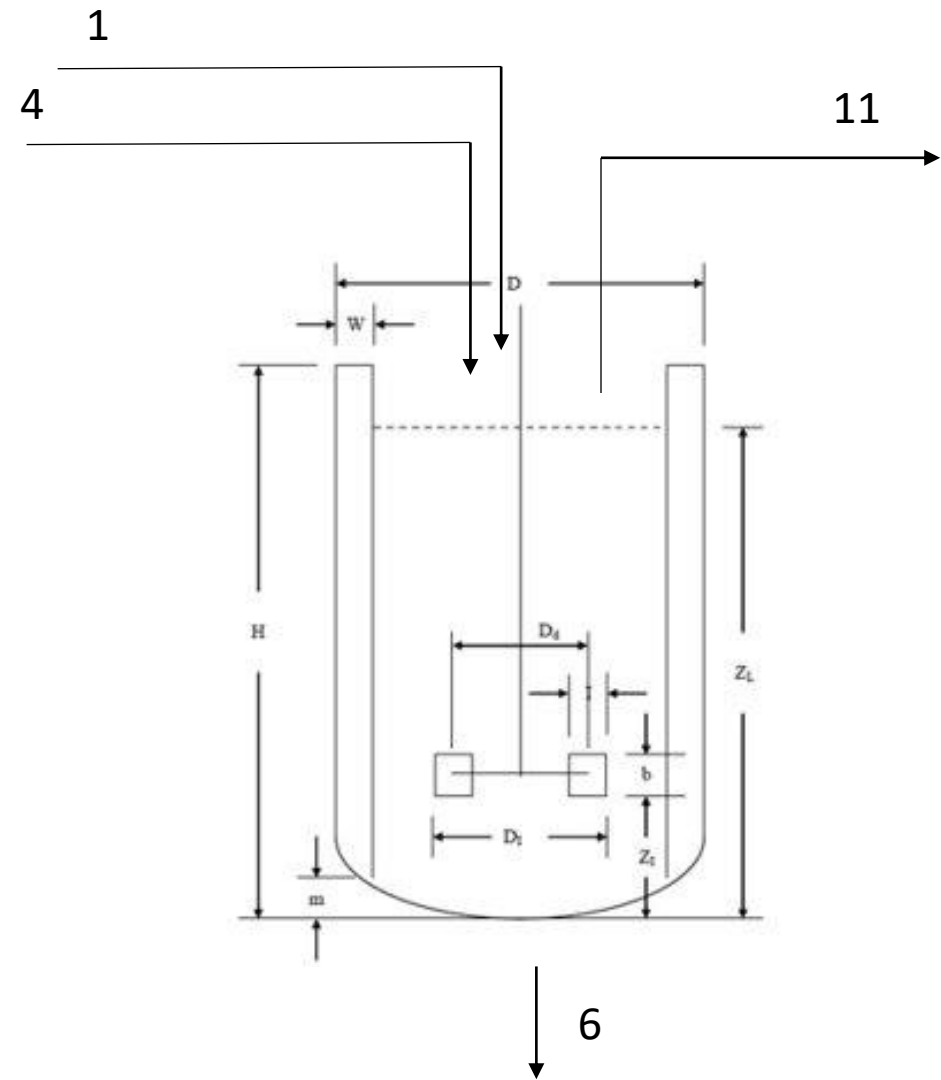
	Units	FINALPRO ▾	GASTOSCR ▾	GYPSUM ▾	H2SO4 ▾	LIQUIDTO ▾	PRODUCT ▾	ROCK ▾	ROCKSLUR ▾	SLURRY ▾	TOCONCEN ▾	WATERVAP ▾
– Mass Flows	lb/hr	47488.1	3597.15	184122	77000	342303	158181	89000	268900	345900	83044.8	35556.7
P2O5	lb/hr	0	0	0	0	0	0	27024.3	0	0	0	0
CAO	lb/hr	0	0	0	0	0	0	38734.8	0	0	0	0
CAL-PHOS	lb/hr	0	0	4285.02	0	4285.02	0	0	71417	4285.02	0	0
SIO2	lb/hr	0	0	5992.71	0	5992.71	0	8557.69	8557.69	5992.71	0	0
CO2	lb/hr	0	3152.83	0	0	0	0	3152.83	3152.83	3152.83	0	0
FE2O3	lb/hr	0	0	2252.02	0	2252.02	0	2252.02	2252.02	2252.02	0	0
AL2O3	lb/hr	0	0	2612.35	0	2612.35	0	2612.35	2612.35	2612.35	0	0
H2O	lb/hr	10680.8	0	22816.3	1135.15	107757	84940.5	0	131554	107757	44593.8	33913
H2SO4	lb/hr	1576	0	806.395	75864.9	3808.44	3002.04	0	0	3808.44	1576.07	0.0703825
H3PO4	lb/hr	35220.1	0	18020.3	0	85106.3	67086	0	42687.9	85106.3	35220.1	5.65657e-09
GYPSUM	lb/hr	0	0	126490	0	126490	0	0	0	126490	0	0
CAF2	lb/hr	0	0	0	0	0	0	6665.99	6665.99	0	0	0
CACO3	lb/hr	0	0	0	0	0	0	0	0	0	0	0
SIF4	lb/hr	11.1925	444.311	846.702	0	3998.8	3152.1	0	3.00584e-23	4443.11	1654.85	1643.66

