

PRODUCTION OF DIMETHYL ETHER

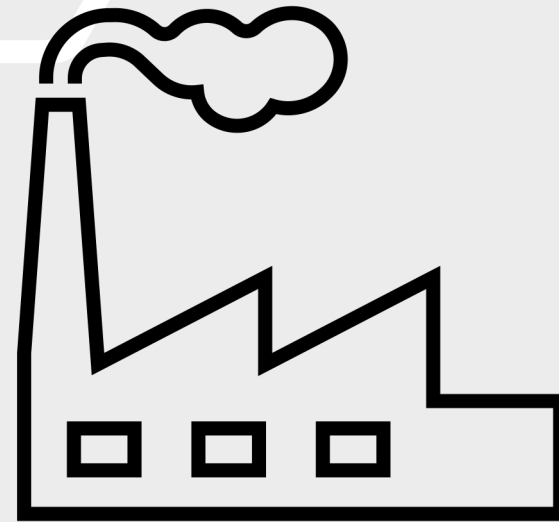
DADA TEAM 4

Amiya Rogers

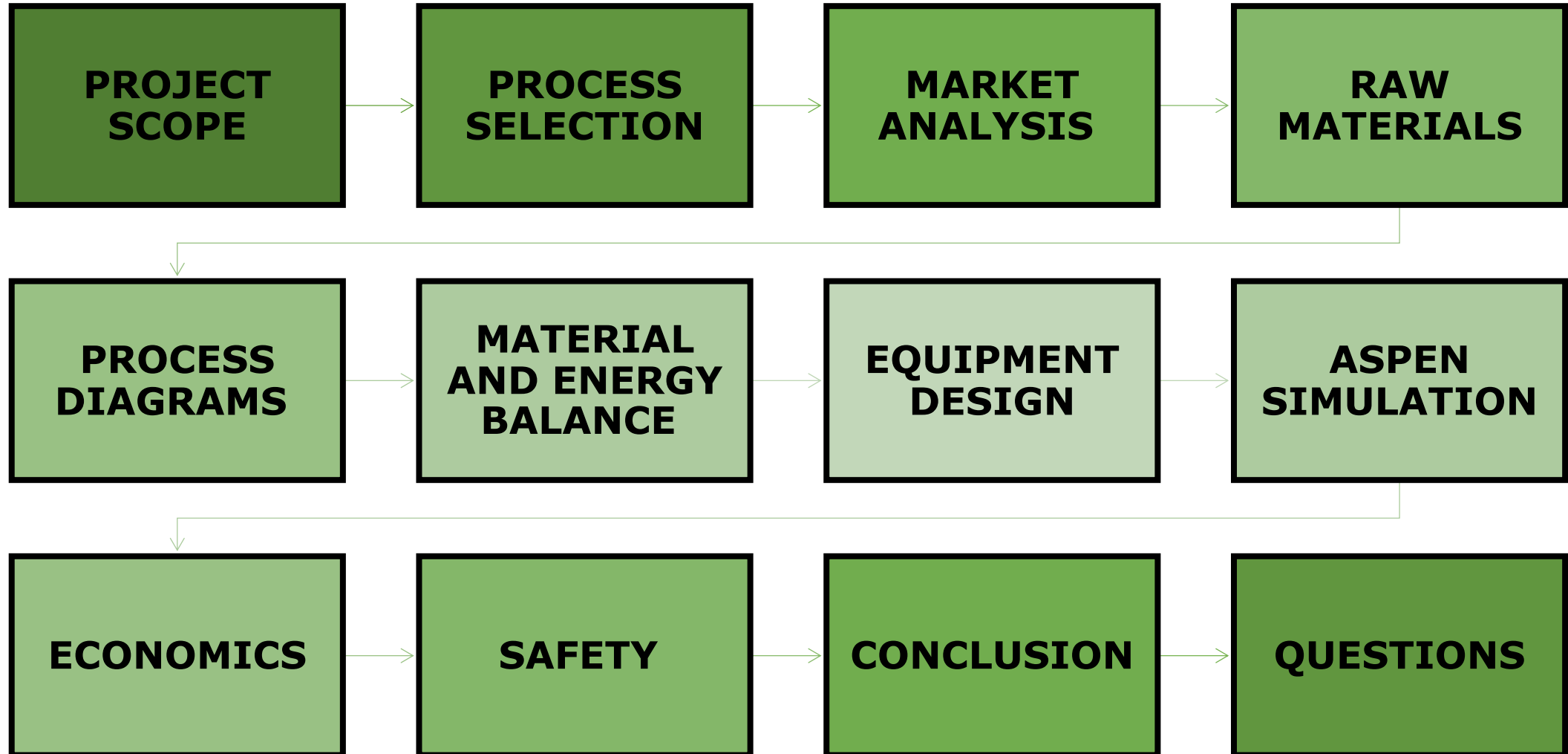
Cinthia Sahin

Laura Ukpede

Taylon Owens



OUTLINE



PROJECT SCOPE

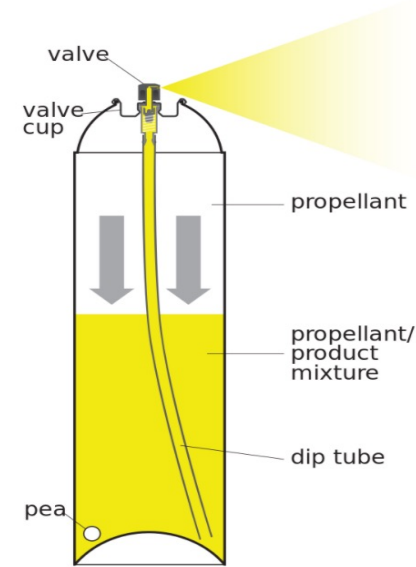
PROBLEM STATEMENT

The purpose of this project is to design a system that produces Dimethyl Ether (DME) at the required 99.9% purity.



PRODUCT USES

- Refrigerant (R-E170)
- Solvent
- Propellant in industrial aerosol products.
- Potential use for transportation fuel, domestic use, and power generation



PROCESS SELECTION

PROCESSES CONSIDERED

ALTERNATIVE	PROCESS	PROS	CONS
1	Methanol Dehydration	- Consumes less time and cost of equipment - Relatively simpler process flow - Catalyst deactivation occurs at relatively high temperature (400 C).	- Requires more downstream separation technologies. - Sourcing of methanol may present challenges. - Marginally lower DME yield.
2	Indirect Synthesis from biogas feedstock	- Marginally higher DME yield. - Water build up in the process is alleviated. - Energy efficiency is maximized.	- Sourcing of biogas feedstocks presents a challenge. - Process requires more equipment. - Relatively costly and time consuming
3	Direct Synthesis from Natural Gas Feed Stock	- Higher Yield of DME. - Low production cost. - Abundantly available feedstock	- Highly exothermic. - Low production rate - Higher operating temperature.

PROCESS SELECTION MATRIX

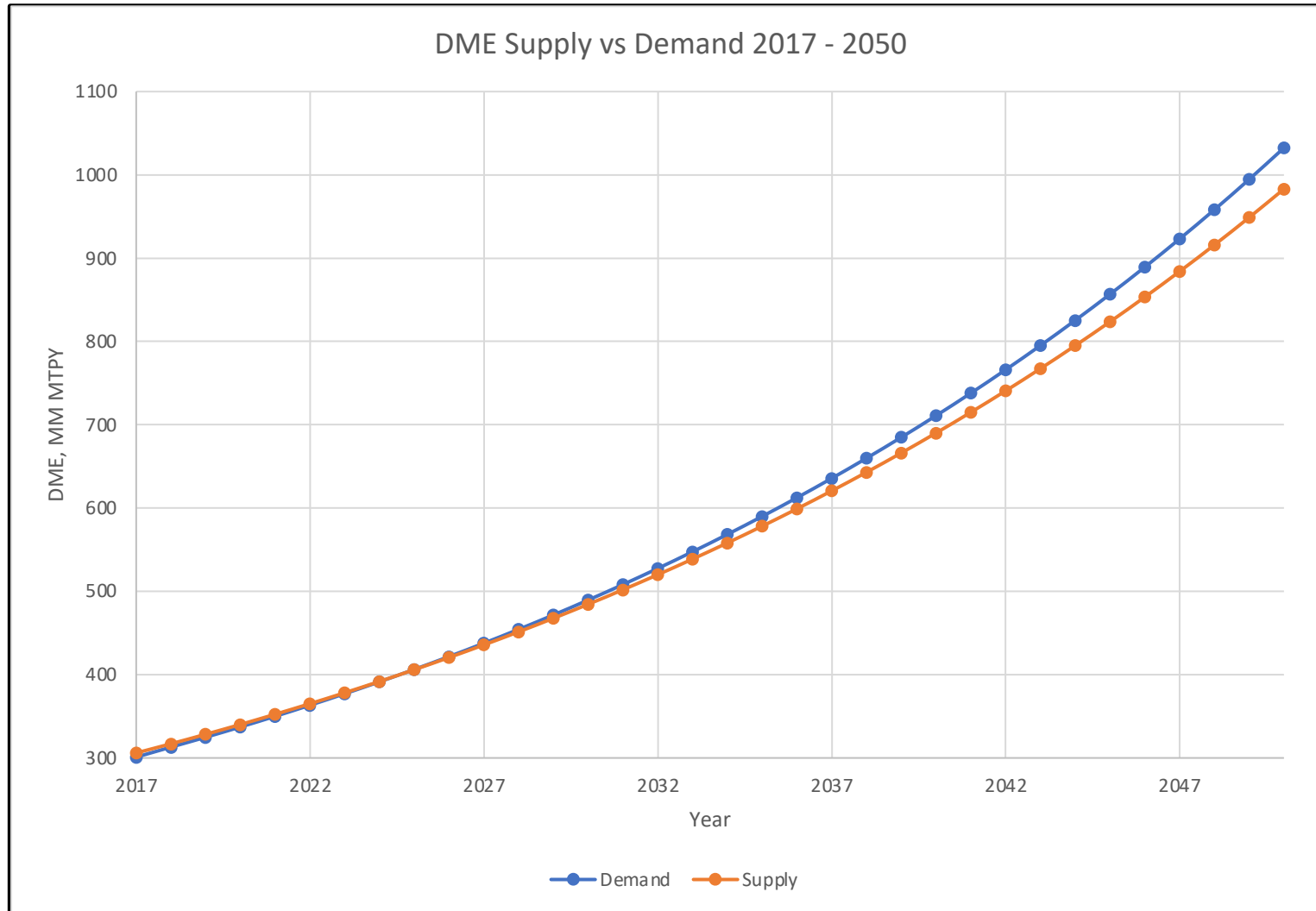
CONSIDERATIONS	ALTERNATIVE 1 Methanol Dehydration	ALTERNATIVE 2 Indirect Synthesis from biogas feedstock	ALTERNATIVE 3 Direct Synthesis from Natural Gas Feed Stock	WEIGHT
Economics	18	10	12	40%
Environmental	13	16	20	25%
Location	14	13	9	25%
Safety	13	13	16	10%
Total	<u>15.25</u>	12.5	13.65	100%

PROJECT PLANNING (GANTT CHART)

PROJECT TITLE:		PRODUCTION OF DIMETHYL ETHER (DME)																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														</
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MARKET ANALYSIS

MARKET ANALYSIS



PLANT STARTUP:

2026

2 Year Build-Time

DEMAND BASIS:

50,000 Metric Tons Per Year
(5% of 1MM Gap)

DEMAND BASIS:

90% Utilization

CLIENT IDENTIFICATION



PLANT LOCATION

LOCATION:

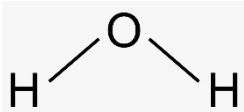
Plaquemine, Louisiana

Plaquemine Cogeneration Facility: Steam and Power
Port of Plaquemines for Cooling Water



RAW MATERIALS

CHEMICAL CONDITIONS

Conditions	Methanol	Dimethyl Ether	Water
Molecular Weight	0.071 lb/mol	0.102 lb/mol	0.039 lb/mol
Chemical Formula	CH ₃ OH	CH ₃ OCH ₃	H ₂ O
Chemical Structure	$ \begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{O}-\text{H} \\ \\ \text{H} \end{array} $	$ \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array} $	
Boiling Point	148.46 ° F	-11.2°F	212°F
Melting Point	-138.28°F	-221.8°F	32°F
Flash Point	49.46°F	-41.98°F	-
Density	0.029 lb/in ³	0.071 lb/in ³	0.036 lb/in ³

RAW MATERIALS



A (Methanol)

