



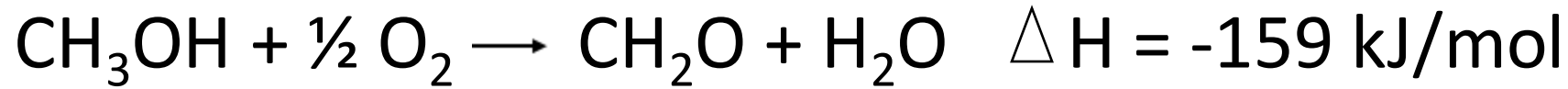
Chem-OI

Dada Team 5: Abdul-Rahman Zakir, Alessia Williams, Nathan Warren, Timothy Waugh, Xavier Williamson

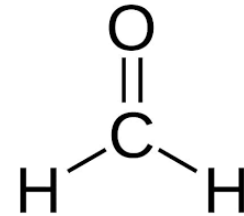
Task	Duration	Start Date	End Date
1) REVIEW & MODIFY	8	1/21/2022	1/29/2022
1.1 Update PFD	8	1/21/2022	1/29/2022
1.2 Regulations	8	1/21/2022	1/29/2022
1.3 Material Balance	8	1/21/2022	1/29/2022
2) SIMULATION	60	2/1/2022	4/1/2022
2.1: Heat Exchangers	30	2/1/2022	3/3/2022
2.2 : Reator	30	3/3/2022	4/1/2022
2.3: Absorption Column	30	3/3/2022	4/1/2022
3) DESIGN	60	2/1/2022	4/1/2022
3.1: Air Feed Heat Exchanger	60	2/1/2022	4/1/2022
3.2: Methanol Vaporizer	60	2/1/2022	4/1/2022
3.3: Reactor	60	2/1/2022	4/1/2022
3.4: Product Stream Heat Exchanger	60	2/1/2022	4/1/2022
3.5: Absorption Column	60	2/1/2022	4/1/2022
4) PIPING & INSTRUMENTATION DESIGN	8	4/1/2022	4/8/2022
4.1 : Sensor Placement	8	4/1/2022	4/8/2022
4.2: Control Valve Placement	8	4/1/2022	4/8/2022
4.3: Waste Management & Storage Placement	8	4/1/2022	4/8/2022
5): ECONOMIC ANALYSIS	15	4/1/2022	4/15/2022
5.1: CapCost	15	4/1/2022	4/15/2022
5.2: Present Value Ratio	15	4/1/2022	4/15/2022
5.3: Net Present Value	15	4/1/2022	4/15/2022
5.4: Payback Period	15	4/1/2022	4/15/2022
6) REPORT & PRESENTATION SYNTHESIS	9	4/15/2022	4/23/2022
6.1 : Synthesize PFD & P&ID	5	4/15/2022	4/19/2022
6.2: Synthesize Waste Management	5	4/15/2022	4/19/2022
6.3: Synthesize Economic Analysis	5	4/15/2022	4/19/2022

Project Schedule

Introduction

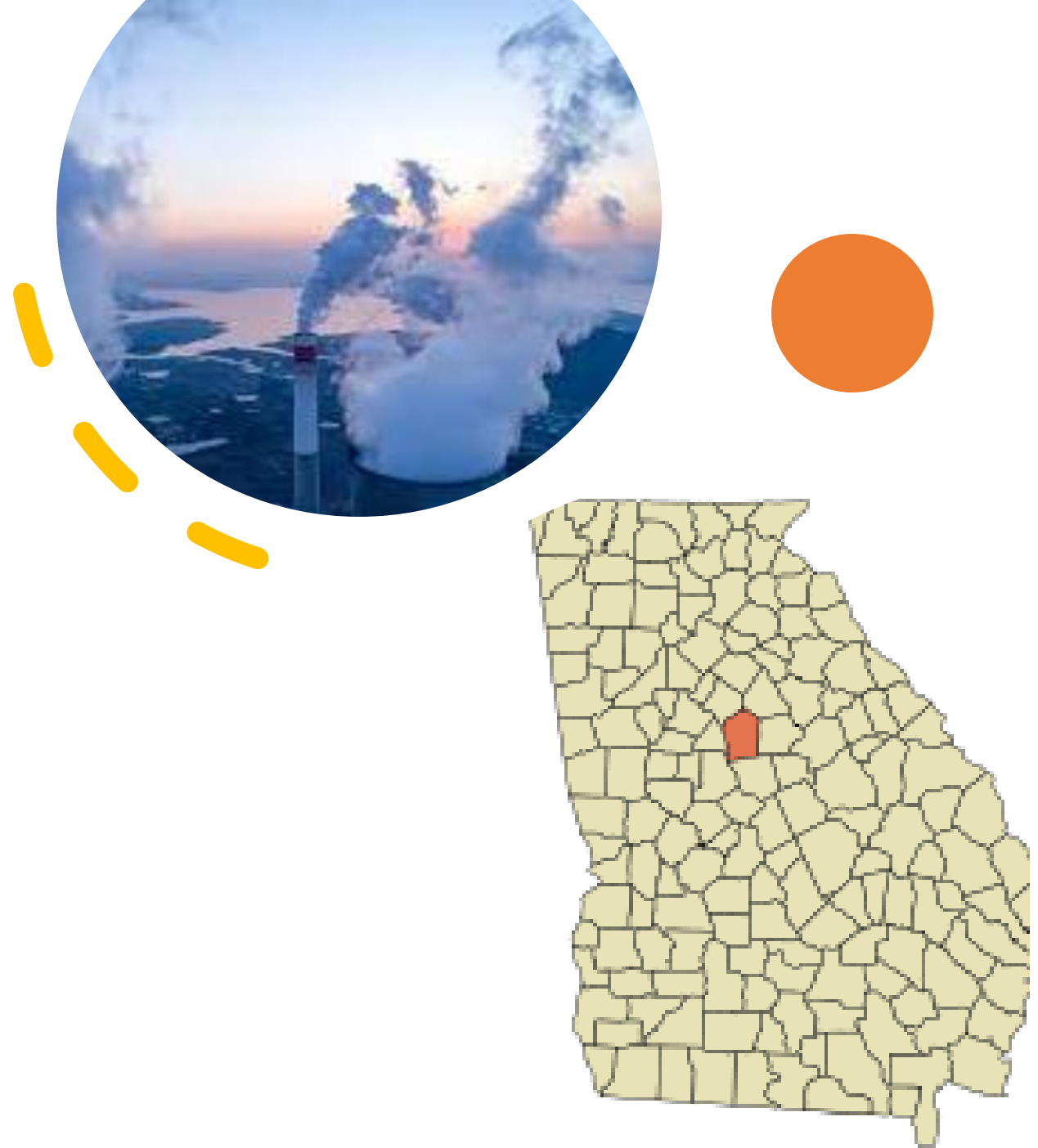


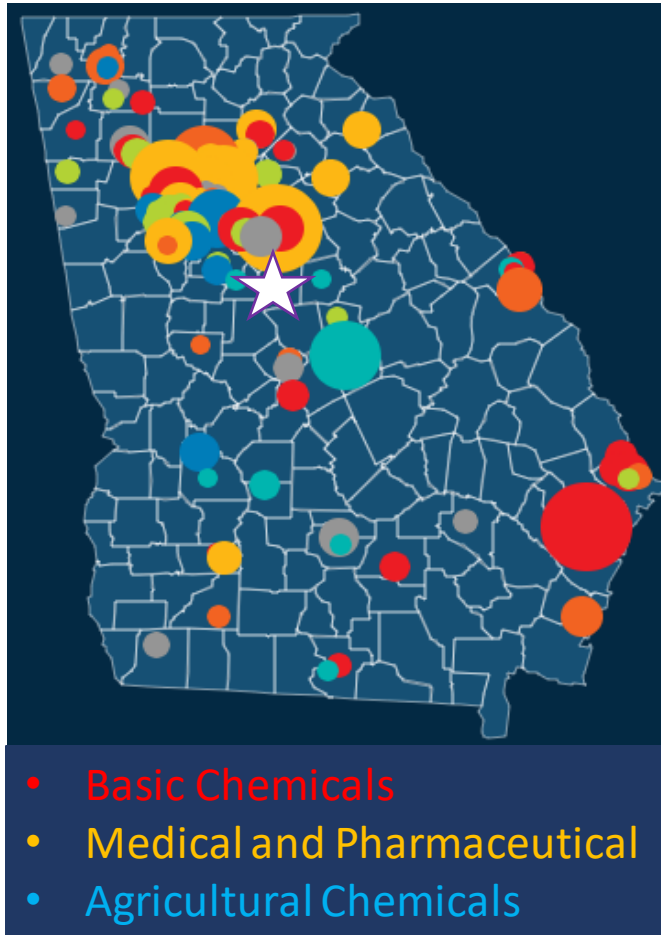
- Product: Formalin- 55 wt% aqueous solution of formaldehyde
- Uses: Resins, antiseptics, fertilizers, etc.
- Plant Location: Monticello, Georgia
- Process: Metal oxide catalyst (Iron-Molybdenum) - exothermic, high conversion, pure products