Theoretical
Mass Balance

Stream	Phosphate Rock	Sulfuric Acid	Phosphoric Acid	Gypsum
Mass flow (lb/h)	89,000	77,000	48,000	183,000

Equipment Design

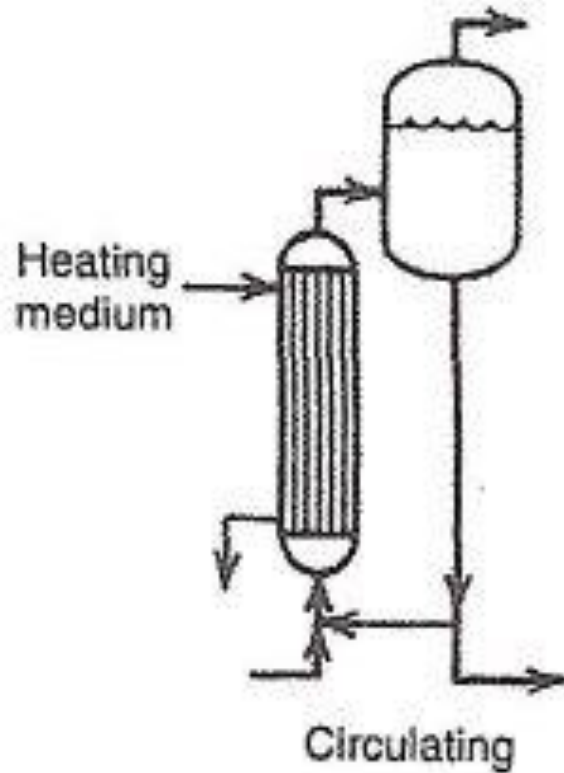
Equipment Design



Reactor			
Identification	Item Number	R-101	
	Types	CSTR	
	No Required	1	
Function	Where sulfuric acid reacts with phosphate rock to produce phosphoric acid		
Operation	Continuous		
Material Handled	Flow Rate (lb/h)	Inlet 345900	Outlet 345900
	Composition		
	P ₂ O ₅	0	0
	CaO	0.01	0.01
	Ca ₃ (PO ₄) ₂	0.17	0
	CaCO ₃	0.02	0
	F	0	0
	CaF ₂	0.02	0
	SiO ₂	0.03	0.02
	H ₂ SO ₄	0.21	0.01
	H ₂ O	0.37	0.33
	H ₃ PO ₄	0.15	0.25
	CaSO ₄ .2H ₂ O	0	0.36
	SiF ₄	0	0.01
	CO ₂	0	Trace
	other	0.02	0.02
Operation Condition	Temperature (°F)	176	
	Pressure (psia)	15	
Design Data	MOC	Stainless steel lined with Hastelloy C	
	Volume (gallons)	49,000 gallons	
	Diameter (ft)	20	
	Height (ft)	25	
	Baffles	4	
	Agitator System		
	Impeller diameter (ft)	10	
	Impeller clearance (ft)	6.5	
	Impeller blade width (ft)	4	
	Speed (rpm)	35	
	Power (hp)	220	
Utility	Cooling system (air flow 480,000 cfm)		
Cost	Purchase cost	\$846,000	
	Total bare module cost	\$1,270,000	
Note	Handle corrosion components: H ₂ SO ₄ , H ₃ PO ₄ , SiF ₄		

14

Equipment Design



Evaporator			
Identification	Item Number	V-301	
	Type	Forced-Circulation	
	No Required	1	
Function	Concentrate the phosphoric acid leaving the filter		
Operation	Continuous		
Material Handled		Phosphoric acid	Steam
	Flow Rate (lb/h)	83,600	44,000
	Volume Flow Rate (gpm)	58.2	88
Operation Condition	Temperature	212°F	
	Pressure	15psia	
Design Data	Volume (gallons)	4,500	
	Diameter (ft)	15	
	Height (ft)	25	
	Heat Transfer Area (ft ²)	1220	
	Heat Duty (MMBTU/h)	54	
Utility	Electricity (MMBTU/h)	1.2	
	Saturated Steam at 15psia		
Cost	Purchased cost	\$1,070,000	

Economic Analysis

Raw Material Cost



Raw Material Cost

Rock
Phosphate

Amount: 374,000 tons/year

Cost: \$52,360,000/year

Sulfuric Acid

Amount: 324,000 tons/year

Cost: \$58,320,000/year

Total Cost

\$110,680,000/year

Major Equipment Capital Cost

Equipment Number	Equipment Type	Number of Spares	Total Purchase Cost (\$)
CV-101	Conveyor Belt		55,800
V-301	Force-Circulation Evaporator		1,070,000
E-101	U-Tube Exchanger		45,200
E-201	U-Tube Exchanger		27,400
S-201	Filter		2,040,000
P-101A/B	Centrifugal Pump	1	26,000
P-202A/B	Positive Displacement Pump	1	10,700
P-103A/B	Centrifugal Pump	1	22,700
TK-101	Sulfuric Acid Storage Tank		529,000
TK-102	Phosphoric Acid Storage Tank		445,000
V-101	Mixer		75,600
R-101	Reactor		846,000
C-101	Grinder		15,600
			Total: 5,729,900

Operating Cost

Operating Labor Costs	
Number of operators	Amount: 3 operators/shift
Number of shifts	Amount: 1050 shifts/year
Pay of each operator	Cost: \$33.67/hr
Total Annual Operating Labor Cost	\$885,000/year