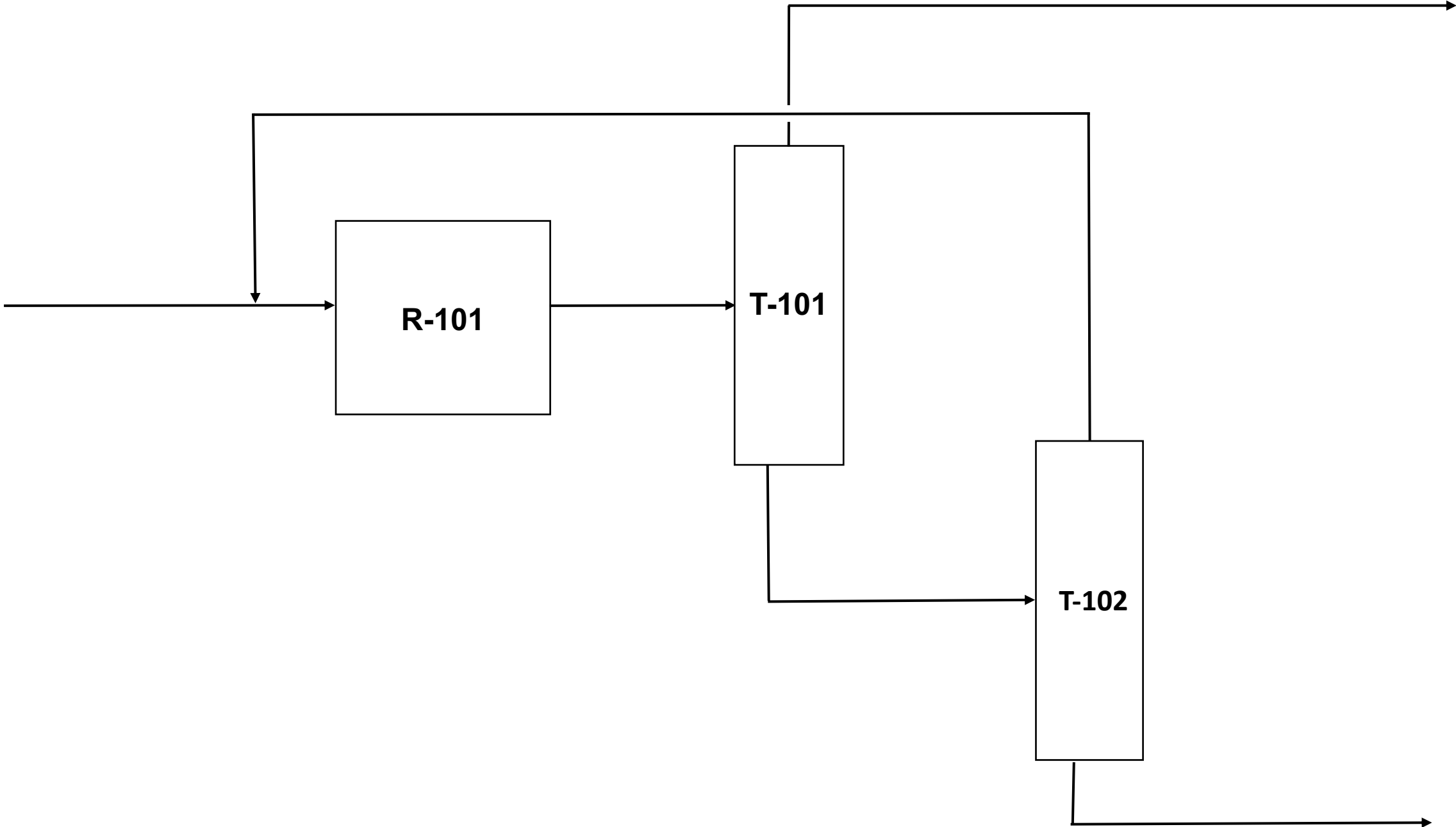
B (DME)

C (Water)

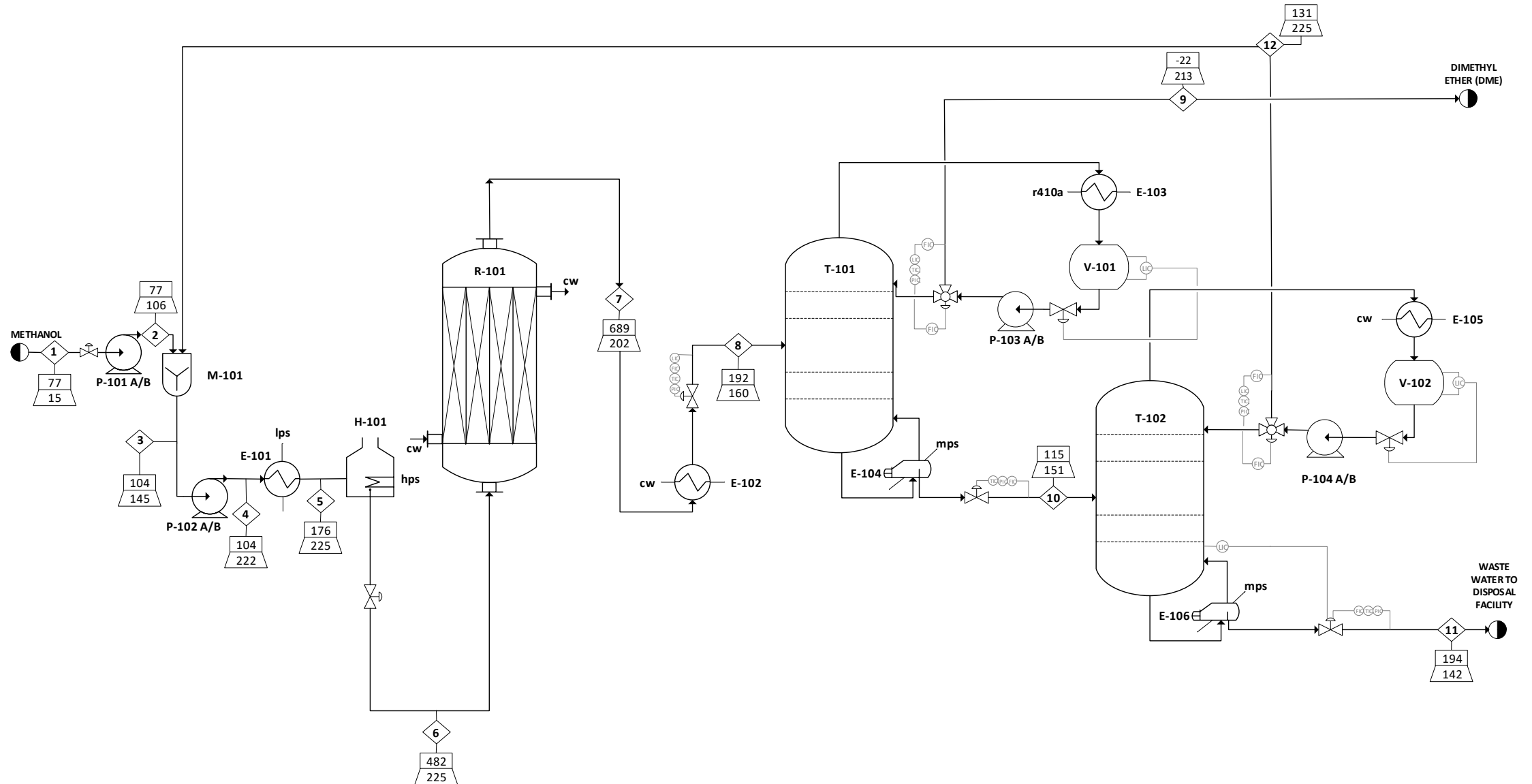
	A	B	C
mol	2	1	1
Molecular Weight lb/mol	0.071lb/mol	0.102 lb/mol	0.040 lb/mol
lb	0.141 lb	0.102 lb	0.040 lb
lb/lb DME	3.06 lb	2.20 lb	.862 lb
cents/lb	\$0.16	\$0.41	\$0.24

PROCESS DIAGRAMS

BLOCK FLOW DIAGRAM



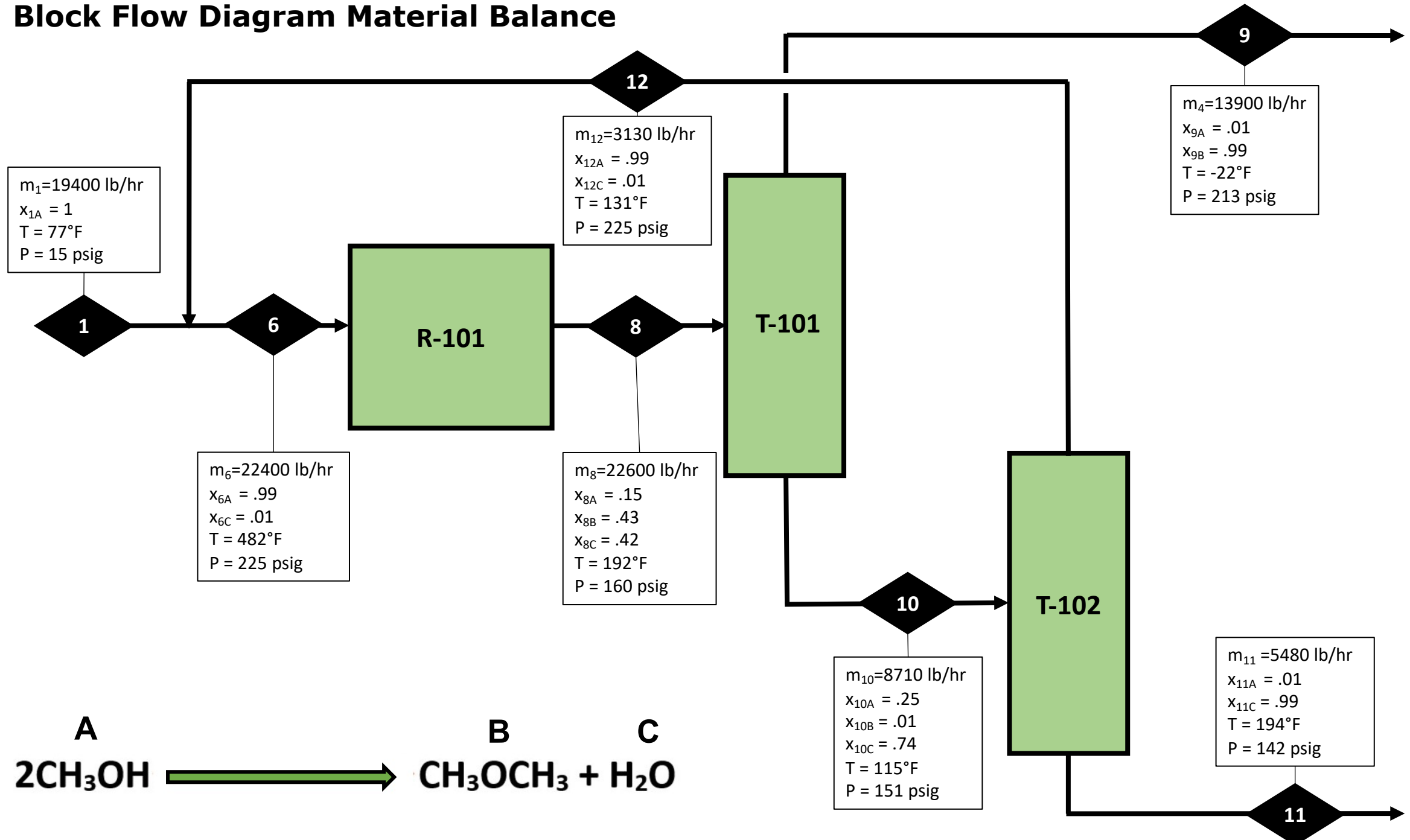
PROCESS FLOW DIAGRAM



Temperature, °F
Pressure, psig

MATERIAL AND ENERGY BALANCE

Block Flow Diagram Material Balance



STREAM CONDITIONS

Stream Description	Pure Methanol to Pump	Pure Methanol to Mixer	Mixed Stream to P-102	Methanol to Vaporizer	Combined Methanol to Furnace	Combined Feed to R-101	Reactor Effluent to Cooler	Methanol+ DME + Water to T-101	Dimethyl Ether Product	Methanol + Water to T-102	Wastewater to Disposal	Recycled Methanol to Mixer
Steam Number	1	2	3	4	5	6	7	8	9	10	11	12
Temperature (F)	77	77	104	104	176	482	689	192	-22	115	194	131
Pressure (psig)	15	106	145	222	225	225	202	160	213	151	142	225
Methanol Mole Fraction	1	1	.99	.99	.99	.99	.15	.15	.01	.25	.01	.99
DME Mass Fraction	0	0	0	0	0	0	.43	.43	.99	.01	0	0
Water Mass Fraction	0	0	.01	.01	.01	.01	.42	.42	0	.74	.99	.01
Mass Flow (lb/hr)	19352	19352	Methanol 22268	Methanol 22268	Methanol 22268	Methanol 22268	Methanol 3374	Methanol 3374	Methanol 97	Methanol 3203	Methanol 97	Methanol 3107
			Water 126	Water 126	Water 126		DME 13907	DME 13907	DME 13776	DME 184	Water 5382	
						Water 126						Water 126

ENERGY BALANCE

Methanol Dehydration R-101	
Temperature	689°F
R-101 Duty	-1.36×10^7 BTU/hr
E-101 Duty	9.67×10^6 BTU/hr
H-101 Duty	5.40×10^6 BTU/hr
E-102 Duty	-1.14×10^7 BTU/hr