Plant Location

- **Location** - Monticello, Georgia
- No extensive emission regulations
- Access to raw materials for production
- Access to water from Jackson Lake





Plant Location

Customers:

- Canal Wood LLC (Monticello, 40% sales)
- Dow Chemical Company (Marietta, 35% sales)
- BASF (Middle, 20 % sales)

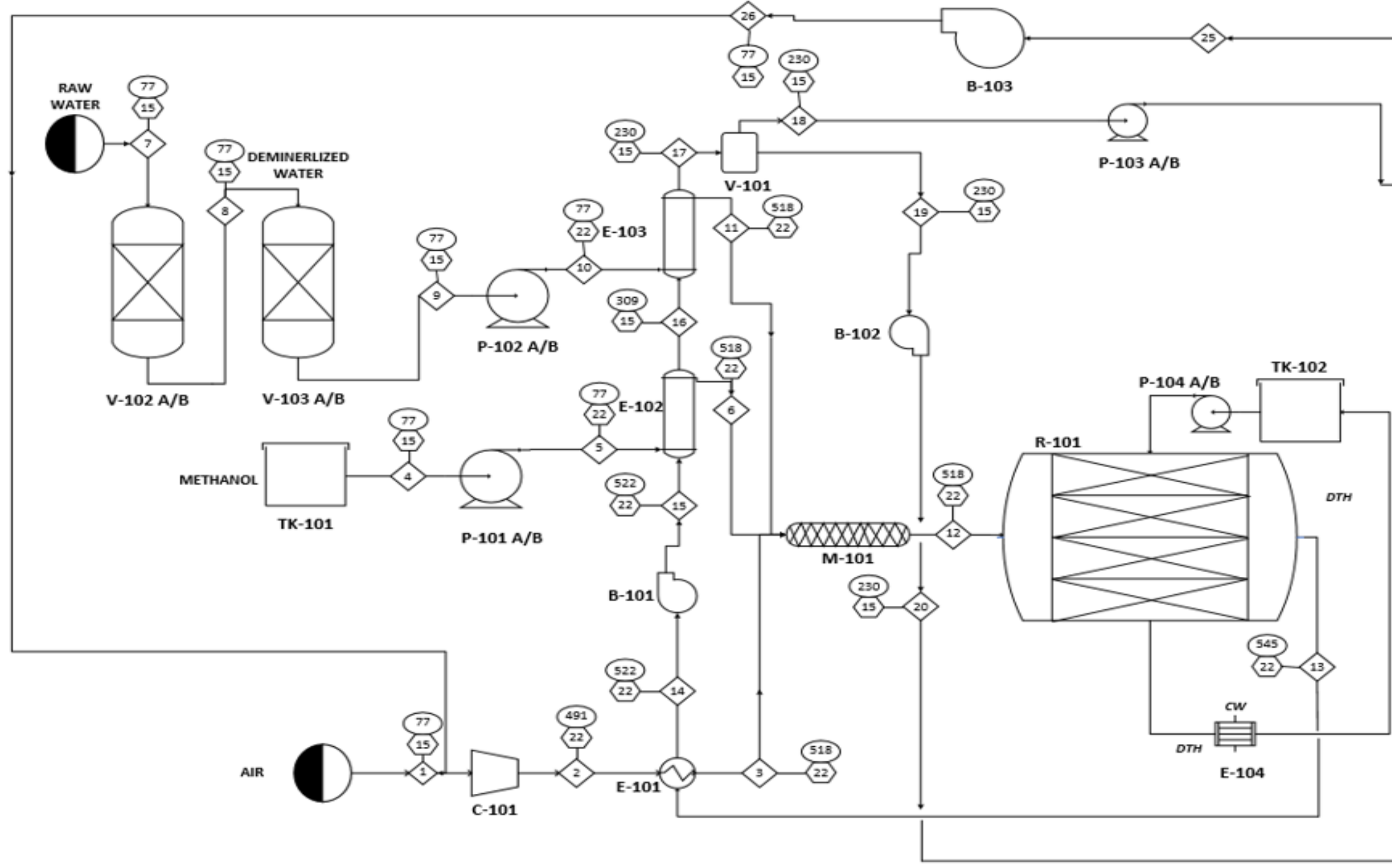
Competition in vicinity:

- Georgia Pacific
- Koch Industries Inc.