Utility Costs	
Electricity	\$81,000
Fuel	\$1,080,000
Steam	\$240,000
Water Treatment	\$212,000
Waste Disposal	\$2,002,000
Water	\$412,000
Total Utility Cost	\$4,027,000/year

Production Cost

Variable Cost	
Raw Material	\$110,680,000/year
Utilities	\$4,027,000/year
Operating Labor	\$885,000/year
Operating Supervision	\$133,000/year
Maintenance & Repairs	\$2,084,000/year
Operating Supplies	\$313,000/year
Laboratory charges	\$133,000/year
Royalties	\$889,000/year
Total	\$124,572,200/year

Fixed Cost	
Taxes (Property)	\$695,000/year
Insurance	\$347,000/year
Total	\$1,042,000/year

General Expenses	
Administration	\$620,000/year
Distribution & Selling	\$4,447,000/year
Research & Development	\$3,558,000/year
Total	\$8,626,000/year

Manufacturing Cost	
Plant Overhead	\$1,861,000/year
Manufacturing Cost	\$80,322,000/year

Fixed Capital Investment

Fixed Capital Investment

Direct Costs

Purchased Equipment, E'	\$6,100,000
Delivery, Fraction of E'	\$610,000
Purchased Equipment Installation	\$3,154,000
Instrumentation & Controls (Installed)	\$2,416,000
Piping (Installed)	\$4,563,000
Electrical Systems (Installed)	\$738,000
Buildings (Including Services)	\$1,208,000
Yard Improvements	\$671,000
Service Facilities (Installed)	\$4,697,000
Total Direct Costs: \$24,156,000	

Fixed Capital Investment

Indirect Cost

Engineering and Supervision	\$2,214,000
Construction Expenses	\$2,751,000
Legal Expenses	\$268,000
Contractor's Fee	\$1,476,000
Contingency	\$2,952,000
Total Indirect Cost: \$9,662,000	

Total Fixed Capital Investment

Fixed Capital Investment	\$33,818,000
Working Capital	\$5,972,000
Total Capital Investment	\$39,790,000

Profitability Analysis

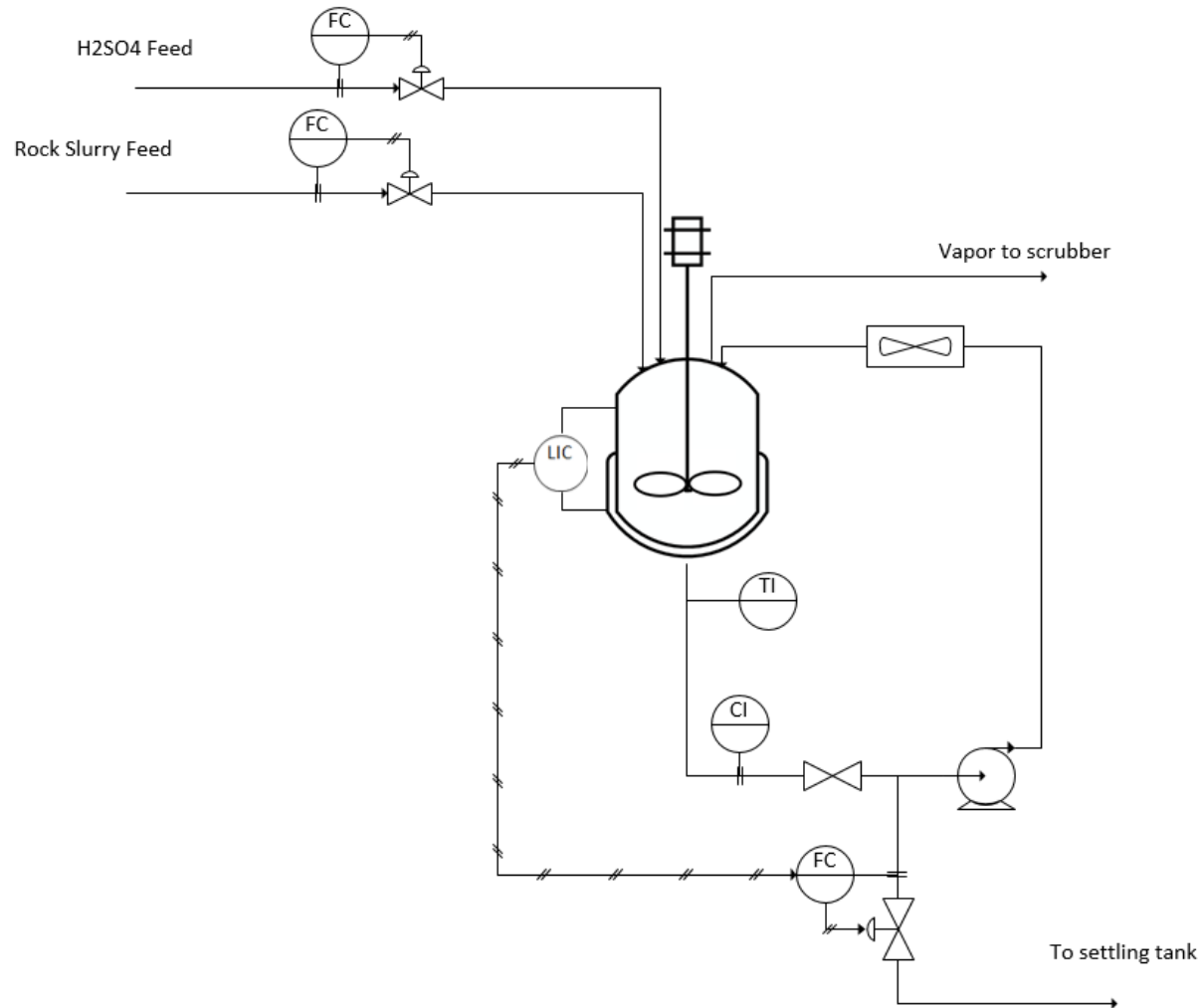
Production Analysis	
Plant Capacity	200,000 tons/year
Total Fixed Capital Investment	\$33,818,000
Total Annual Product Value	\$219,490,000/year
Total Production Cost	\$88,948,000
NPV (Net Present Value)	\$61,530,000
ROR (Return on Investment)	165.5%/year
Pay Back Period	5 months
DCRR (Discounted Cash Flow Rate of Return)	15.2%