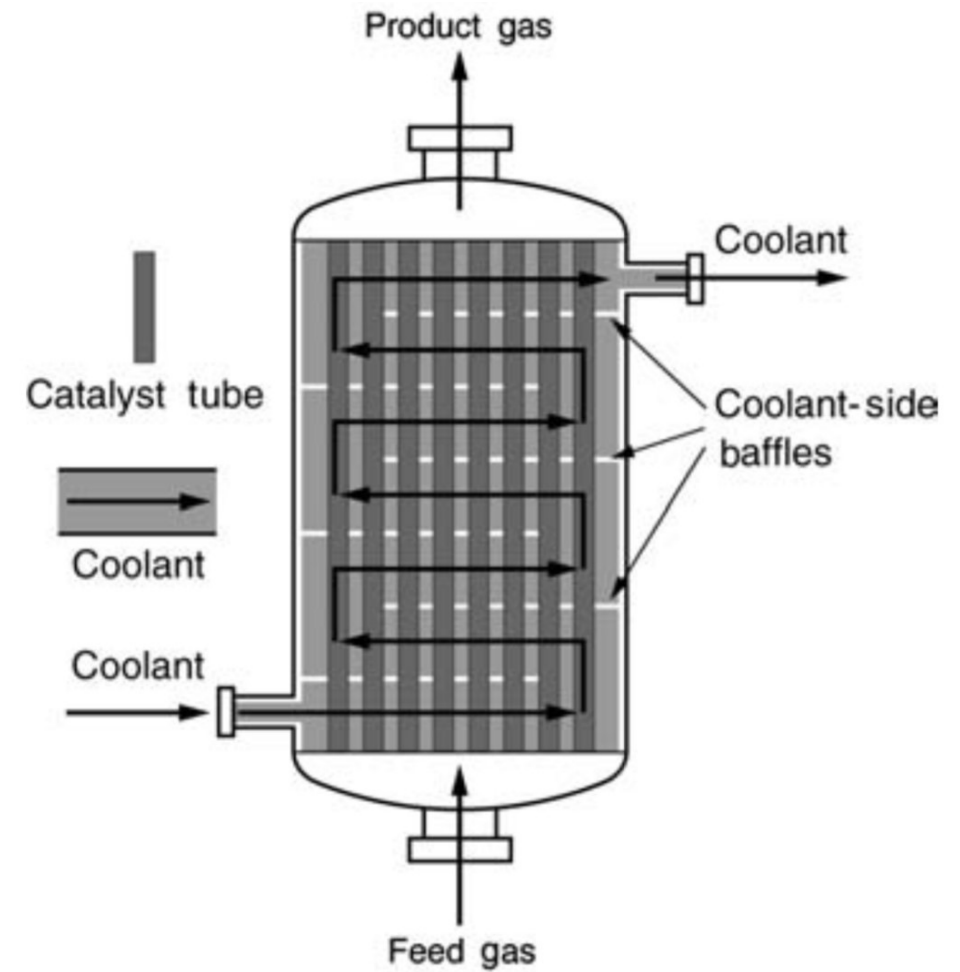
DME Distillation T-101	
Temperature	86°F/114.8°F
E-103 Duty	-3.39×10^6 BTU/hr
E-104 Duty	2.36×10^6 BTU/hr

Methanol Distillation T-102	
Temperature	158°F/194°F
E-105 Duty	-1.18×10^7 BTU/hr
E-106 Duty	1.14×10^7 BTU/hr

EQUIPMENT DESIGN

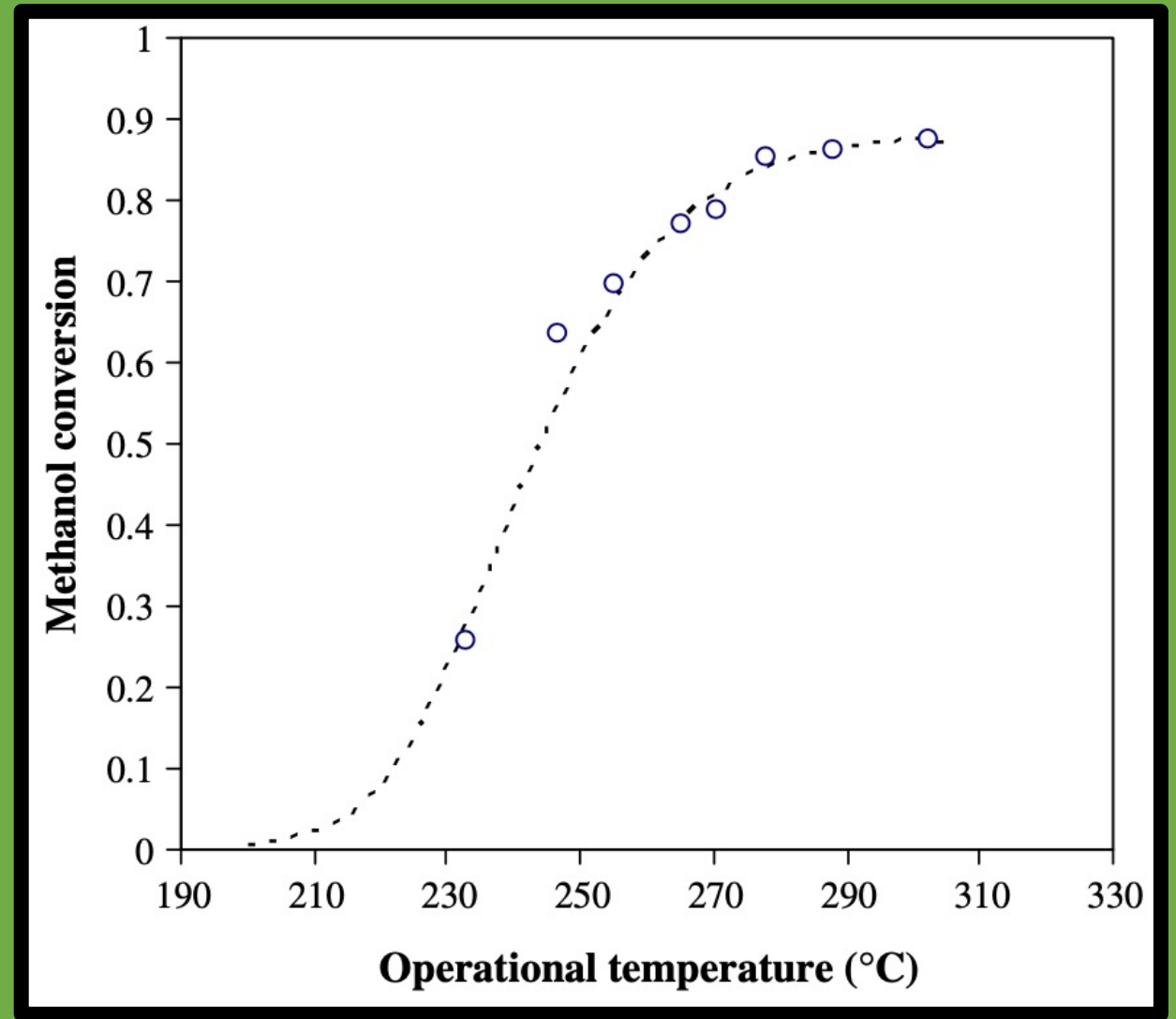
REACTION KINETICS

- Reaction: Methanol Dehydration
- Reactor Type: Catalytic Packed Bed Reactor
- Catalyst: $\gamma\text{-Al}_2\text{O}_3$
- Conversion: 90%
- Exothermic Reaction



CATALYST: γ -Al₂O₃

- Operates at high pressure
- Commonly used catalyst for Methanol Dehydration
- High activity
- Increase temperature ensures increased conversion



R-101 Specifications Sheet

Identification	
Item	Catalytic Packed Bed Reactor
Item No	R-101
Function	Dehydration of methanol to produce DME and water
Operation	Continuous
Catalyst	γ -Al ₂ O ₃
Catalyst Weight	54900 lbs

Materials Handled	In	Out
Mass Flow (lb/hr)	22400	22600
Mole flow (lbmol/hr)	702	702
Component Flow lbmol/hr		
Dimethyl Ether	0	302
Methanol	695	105
Water	7	295
Temperature (°F)	482	689
Pressure (psig)	225	202
Vapor Fraction	1.0	1.0

Design Data	
Diameter (ft)	4.36
Overall height (ft)	14.7
Number of Tubes	34
Maximum Pressure rating (psig)	218
Combined Tube Volume ft ³	62.3
Area (ft ²)	40.7
Construction of Material	Carbon Steel
Utilities (CW)	28600
Duty (Btu/hr)	-1.36x10 ⁷
Comments	-Temperature maintained by cooling water. - Shell side Methanol -Tube Side Water

T-101 Specifications Sheet

Identification	
Item	1 st distillation column
Item No	T-101
No. Required	1
Function	Separates DME from methanol and water
Operation	Continuous
Material Of Construction	Carbon Steel

Design Data	
Number of actual trays	22
Total tower height (ft)	52.5
Column diameter (ft)	2.62
Maximum Pressure rating (psig)	218
Reflux ratio	1.7
Tray Spacing (ft)	2.00

Materials Handled	Feed Methanol + DME + Water	Liquid Distillate Methanol + DME	Liquid Bottoms Methanol + Water
Mass Flow (lb/hr)	22600	13900	8710
Mole flow (lbmol/hr)	702	302	400
Component Flow lbmol/hr			
Dimethyl Ether	302	299	400
Methanol	105	3.02	100
Water	295	0.00	296
Temperature (°F)	192	86	115
Pressure (psig)	151	165	162
Vapor Fraction	1	1	0.0

Associated Components					
Condenser (E-103)	CW = 185000 lb/hr	A = 330 ft ²	Q = 3.21 x 10 ⁶ Btu/hr	- Fixed Head - Carbon Steel	Max Pressure = 145 psig
Reboiler (E-104)	mps = 2770 lb/hr	A = 72.2 ft ²	Q = 2.24.10 ⁶ Btu/hr	- Floating Head -Carbon Steel	Max Pressure = 160 psig
Reflux Drum (V-101)	L = 9.48 ft	D = 3.74 ft	Carbon Steel	Max Pressure = 149 psig	
Reflux Pump (P-102 A/B)	Power = 5.2 kW	Efficiency = 40 %	ΔP = 66.7 psig	Centrifugal/Carbon Steel	

T-102 Specifications Sheet

Identification	
Item	2 nd distillation column
Item No	T-102
No. Required	1
Function	Separates methanol from water
Operation	Continuous
Materials Of Construction	Carbon Steel

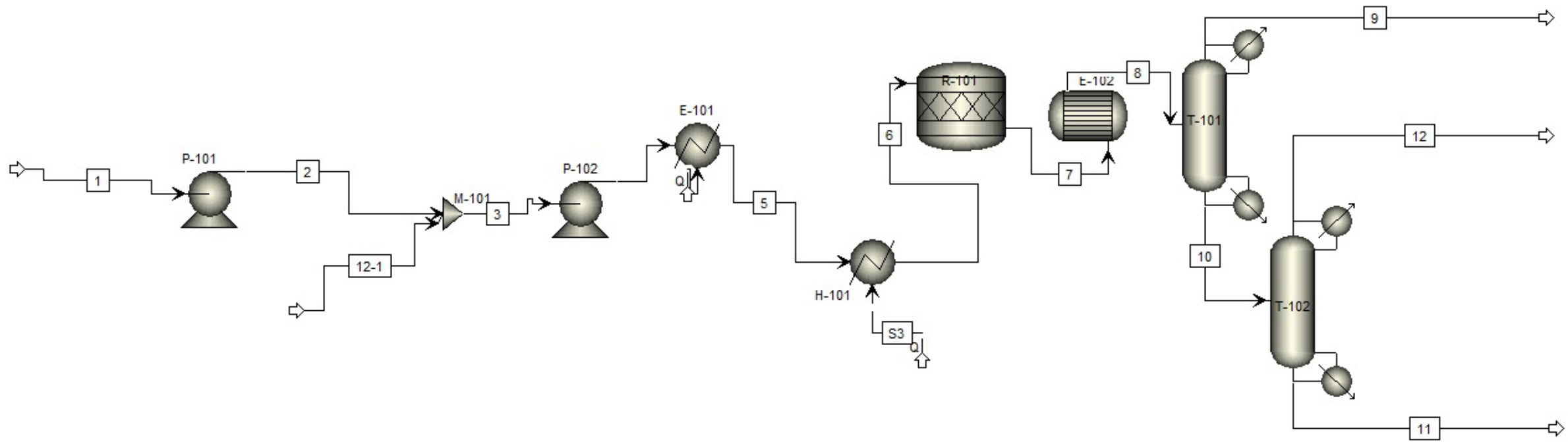
Design Data	
Number of actual trays	15
Total tower height (ft)	65.6
Column diameter (ft)	3.81
Maximum Pressure rating (psig)	218
Reflux ratio	4.5
Tray Spacing (ft)	2.62

Materials Handled	Feed	Liquid Distillate	Liquid Bottoms
Mass Flow (lb/hr)	8710	3120	5480
Mole flow (lbmol/hr)	400	98	302
Component Flow lbmol/hr			
Dimethyl Ether	3.99	0.00	0.00
Methanol	100	97	3.02
Water	29	0.970	299
Temperature (°F)	114	158	194
Pressure (psig)	162	106	107
Vapor Fraction	0.0	1.0	0.0