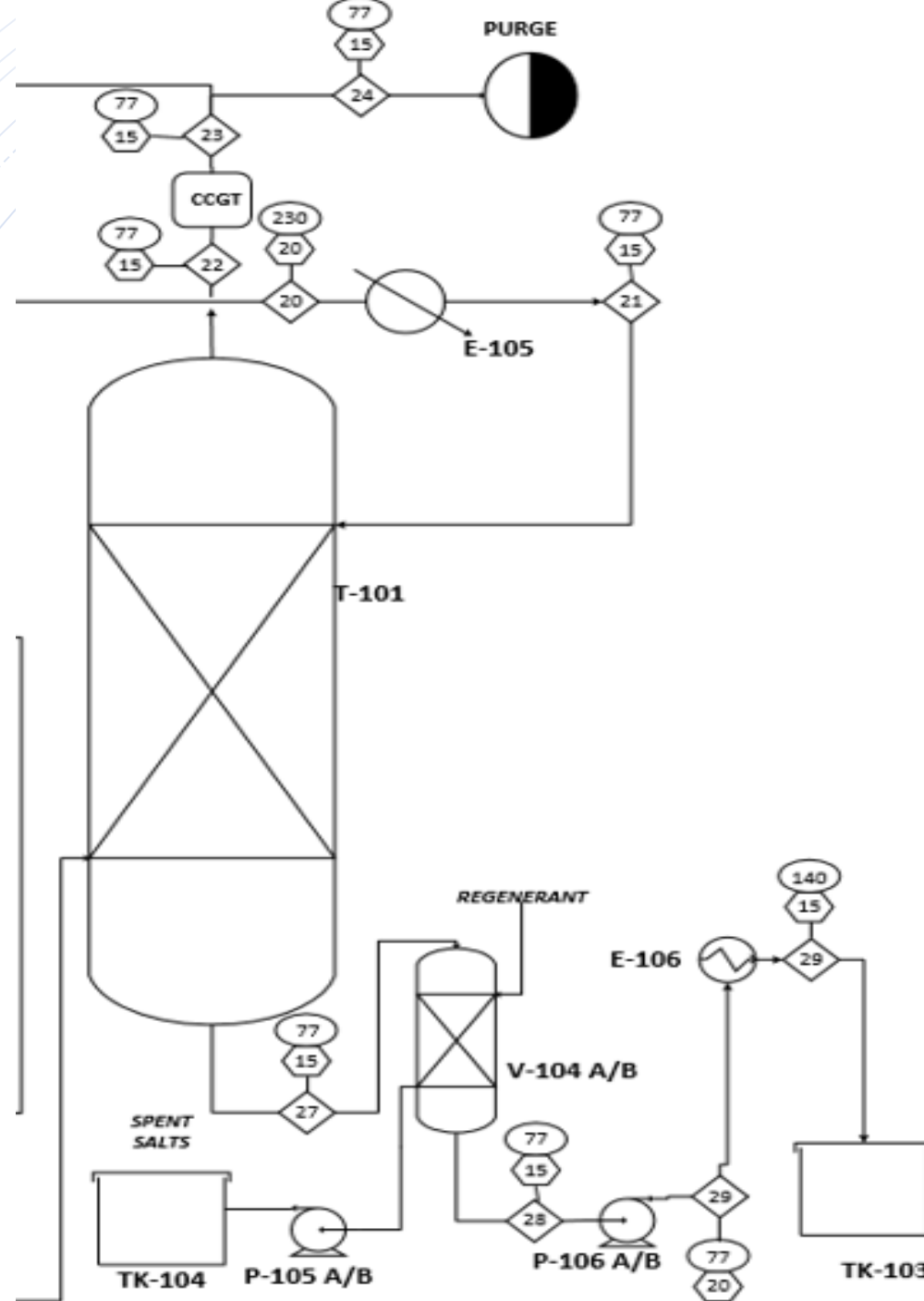
PFD

PFD
1/2

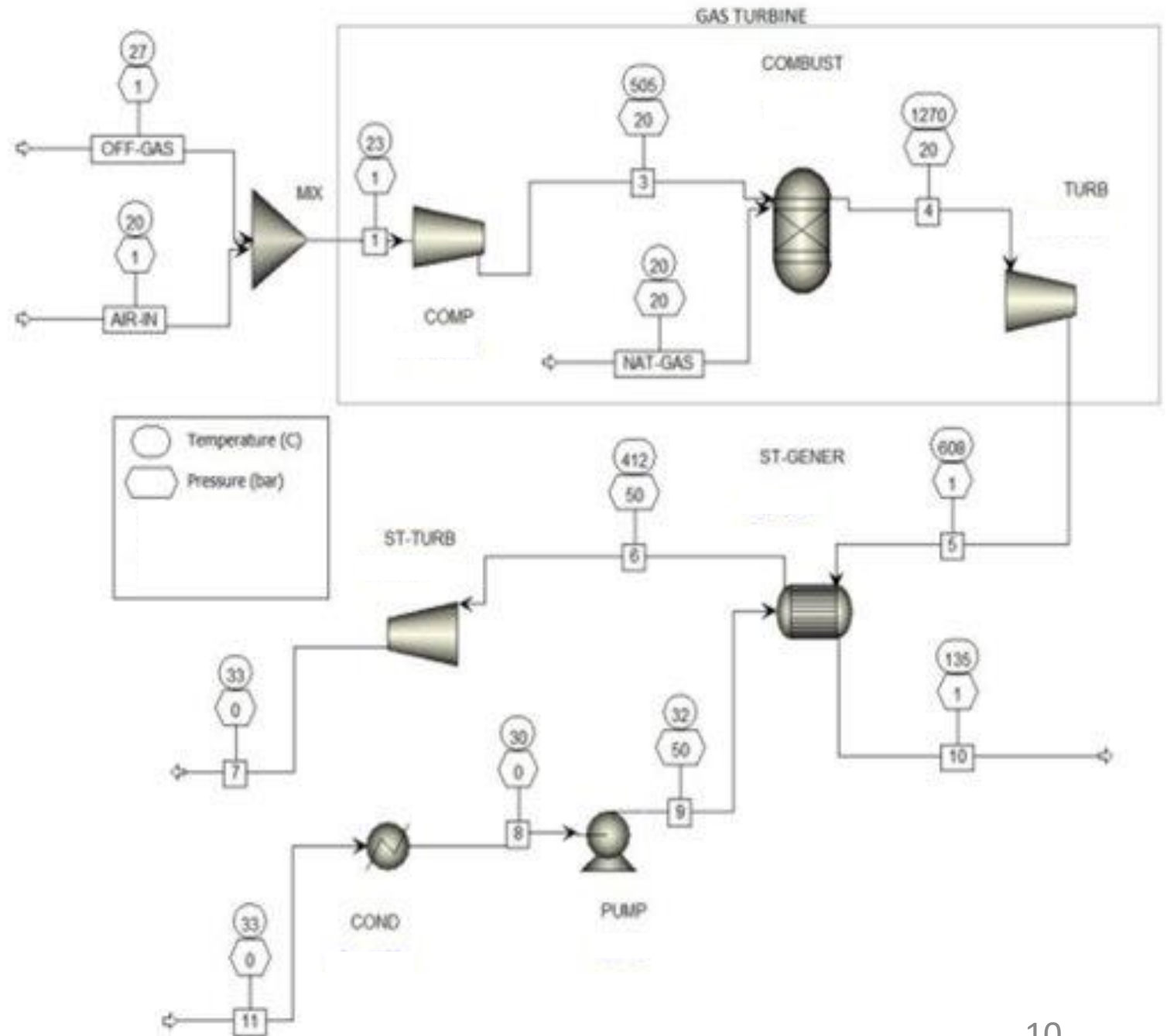


PFD

2/2

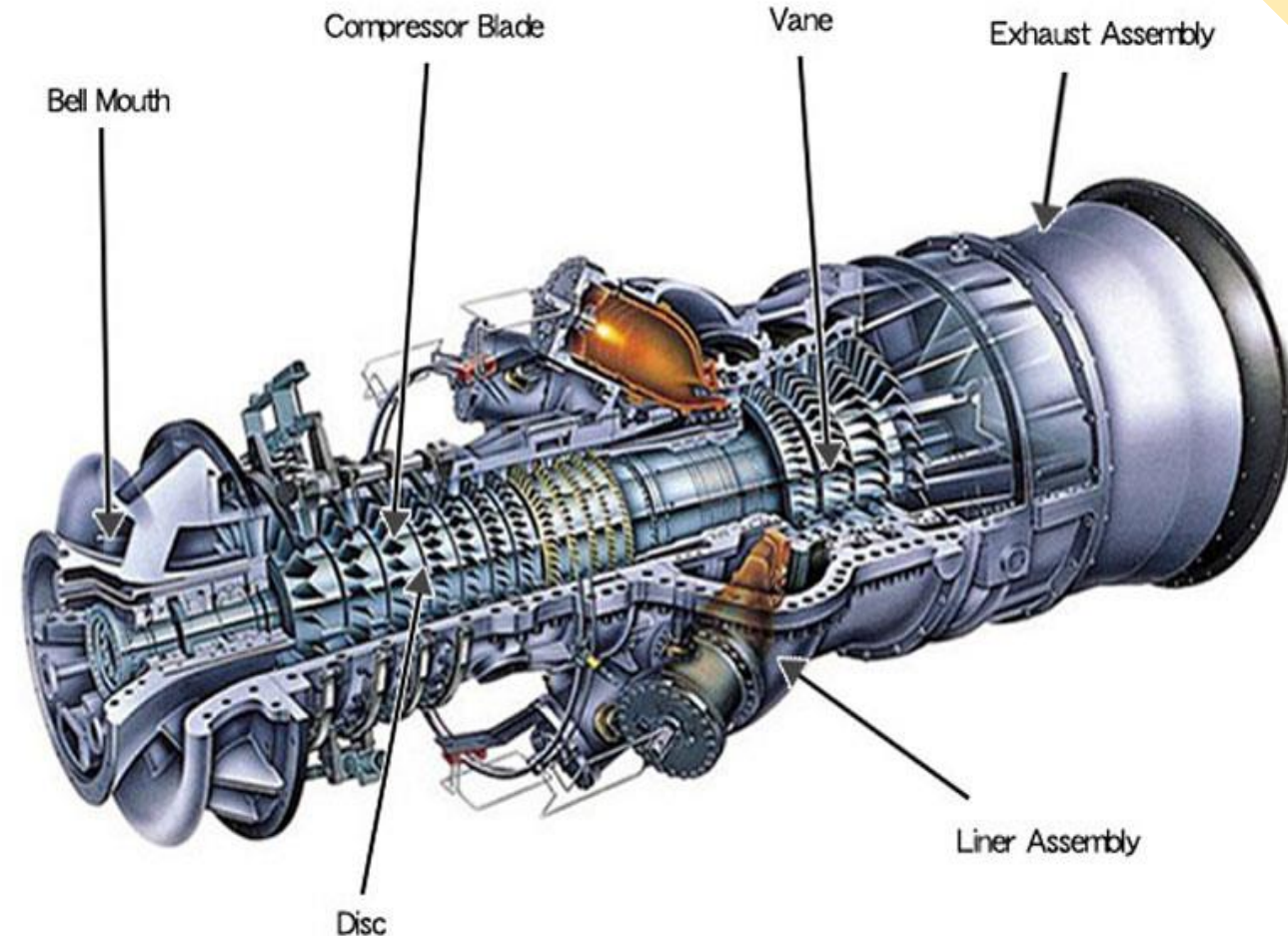


Combined-Cycle Gas Turbine (CCGT)