Safety Analysis

Hazard Analysis of Reactor

Keyword	Guideword	Element	Deviation	Cause	Consequence	Safeguard	Action
Temperature	No	Heat transfer	Temperature increases	No heat being removed from the reactor	Plugging of pipes, failure of air cooler to cool product	Temperature sensors	Send signal to turn off reactor flow line
	High	Heat transfer	Temperature decreases	Failure of temperature control allowing too much cooling from the air cooling than what is needed	Accumulation of unreacted material, possible of plugged pipes	Inspect temperature setpoints, decrease air blow	Send signal to turn off/slow down air cooler Reduce flow rate to the air cooler
	Low	Heat transfer	Temperature increases	An adequate amount of heat is not being removed from the reactor; air cooler pipes clogged	Might cause pipe freezing, possible failure of air cooler	Temperature measurement of air cooler and product leaving reactor	Send signal to turn off reactor flow line Send a signal to external air cooler to increase flow of air
Level	Low	Low liquid level in reactor	Underflow	Clogging from phosphate rock, leaks from corrosion of sulfuric acid	Not enough production	Level control system, flow control of slurry & sulfuric acid feed	Partial close product FCV leaving reactor, open reactants' valves
	High	High liquid level in the reactor	Overflow	Build up in the reactor, more flow of reactants into reactor than anticipated	Overflow of product in reactor	Close flow control valve of feed streams into reactor, and open product stream into settling tank	Shut down the reactor to clean up

P&ID of Reactor



MAWP: 100 psia
MAWT: 482°F

Process Safety & Handling

- Potential HF and SiF₄ release
- Potential dust explosion
- Waste treatment
- Gas scrubber

Sulfuric Acid	Rock Phosphate	CaSO4.2H2O (Gypsum)	Hydrogen Fluoride	Silicon Tetrafluoride
Exposure limit: 1 mg/m ³ , 8-hour work shift	Exposure limit: 30 mg/m ³ (total dust) 10 mg/m ³ (respirable fraction), 8-hour work shift	Exposure limit: 15 mg/m ³ , 8-hour work shift	Exposure limit: 2.5 mg/m ³ , 8-hour work shift	Exposure limit: 5 ppm, at any time
Not flammable or combustible, reacts violently with water	Fire/explosive hazard when a dust could lead to explosion	Nonflammable, Contact with powerful oxidizing agents may cause fire or explosions	Nonflammable, but when in contact with water may create corrosive fumes of fluoride	Nonflammable, but reacts with moist air to form hydrogen fluoride fumes
Ensure proper ventilation	Ensure proper ventilation	Ensure proper ventilation		

Process Safety & Handling (cont'd)



	Sulfuric Acid	Rock Phosphate	Gypsum	HF	SiF ₄
Health Hazard	3	1	2	4	3
Fire Hazard	0	0	0	0	0
Instability Hazard	2	0	0	1	0
Specific Hazard		-	-	-	

Recommendations

- Utilized water and air leaving the heat exchanger
- Gas treatment process, defoamer in reactor
- Proceed:
 - Detailed economic analysis of the equipment material
 - P&ID for each section
 - Plant outline
- Future Expanding
 - Morocco location

Thank you!

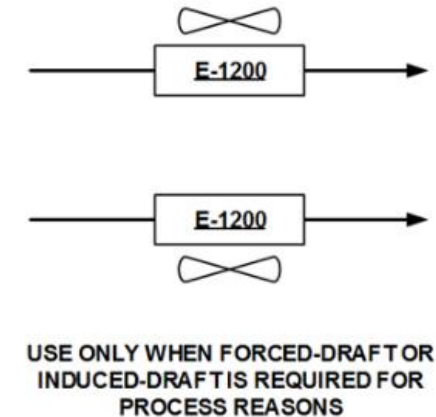
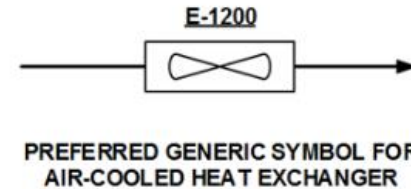
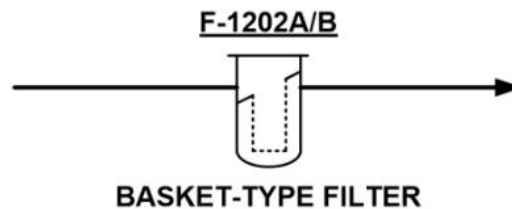
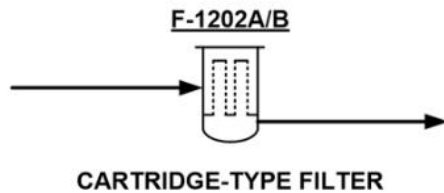
PFD Icons