Associated Components					
Condenser (E-105)	CW = 649000 lb/hr	A = 74.45ft ²	Q = 1.18x10 ⁷ Btu/hr	- Fixed Head - Carbon Steel	Max Pressure = 102 psig
Reboiler (E-106)	mps = 100 lb/hr	A = 272 ft ²	Q = 1.14x10 ⁷ Btu/hr	- Floating Head - Carbon Steel	Max Pressure = 160 psig
Reflux Drum (V-102)	L = 8.30 ft	D = 12.3 ft	Carbon Steel	Max Pressure = 2160 psig	
Reflux Pump (P-103 A/B)	Power = 1.0 kW	Efficiency = 40 %	ΔP = 55.5 psig	Centrifugal/Carbon Steel	

ASPEN SIMULATION

SIMULATION

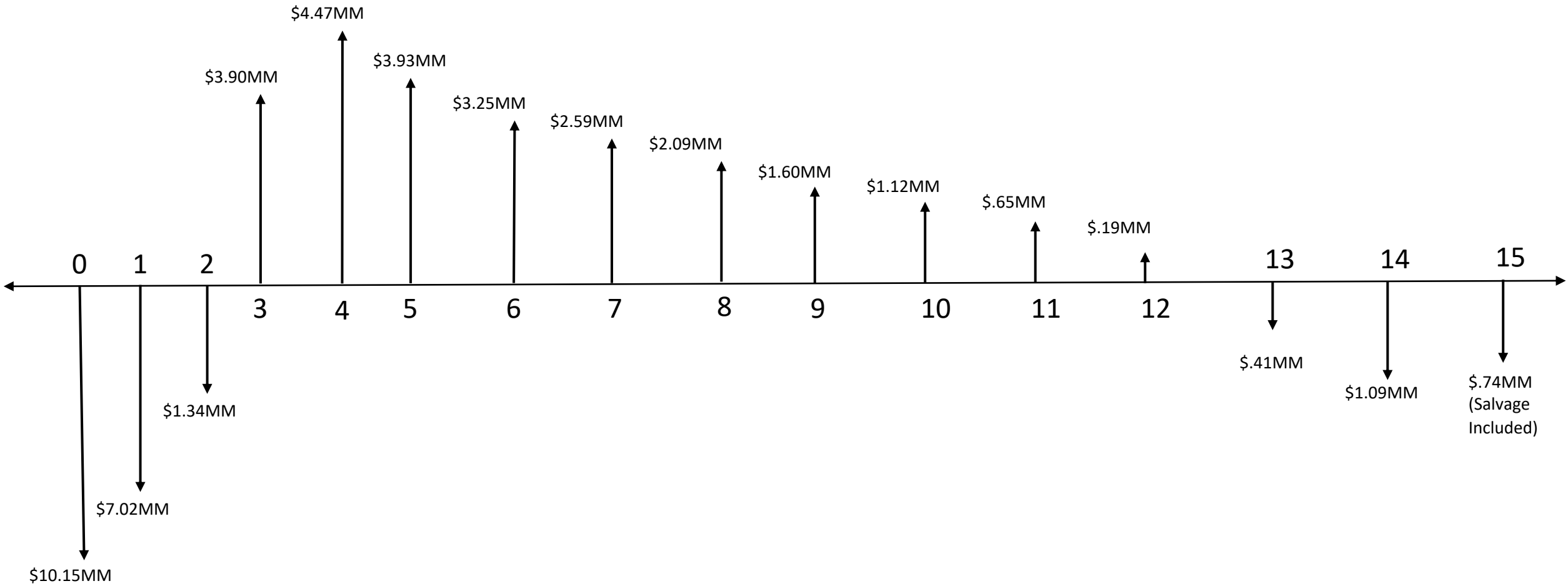


ECONOMICS

Economic Analysis

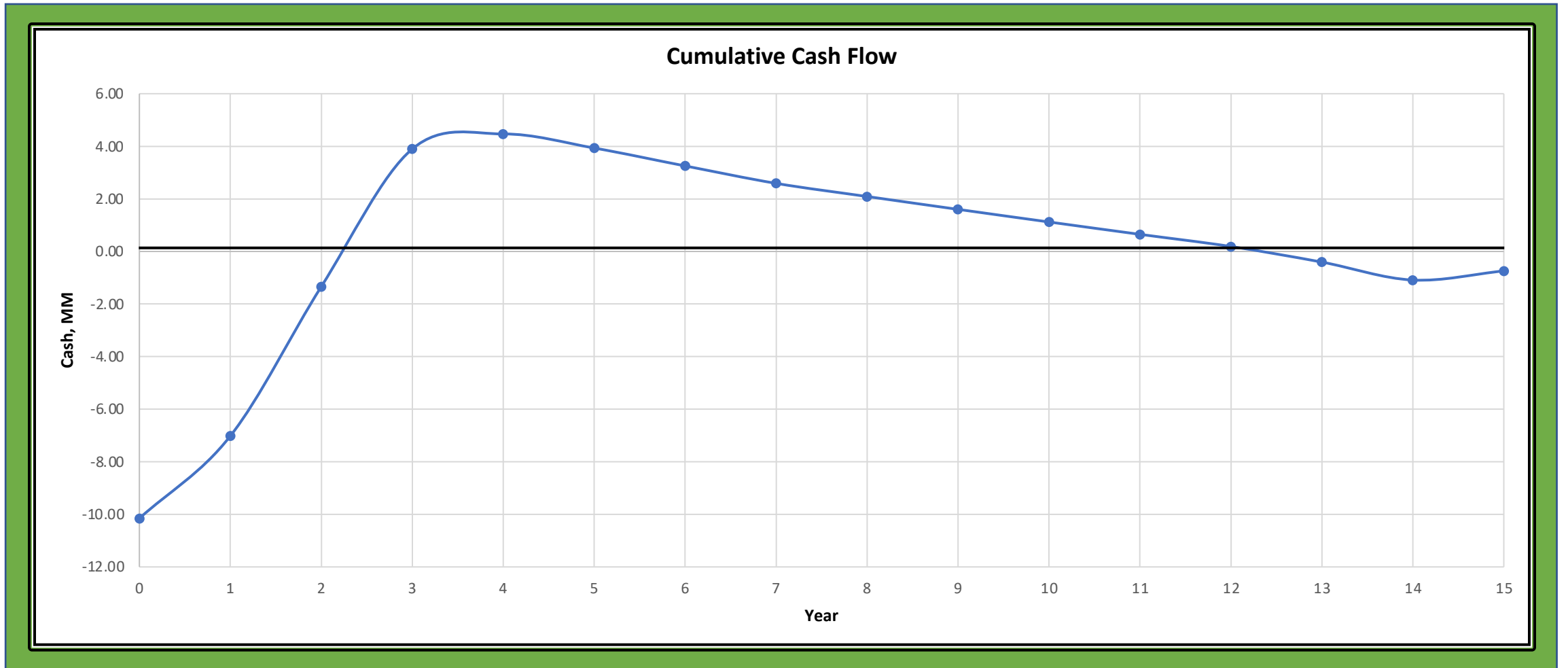
Economic Evaluation	
Total Capital Investment, 10^6	\$10.2
Annual Total Production Costs, 10^6	\$34
Annual Sales, 10^6	\$37
Payback Period, yrs	4.2
Return on Investment, %/year	22
Discounted Cash Flow Rate of Return, %/yr	13
Net Present Value, 10^6	\$8
Salvage Value, 10^6	\$1
Cumulative profit, 10^6	\$23

TCI Cash Flow Diagram



*Assume 2% TPC Inflation Rate + Depreciation

Cash Flow



SAFETY

PROCESS SAFETY HOLDING & HANDLING

HOLDING

Dimethyl Ether

- Keep away from heat
- Equipment must be grounded
- Store in a cool, well-ventilated area
- Keep away compressed oxygen or strong oxidizers
- Stored between 7-14 bar & up to 52°C

Methanol

- Methanol maximum exposure of 200 ppm (OSHA & EPA)
- Tightly closed container
- Well –ventilated area.
- Equipment must be grounded and bonded.

HANDLING

- Use of ventilators and breathing protection or local exhaust.
- The use of cold-insulating gloves.
- Oversee the use of Personal Protective Equipment (PPE).



SAFETY CONSIDERATIONS

Factor	Consideration
Markings and Labelling	Clear indications of toxicity and flammability reports on equipment at the plant. Toxicity (Exposure limits) - 1900 mg/m ³ , 1000 ppm. ("Dimethyl ether", 2021) NFPA Flammability no. - 4
Waste disposal	Determination of toxicity and physical properties to determine the proper waste classification and disposal methods.
Container disposal	Draining the containers thoroughly and venting in a safe place away from fire and sparks. Critical temperature – 126.9°C ("Dimethyl ether", 2021) Auto-ignition temperature - 350°C
Local Legislation	Waste disposal in accordance with local, regional and national laws and regulations

Safety Guidelines in Accordance with Rules and Regulations of Plaquemine, Louisiana

Pre-Line Opening Job Preparations

- The shutting down and energy isolation of all process systems prior to any line opening involving process piping, equipment or vessels (4.1.1).
- The draining and/or depressurization of all process piping, equipment or vessels to ensure clearance of hazardous materials (4.1.2).
- Ensuring temperatures for the process piping, equipment or vessels have sufficiently cooled to allow for safe work (4.1.3).

Line Opening Job Planning

- The barricading of affected areas with a minimum of 10 ft radius as a precautionary area (4.2.1.1)
- The issuance of permits strictly by authorized personnel (4.2.2.1)



HAZARD ANALYSIS T-102 FEED LINE

No.	Parameter	Guideword	Deviation	What if?	Possible Causes	Consequence	Safeguards	Action
1	Pressure	More	Pressure increase in the feed line	There is pressure build up in the feed line leading into the tower	-Blockage in the system	- Failure of feed line tube - Risk of expansion of column and bursting	Installation of quick-pressure relief valves at strategic locations before and after the column.	- Installation of a secondary pressure relief device. - Checking maintenance schedule and procedures
		Less	Pressure decreases in feed line	There are sudden pressure losses in the streams leading to the column	- Leakages in the system	- Insufficient reactant material entering the column	Pressure alarms at the feed, distillate and bottom streams	- Installation of pressure gauge - Checking maintenance schedule and procedures
2	Flow	Reverse	Backflow from T-102	The contents of the tower flow back to the feed line	- Clogging and blockages within the tower	- Pressure and temperature increase in the column	- Check valve to prevent backflow	- determining the best utilization of energy from recycle stream while preventing backflow - Following the stipulated maintenance schedule and procedures
3	Temperature	More	Increase in feed temperature	There is sudden increase in temperature at the feed of T-102	- Clogging of inlet into tower	Subsequent increase in pressure, risk of explosion and ineffectiveness of the tower	- Temperature alarms at feed entry point. - Panel alarms to warn of high pressure or temperature	-Installation of a temp gauge - Checking maintenance schedule and procedures