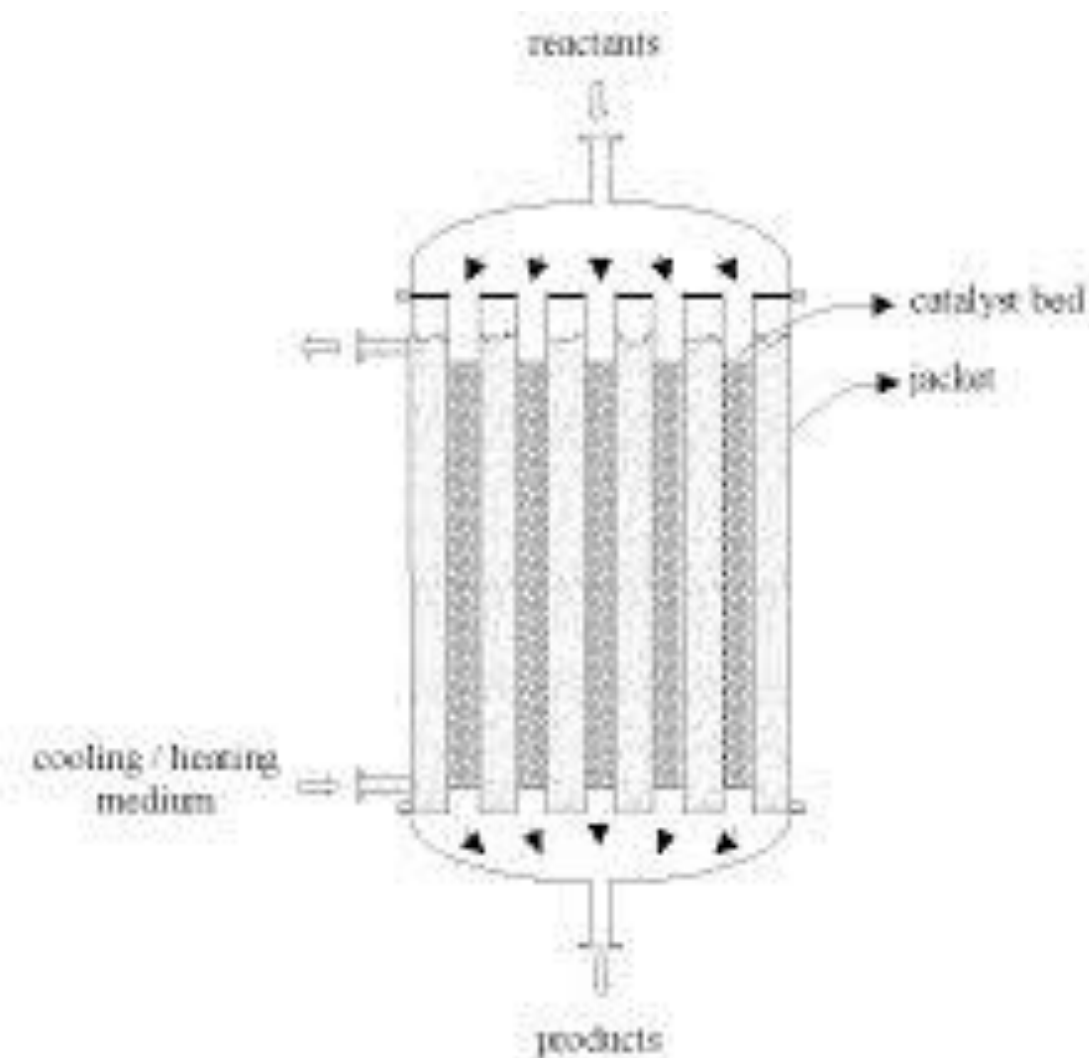


Combined-Cycle Gas Turbine (CCGT)

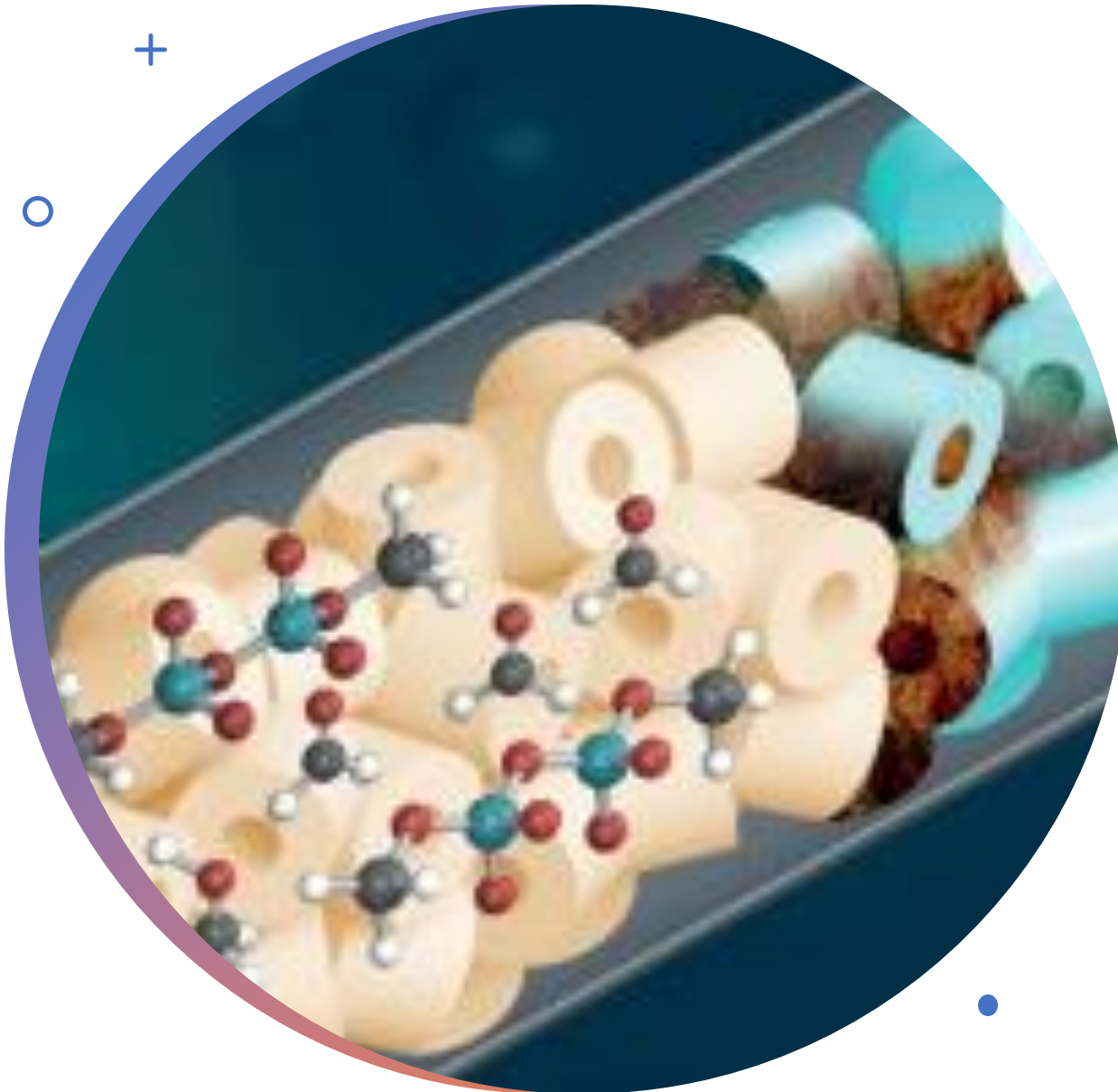
- Co-incineration with natural gas of waste gases with CCGT is used to remove formaldehyde and volatile organic compounds (VOCs) to 0.
- The CCGT recovers waste heat from turbine exhaust gas to generate steam providing electricity.
- Saves electricity cost needed to operate the formaldehyde production process.