Heat Exchanger Symbols – Air Cooled

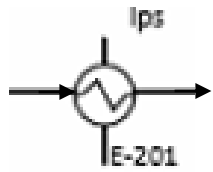


Filters Symbols

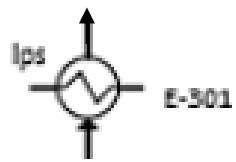
- Pump Strainers
 - Do not show on PFDs (detail on P&ID)
- Simple Filters (basket, cartridge, etc.)
 - Avoid premature specification of filter type
 - Omit vent and drain plans



PFD symbol



Process fluid
on tube side



Process fluid
on shell side

Phosphoric Acid Composition

Phosphoric Acid Composition
Phosphorous Pentoxide (P ₂ O ₅): 54%
Free Water: 22.4%
Sulfate(SO ₄): 2.8%
Aluminum (Al ₂ O ₃): 0.7%
Iron(Fe ₂ O ₃): 0.6%
Fluoride(F): 0.15%
Magnesium(MgO): 0.3%
Calcium(CaO): 0.01%

$$\%P_2O_5 \times 1.38 = \% H_3PO_4$$

Rock Phosphate Composition

Rock Phosphate Composition in Florida
CaO: 48%
P ₂ O ₅ : 33-29%
SiO ₂ : 9.48%
F: 3.60%
CO ₂ : 3.48%
C: 2.18%
Al ₂ O ₃ : 1.76%
Fe ₂ O ₃ : 1.33%
S: 1.05%
Na ₂ O: 0.89%
K ₂ O: 0.11%
Cl: 0.05%

Reactor Calculation

- Retention time: $\tau = \frac{V_o}{\dot{V}} = 1.5h$
 - Type: CSTRs in series (3 tanks)
 - 25,000lb/h P_2O_5 produced
 - Residence time: 1.5h
 - Volume: $V = Q\tau = 380 \text{ gpm} \times 90 \text{ min} = 34,200 \text{ gallon}$
 - Size:
 - Volume: 1.4 safety factor = 49000 gallon = 8000 ft
 - $D = \sqrt[3]{V/0.785} = 21\text{ft}$
 - Diameter (D): assume 20ft
 - Liquid height: 20ft
 - Height: 25ft
 - Baffles: 1ft, locate 0.5ft from the wall
 - Agitation:
 - Impeller diameter: (1/4 to 1/2 D) $1/2D = 10\text{ft}$
 - Impeller clearance (distance to bottom): (1/6 to 1/2 D) $= 1/3D = 6.5 \text{ ft}$
 - Impeller blade width: (1/4 to 1/6 D) $= 1/5D = 4\text{ft}$
 - Speed: 35rpm
 - Supplies for heat exchange: air
 - Mechanical energy introduced to the system 2500BTU/h for agitation system
 - Cooler heat load = 88,000 BTU/hr/tpd $P_2O_5 = 26,400 \text{ BTU/hr}$
- Assumption:
- Well-mixed
 - Dissolution extent of phosphate: 0.94
 - Steady-state
 - Rate control of reaction is mass transfer

Reaction Kinetics

On the Modelling of Phosphate Rock Acidulation Process

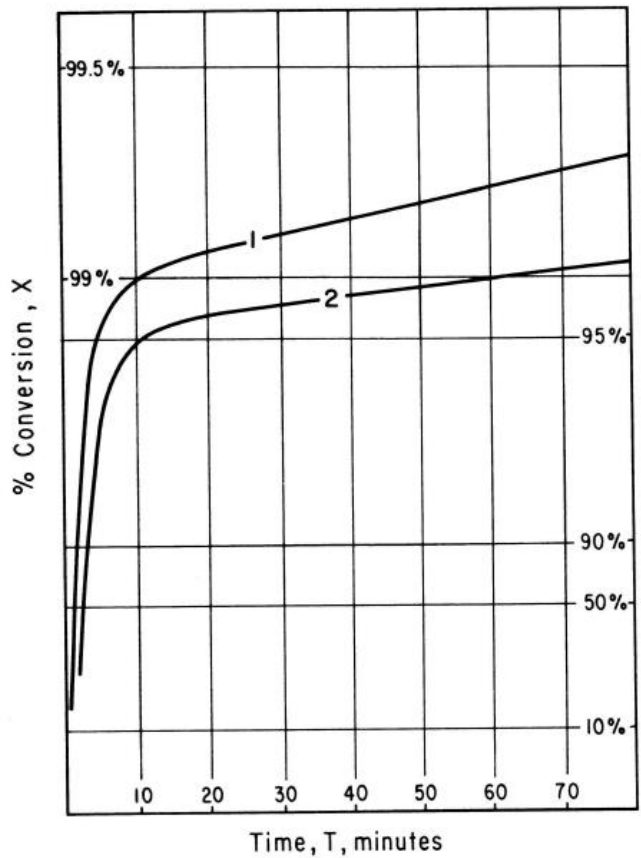
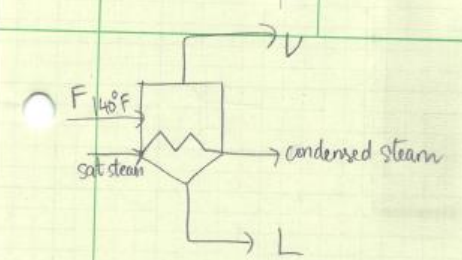


Fig. 1. Kinetics of acid attack for two Tunisian phosphate rocks in 30% P_2O_5 acid at 75°C.
Curve 1: Gafsa rock, 30% over 0.152 mm
Curve 2: Kaala Djerda rock, fraction between 0.400 mm and 0.800 mm (7).