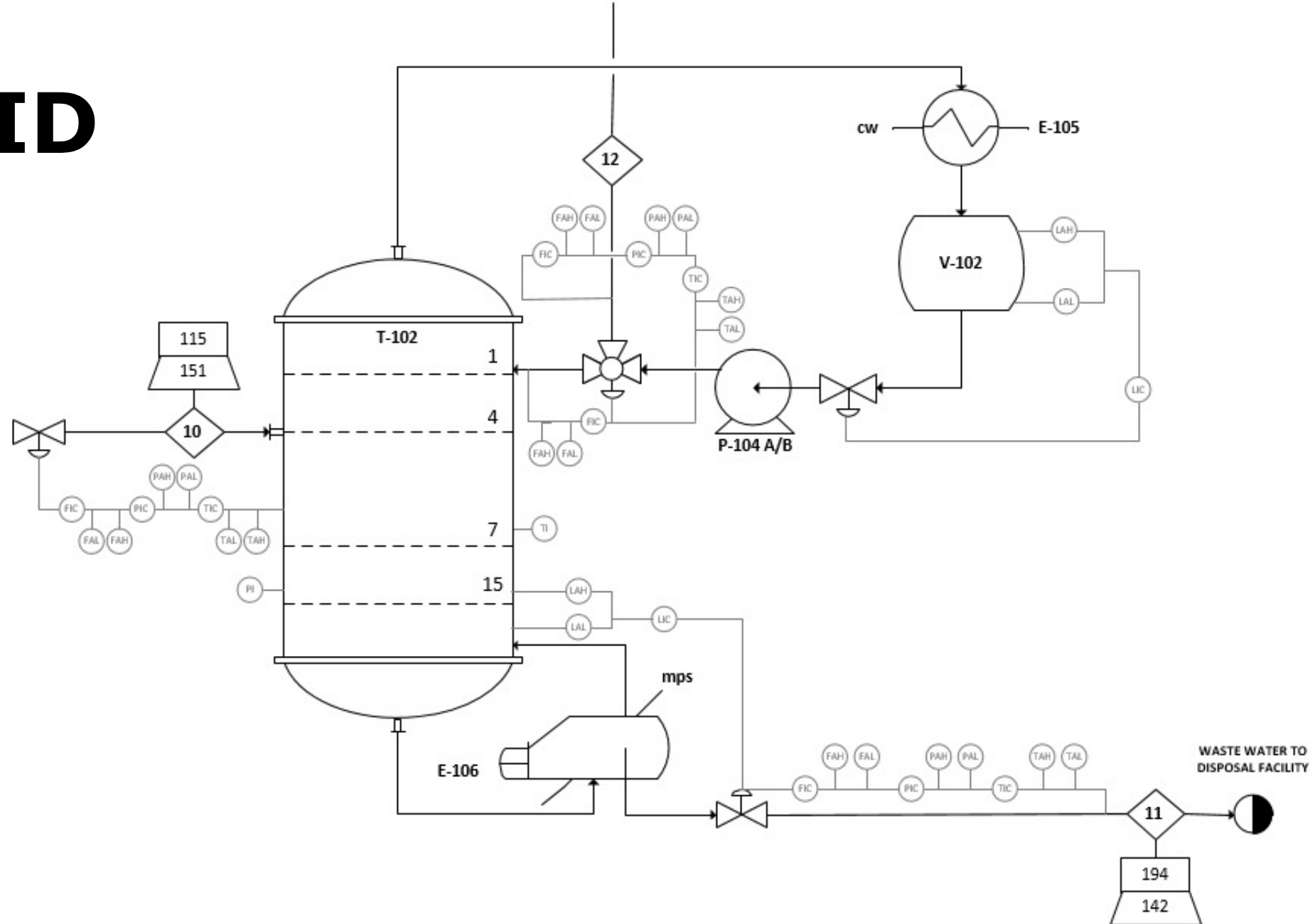
HAZARD ANALYSIS T-102 DISTILLATE LINE

No.	Parameter	Guideword	Deviation	What if ?	Possible Causes	Consequence	Safeguards	Action
1	Pressure	More	Pressure increase in the distillate line	There is pressure build up in the distillate line transporting recycled methanol to the mixer	-Blockage in the mixer or further up the distillation line	- Failure of distillate line tube - Risk of expansion of mixer and bursting. - Failure of mixer	Installation of quick-pressure relief valves at strategic locations before the mixer.	- Installation of a secondary pressure relief device. - Checking maintenance schedule and procedures
		Less	Pressure decreases in feed line	There are sudden pressure losses in the stream leading to the mixer	- Leakages in the distillate line	- Inefficiencies within the tower leading to less methanol distillate	Pressure alarms at the exit of the column where the distillate line begins.	- Installation of pressure gauge - Checking maintenance schedule and procedures
2	Flow	Reverse	Backflow to T-102	The contents of the distillate line flow back to the tower	- Clogging and blockages within the line	- Pressure and temperature increase in the column	- Check valve to prevent backflow	- determining the best utilization of energy from recycle stream while preventing backflow- Following the stipulated maintenance schedule and procedures
3	Temperature	More	Increase in distillate line temperature	There is sudden increase in temperature at distillate line transporting recycled methanol	- Clogging of inlet into the mixer	Subsequent increase in pressure, risk of explosion and ineffectiveness of the tower	- Temperature alarms at mixer entry point. - Panel alarms to warn of high pressure or temperature	-Installation of a temp gauge - Checking maintenance schedule and procedures

HAZARD ANALYSIS T-102 BOTTOM LINE

No.	Parameter	Guideword	Deviation	What if?	Possible Causes	Consequence	Safeguards	Action
1	Pressure	More	Pressure increase in the bottom line	There is pressure build up in the bottom-line transporting wastewater to treatment plant	-Blockages within bottom line	- Failure of bottom-line tube - Risk of expansion and bursting of the line.	Installation of quick-pressure relief valves at strategic locations within the line.	- Installation of a secondary pressure relief device. - Checking maintenance schedule and procedures
		Less	Pressure decreases in bottom line	There are sudden pressure losses in the stream within the bottom line leading away from the tower	- Leakages in the bottom line	- Inefficiencies within the tower causing decreased flow of wastewater from the tower	Pressure alarms at the exit point from the tower joining the bottom line	- Installation of pressure gauge - Checking maintenance schedule and procedures
2	Flow	Reverse	Backflow to T-102	The contents of the bottom-line flow back to the tower	- Clogging and blockages within the line	- Pressure and temperature increase in the column	- Check valve to prevent backflow	- determining the best utilization of energy from recycle stream while preventing backflow - Following the stipulated maintenance schedule and procedures
3	Temperature	More	Increase in bottom line temperature	There is sudden increase in temperature at bottom line transporting wastewater to the treatment plant	- Clogging of the line at various points	Subsequent increase in pressure, risk of explosion and ineffectiveness of the tower	- Temperature alarms at exit point of the tower to the bottom line. - Panel alarms to warn of high pressure or temperature	-Installation of a temp gauge - Checking maintenance schedule and procedures

P&ID



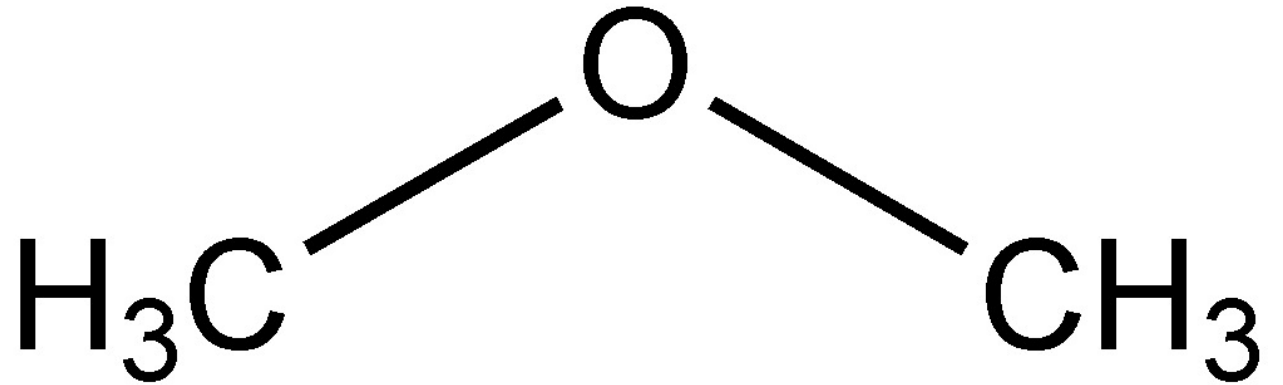


WASTEWATER TREATMENT

- Reduce Pollutants in Water
 - Negative health effects on life species
- Useful for all aspects of life
 - Irrigation or Recreational Use
- Send Wastewater to SNF Holding Company
 - Plaquemine Facility

CONCLUSION

- Methanol Dehydration To Form DME
- 99.9% Purity DME
- 90% Plant Utilization (329 Days)
- Collect Salvage After Year 12
- \$23MM Profit, 22% ROI
- Recommend Pursuing Design



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Roy G. Perry College of Engineering Faculty & Staff

Thank you!

QUESTIONS?

APPENDIX

REFERENCES

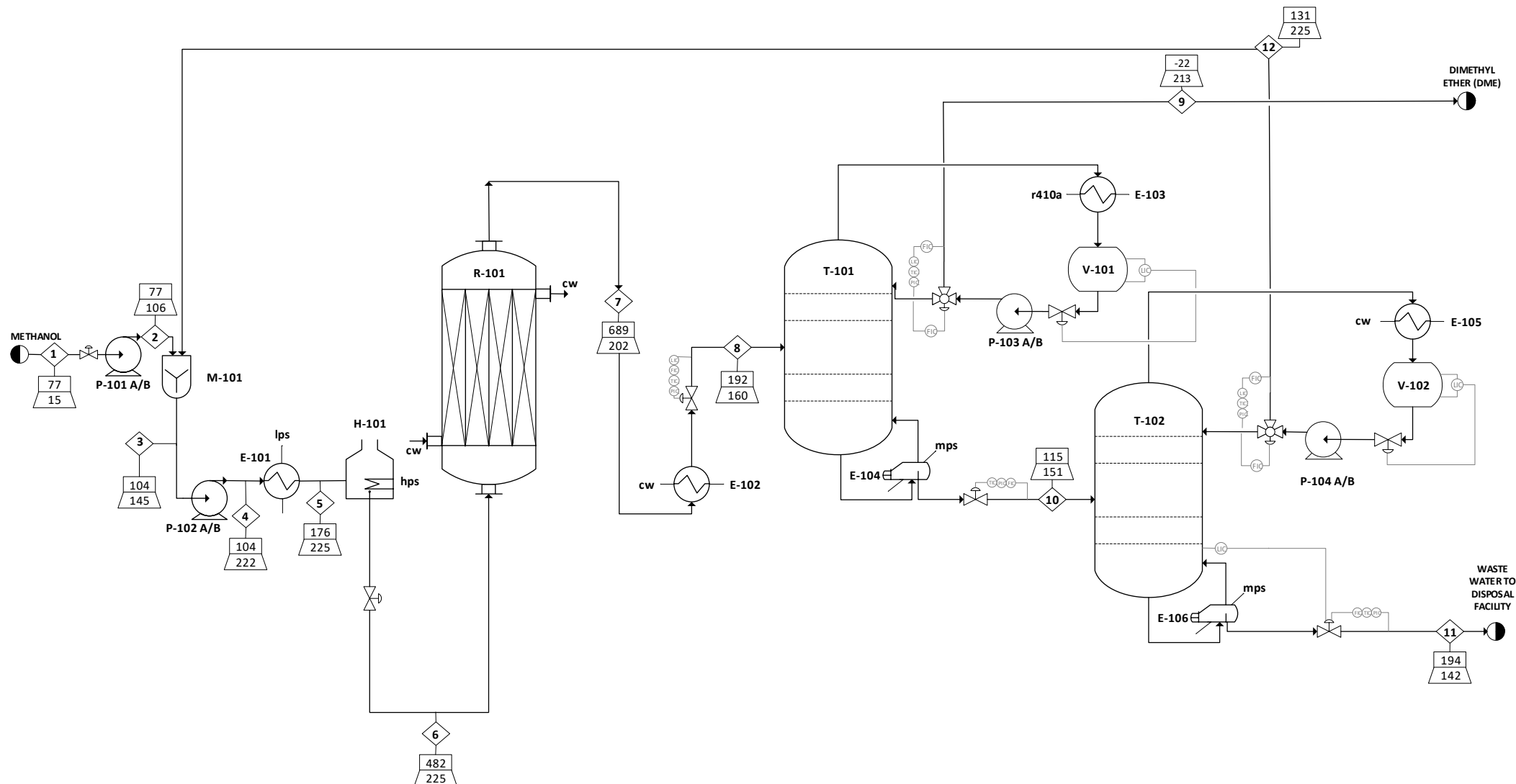
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STOICHIOMETRY



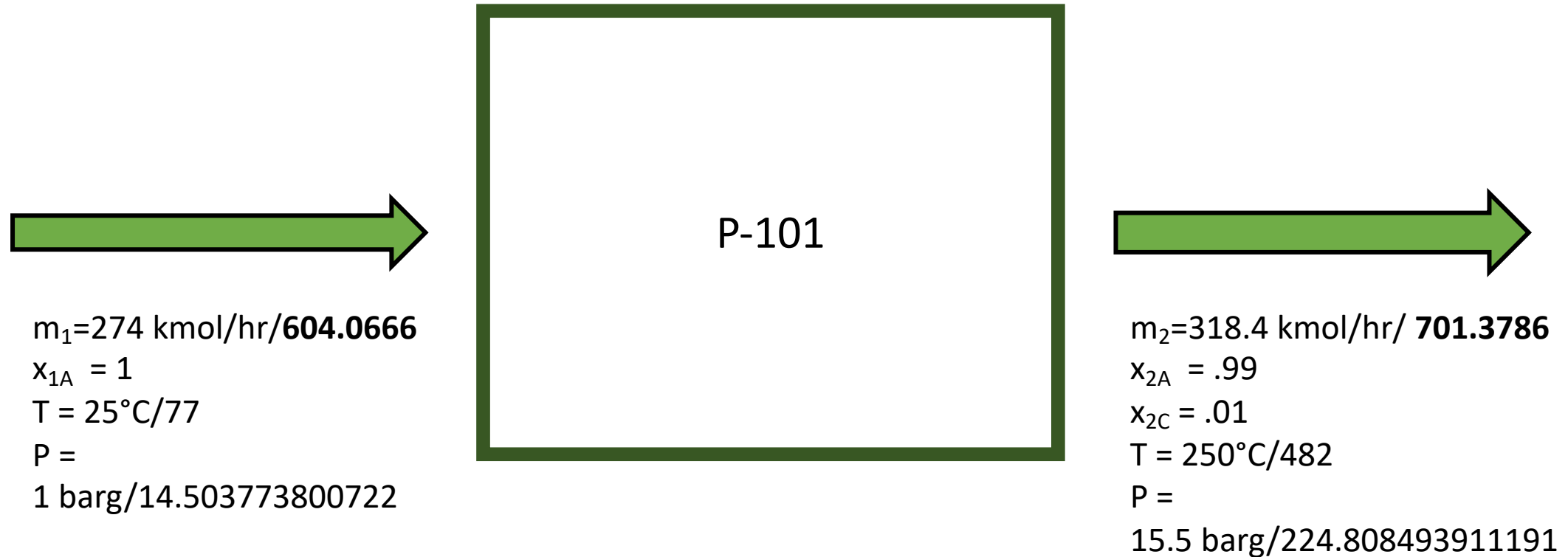
	A (Methanol)	B (Dimethyl Ether)	C (Water)
lb-mol	2	1	1
Molecular Weight lb/lbmol	32.04	46.07	18