Reactor Specification Sheet

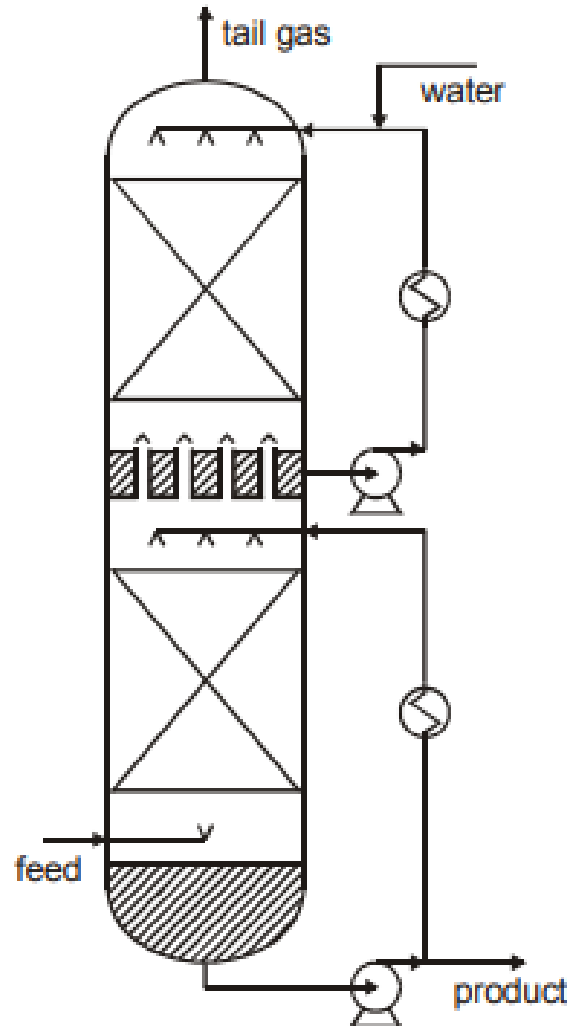


Reactor				
Identification:	Item:	Multi-Tubular Reactor		
	Item No:	R-101	Date:	4/21/2020
	No. Required:	1	By:	XW
	C _{PE} (\$)	\$ 146,000	C _{BM} (\$):	\$585,000
Function: To react methanol and oxygen to yield formaldehyde (product) and water (co-product).				
Operation: Continuous				
	Inlet	Outlet		
Materials Handled:				
Total Flow (lb/hr):	117,00	117,000		
Volumetric Flow (ft ³ /min)	1700	2500		
Component Flows (lbmol/hr):				
Formaldehyde	0	300		
Methanol	300	0		
Water	150	450		
Oxygen	300	150		
Nitrogen	3400	3400		
Temperature (°F):	518	545		
Pressure (psia):	22	15		
Vapor Fraction:	1.0	1.0		
Design Data:				
Q (MBTU/hr):	-800	Material:	Stainless Steel	
U _o (BTU/hr-ft ² -°F):	100	Design Temperature (°F):	660	
Total A _o (ft ²):	47	Design Pressure (psia):	50	
Tubes per Reactor	38	LMTD (°F):	174	
Tube Length (ft)	5			
Utilities:				
Dowtherm (lb/hr):	22,000			
Catalyst Data:				
Type:	Iron-Molybdenum	Density (lb/ft ³):	45	
Total Weight (lb):	11,000	Void Fraction:	0.60	
Catalyst Load (lb):	289			



- Material – Methanol and Formaldehyde does not react with Stainless Steel.
- Safe Temp. Operation Range is 480 F - 660 F. Operating at 518F allows hotspots at safe process temperatures; (above 660F formaldehyde oxidizes to CO by product – reduced plant productivity)
- Optimal presence of Steam – reduces Mo's consumption rate; too much water blocks active sites and diminishes methanol reduction
- Excess Oxygen in Feed – prevents removal of oxygen from catalyst surface during reaction
- Catalyst Function
 - $\text{Fe}_2(\text{MoO}_4)_3$ active phase
 - Excess MoO_3 ensures oxygen availability, improves formaldehyde selectivity, electron donor phase
 - Optimal yield and formaldehyde selectivity molar ratio ($\text{Mo/Fe} = 2.4$)

Absorption Column Specification Sheet



Absorber Column

Identification:	Item:	<i>Absorption Column</i>		
	Item No:	<i>T-101</i>	Date:	<i>4/21/2022</i>
	No. Required:	<i>1</i>	By:	<i>XW</i>
	CPE (\$)	<i>\$ 98,000</i>	CBM (\$):	<i>\$ 426,000</i>

Function: To separate most of the formaldehyde from the reactor effluent stream and provide the product stream to the product cooler.

Operation: Continuous

	Feed	Water	Purge	Product
Materials Handled:				
Total Flow (lb/hr):	117,000	81,000	101,000	17,000
Volumetric Flow (ft ³ /min)	1,450	130	308,000	294
Component Flows (lbmol/hr):				
Formaldehyde	300	0	16	284
Methanol	0	0	0	0
Water	450	450	0	450
Oxygen	150	0	150	0
Nitrogen	3,400	0	3,400	0
Temperature (°F):	230	77	77	77
Pressure (psia):	22	22	15	15
Vapor Fraction:	1.0	0.0	1.0	0.0

Column Design Data:				
Height of Column (ft):	33	Orientation:	Vertical	
Diameter of Column (ft):	7	Packing type:	Random	
Internals:	Ceramic Pall Rings	Void fraction:	0.92	
Height of Packing (ft):	25			
Column Material	Stainless Steel			
Design Pressure (psia):	50			
Design Temperature (°F):	300			

- Packed Column – continuous interaction of vapor and liquid phases, smaller pressure drop
- Ceramic Pall Ring packing (random) – reduces corrosion, chemically inert
- Improved Absorption/production of methylene glycol at higher pH (pH 8-9) – caustic wash addition to solvent
- External liquid recirculation with heat exchangers for tight temperature control





HAZOP

Nodes	Parameter	Guideword	Cause	Consequence	Action
Mixture Feed	Flow	No	Closed or failed feed valve	Build-up of pressure and chance of equipment failure/ destruction	Have the valve auto-fail to open to ensure flow and prevent a blockage of the flow
	Concentration	High	Excessive flow from feed	Potential for runaway reaction or explosion	N ₂ flush tank placed at reactor entrance to drop concentration
Reactor Tubes	Temperature	High	Heating element responsible for temperature control of reactor spikes	The reactor overheating can lead to a runaway reaction	Have a temperature control system to ensure temperature does not exceed limit.
	Pressure	Low	Blockage from catalyst degradation	Poor reaction efficiency	Follow maintenance schedule for catalyst bed
Dowtherm Inlet	Flow	Less	Partially closed valve	Enough heat of reaction might not be removed causing less products	Have a sensor that will monitor Dowtherm flowrate into the reactor

HAZOP Consequences and Actions

Main Parameters:

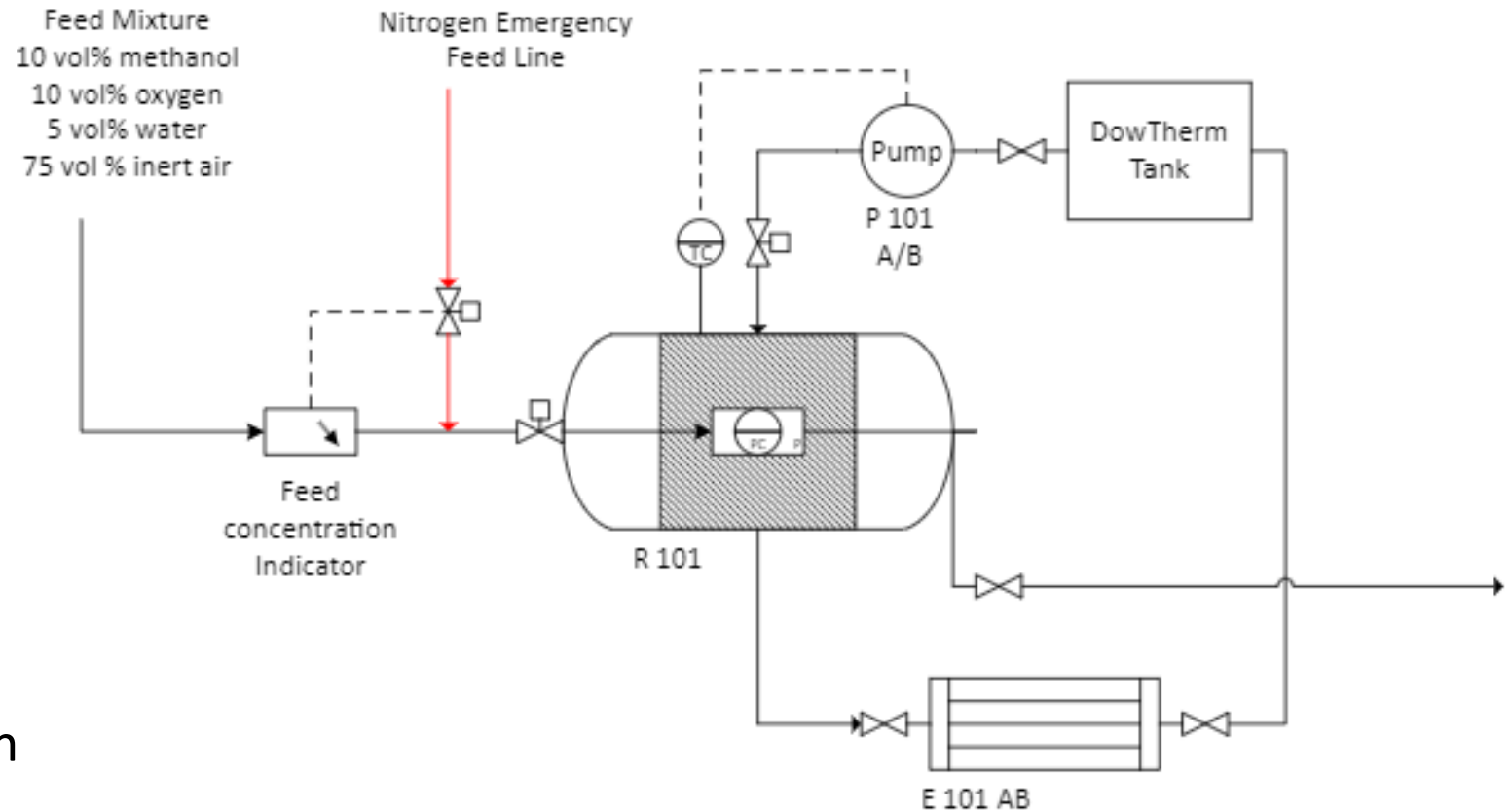
- Concentration
- Temperature

Consequences:

- Uncontrollable/runaway reaction
- Increased hotspot temperatures
- Build up of pressure

Actions:

- Nitrogen flush at reactor entrance
- Increase flow of dowtherm in shell



Major Safety Issues and Preventative Measures

- Deflagration Risk – flash fire within process

- Methanol flow meters
- Oxygen meters during normal operation
- Methanol accumulation – drain below the vaporizer
- Temperature measurements to detect fires
- No exposed catalyst on tube sheet after reloading
- Final safety: the rupture discs



- Paraformaldehyde Build-Up - Self-propagating, increases risk of deflagrations/fires, possible seizure of rotational equipment (absorber and process stream heat exchangers susceptible to build up)

- Tight temp control in absorption column (favor higher temps), ensure continual fluid flow (no stand stills)

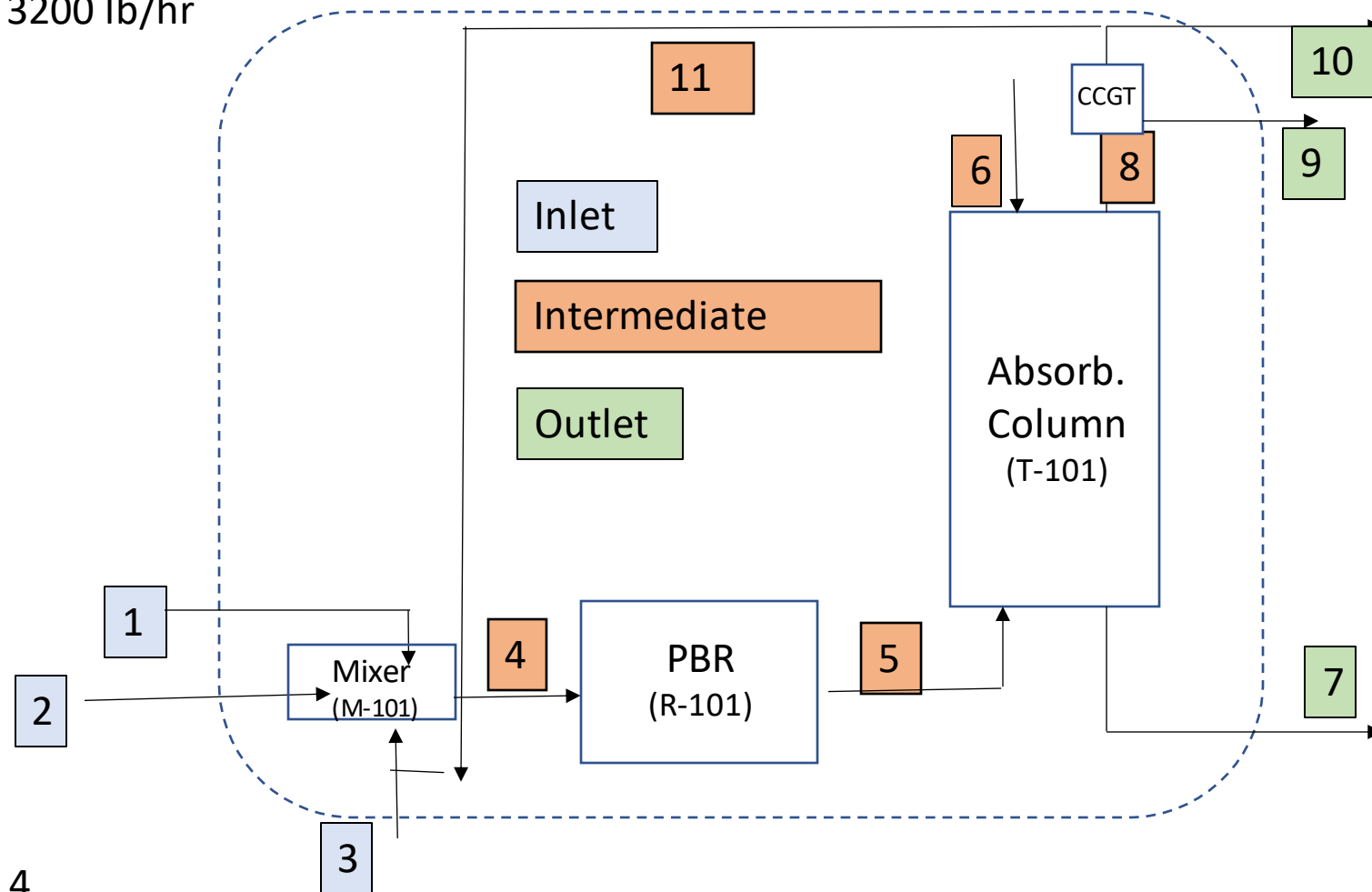
- HTF (DowTherm) Fires

- Check for tube leaks – pressurize HTF system, odor check then visually check for leaks if a smell is detected

Material and Energy Balance

Stream 11

- Inert recycle – 63000 lb/hr
- O₂ – 3200 lb/hr



Stream 4

- CH₃OH – 9600 lb/hr
- O₂ – 9600 lb/hr
- Inert air – 32000 lb/hr
- Inert recycle – 63000 lb/hr
- H₂O – 2700 lb/hr

Stream 5

- CH₂O – 9000 lb/hr
- H₂O – 8100 lb/hr
- Inert air – 95000 lb/hr
- O₂ – 4800 lb/hr

Stream 6

- H₂O – 8100 lb/hr

Stream 8

- Inert air – 95000 lb/hr
- CH₂O – 470 lb/hr
- O₂ – 4800 lb/hr

Overall Balance

Stream 1 (In)

- H₂O – 2700 lb/hr

Stream 2 (In)

- CH₃OH – 9600 lb/hr

Stream 3 (In)

- O₂ – 6300 lb/hr
- Inert air – 31000 lb/hr

Stream 7 (Out)

- CH₂O – 8500 lb/hr
- H₂O – 8100 lb/hr

Stream 9 (Out)

- CH₂O – 470 lb/hr

Stream 10 (Out)

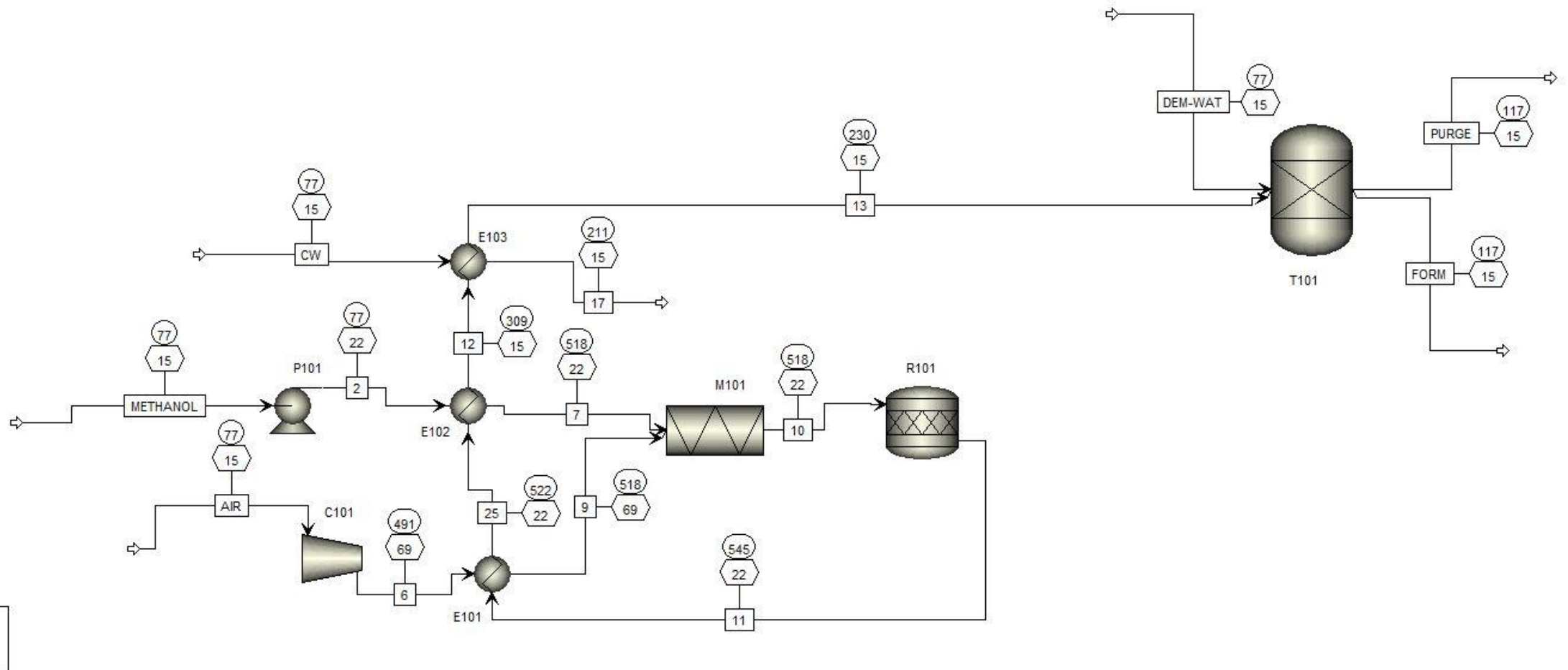
- Inert air – 32000 lb/hr
- O₂ – 1600 lb/hr