Evaporator Calculation



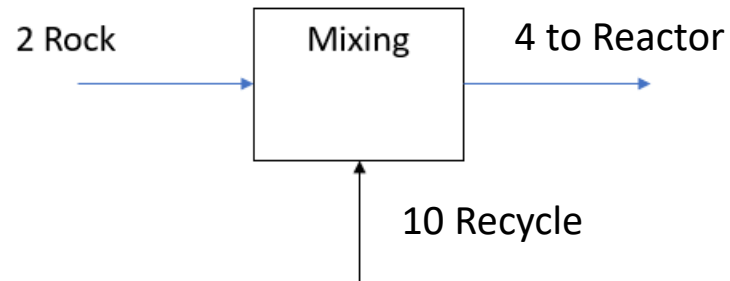
$F = 88,600 \text{ lb/hr}$ ($x_F = 0.413$)
 $V = 35,600 \text{ lb/hr}$ (water only)
 $L = 48,000 \text{ lb/hr}$ ($x_L = 0.72$)
 Operating at 212°F , 15 psia
 $m_F = m_V + m_L$

Enthalpy in = Enthalpy out
 $m_F H_F + m_S H_S^V = m_V H_V + m_L H_L + m_S H_S^L$
 Rearrange
 $m_S (H_S^V - H_S^L) = m_V (H_V - H_F) + m_L (H_L - H_F)$
 Steam table, @ 212°F , 15 psia, $\hat{H}_V = 2676 \text{ kJ/kg} = 1151 \text{ BTU/lb} = H_S^V$
 $H_L = c_{pL} (T_L - 70^\circ\text{F}) = 0.6935 (212 - 70) = 98.5 \text{ BTU/lb}$
 $\downarrow$ Perry (cp of H_3PO_4 @ 21.3°C) p. 2-188
 $H_F = c_{pF} (T_F - 70^\circ\text{F}) = 0.5046 (140 - 70) = 35.3 \text{ BTU/lb}$
 $\Delta H_S^{\text{vap}} = 970.3 \text{ BTU/lb}$ @ 212°F
 $m_S = \frac{35,600 (1151 - 35.3) + 48,000 (98.5 - 35.3)}{970.3} = \boxed{44,000 \text{ lb/hr}}$
 Heat exchange = $m_F H_F + m_S H_S^V$
 $= 88,600 \times 35.3 + 44,000 \times 1151$
 $= 54,050,000 \text{ BTU/hr} = 57,000 \text{ MJ/hr}$
 From Fig 4.4, viscosity = 0.0003 Pa.s, $U = 3,500 \text{ J/s.m}^2.\text{K}$
 (Chemical process design)
 $Q = U A \Delta T \Rightarrow A = \frac{57 \times 10^9 / 3600}{3,500 \times (110 - 60)} = 113 \text{ m}^2 = 1,220 \text{ ft}^2$
 Power consumption (Fig 4.5) = $3 \text{ kW/m}^2 \Rightarrow 340 \text{ kW}$
 $= 1.2 \text{ MM BTU/hr}$
 Steam in @ 17.5 psia

Assumption:

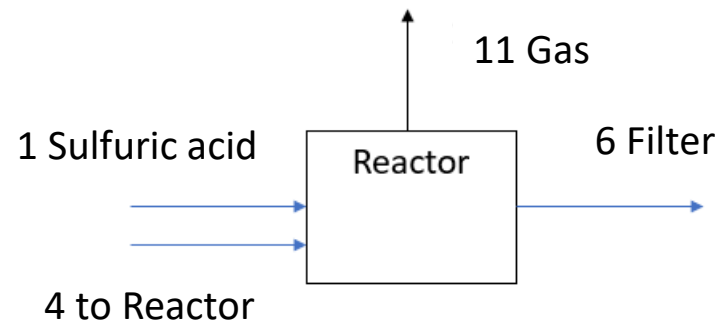
- The feed stream contains only water and phosphoric acid
- Steam leaving as condensed steam
- Steady-state