P-101 A/B Feed Pump	M-101 Fresh & Recycled Methanol Mixer	P-102 A/B Combined Feed Pump	E-101 Methanol Vaporizer	H-101 Fired Heater	R-101 Methanol Catalytic Packed Bed Reactor	E-102 DME Cooler	T-101 DME Distillation Tower	E-103 T-101 Condenser	E-104 T-101 Reboiler	V-101 T-101 Reflux Drum	P-103 A/B T-101 Reflux Pump	T-102 Methanol Distillation Tower	E-105 T-102 Condenser	E-106 T- 102 Reboiler	V-102 Methanol Reflux Drum	P-104 A/B T-102 Reflux Pump
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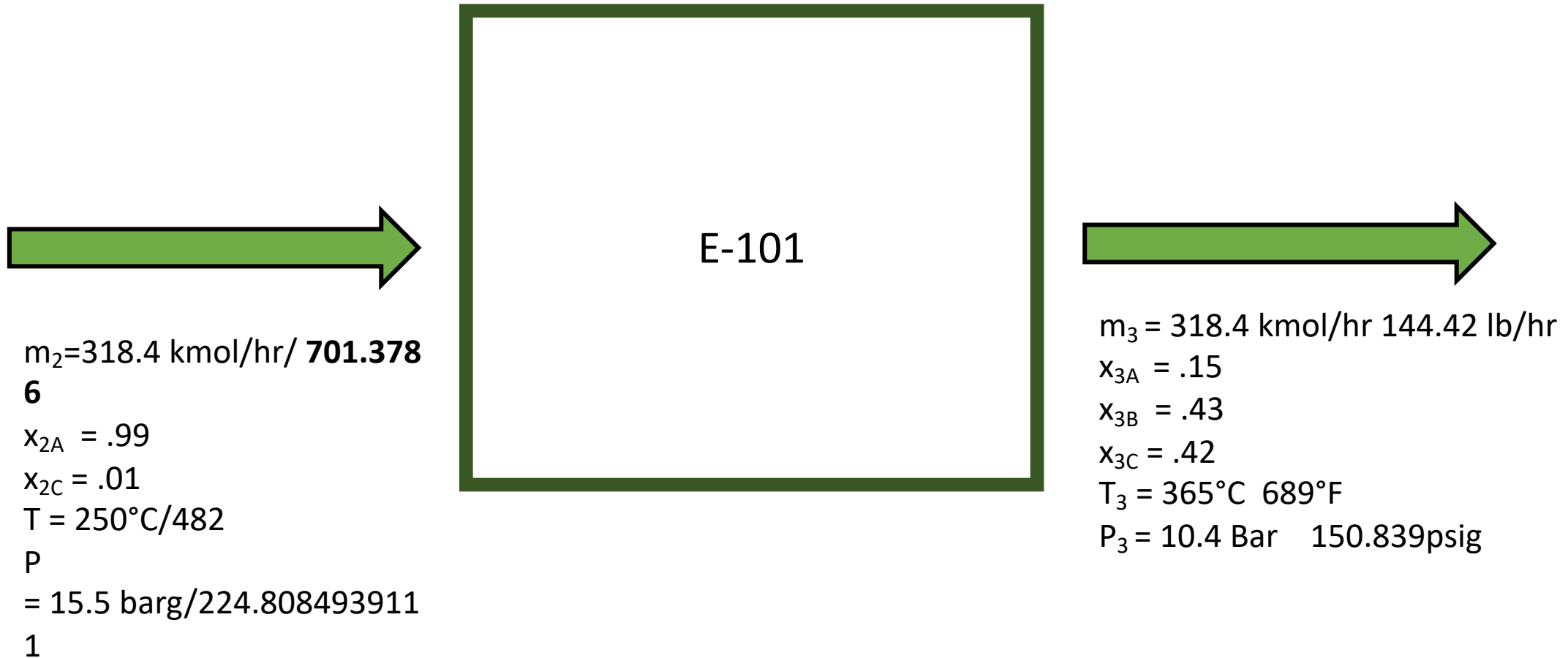