Total mass = 50000 lb/hr

Energy Balance

Equipment Name	MBtu/hr
Methanol Vaporizer (E-101)	4,500
Water Vaporizer (E-102)	7,600
Air Exchanger (E-103)	400
Absorption Column (T-101)	5.5
Reactor (R-101)	-800
Dowtherm Condenser (TK-102)	800

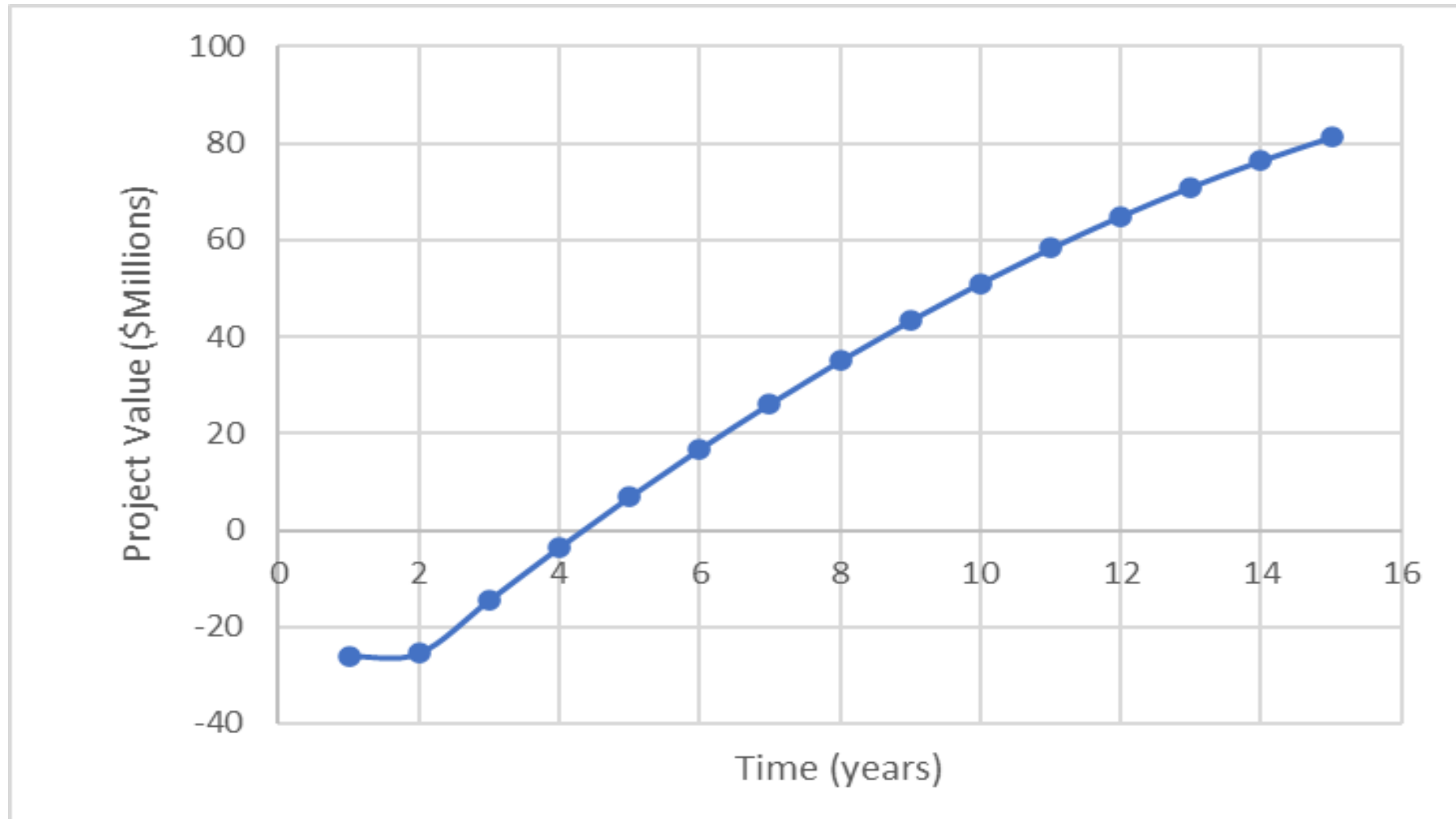
Aspen





Economics

Plant Cash Flow Diagram

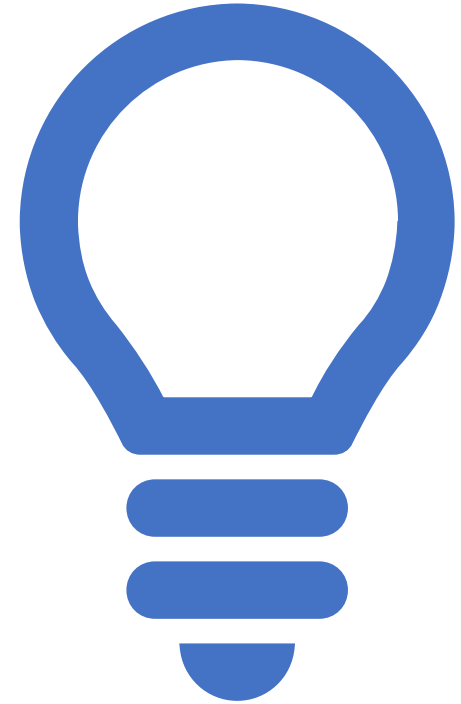


Production Cost (in millions)	
Raw Material Utility Operation	\$25.52/year
Production Revenue (in millions)	
Formalin	\$35.94/year
Difference Cost: \$10.42/year	
Total Investment (in millions)	
Fixed Capital Investment (FCI)	\$38.2
Working Capital	\$5.27
Total Investment	\$43.47

Profitability Analysis	
Plant Capacity (in millions)	120 lbs/year
Net Present Value (in millions)	\$210.77
Rate of Return on Investment (ROI)	28.8%
Payback Period	4.5 years
Discounted Cash Flow Rate of Return (DCRR)	10.00%

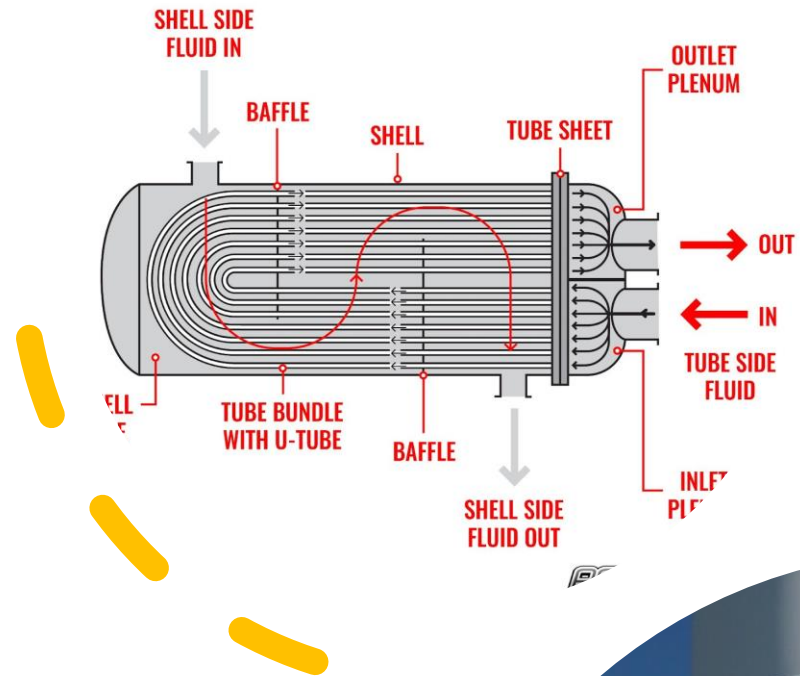
Future Recommendations

- Consider not moving forward with plant construction (unattractive payback period)
- Improve pressurization efficiency via Turbocharger
- Sell electricity back to the grid from total plant steam generation (dowtherm and CCGT) - increase profit