Mass Balance for Major Equipment



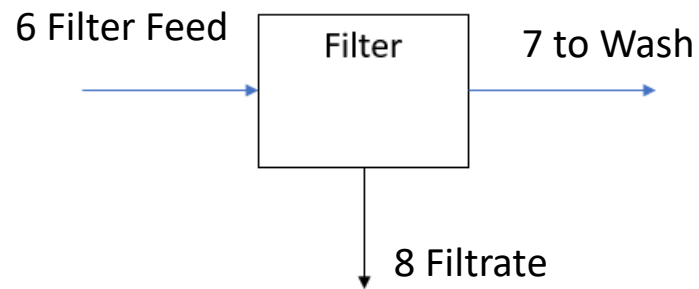
	2 (Rock)	10 (recycle)	4 (to reactor)
P ₂ O ₅	26700	0	0
Ca ₃ (PO ₄) ₂	0	0	58300
CaO	43000	0	2800
CaCO ₃	0	0	7000
F	3200	0	0
CaF ₂	0	0	6600
SiO ₂	8500	0	8500
H ₂ SO ₄	0	0	0
H ₂ O	0	129400	129400
H ₃ PO ₄	0	50500	50500
CaSO ₄ ·2H ₂ O	0	0	0
SiF ₄	0	0	0
CO ₂	3100	0	0
Other	4500	0	5800
Total	268900		268900

Mass Balance for Major Equipment

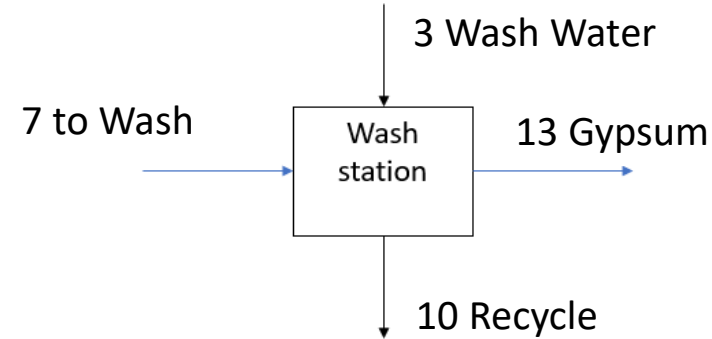


	1 Sulfuric Acid	4 to Reactor	6 to Filter	11 Gases
P ₂ O ₅	0	0	0	0
Ca ₃ (PO ₄) ₂	0	58300	2300	0
CaO	0	2800	0	0
CaCO ₃	0	7000	0	0
F	0	0	0	0
CaF ₂	0	6600	0	0
SiO ₂	0	8500	6000	0
H ₂ SO ₄	0	0	3000	0
H ₂ O	71200	129400	112800	0
H ₃ PO ₄	5800	50500	85100	0
CaSO ₄ ·2H ₂ O	0	0	123600	0
SiF ₄	0	0	3900	440
CO ₂	0	0	0	3100
Other	0	5800	5800	0
Total	345900		346040	

Mass Balance for Major Equipment (cont'd)

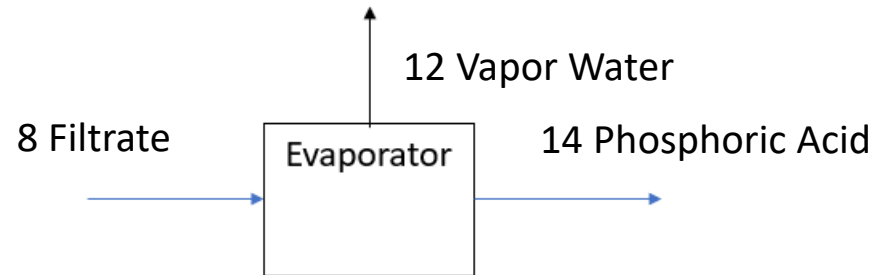


	6 Filter Feed	7 To wash	8 Filtrate
P ₂ O ₅	0	0	0
Ca ₃ (PO ₄) ₂	2300	2300	0
CaO	0	0	0
CaCO ₃	0	0	0
F	0	0	0
CaF ₂	0	0	0
SiO ₂	6000	6000	0
H ₂ SO ₄	3000	1800	1200
H ₂ O	112800	66600	46200
H ₃ PO ₄	85100	50500	34600
CaSO ₄ ·2H ₂ O	123600	123600	0
SiF ₄	3900	2300	1600
CO ₂	0	0	0
Other	5800	5800	0
Total	342500		342500



	3 Washed Water	7 to Wash	10 Recycle	13 Gypsum
P ₂ O ₅	0	0	0	0
Ca ₃ (PO ₄) ₂	0	2300	0	2300
CaO	0	0	0	0
CaCO ₃	0	0	0	0
F	0	0	0	0
CaF ₂	0	0	0	0
SiO ₂	0	6000	0	6000
H ₂ SO ₄	0	1800	0	1800
H ₂ O	104000	66600	129400	41200
H ₃ PO ₄	0	50500	50500	0
CaSO ₄ ·2H ₂ O	0	123600	0	123600
SiF ₄	0	2300	300	2000
CO ₂	0	0	0	0
Other	0	5800	0	5800
Total	362900		362900	

Mass Balance for Major Equipment (cont'd)