 Temperature, °F
 Pressure, psig

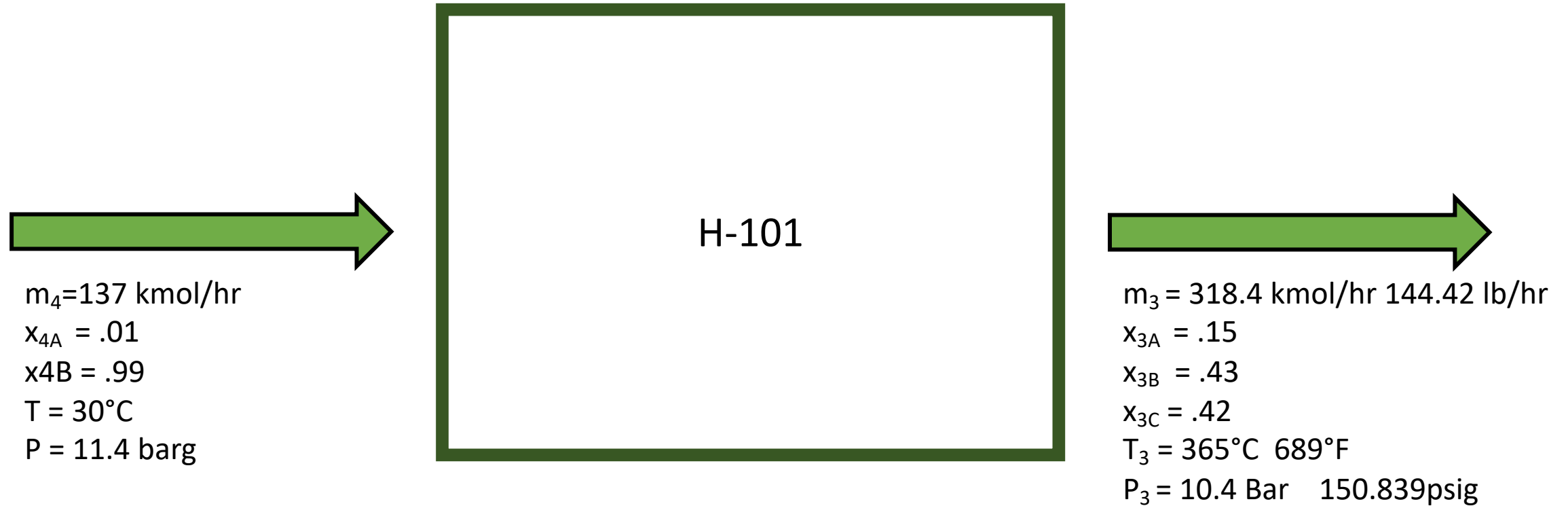
Pump Material Balance



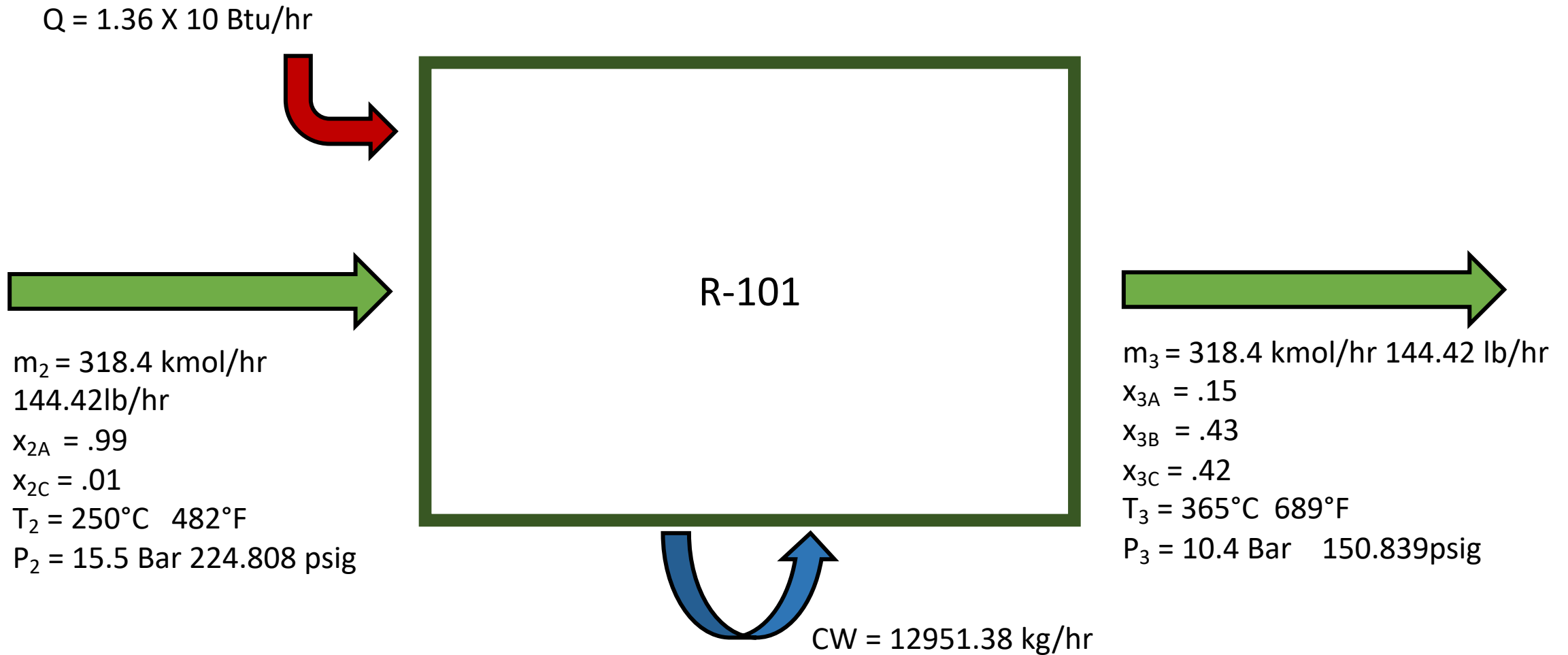
Vaporizer Material Balance



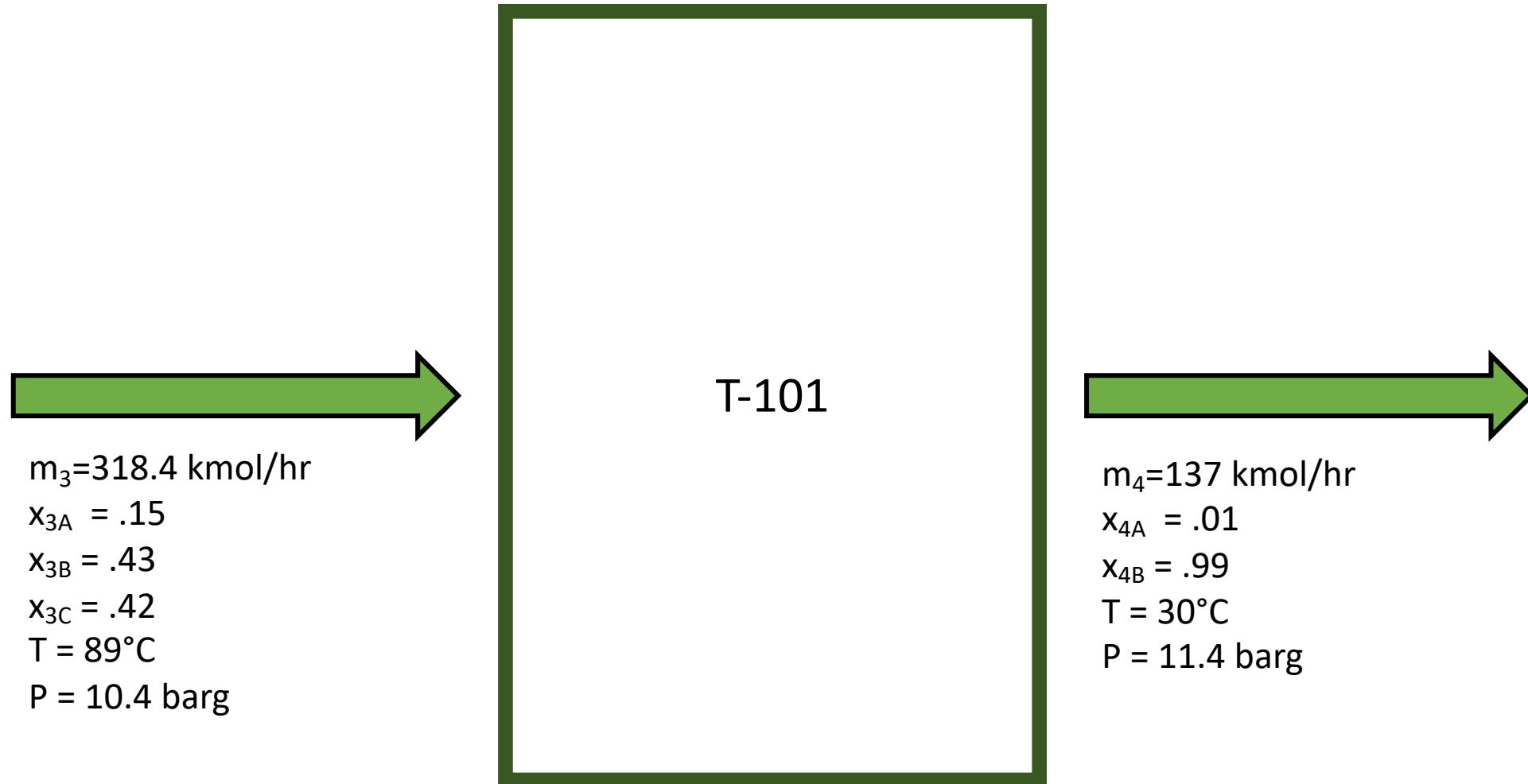
Furnance Material Balance



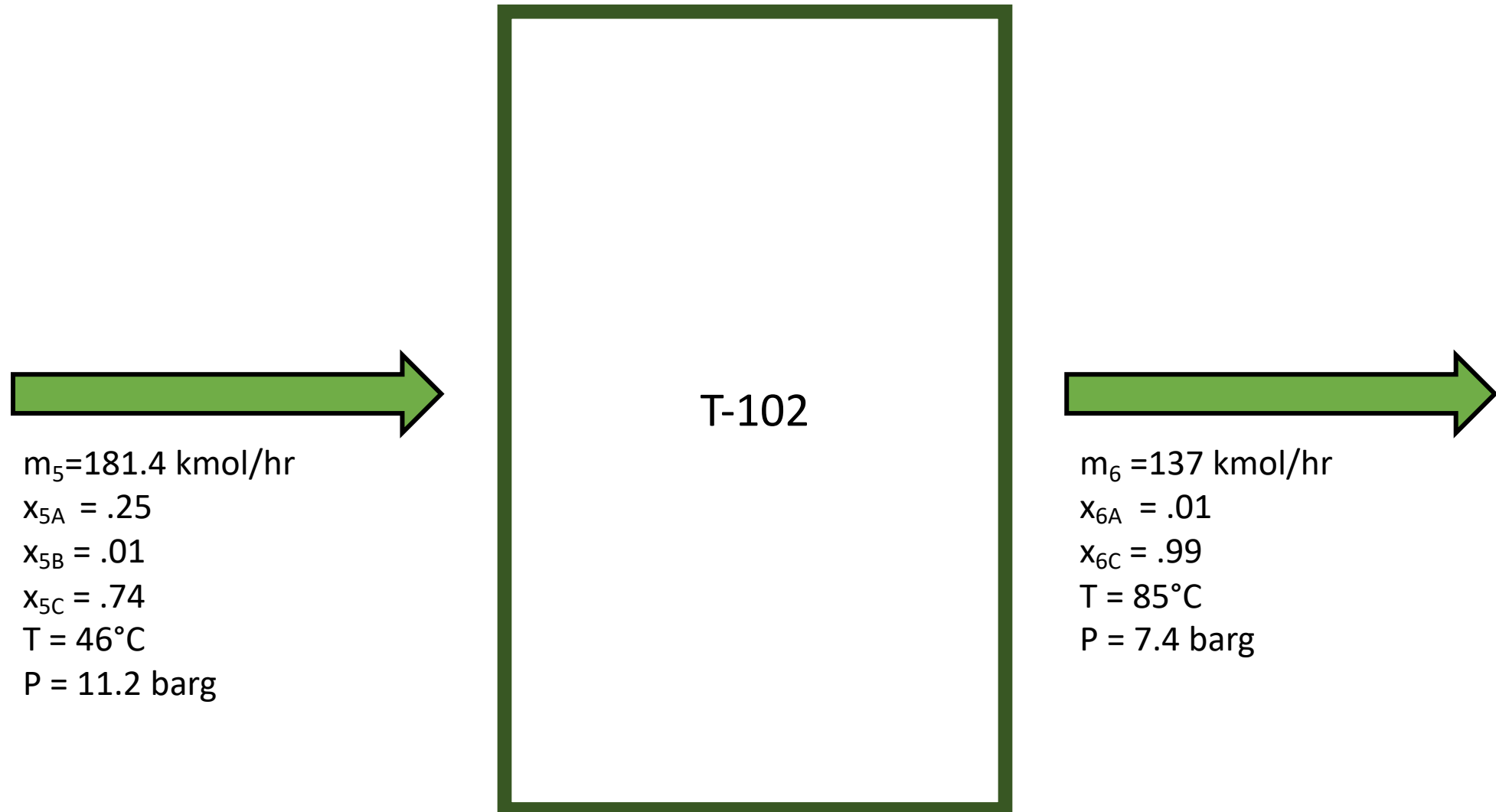
Dehydration Reactor Material Balance



1st Distillation Column Material Balance

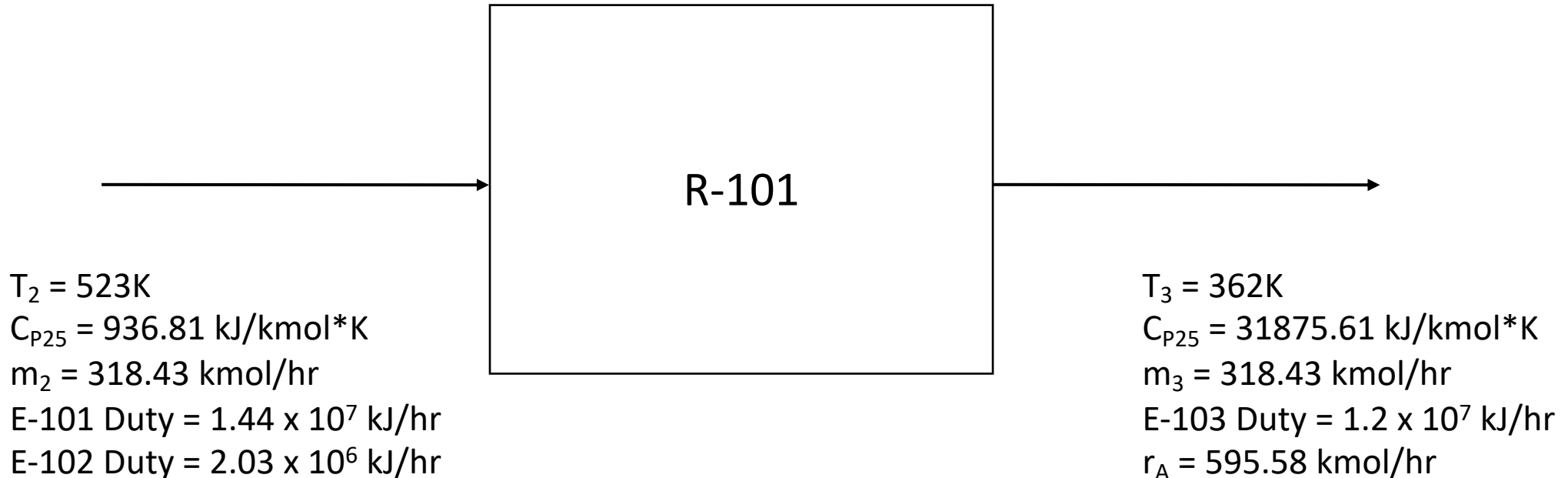


2nd Distillation Column Material Balance



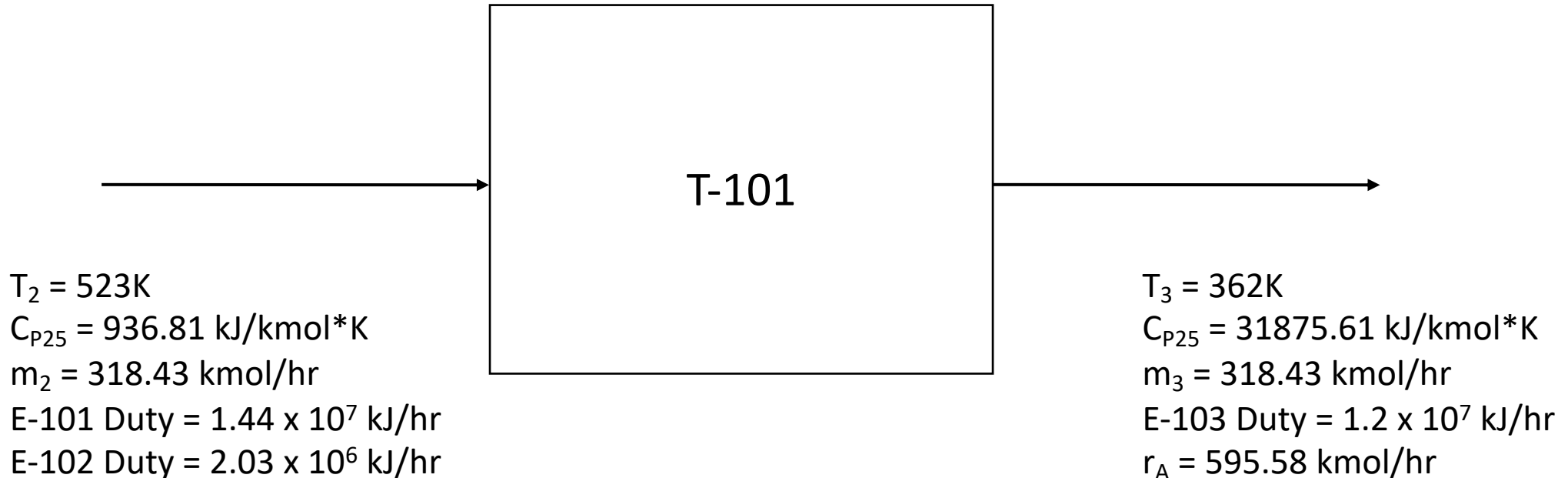
ENERGY BALANCE

$$\Delta H_{\text{RXN } 280} = -5.9 \times 10^6 \text{ kJ/kmol}$$



ENERGY BALANCE

$$\Delta H_{\text{RXN } 138} = -5.9 \times 10^6 \text{ kJ/kmol}$$



ENERGY BALANCE

Stream	1	2	3	4	5	6	7	8	9	10	11
Molar Enthalpy (kJ/kmol)	-238400	-238305	-201079	-200560	-164896	-198934	-234554	-179812	-239321	-280413	-233583
Mass Enthalpy (kJ/kg)	-7440.2	-7437.2	-6275.5	-6263.1	-3579.3	-6212.3	-7324.6	-3915.0	-12513.8	-15445	-7321.9
Molar Entropy (kJ/kmol*K)	-240.2	-239.9	-150.1	-148.6	-211.9	-120.2	-206.5	-244.2	-162.9	-148.7	-213.1
Mass Entropy (kJ/kg*K)	-7.5	-7.5	-4.7	-4.6	-4.6	-3.8	-6.4	-5.3	-7.6	-8.2	-6.7

R-101 Design Equations

$$\textcircled{1} \text{ Mole Balance: } F_{A0} \frac{dx}{dw} = -r'_A = \frac{\text{kg mol}}{\text{kg cat} \cdot \text{hr}}$$

$$\textcircled{2} \text{ Rate Law: } -r'_A = k C_A^2 = \frac{\text{kg mol}}{\text{kg cat} \cdot \text{hr}}$$

$$\textcircled{3} \text{ Stoichiometry: } C_A = \frac{C_{A0}(1-x)}{1+\epsilon x} \frac{P}{P_0} \frac{T_0}{T}, \quad \frac{P}{P_0} = p \quad (\text{pg. 169})$$

$$\begin{aligned} \frac{dp}{dw} &= -\frac{\alpha}{2p} (1+\epsilon x) \frac{T_0}{T} \\ \frac{T_0^2 p}{T} \frac{dp}{dw} &= -\alpha \\ \frac{T_0^2 p^2}{T} \frac{dp}{dw} &= -\alpha \quad (\text{pg. 174}) \end{aligned}$$

$$\textcircled{4} \text{ Combine: } \frac{dx}{dw} = \frac{k C_{A0}^2 (1-x)^2}{F_{A0} (1+\epsilon x)^2} \left(\frac{P}{P_0} \right)^2 \left(\frac{T_0}{T} \right)^2 = \text{kg cat}^{-1}$$