Start Up

- Twice a year
- Electric powered vaporizers and exchangers
- N₂ flush at entrance to reactor

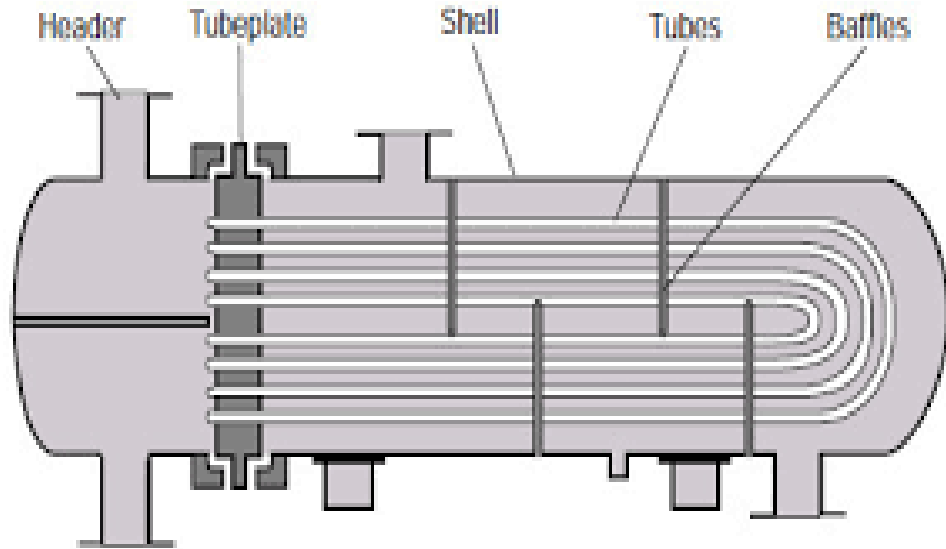


Longevity of Equipment/Maintenance

- Resistance to coking within reactor by adding water to the feed stream
- Operating under maximum capacity limit of equipment
- Remove Paraformaldehyde buildup during plant shutdown with caustic wash solution (1-2 wt%)
 - Manholes on absorber prevent pressurization and allow ventilation during cleaning
- Prioritize Proactive Work – Condition Based Maintenance
 - Vibration monitoring and analysis, control valve monitoring, Corrosion control, thermography
- Ensuring Methanol Quality
 - Poor quality methanol causes foaming in absorber



Methanol Vaporizer Specification Sheet



Methanol Vaporizer

Identification:	Item:	<i>Shell and Tube Heat Exchanger</i>		
	Item No:	<i>E-101</i>	Date:	<i>4/16/2020</i>
	No. Required:	<i>1</i>	By:	<i>HM</i>
	CPE (\$)	<i>\$ 233,000</i>	CBM (\$):	<i>\$ 1,440,000</i>

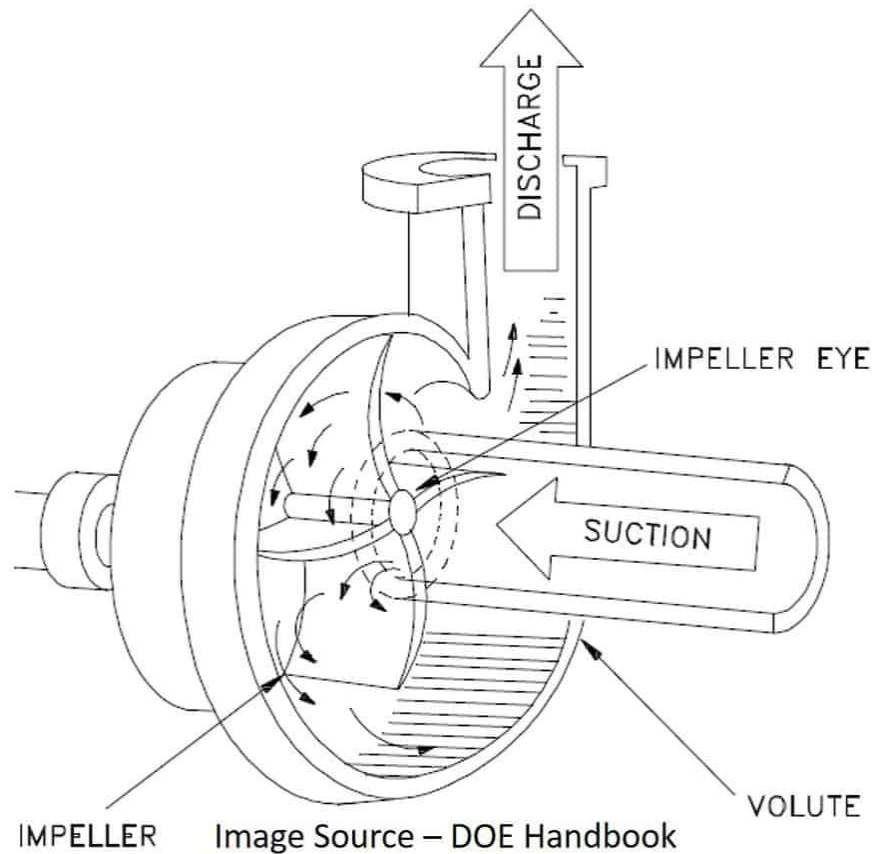
Function: To heat and vaporize methanol feed prior to entry into the static mixer and reactor.

Operation: Continuous

	Inlet	Outlet
Materials Handled:		
Total Flow (lb/hr):	9,600	9,600
Volumetric Flow (ft ³ /min)	196	196
Component Flows (lbmol/hr):		
Formaldehyde	0	0
Methanol	300	300
Water	0	0
Oxygen	0	0
Nitrogen	0	0
Carbon Monoxide	0	0
Temperature (°F):	68	518
Pressure (psia):	22	15
Vapor Fraction:	0.0	1.0

Design Data:				
Q (MBTU/hr):	4,500	Material:	Stainless Steel	
U _o (BTU/hr-ft ² -°F):	21	LMTD (°F):	125.0	
A _o (ft ²):	51,000			
Design Temperature (°F):	550			
Design Pressure (psia):	50			

Methanol Feed Pump Specification Sheet



Methanol Feed Pump

Identification:	Item:	<i>Centrifugal Pump</i>		
	Item No:	<i>P-101 A/B</i>	Date:	<i>4/18/2022</i>
	No. Required:	<i>2</i>	By:	<i>XW</i>
	CPE (\$)	<i>\$ 11,000</i>	CBM (\$):	<i>\$ 55,000</i>

Function: To pump methanol feed from 15 psia to 22 psia.

Operation: Continuous

	Inlet	Outlet
Materials Handled:		
Total Flow (lb/hr):	9,600	9,600
Volumetric Flow (ft ³ /min)	196	196
Component Flows (lbmol/hr):		
Formaldehyde	0	0
Methanol	300	300
Water	0	0
Oxygen	0	0
Nitrogen	0	0
Carbon Monoxide	0	0
Temperature (°F):	68	68
Pressure (psia):	15	22
Solid Fraction by Volume:	0.0	0.0

Design Data:				
Flow Rate (gpm):	660			
ΔP (psia):	7			
Material:	Stainless Steel			
Hydraulic Power (hp):	4			
Shaft Power (hp):	5			

Utilities:				
Electricity (kW):	4			

Process Selection

Attribute	Weight	Silver Catalyst Process	Score	Metal Oxide Catalyst Process	Score
Conversion	0.20	85% conversion	85	99% conversion	100
Catalyst Life	0.05	3 -4 months, regeneration, expensive, relatively instable	40	Lifespan 12 - 18 months, regeneration not practical, economical, relatively stable	60
Risk	0.20	Operates ABOVE explosion limit, requires very high reactor temperatures	50	Operates BELOW explosion limit, oxygen in absorber increases fire risk, hot oil used, increases fire risk	40
Steam Production	0.05	Insufficient steam production to meet plant power needs	40	Sufficient Steam Production to meet plant power needs	80
Environmental Impact	0.05	1.55 kg/MG uncontrolled CH2O emissions; 0.2% formladehyde in steam condensate	30	0.98 kg/MG uncontrolled Formaldehyde emissions	70
Product Quality	0.15	More Impurities	30	Less Impurities, higher obtainable concentration, specialized products	90
Utility Cost	0.10	\$1.65 M/Year	70	\$2.3 M/Year	50
Capital Cost	0.10	\$7.1 M	50	\$6.2 M	70
Installation Cost	0.05	High installation cost	20	Low installation cost	100
Payback Period	0.05	2.8 years	70	3.5 years	50
Total	1.00		53.5	33	71.5

Plant Ion Exchange

Deionization of Water

Deionization of Formalin Stream

- Polystyrene-divinylbenzene resin
- Strong Base Anion
- Resin Regeneration