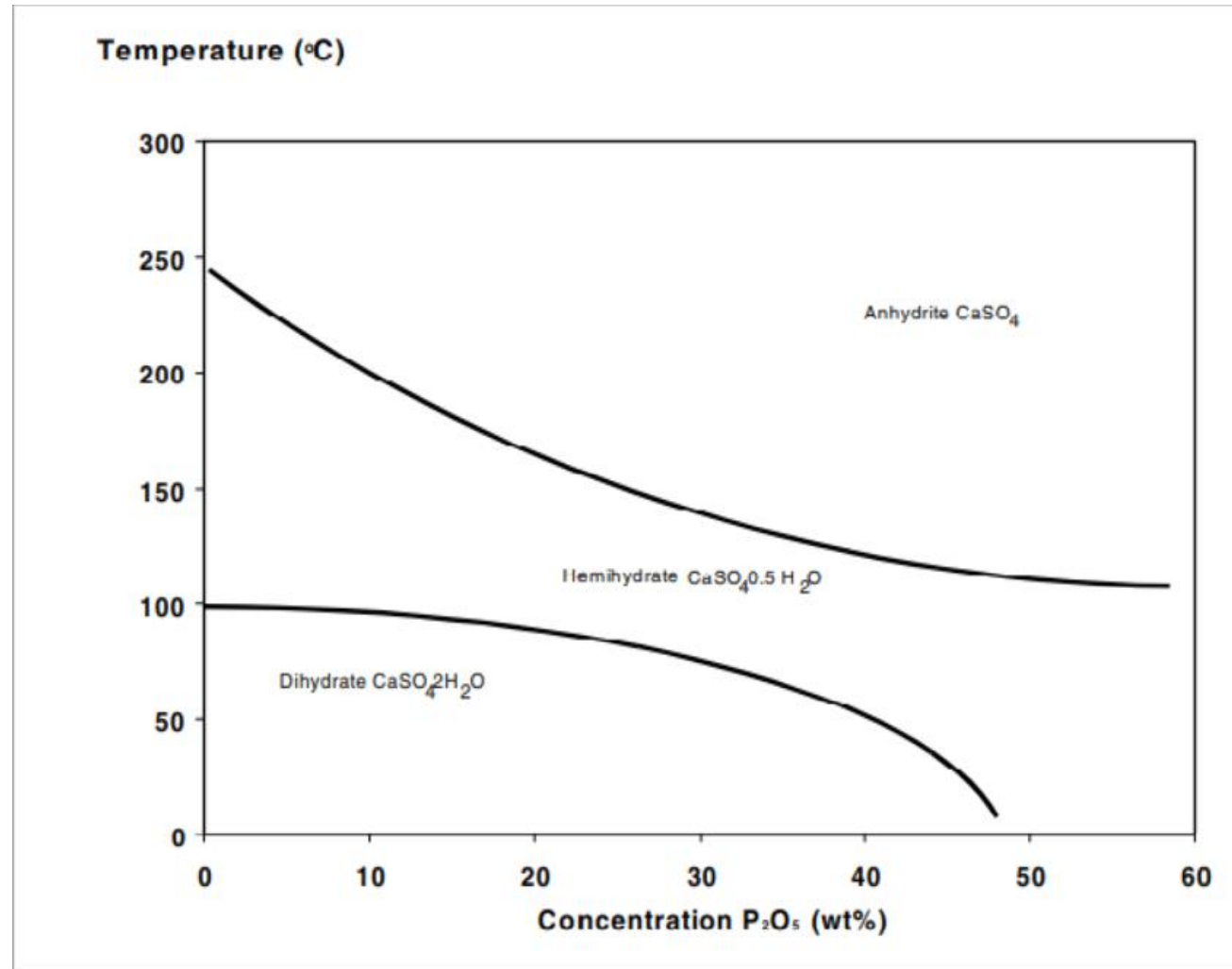


	8 Filtrate	12 Vapor Water	14 PA
P ₂ O ₅	0	0	0
Ca ₃ (PO ₄) ₂	0	0	0
CaO	0	0	0
CaCO ₃	0	0	0
F	0	0	0
CaF ₂	0	0	0
SiO ₂	0	0	0
H ₂ SO ₄	1200	0	1200
H ₂ O	46200	35600	10600
H ₃ PO ₄	34600	0	34600
CaSO ₄ ·2H ₂ O	0	0	0
SiF ₄	1600	0	1600
CO ₂	0	0	0
Other	0	0	0
Total	83600		83600

Heat Exchanger: Specification Sheet

Heat Exchanger			
Identification	Item Number	E-103	
	Type	Shell and Tube	
	No Required	1	
Function	Condense the evaporated steam into water for recycling into filter		
Operation	Continuous		
Design Data		Tube Side	Shell Side
	Flow Rate (lb/h)	80,500	
	Stream Number		
	Temperature (°F)		
	In	140	77
	Out	150	120
	Pressure (psia)	15	
	Utility Temperature	140	
	Heat Transfer Area (ft ²)	1300	
	Heat Duty (BTU/h)	1450	
	Shell Diameter (in)		
	Number of Tubes	408	
	Tube Diameter (in)	0.75	
	Tube Length (ft)	16	
	Material of Construction		
	Shell	SS	
	Tube	SS	
Utility	Cooling water		
Cost	Purchased	\$48,900	
	Total bare module cost	\$301,000	
	Utility cost	\$11,200	
Note			

Regions indicating precipitated Gypsum



Gypsum Further Consideration

- Especially beneficial to clay soils and is also used to treat sodic soils, increase crop yields
- Conversion to sulfur, use as landfill cover
- Production of ammonium sulfate
- Recover rare earth uranium

Basic Safety

- Full PPE is required including respiratory protection devices when high concentrations of phosphoric acid and sulfuric are required
- When handling phosphate rock full PPE is required including safety goggles with a full-face shield
- Phosphoric acid should be stored in stainless 316 or polypropylene and away from incompatible materials, excess heat, oxidizing agents, and strong acids
- Sulfuric acid should be stored in a cool, dry location, out of direct sunlight and away from heat and ignition sources