R-101 Design Equations

$$Q = UA\Delta T_{lm} f_r$$

$$Q = \dot{m} C_p \Delta T$$

$$T_{HIN} = 250^\circ\text{C}$$

$$T_{HOUT} = 305^\circ\text{C}$$

$$T_{CIN} = 30^\circ\text{C}$$

$$T_{COUT} = 45^\circ\text{C}$$

$$\dot{m} = 318.43 \text{ kmol/hr}$$

$$\dot{m} = 318430 \text{ mol/hr}$$

$$C_p = 110 \text{ J/mol K}$$

$$\Delta T = 305 - 250 = 115 + 273$$

$$= 388 \text{ K}$$

$$Q = \dot{m} C_p \Delta T$$

$$= 318430 \frac{\text{mol}}{\text{hr}} (110 \frac{\text{J}}{\text{mol K}}) (388 \text{ K})$$

$$Q = 1.433 \times 10^{10} \text{ J/hr}$$

$$U = 500 \text{ BTU/hr-ft}^2\text{ }^\circ\text{F}$$

$$\Delta T_{lm} = 204.7^\circ\text{C} \rightarrow 508.46^\circ\text{F}$$

$$f_r = 1.0$$

$$Q = 1.433 \times 10^{10} \text{ J/hr}$$

$$Q = 13582219.3 \text{ BTU/hr}$$

$$Q = UA\Delta T_{lm} f_r$$

$$A = \frac{Q}{U\Delta T_{lm} f_r}$$

$$= \frac{13582219.3 \text{ BTU/hr}}{(500 \frac{\text{BTU}}{\text{hr-ft}^2\text{ }^\circ\text{F}}) (508.46^\circ\text{F}) (1.0)}$$

$$A = 53.425 \text{ ft}^2$$

$$A = 4.963 \text{ m}^2$$

$$\text{Tubes: } A_T = \pi D L, n = A/A_T$$

$$D = 1.060 \text{ in} = 0.02667 \text{ m}$$

$$L = 14.477 \text{ ft} = 4.479 \text{ m}$$

$$A_T = (3.14) (0.02667 \text{ m}) (4.479 \text{ m})$$

$$A_T = 0.375 \text{ m}^2$$

$$n = \frac{A}{A_T} = \frac{4.963 \text{ m}^2}{0.375 \text{ m}^2}$$

$$n = 13.2 \approx 14 \text{ Tubes}$$

$$W = 24923 \text{ Kg cat}$$

$$1790.214 \text{ Kg cat per Tube}$$

$$\frac{Q}{A\Delta T_{lm} f_r} = U$$

$$\frac{13582219.3 \text{ BTU/hr}}{(107.039 \text{ ft})(508.46^\circ\text{F})(1)}$$

$$U = 249.167 \frac{\text{BTU}}{\text{hr-ft}^2\text{ }^\circ\text{F}}$$

$$U = 200 \frac{\text{BTU}}{\text{hr-ft}^2\text{ }^\circ\text{F}} \left(\begin{array}{l} \text{within} \\ \text{range} \end{array} \right)$$

$$A = \frac{13582219.3 \text{ BTU/hr}}{(200 \frac{\text{BTU}}{\text{hr-ft}^2\text{ }^\circ\text{F}}) (508.46^\circ\text{F}) (1.0)}$$

$$A = 133.56 \text{ ft}^2$$

$$A = 12.408 \text{ m}^2$$

T-101 Design Equations

Water: 100°C

$$N_{min} = \frac{\ln \left[\left(\frac{x_{1k}}{x_{2k}} \right)_D \left(\frac{x_{1k}}{x_{2k}} \right)_B \right]}{\ln \alpha_{1k}}; \alpha_{1k} \approx 9 \text{ (Research)}$$

$$= \frac{\ln \left[\left(\frac{.99}{.01} \right) \left(\frac{.25}{.01} \right) \right]}{\ln(9)} = 3.5 \approx 4$$

R_{min} : $q = 0.0$ for saturated vapor (Perry's 13-36)

$$1 - q = \sum_j \frac{\alpha_{jk} x_{jk,F}}{\alpha_{jk} - \phi}$$

$$\alpha_{1k} - \phi = \alpha_{1k} x_{1k,F}$$

$$\phi = \alpha_{1k} - \alpha_{1k} x_{1k,F} = \alpha_{1k} (1 - x_{1k,F}) = 5.13 \checkmark$$

$$R_{min} = \sum_j \frac{\alpha_j x_{j,D}}{\alpha_j - \phi} - 1$$

$$= \frac{9 \cdot .99}{9 - 5.13} - 1 = 1.3$$

$$R/R_{min} = 1.2 - 1.3 \text{ (pg 235 in short cut design book)}$$

$$\therefore R = (R_{min})(1.3) = 1.7$$

Gilliland correlation

Number of theoretical trays (pg 236 short cut book)

$$\frac{R - R_{min}}{R + 1} = \frac{1.7 - 1.3}{1.7 + 1} = .15 \therefore \text{use chart on left}$$

$$0.15, \frac{N - N_{min}}{N + 1} = .45$$

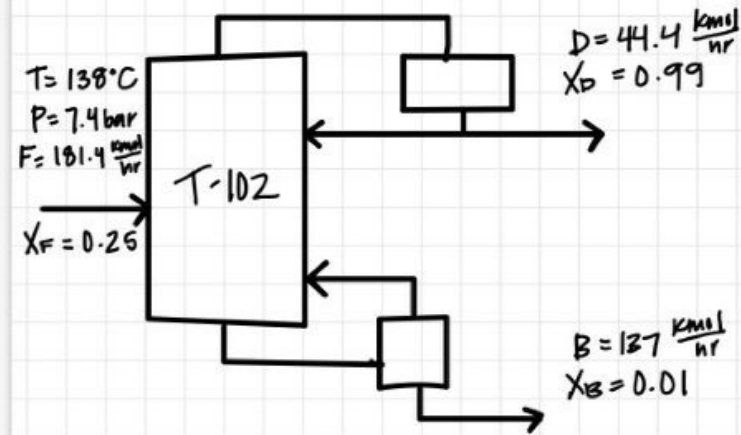
$$.45N + .45 = N - N_{min}$$

$$N_{min} + .45 = .55N$$

$$N = \frac{N_{min} + .45}{.55} = \frac{4.45}{.55} = 8.09 \approx 9$$

$$N/N_{min} = 1.8 - 2.5 = 8/4 = 2.25 \checkmark$$

T-102 Design Equations



Rectifying

$$y_{N+1} = \frac{R}{R+1} X_N + \frac{X_D}{R+1}$$

$$y_{N+1} = \frac{4.472}{4.472+1} X_N + \frac{0.99}{4.472+1}$$

$$y_{N+1} = 0.817 X_N + 0.181$$

↳ rectifying operating line

Stripping

Feed: $X_F = 0.25$

$T = 411 \text{ K}$

$P = 7.4 \text{ bar}$

$$y = \frac{q}{q-1} X - \frac{X_F}{q-1} ; q = \frac{H_V - H_F}{H_V - H_L}$$

$$u = \frac{0.05}{0.05-1} X - \frac{0.25}{0.05-1} \rightarrow y = -0.05 X + 0.24$$

↳ stripping operating line

q-line

$$q = \frac{H_V - H_F}{H_V - H_L} = \frac{2704.24 - 2053.42}{2704.24 - 700.885}$$

$q = 0.05$

Interpolate

$$\begin{aligned} H_L &= 703.241 & y_1 &= 703.241 & y_2 &= 709.301 \\ X_1 &= 725 \text{ KPa} & X_2 &= 750 \text{ KPa} \end{aligned}$$

$$y = 703.241 + (740 - 725) \left(\frac{709.301 - 703.241}{750 - 725} \right)$$

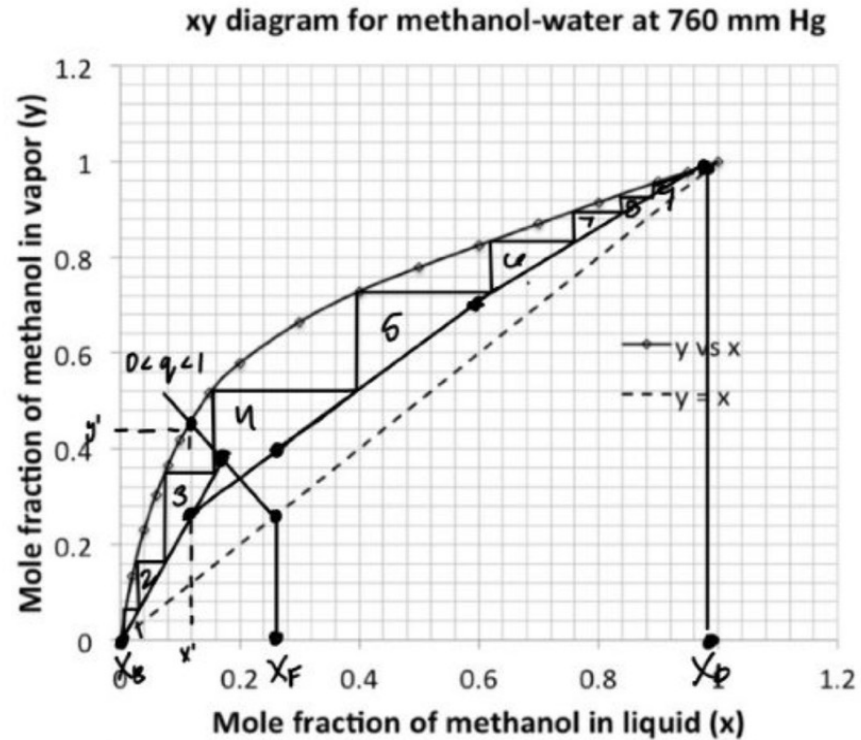
$$H_L = 700.885 \text{ kJ/kg}$$

$$\begin{aligned} H_V &= 2703.4 & y_1 &= 2703.4 & y_2 &= 2704.8 \\ X_1 &= 725 \text{ KPa} & X_2 &= 750 \text{ KPa} \end{aligned}$$

$$H_V = 2704.24 \text{ kJ/kg}$$

$$H_F = 2053.42 \text{ kJ/kg}$$

T-102 Design Equations



$$x' = 0.1$$

$$y' = 0.3$$

$$\text{SDL: } y = -0.05x + 0.26$$

$$\text{ROL: } y_{n+1} = 0.917x_n + 0.191$$

$$9 + 1 = \underline{10 \text{ stages}}$$

Minimum Reflux Ratio

$$\frac{R_m}{R_m + 1} = \frac{x_D - y'}{x_D - x'} \xrightarrow{\text{pinch point}} \frac{0.99 - 0.3}{0.99 - 0.1} = 0.775$$

$$\frac{R_m}{R_m + 1} = 0.775 \rightarrow R_m = 0.775R_m + 0.776 \rightarrow 0.225R_m = 0.775 \rightarrow \underline{R_m = 3.44}$$

Reflux Ratio

$$1.3 = \frac{R}{R_{\min}}$$

$$\underline{R = 4.472}$$

EPA & OSHA Regulations

OSHA (Methanol)

- The sampling group
- The sampling time at 60 min.
- The sampling volume at 3 L or 5L when humidity is greater than 50%

EPA (Methanol)

- Occupational exposure through inhalation.
- Exposure through the ambient air from its evaporation during solvent uses.
- Acute effects by inhalation and/or ingestion resulting in blurry vision and disorientation.
- Chronic effects including insomnia, elevated levels of liver enzymes and decreased brain weight.

EPA (DME)

- Tolerance exemptions that are associated with Dimethyl Ether (DME)
- Regulations of the emission standards associated with DME



Total Capital Investment

Direct Costs	
Purchased equipment, E'	1.496
Delivery, fraction of E'	0.150
Subtotal: delivered equipment	1.646
Purchased equipment installation	0.773
Instrumentation&Controls(installed)	0.592
Piping (installed)	1.119
Electrical systems (installed)	0.181
Buildings (including services)	0.296
Yard improvements	0.165
Service facilities (installed)	1.152
Total direct costs	5.924
Indirect Costs	
Engineering and supervision	0.543
Construction expenses	0.675
Legal expenses	0.066
Contractor's fee	0.362
Contingency	0.724
Total indirect costs	2.370
Fixed capital investment (FCI)	8.294
Working capital (WC)	1.465
Total capital investment (TCI)	9.758

Utilities

Steam		
LPS	MPS	HPS
\$1.16MM	\$.355MM	\$.392MM
TOTAL		\$1.91MM/yr

Cooling Water	
Amount Required, ft ³ /yr	9.92 x 10 ⁶
TOTAL	\$14,000/yr

Electricity	
Amount Required, kWh/yr	1.06 x 10 ⁵
TOTAL	\$5,000/yr

Wastewater Disposal	
Amount Required, ft ³ /yr	7.03 x 10 ⁵
TOTAL	\$11,000/yr

Refrigerant, r140a	
Amount Required, BTU/yr	4.10 x 10 ⁸
TOTAL	\$5,000/yr

Materials & Labor

Raw Materials		
Name of Material	Price, \$/lb	Annual Amount MM kg/year
Methanol	.16	~71
TOTAL		\$25.28MM/yr

Labor		
Number of Operators per Shift	Shifts Per Day	Operator Rate, \$/hr
3	3	34
TOTAL		~\$1MM/yr

Product		
Name of Material	Price, \$/lb	Annual Amount MM kg/year
DME	.41	50
TOTAL		\$45MM/yr

EMISSIONS

- The use of DME reduces carbon emissions by an average of 25%.
- DME synthesis from methanol is a low carbon footprint process.
- The total final emissions are negative at an estimate of **-39 ktCO₂eq per year**

Process stream	Units	Value
Methanol	KgCO _{2eq} /t	-1643
Wastewater	KgCO _{2eq} /t	500

ASPEN STREAM TABLES

Stream	Methanol	Recycle*	DME + Methanol + Water	Methanol + Water	DME	Recycle	Water
Mole Flows kmol/hr	274	44.4	318.4	177.13	141.27	34.72	142.01
Mass Flows kg/hr	8779.55	1416.44	10196	3687.81	6508.18	1117.85	2569.96